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Proceedings of the Regional Peer Review of an Alternate Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region

Meeting Dates: September 24-25, 2020
Location: Virtual meeting

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Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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SUMMARY

A Regional Peer Review process was held virtually over September 24-25, 2020, to provide a review of an alternate Precautionary Approach (PA) Framework for Snow Crab in the Newfoundland and Labrador (NL) Region brought forward by the Fish, Food, and Allied Workers (FFAW) union. This Proceedings Report includes abstracts of meeting presentations, a summary of the following discussions, and a series of consensus statements agreed upon by the meeting participants regarding the specific questions provided by the Terms of Reference (ToR). The working paper submitted by the FFAW for review, the meeting's ToR, agenda, and list of participants are appended.

Participation included scientists and resource managers from multiple Fisheries and Oceans Canada (DFO) Regions, university researchers, the Provincial Government of NL, Indigenous groups, a land-claims organization, harvesters, and other industry stakeholders with expertise in fisheries science. The peer review process was conducted by four independent reviewers – two from outside the NL Shellfish section and two from outside DFO. The meeting was asked to review the sources of data used in the alternate PA Framework, the reference point methodologies, and proposed approaches for the identification of reference points. After an in-depth group analysis, participants agreed that there were significant issues with the proposed approach and reference points, and reached consensus that the proposed alternate PA should not be adopted.

ACRONYMS

CPUE	Catch Per Unit Effort	**LRP**	Limit Reference Point
CSAS	Canadian Science Advisory Secretariat	**MSY**	Maximum Sustainable Yield
DFO	Fisheries and Oceans Canada	**NL**	Newfoundland and Labrador
DMF	Decision Making Framework	**PA**	Precautionary Approach
ERI	Exploitation Rate Index	**TOR**	Terms Of Reference
FFAW	Fish, Food, and Allied Workers	**USR**	Upper Stock Reference
HCR	Harvest Control Rule		

DEFINITIONS

Precautionary Approach: "The Precautionary Approach is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty... The application of precaution requires increased risk avoidance where there is risk of serious harm and uncertainty is great" (DFO 2006).

PA Framework: "[A] decision-making framework for implementing a harvest strategy that incorporates the Precautionary Approach (PA). The framework applies where decisions on harvest strategies or harvest rates for a stock must be taken on an annual basis or other time frame to determine Total Allowable Catch or other measures to control harvests" (DFO 2009).

Critical Zone: The stock status zone below the limit reference point; "Removals from all sources must be kept to the lowest possible level until the stock has cleared the Critical Zone. A rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical Zone within a reasonable [time period]" (DFO 2009).

Limit Reference Point: "The LRP represents the stock status below which serious harm is occurring to the stock. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities … The LRP is based on biological criteria and established by Science through a peer reviewed process" (DFO 2009).

Cautious Zone: The stock status zone between the LRP and the USR. "Harvest rate (taking into account all sources of removals) should progressively decrease from the established maximum and should promote stock rebuilding to the Healthy Zone" (DFO 2009).

Upper Stock Reference: "..the USR is the stock level threshold below which removals must be progressively reduced in order to avoid reaching the LRP. For this reason, under this framework, the USR, at minimum, must be set at an appropriate distance above the LRP to provide sufficient opportunity for the management system to recognize a declining stock status and sufficient time for management actions to have effect…Secondly, the USR can be a target reference point determined by productivity objectives for the stock, broader biological considerations and social and economic objectives for the fishery" (DFO 2009).

Healthy Zone: The stock status zone above the upper stock reference. "Socio-economic considerations prevail. Conservation measures consistent with sustainable use apply. Harvest rate (taking into account all sources of removals) not to exceed established maximum" (DFO 2009).

Removal reference: "The removal reference is the maximum acceptable removal rate for the stock ... The Removal reference includes all mortality from all types of fishing. To comply with the United Nations Agreement on Straddling and Highly Migratory Fish Stocks, the Removal reference must be less than or equal to the removal rate associated with maximum sustainable yield" (DFO 2009).

Exploitation Rate Index: "The exploitation rate index (ERI) is defined as annual landings divided by the previous two-period moving average survey biomass estimate and represents the level of fisheries-induced mortality imposed on the resource each year" (Mullowney et al. 2020).

Harvest Control Rule/Harvest Decision Rule: "[Harvest decision rules] provide details on the harvest rates and possibly other management procedures that are required in each zone or steps within a zone. The pre-agreed harvest decision rules and management actions should vary in relation to the reference points, and be designed to achieve the desired outcome by affecting the removal rate. The removal rate should take into account total removals from all fisheries" (DFO 2009).

EXECUTIVE SUMMARY

A Canadian Science Advisory Secretariat (CSAS) process was held September 24-25, 2020, to review the technical merits of a proposed PA Framework for NL Snow Crab (herein referred to as the alternate framework) submitted by the FFAW.

Participation included scientists and resource managers from multiple DFO Regions, university researchers, the Government of NL, Indigenous groups, a land-claims organization, harvesters and other industry stakeholders with expertise in fisheries science. The peer review process included four independent reviewers – two from outside DFO and two from outside the NL Shellfish section, which developed the accepted 2018 PA Framework.

The peer review meeting addressed the following objectives:

1. Does the alternate framework use the best available scientific information?
2. Does the alternate framework use a biological basis for assessment of the resource?
3. Does the alternate framework enable sustainable management of the resource?
4. Does the alternate framework meet the requirements of the current DFO PA Framework Policy?
5. Does the alternate framework fit within constraints of the Fisheries Act and strategic directions of the Department?

Specifically, the meeting was asked to review the sources of data used in the alternate framework, as well as the reference point methodologies and approaches used for the identification of reference points.

Review of Data Sources

The FFAW conducted consultations with Snow Crab harvesters from southern Labrador and from the southern and eastern coasts of Newfoundland to gather information on their fishery objectives and on catch rates that harvesters considered to be healthy or that should be avoided. It was agreed that this information could be useful in helping to establish an Upper Stock Reference Point (USR) and Harvest Control Rule (HCR), especially with some additional work to include an analysis that quantifies the risk tolerances and the probability of meeting or exceeding those thresholds. The meeting acknowledged the importance of these efforts and ongoing engagement of the fishing community and other stakeholders regarding the PA Framework for NL Snow Crab.

All other data sources considered in the alternate PA Framework were provided by DFO Science. The alternate PA Framework focused on the use of raw annual mean catch per unit effort (CPUE) to set operational reference points (Upper and Lower) and used the exploitation rate index (ERI) to develop a target removal reference. The ERI was calculated as annual landings divided by the survey biomass estimate of the previous year and represents the level of fisheries-induced mortality imposed on the resource each year. This estimate differs from that used in DFO Science's 2018 PA Framework, which was calculated as annual landings divided by the previous two-period moving average survey biomass estimate (Mullowney et al. 2018).

Raw annual mean CPUE was used in the alternate PA Framework because it was considered by the working paper authors the most appropriate metric for developing relationships with discarding, as it reflects annual changes in fishing practices. However, concerns were expressed by participants about using the raw CPUE in developing reference points, as this index has been demonstrated to be positively biased and lag 1–3 years behind the current survey-based biomass estimates and, therefore, represents past exploitable biomass rather

than current exploitable biomass. In addition, raw CPUE does not take into account environmental factors and spatial dynamics of the resource. For example, concern was expressed that the alternate framework did not incorporate environmental factors such as the North Atlantic Oscillation (NAO) which has been shown to influence Snow Crab.

It was acknowledged that model prediction of future CPUE based on survey and environmental information, as described in DFO Science's 2018 PA Framework, would represent an appropriate index of stock status and basis for a HCR. The 2018 PA Framework's usage of predicted CPUE was considered by most meeting participants to be consistent with harvesters' emphasis on the importance of understanding incoming recruitment for management of the NL Snow Crab fishery. However, working paper authors expressed a preference for using "direct information" (i.e., raw data, not modelled values) whenever possible.

The ERI was generally considered to be an appropriate index to support the development of a proxy F- (fishing mortality) based removal reference, and there was support for the proposed approach. Moreover, because the ERI is based on survey biomass estimates, the alternate framework was not limited to information from the fishery. Concern was expressed that the ERI did not capture all sources of mortality including discard mortality.

The reference point methodologies and proposed approaches for the identification of reference points were reviewed within the context of the following questions:

Does the alternate framework use the best available scientific information?

While the alternate PA Framework used valid information provided by DFO Science, the meeting agreed that it did not use the most appropriate CPUE series, did not make use of survey data or environmental information to determine stock status, and lacked a HCR based on predictive modelling. It also did not use appropriate analytical methods to establish the USR. The alternate PA Framework did, however, use survey data, specifically the ERI, to estimate a removal reference, which would be the basis of a HCR.

Does the alternate framework use a biological basis for assessment of the resource?

The alternate PA Framework proposed adoption of the 2018 egg clutch index and associated reference points provisionally while adjustments to reference point levels or alternative metrics (and associated reference points) are explored. However, the egg clutch index was not formally integrated into the final determination of stock status or a HCR.

Does the alternate framework enable sustainable management of the resource?

The primary concerns with the ability of the alternate PA Framework to enable sustainable management of the resource were:

- The alternate framework's assessment methods did not reflect the current status of the stock and did not take into account important predictive factors (such as environmental conditions and incoming recruitment); meeting participants felt that it better reflected the status of the fishery rather than the status of the stock.
- The alternate PA Framework's definition of recovery and recovering was unclear (i.e., it was unclear whether 3Ps Snow Crab was considered recovered in the alternative framework).
- There was concern with using a single CPUE-based LRP across all assessment divisions (ADs), given variability in the spatial dynamics of the population. Several meeting participants expressed that AD specific LRPs may be appropriate.
- The proposed LRP (3.5 kg/trap haul) may be too low to protect the stock from risk of serious and irreversible harm.

As currently proposed, the alternate framework was considered incomplete and unlikely to support sustainable management of the NL Snow Crab resource.

Does the alternate framework meet the requirements of the current DFO PA Framework Policy?

The alternative framework did not meet the requirements of the DFO PA Framework Policy.

Does the alternate framework fit within constraints of the *Fisheries Act* and strategic directions of the Department?

As discussed above, the meeting felt that the alternate PA Framework (e.g., without an explicit HCR) did not reflect the strategic direction of the Department (e.g., ecosystem considerations).

Other Considerations

Concerns were clearly expressed by the fishing industry about the current USR, which they consider to be unrealistically high for some areas, with three of five ADs having rarely been considered healthy throughout the history of the fishery.

Upon discussion, the authors agreed that the predicted CPUE model, as described in DFO Science's proposed 2018 PA Framework (and updated at subsequent stock assessments), did address some of the key considerations highlighted by harvesters during consultation meetings and should be used as the basis of a tool for implementing a HCR in a complete framework.

Research Recommendations

Harvesters' recommendations for upper and lower reference points were not recommended for adoption. It was suggested that consideration of spatially-based reference points may be warranted to account for differences in productivity, growth, and recruitment in the different areas. It was considered important to ensure the usage of spatial scales that are appropriate both in terms of the biology/ecology of Snow Crab and the decisions that the Department is trying to support. Participants believed this is worth pursuing in the future, but in the meantime this should not limit the ability to provide information and advice during the annual NL Snow Crab assessment peer review process.

Management Strategy Evaluation (MSE) was suggested for future work to help quantify the probabilities associated with meeting targets and exceeding risk tolerance thresholds. MSE can also be used to define objectives, evaluate the performance of alternative reference points, HCRs, and potential impacts of a changing climate.

INTRODUCTION

In June 2018, a Regional Peer Review meeting was held to consider a Precautionary Approach (PA) Framework for Snow Crab in the NL Region developed by the DFO-NL Shellfish section (Mullowney et al. 2018). A set of Limit Reference Points (LRPs) defining the bounds of the Critical Zone were proposed and accepted through consensus of meeting participants, including industry and external reviewers (DFO 2019a). Upper Stock References (USRs) defining the Cautious and Healthy Zones were proposed, but were not formally accepted pending further development to be conducted by managers as per the Government of Canada guidance on PA Framework development (DFO 2009).

The Cautious and Healthy Zones defined by the 2018 PA Framework meeting (i.e., zones created by the proposed USR) were not used by Resource Management for decisions regarding the 2019-20 fishing seasons as this reference point remained provisional in the absence of further development and acceptance by stakeholders and managers (DFO 2019b; DFO 2020). Following the 2018 PA Framework review and the 2019 NL Snow Crab stock assessment, concerns regarding the appropriateness of the new framework were raised by some sectors of industry. These concerns led the Fish, Food and Allied Workers Union (FFAW) to develop and propose an alternate PA Framework, which was the topic of review for this meeting. While the previously accepted 2018 framework was frequently discussed during the plenary meeting, an in-depth review of that framework was already completed and was beyond the scope of the meeting.

OPENING REMARKS OF THE CHAIR

Presented by T. Worcester

The role of the Canadian Science Advisory Secretariat (CSAS) is to provide oversight and direction for the peer review process. Participants in a CSAS peer review are expected to participate fully in the discussions and offer objective, informative, and constructive input. The purpose of this review meeting is to consider the appropriateness of the data, methods, and conclusions of the working paper, and to generate consensus on the conclusions, recommendations, and science advice. For the purpose of DFO CSAS peer-review meetings, consensus should be reached based on consideration of scientific data and information and not on external considerations such as the potential socio-economic impacts of potential future decisions that are beyond the scope of the science review process.

CONTEXT OF THE ALTERNATE PA FRAMEWORK PROPOSAL

Presented by B. Healey (DFO-NL Science) and M. Henri (DFO-NL Resource Management)

A brief explanation of the history of the PA Framework for this stock was provided. It was emphasized that the development and acceptance of a PA Framework is of critical importance, and that all parties share a common goal of fostering a long-term, sustainable Snow Crab fishery in NL. Meeting participants were reminded that the scope of this meeting was a review of the technical merits of the proposed alternate PA Framework. Questions or concerns regarding implementation belong to a separate and broader discussion, which will be led by Resource Management in the future.

A special thanks was also extended to the Chair, reviewers, and all meeting participants for the care and attention that was given to this review. The collective commitment to independent review was essential to the purpose of this meeting, which was to conduct a fair and objective evaluation of the proposal and to reach meaningful consensus.

PRESENTATIONS

A MODIFIED DECISION-MAKING FRAMEWORK FOR THE NEWFOUNDLAND AND LABRADOR SNOW CRAB FISHERY

Presented by E. Carruthers and E. Dawe (FFAW)

Abstract

In this paper, we propose a modified decision-making framework (DMF) for Newfoundland and Labrador (NL) Snow Crab (*Chionoecetes opilio*) as a more practical framework than the 2018 NL Snow Crab DMF (Mullowney et al. 2018a), which we refer to as the base DMF. The proposed DMF is generally similar to the base framework, having been developed by building upon the strengths of the base DMF. Both DMFs include a first-level set of biological reference points (RPs) based on an egg clutch index and a primary operational framework with catch per unit effort (CPUE) as the stock index and a survey exploitation rate index (ERI) as the removal reference. One major difference is that the base DMF includes a third metric with RPs based on an index of the percentage of crabs released or 'discarded' in the fishery. This metric was not included in the proposed DMF, but rather the data on percent discarded were used in relation to CPUE to determine an upper stock reference (USR) that minimizes wastage due to discarding. The second major difference between the DMFs relates to methods used to determine RPs and their resultant estimates; limit and upper RPs were higher in the base framework (5.0 and 12.6 kg/trap respectively) than in the proposed framework (3.5 and 8.0 kg/trap respectively). The base framework used a suite of generic approaches to determine RPs, whereas the proposed framework used the most appropriate scientific data available together with information from the fishing industry. Accordingly, we concluded that the proposed modified DMF was the more appropriate operational framework.

Discussion

During the presentation, participants requested clarification of the overall objectives of the proposed alternate PA Framework. The overall objective, as indicated in the working paper (see Appendix IV) was to develop a modified framework that would be acceptable to the fishing industry, based on the original 2018 framework, but which included reference points (LRP and USR) that better reflected the fishers' experience and a target removal reference to regulate fishing mortality in the Healthy Zone. The scope did not extend to the development of specific Harvest Control Rules (HCRs), as that should more appropriately include input by managers; nor did it consider tools for implementation of presently undeveloped HCRs. More specific objectives that were brought forward from harvester consultations included:

1. minimize discards,
2. predict and protect incoming recruitment, and
3. ensure a stable fishery.

These objectives were revisited throughout the meeting.

One of the criticisms the working paper authors made of the 2018 PA Framework was that the egg clutch fullness metric did not have a measurable relationship to CPUE, and this was presented as a basis of concern for the reliability of this metric. However, DFO scientists and external reviewers agreed that this was not a surprising result. Egg clutch fullness and sperm limitation were not expected to relate directly to CPUE, as male crab may mature below 95 mm carapace width (CW) and contribute to reproductive capacity of the population before entering the fishery. An expert on Snow Crab reproductive biology clarified that previous research on mating success and clutch fertility has indicated that a clutch fullness metric relates to operational sex ratio rather than >95 mm CW male abundance, which is the portion of the population that is measured by CPUE (e.g., Sainte-Marie et al. 2002, Ogburn 2019). Furthermore, males and females from the same year class do not recruit into the reproductive population simultaneously. Females reach sexual maturity earlier and drive sex ratio at the population level. The existing abundance of reproductively mature males in the population defines the baseline-level insemination success in any given year, and by extension, clutch fertility. If recruitment were steady, this asynchronous male/female recruitment would not influence reproductive capacity estimates. However, Snow Crab are subject to pulse recruitment events and this combination of features can lead to highly variable reproductive capacity, particularly under pressure of a fishery that only targets mature males.

The acceptance or rejection of the egg clutch fullness metric was revisited several times throughout the meeting. Although the proposed alternate PA Framework did not incorporate egg clutch fullness, the authors did not explicitly reject this metric. The distinction between rejection and "provisional acceptance" without implementation caused confusion among participants, many of whom understood from the working paper that the egg clutch metric had, in fact, been rejected by the authors. Authors of the working paper reiterated many times that, as the only biological metric available to them, they were not rejecting egg clutch fullness. They explained that the egg clutch index, as adopted directly from the base framework, did not represent a complete framework in that it was not linked to a removal reference or a HCR. Therefore, they suggested that this index (with its RPs) should represent a metric of first consideration in annual management decisions before applying the single operational framework based on CPUE to implement the HCR and adjust the Total Allowable Catch (TAC). The authors explained that there were concerns with reliability of the index associated with low sample sizes in some Assessment Divisions (ADs), sampling platforms, and potential subjectivity in data collection. The meeting discussion later led to the suggestion that operational sex ratios should be developed to either validate or replace the egg clutch index.

Several participants expressed concern regarding the lack of an explicit definition for "stock recovery" in the proposed alternate framework. Specifically, participants noted that the terms "recovery" and "recovering" were used throughout the text of the document to refer to any increase of CPUE over any increment of time, without acknowledgement of Snow Crab generation time. Research on growth and maturation has demonstrated that it takes 8–10 years for a male Snow Crab in the NL Region to grow from settlement to legal fishery size (95 mm CW; Mullowney et al. 2017). Including the pre-settlement stage, generation time is estimated at 9–11 years. Experts emphasized that any increase in CPUE on a shorter time scale cannot represent true recovery from a low biomass condition. These short-term increases likely represent recruitment of already existing crab into the fishery, changes in distribution of the stock, and/or changes in fishing behavior. Single recruitment events may also represent different year classes, due to the prevalence of skip-molting and known differences in growth rates across the large geographic range of the stock. These sources of uncertainty should be considered when interpreting a fishery index like CPUE as an indicator of stock recovery.

Authors acknowledged that they did not provide an explicit definition of recovery in the text; however, they clarified in the meeting that they accepted the definition provided by the 2018 framework (i.e., return to or above the USR 8–10 years after a CPUE low). The working paper authors indicated that the CPUE recovery metric was consistent with one of the approaches used in the 2018 PA Framework.

The proposed alternate framework included an USR of 8 kg/trap, based (in part) on what was described as a CPUE "breakpoint" between 7–7.9 kg/trap, below which there is a relatively sharp increase in the percentage of the catch discarded, with discard rates exceeding 30%

more frequently at CPUEs below 7.5 kg/trap. However, participants noted this CPUE threshold was not the result of a true breakpoint analysis, but represented a subjective visual interpretation of percentage of discards plotted against CPUE. External reviewers agreed that this method lacked statistical support. The DFO Shellfish section presented a breakpoint analysis of the data that showed that the breakpoint was at a CPUE of 5.3 kg/trap and suggested that this value should more appropriately be considered as a LRP, rather than an USR. The working paper authors disagreed, noting the 5.3 kg/trap breakpoint analysis would not be appropriate for a LRP because the breakpoint analysis DFO presented was based on the economic consideration of minimizing wastage and did not relate directly to serious or irreversible harm to the stock.

The proposed USR of 8 kg/trap was also based on broad agreement among Snow Crab fleets on what constituted “steady, good fishing”. Harvesters’ agreement on an 8 kg/trap USR was arrived at by consensus during consultations and was based on harvesters’ understanding of the history of their fishery. Meeting participants requested more documentation on the consultations and discussions that led to a consensus of 8 kg/trap for an USR. The working paper authors noted that the higher USR of the DFO 2018 framework was very close to the level of CPUE stability due to trap saturation and could, therefore, be difficult to reach. Moreover, because the 2018 USR was close to the level of trap saturation, there would be limited ability to detect changes in stock status within the Healthy Zone. By contrast, the much lower USR proposed in the alternate framework was well below the level of trap saturation.

Meeting participants pointed out that the self-described undesirable time periods for the fishery included periods where discards were below 30% of the catch, indicating that this proposed USR would not serve the objectives put forward by the harvesters. The authors explained that a discard rate of 30% was not presented as a threshold but rather to illustrate that the frequency of high levels of discards increased relatively sharply below 7–7.9 kg/trap. They did acknowledge that their proposed USR could have been evaluated with more appropriate statistical analysis and asked for suggestions. A beta regression was recommended and supported by several reviewers. One reviewer recommended using the fishery objectives identified through the consultation process to identify a maximum level of discards that could be tolerated and applying that value to the beta regression to identify an appropriate CPUE value for the USR.

When participants asked about the rationale for setting the USR on a CPUE index of discards, the authors expressed a reluctance to use discard data directly in reference point setting due to concerns of insufficient observer coverage. They argued that developing an USR based on the relationship of percent of catch discarded with CPUE – rather than based directly on the discard data – accounted for the uncertainty in the reliability of the discard data. However, meeting participants pointed out that the working paper did not demonstrate:

1. that the direct discard estimates could not be reliably used, or
2. that CPUE provided the best available proxy.

While the meeting rejected the results of this initiative, based on lack of statistical support, there was no criticism of the fundamental approach, and the authors accepted recommendations on how the approach could be improved. A co-author of the proposed alternate PA Framework indicated that the Proceedings of the June 2018 meeting stated that the “inclusion of a discard rate index in the PA framework, as proposed here, will require an increase in observer data quantity and quality moving forward” (DFO 2020). Scientists who worked on the 2018 base framework strongly recommended improvements to observer coverage, however this was not an explicit condition of acceptance by that meeting.

One participant asked authors of the working paper to discuss their interpretation of the relationship between CPUE and discards, specifically whether higher discard rates were caused by the presence of more recruits (i.e., undersized crab coming up in the population), or because larger individuals are depleted by the fishery. They explained that it is impossible to distinguish between those two scenarios from the catch data and hypothesized that the negative correlation between CPUE and discard rate was driven by a combination of new recruitment and depletion of large crabs. One co-author also noted that due to the lag between changes in biomass and changes in TAC, low CPUE coincides with periods of very high fishing effort to land the assigned quota. Under such high fishing effort conditions, the same undersized and soft-shelled crabs may be caught, handled, and discarded multiple times. It is unclear how prevalent repeat captures are, or whether they have lethal or long-lasting, sub-lethal effects.

One of the working paper co-authors stated that they did not believe that the strict application of a HCR derived from a linearly decreasing ERI throughout the Cautious Zone was necessary. Instead, they would prefer to see the stock managed by exploitation rate ranges within each stock status zone, emphasizing that the removal reference in the Healthy Zone should not be exceeded. Meeting participants noted that many other frameworks apply running means or running median values to help address issues of variability in model results and to support fishery stability. Working paper authors stated that the proposed alternate PA Framework should be used in conjunction with a model to predict CPUE in the following year, making it possible for managers to plan. Meeting participants highlighted that the 2018 framework included a predictive model of CPUE for this purpose (Mullowney et al. 2018).

There was considerable discussion throughout the meeting on the different CPUE indices, with external reviewers noting that it would have been helpful if all analyses for both the 2018 DFO and alternate PA Framework had used the same data types. Three types of CPUE time series data were discussed: the raw CPUE data, standardized CPUE data, and model-predicted CPUE data. The working paper authors used raw CPUE data, arguing it was the more appropriate time series for the development of an USR based on the relationship between CPUE and discards. However, meeting participants pointed out that the predicted-CPUE metric:

1. better represented current biomass,
2. addressed harvesters' request for a predictive model, and
3. included environmental (NAO) and survey biomass estimates in the estimation of reference points.

The proposed alternate PA Framework also presented a target removal reference designed to support the objective of fishery stability by maintaining the ERI and fishing mortality at an appropriate level. This target removal reference was estimated as the ERI that is associated with stable or improving CPUE in the subsequent year, which was estimated as an ERI of 0.42. Internal and external reviewers commended the proposed removal reference and agreed that this idea should be moved forward with some clarifications and minor revisions. As presented, the relationship between ERI and CPUE was measured as absolute change in CPUE; reviewers and authors agreed that it would be more appropriate to measure percentage change from year to year. The same magnitude change in CPUE is more important when catch is at low levels, and this would be addressed by analyzing percentage change instead of absolute values. It was also noted that the ERI included adolescent male crabs; however, these crab may be unavailable or undesirable to the fishery in the following year because they can remain in soft shell condition in the following year and possibly subsequent years if they both continue to molt and remain adolescent. As explained during the meeting, the amount of adolescent crabs entering the fishery varies from year to year, and this source of uncertainty should be addressed before the ERI is applied to management decisions. A DFO research scientist clarified that excluding adolescents did not result in a significant change to the proposed removal reference, and this would be simple to address in a revised version. One participant expressed the opinion that the stock is overexploited and raised concerns that if 0.42 represents the ERI level at which CPUE remains stable at 8 kg/trap, then it is too high for the purpose of maintaining high catches in the long-term.

There was also discussion of high exploitation rate periods in the fishery, particularly in AD 2HJ. One of the working paper authors suggested that the recent high exploitation rate period (2015–16) was due to contraction of the resource's distribution. Under the proposed alternate framework, the fishery dips into the Cautious Zone during this period, but subsequently returns to the Healthy Zone. A reviewer suggested that one weakness of this framework was that the relatively low USR does not protect the resource from effects of excessive exploitation, such as in AD 2HJ where the resource remains in the Healthy Zone due to hyperstability of CPUE while the biomass declines and contracts. The proposal authors responded that the proposed framework was more robust to such effects of hyperstability than was the base framework because it included a target removal reference (not included in the base framework) that would maintain the ERI and fishing mortality at a more appropriate level during such periods of biomass decline and contraction. Moreover, because the ERI was based on survey biomass, ERI would increase if the stock was decreasing and contracting. Thus, even under these circumstances ERI would be kept below the reference level.

Consultation with harvesters focused on identifying a level of CPUE that was felt to be sustainable and could be used as an USR. Harvester groups were asked to identify a CPUE level that they felt could be maintained in the long-term. These consultations resulted in consensus that about 8 kg/trap represented a level that they felt could be sustained and that they would support as an upper threshold. Concern was raised about whether harvesters were given sufficient information in the consultations to make recommendations with respect to an alternative to the 2018 DFO PA Framework. The working paper presented recommendations made by harvesters, including the development of a predictive CPUE model. Meeting participants noted that this suggestion closely described the predictive CPUE model that was used as the basis of the DFO 2018 PA Framework, and participants questioned whether harvesters were fully informed about previous work on this topic. Authors of the proposed alternate PA Framework explained that when the 2018 PA Framework was presented, the major criticisms from industry were about how the USR related to the history of the fishery (i.e., some management areas would have never met the threshold for the Healthy Zone). In the initial set of consultation meetings, the FFAW asked participants to identify objectives for the fishery. These discussions highlighted the importance of fishery stability, protection of recruitment, and a desire to minimize wastage. They clarified that they did not present the DFO CPUE model to harvesters because the objective was to develop an alternate PA Framework. One author also noted that there were concerns at that time with the DFO predicted-CPUE model, including bias in the model residuals. DFO scientists clarified that the model was peer reviewed and accepted in the previous framework meeting in 2018, has been updated, improved, and used in the years since, and is considered to be working well.

The discussion of the scope of the consultations led one reviewer to request clarification on the method and structure of these meetings with harvesters, as these details were not included in the working paper. A thorough understanding of how these consultations were conducted would ensure comparability among areas within the NL Region (e.g., no consultation has been conducted in 2J North recognizing that co-management partners in Nunatsiavut have independent processes and consultation responsibilities) and would offer some clarification on interpretation of the results.

The authors were asked whether the North Atlantic Oscillation (NAO), which is a significant driver of this stock (Mullowney et al. 2018), was incorporated into the proposed indices. Environmental drivers were not incorporated into the proposed alternate PA Framework. The authors clarified that they were provided with two CPUE databases (raw and standardized), and they chose to use the raw CPUE, considering it more appropriate for developing the relationship of CPUE with percent discarded because it was unadjusted for variation in fishing practices that affect discarding. The NAO is included in the predicted-CPUE, an index previously accepted in the 2018 framework, but was not included in the proposal put forward at this meeting.

Questions were also raised about whether CPUE represented the best indicator of stock status. This question was fundamental to the structure of the proposed alternate framework, and some participants did not feel it was adequately demonstrated in the working paper. One reviewer also noted that the proposed alternate framework appeared to make an effort to account for the history of fishing on this stock (i.e., what was considered a Healthy Zone by harvesters) and yet the result was to adopt the lowest performing management areas as reference points for the entire region. Several reviewers questioned whether a single reference point was appropriate for all divisions, noting that this fishery includes a huge territory from Labrador to southwest Newfoundland. The proposed LRP was defined by the conditions of the most northerly and the most south westerly divisions, which yielded relatively low landings compared to the overall commercial fishery. It was noted that while some areas have recovered from low CPUE, the role of immigration in this recovery is unknown. Reviewers expressed serious concern that there was no evidence that the entire shelf would be able to recover from the low level identified in this framework as $C_{Recovery}$ (3.5 kg/trap) and put forward as the LRP for the whole region.

Authors of the proposal stated that the use of CPUE, which is a density metric, “puts the divisions on the same playing field” and that separating reference points by division would only be required if the framework was based on biomass. This argument was not accepted by the meeting participants. Authors repeated that harvesters at the nineteen consultation meetings supported the proposed USR and LRP, despite consistently lower CPUE in NAFO Div. 2J. As noted in the working paper, harvesters from areas with consistently higher CPUEs (e.g., AD 3LNO) indicated that they could accept an USR threshold of 8 kg/trap, but they would aim to maintain fishery catch rates well above that level. With respect to the proposed LRP, harvesters at consultation meetings indicated that below 3.5 kg/trap were stock status levels to be avoided. One meeting participant noted, however, that without a clear description of the consultation methods or detailed minutes/survey results from those meetings, there was no record of consensus or what other issues/objections were raised. A member of the Snow Crab industry agreed that CPUE is the strongest indicator of stock status for harvesters and reiterated the importance of maintaining a healthy fishery in the long-term for the communities who have relied on this resource for generations.

DFO SHELLFISH SCIENCE REVIEW OF THE FFAW PRECAUTIONARY APPROACH PROPOSAL FOR NEWFOUNDLAND AND LABRADOR SNOW CRAB MANAGEMENT

Presented by D. Mullowney (DFO-NL Region, Science Branch, Shellfish Section)

Abstract

This presentation was developed and presented by DFO Science in response to the alternate PA Framework proposal for Snow Crab presented by the FFAW. We highlighted substantive philosophical and analytical deficiencies in the proposal throughout. Ultimately, we found the proposal over-emphasized management of the fishery and under-emphasized management of the resource and recommended that most aspects of the alternate proposal not be accepted or

incorporated into the current PA Framework. The alternate proposal was shown to omit all but most recent fisheries CPUE information in the assessment of stock status, along with virtually all biological aspects and reasoning inherent in the existing approach pertaining to management of the resource. Issues with the singular approach focused on most recent CPUE to assess stock status were shown to be exacerbated by the hyper stable tendencies of CPUE, reflecting both latent and positively-biased responses to survey-detected changes in stock size. Consequently, the proposal was deemed incapable of supporting long-term sustainable utilization of the resource through promotion of a system of latent management responses to changes in stock biomass. Moreover, we highlighted deficiencies and inaccuracies in quantitative methods and interpretations throughout, including repeated claims of a minimization of discards through adoption of the proposed USR level for fisheries CPUE. We remade plots and undertook intended analyses. We further highlighted contradictions inherent in omission of key components of the existing framework, such as predictive modelling for stock status indicators, while coincidentally recommending such approaches be developed. Not all aspects of the proposed framework were deemed inappropriate. In particular, we recommended adoption of the proposal to lower the existing upper removal reference from the existing level of 63% annual harvest rate to 42%.

Discussion

The working paper authors clarified that the main objectives of the proposed alternate PA Framework were to reduce discards and ensure fishery stability. Those objectives and input from harvesters led the proposal to use predicted CPUE as the primary metric of the proposed alternate PA Framework. The authors noted that defining a biological LRP (as required by PA policy) was a challenge for this stock. However, there was broad agreement in the meeting that the analysis used in the working paper to evaluate the utility of egg clutch fullness as an index of reproductive capacity was flawed.

Several participants argued that raw CPUE could not be treated as a real-time index of stock size, due to the hyperstability of CPUE (Mullowney et al. 2020). For example, a DFO scientist also pointed out that the CPUE signal has remained stable in AD 2HJ over a period that researchers expected it to fall due to prolonged high exploitation. This was likely due to a contraction of the stock into Cartwright and Hawke Channels. During this period, harvesters who previously fished in 2H were permitted to move down into 2J, so the fishery has followed the contraction of the biomass. The current phase of the NAO is associated with biomass increase for this stock, which is consistent with model projections for the region. However, this pattern was not consistent with recent biomass indices in 2HJ, where researchers have also recorded a reduction in male size at terminal molt (Mullowney and Baker 2020). As previously noted, the proposal authors pointed out that the inclusion of a F-proxy removal reference level (ERI of 0.42) based on the trawl survey would help address impacts from hyperstability by maintaining the exploitation rates and fishing mortality at appropriate levels, independent of CPUE.

There was disagreement between the working paper's authors and some meeting participants about the appropriate definition of a LRP for this stock. The proposed alternate PA Framework sets the LRP at a CPUE of 3.5 kg/trap, a level that was defined by fishery performance and the lowest level from which the stock has recovered at the individual AD level. The 2018 framework identified a LRP of 5 kg/trap, based on an ensemble approach that averaged the results of five different proxy methods for calculating a LRP, including biological indices (Mullowney et al. 2018). The working paper's authors criticized the ensemble approach as “arbitrary”, being inconsistent with DFO guidance on developing proxy RPs (DFO 2009); however, some meeting participants argued that if the ensemble was considered arbitrary by the authors, then selecting the lowest of the five presented options (i.e., $C_{Recovery}$ = 3.5 kg/trap) and applying it without the support of biological evidence does nothing to address that issue. A co-author of the working paper clarified that their criticism was based primarily on two of the five ensemble methods, and only the estimate they adopted (3.5 kg/trap) was consistent with their interpretation of DFO guidance. An in-depth review of the previously accepted 2018 framework was beyond the scope of this meeting, and these issues were not discussed in further detail.

The proposed USR was criticized for a lack of analytical support. The meeting agreed that a beta regression would be the most appropriate method for identifying a threshold that would maximize CPUE and minimize discards. The review conducted by the DFO-NL Shellfish section included a breakpoint and first derivatives analysis to compare to the visual interpretation that was proposed. That analysis indicated that the breakpoint occurred at 5.3 kg/trap, well below the suggested 8 kg/trap. It was pointed out that 7.5 kg was developed in the 2018 PA Framework as a level that would support a sustainable fishery. One researcher suggested that the CPUE-discard breakpoint analysis may be more appropriate to a LRP than an USR because it also represented the threshold over which discards were maximized. Under this interpretation, the proposed USR did not meet its own stated objective. As previously noted, the authors felt that the rationale used in the breakpoint analysis estimate should not be considered for a LRP because it did not explicitly link to serious harm to the stock.

A member of the fishery clarified that, although the 2018 PA Framework was peer reviewed and accepted, harvesters were not included in the review process, and instead the framework was presented to industry as a finished product. Harvesters felt that this exclusion was unfair and has led to the subsequent objections to the 2018 PA Framework. This participant also stated that the 12 kg/trap was not a justifiable USR. Based on that reference point, the fishery in NAFO Div. 3K has rarely entered the Healthy Zone, despite a long fishing history that harvesters perceived as healthy and sustainable. Participants from the Snow Crab industry expressed several times throughout the meeting that the 2018 framework set the USR at an unrealistically high level based on the history of the fishery. DFO scientists agreed that the USR should be informed by harvesters and reiterated that the USR recommended by the 2018 framework was not formally accepted and was meant to be reviewed, and revised if necessary, through a separate process conducted by managers and stakeholders.

Several meeting participants supported the removal reference of 0.42 and acknowledged that the previous framework relied on collapse-level logic that may not have been sufficiently conservative. The removal reference presented in the proposed alternate PA Framework aligned well with research on Snow Crab in Alaska and the Southern Gulf of St. Lawrence, where Maximum Sustainable Yield (MSY) was identified at exploitation rates of 26–42% (Siddeek et al. 2004). One reviewer suggested that simulations may identify a more appropriate exploitation rate, for example, the Gulf and the Scotian shelf have used simulations to identify lower removal reference rates (0.35 and 0.2, respectively; DFO 2018a, DFO 2018b). The working paper noted concern from the industry about wastage due to aging crab in the stock. DFO scientists clarified that this would not occur at a harvest rate of 0.42, even without accounting for natural mortality.

The review conducted by DFO Shellfish noted that the proposed alternate PA Framework lacked a HCR. Authors accepted this critique and explained that the working paper should be considered as a response to the 2018 framework meeting, which was dominated by discussion on the lower and upper reference points. Further, as per DFO policy, HCRs are to be developed at working groups with fisheries management, science, and stakeholders. The working paper also did not acknowledge the existing predictive CPUE model, while simultaneously calling for the development of such a model, and further claimed to use the best available scientific information while not including important environmental drivers (e.g., NAO index). The working paper authors reiterated that the proposal included trawl survey biomass data as part of the ERI used to develop a target removal reference. They acknowledged that the working paper did not mention the predictive CPUE model, which addressed a key harvester fishery objective as was highlighted at the consultation meetings.

There was brief discussion of the Collaborative Post-Season (CPS) trap survey. The design of the CPS survey has changed in recent years (Baker et al. 2021), and a member of industry commented that the sites he surveyed were not crab habitat and seemed irrelevant to the purpose of the survey. It was clarified that randomly stratified sites have been added to the survey, which may sometimes fall outside of optimal fishing grounds. About half of the fixed stations on fishing grounds have also been retained in the survey and will continue to inform scientists and managers who rely on these data.

There was broad support for the proposed alternate PA Framework's removal reference. Both proposals incorporated CPUE and recognized this metric as an important indicator of fishery performance, though there was significant objection to the use of raw CPUE.

The meeting agreed that there was a need and opportunity for further work to establish an appropriate USR for this stock. The 2018 framework proposed an USR that harvesters found to be unrealistically high; the proposed alternate PA Framework presented an USR that was criticized for a lack of robust supporting analysis. The meeting recommended that a revised USR should be pursued in another forum between stakeholders and managers.

Authors of the proposed alternate PA Framework reiterated that their proposed LRP was focused on $C_{Recovery}$. Again, they argued that the peer reviewed and accepted 2018 LRP was inappropriate, expressing disagreement with the proxy approaches used for determining reference points, including the applied definition of "productive period" for the stock, and the use of trap saturation as an index of biomass. This critique was not discussed in further detail, as a review of the 2018 framework was not within the scope of this meeting.

BIOLOGIAL CONTEXT FOR SNOW CRAB

Presented by Bernard Sainte-Marie (DFO-Quebec Region, Science Branch, Benthic Sciences Section)

Although not scheduled in the meeting agenda, Dr. Bernard Sainte-Marie provided a short ad-hoc presentation to provide additional context on the biology and life history of Snow Crab to facilitate discussion and consensus.

Abstract

Cohort 0 abundance from a beam trawl survey in Bay Ste. Marguerite showed high, cyclic variation (over an order of magnitude) over the 30-year time series. Cohort 0 could be tracked to legal sized male abundance on an eight year lag, indicating that there was at least nine years of growth between larval settlement and recruitment into the fishery. The long-term trend in the lagged NAO and cohort 0 abundance appeared to be similar, but the NAO did not explain the high frequency abundance oscillations that may instead be driven by smaller-scale benthic density dependent dynamics (i.e., cohort resonance). For the Newfoundland and Labrador Region, the modeled AD-specific CPUE indices (developed by DFO-NL Shellfish section) relied on a relationship to NAO but also did not fully capture the high frequency in variability represented by the peaks and troughs of standardized CPUE, for example in 2HJ. Moreover, the peaks and troughs of CPUE were not quite synchronous and may have been of different amplitudes across ADs. Thus, region-aggregated CPUE or biomass indices may not reflect well the dynamics within some ADs. The proposed alternate PA Framework for Snow Crab in the NL Region aimed to stabilize CPUE from year to year. This would require a method to control for or

attenuate the high frequency oscillations, but it was questionable whether this could be achieved through a single region-wide set of reference points and harvest control rule. This provided support for the reviewers' suggestion to develop multiple LRPs/USRs throughout the region.

Discussion

The working paper authors expressed interest in the potential of using the ratio of adult males against multiparous females as an index of reproductive capacity, to supplement or replace the egg clutch fullness metric. They also noted that the egg clutch fullness metric was not associated with an explicit HCR in the 2018 PA Framework; however, a sex ratio metric may better facilitate management decisions.

Participants discussed the earlier critique that there was no evidence that the entire region would recover from a CPUE low observed in one low-performing fishing area. This presentation noted some connectivity between the Snow Crab stock in 2J3K and in the Gulf. However, one of the co-authors disputed reviewer claims that NL Snow Crab represented a panmictic population because there was little or no exchange into 2J from upstream areas. Based on this, the author described NAFO Div. 2J as the most vulnerable fishing area in terms of potential recovery from a low biomass, low CPUE scenario.

REVIEWER REPORTS

REVIEW BY A. COOK, DFO-MARITIMES SHELLFISH SECTION

The reviewer expressed his appreciation for the work put into the alternative framework, especially the consultation with harvesters, "the natural scientists who are out on the water and tracking the resource". However, he also emphasized the guidance provided by the Precautionary Approach: a LRP must be based on scientific evidence. Socioeconomic considerations are appropriate only for the development of USRs and harvest control rules. The alternative framework, as presented, referred to control points and reference points without clear distinction, which caused some confusion. The LRP, for example, was treated as an operational control point, which was incorrect based on the Precautionary Approach. By definition, the LRP should be based on biology and has to be a safe distance below any operational control point so that there is time to take action, and for that action to take effect before the resource reaches the LRP. The USR, however, can and, in the opinion of this reviewer, should be developed based on consultation with industry.

He noted that, as discussed throughout the meeting, there were limitations to the application of raw CPUE data and noted his appreciation that the document authors agreed to move forward with the predicted CPUE. Similarly, the reviewer agreed with other meeting participants who pointed out that the lack of relationship between egg clutch fullness and CPUE was not a meaningful finding for the purpose of this work.

Again, the reviewer spoke about the value of harvester consultations and was interested in further details from this process. For example, what factors appeared to be influencing catch rates? Consultation may have been able to highlight a few common responses that could have been measured and incorporated into future model iterations.

REVIEW BY Y. CHEN, UNIVERSITY OF MAINE

The proposal had potential for further development and testing, however use of CPUEs for the LRP and USR in the proposed DMF seemed to be inconsistent with the Precautionary

Approach. While CPUE was a good metric of fishery performance, there was adequate evidence to say it was, at best, an uncertain measure of stock dynamics. Similarly, fishing mortality may not have captured the full impact as it could not capture discards and post-release soft-shell mortalities.

The proposed framework established a relationship between ERI and CPUE, which provided support for the proposed HCR. However, there was an implicit assumption that recruitment depended on the abundance of legal sized crabs; females were an important stock component with no management cues in the proposed framework.

The DMF with one set of spatially-aggregated LRP, USR, and ERI for all ADs may not have reflected the best available scientific information. This stock covers a large area with documented differences in life history across different ADs, as well as different fishery histories.

Although CPUE seemed to be correlated to some stock biological measures (e.g., survey abundance), the relationships had a lot of uncertainty, and timing and mechanisms were not well-defined and understood. More evidence was needed to conclude that the proposed framework used the best available scientific information.

The framework's ability to enable "in-season" management, would be dependent on how fast the landing data were made available for the CPUE estimation. With the evidence presented, I was not convinced that the proposed DMF enabled real-time sustainable management of the resource.

Whether the proposed DMF met the requirements of the current DFO PA Framework Policy depended on how reliable the CPUE could describe stock dynamics and how the LRP and UPR were parameterized. More evidence was needed to conclude that the proposed DMF met this requirement.

I appreciated that the alternate framework included a good foundation of stakeholder engagement and consultation, as well as general HCRs to reduce fishing intensity when the fishery indicators were not desirable. However, given the uncertainty associated with the LRP and USR (how they were defined and parameterized), more evidence was needed in order to conclude that the alternate framework would fit within the constraints of the Fisheries Act.

Discussion

External and DFO reviewers commented on the lack of a mechanism for real-time management in the proposed alternate PA Framework (i.e., decisions are based on the most recent CPUE, which tracks approximately two years behind biomass, and does not offer projection into the following year). External reviewers also raised concern that a single LRP or USR may not be appropriate for all management areas. Authors of the proposed framework reiterated that their approach relies on density (i.e., CPUE), instead of biomass estimates, which they considered to be broadly applicable throughout the region. A reviewer disagreed with that statement, noting that although CPUE is related to density, this may not be a strength of the approach. Density is highly variable under seasonal fishing pressure, and it was suggested that a comprehensive framework must also consider biomass. Further, CPUE is often treated as an index of biomass; however, it is known to be hyper stable. The proposal authors reiterated that their framework included survey biomass in the ERI and, consequently, in the target removal reference. Reviewers and participants emphasized that using the predictive model for CPUE, which incorporated biomass estimates and environmental drivers, could reduce these concerns. One author clarified that within each management area, CPUE was correlated to post-season trawl survey biomass (i.e., a local index of biomass); however, CPUE could not be treated as a direct index of biomass across management areas. The reviewer agreed but pointed out that this statement returned to the question of whether a single LRP was suitable to all management areas.

A participant explained that many harvesters hoped that a PA would be developed to fit individual fishing zones, taking into account spatial variation throughout the region. A second participant supported the recommendation to explore PA Framework development at a sub-regional level, noting that NAFO Div. 2H and 2Jn are at the edge of the management area under unique environmental conditions. This sub-region is already managed in parallel to the rest of the stock through a co-management framework with the Nunatsiavut Government. Data collected for the northern extent of the fishery are also more limited and subject to more uncertainty than the data available for the Newfoundland Snow Crab fishery further south. Another participant expressed hesitation about splitting the PA Framework by fishing area, and explained that Snow Crab biomass estimates are highly correlated throughout the region, which is made up of 45 fishing areas. Participants agreed that 40+ individual PA Frameworks may not be appropriate and/or would require a prohibitive amount of work to create and to maintain. However, many agreed that more research into the spatial variability of this stock would be a worthwhile effort. Another participant suggested that this research recommendation should not restrict further progress on a unified PA Framework or the provision of science advice in the meantime. Snow Crab in NL cover a very large stock area and spatial variation is inherent to the large extent of this population. However, it remains a single, large population, and management advice must be based on a spatial scale that is appropriate to the stock. Concerns were also raised about the spatial resolution of the data; if large datasets are split too finely, noise may overtake the signal from the stock, particularly for broad scale environmental drivers like the NAO.

REVIEW BY P. REGULAR, DFO-NL GROUNDFISH SECTION

In their working paper, the authors presented an alternate decision-making framework to the “base” approach proposed in Mullowney et al.(2018) for the Newfoundland and Labrador Snow Crab fishery. The document stated that several concerns were raised by the industry regarding the base approach and, consequently, an independent analysis was initiated. Industry-led analyses, such as the one presented in this working paper, contribute to healthy and constructive scientific discourse that aids the development of balanced management approaches. This is not only important for the successful co-management of Snow Crab, but direct engagement of fishery interests is an integral component of DFO’s decision-making framework (DFO 2009). The socio-economic considerations captured in this analysis were particularly important as objectives were outlined via consultations with the fishing industry. My general interpretations of the fishery objectives were to:

1. anticipate and avoid periods of low CPUE (<3.5 kg/trap) and high discards, and
2. maintain CPUE above 8 kg/trap.

This implied that these conditions make for an economically viable fishery. Analyses of the CPUE and discards data that were presented in the paper aligned with these upper and lower “operational reference points”. My main general concern with the proposed approach, however, was its unidimensional focus on operational reference points; the lack of biological considerations made the proposal an incomplete framework, and it left me concerned that short-term economic viability of the fishery would be prioritized over long-term sustainability. My concern stemmed from a combination of policy, analytical, and pragmatic considerations.

Policy Considerations

While it is in line with DFO policy to utilize socio-economic information to help define an USR, LRPs are to be *"based on biological criteria"* yet the authors stated that their *"CPUE-based lower limit does not…represent a biological limit reference point because it is not tied to the reproductive capacity or long-term productivity of the stock".* The authors voiced various concerns regarding the egg clutch reference point, and I got the impression that it was dismissed as a useful biological reference point; the provisional acceptance of the index was overshadowed by the concerns and research recommendations voiced in the document. One of the main reasons they cast doubt on the egg clutch index stemmed from the lack of evidence of a consistent relationship between CPUE, a presumed index of male spawning stock size, and female egg clutch proportions. Here the authors fell into a common logical fallacy of mistaking absence of evidence with evidence of absence. Of course, there is a relationship between spawning males and females; we all know it takes two. We cannot use our ignorance of the functional relationship between males and females as a reason to dismiss the importance of the interaction. Moreover, our lack of understanding of the mechanistic link between male abundance and female egg clutch proportions does not preclude the utility of the egg clutch index as a proxy for reproductive capacity. While this may be why the authors provisionally accepted the egg clutch index, superficial treatment of the index and other biological considerations left me concerned that this framework lacked a LRP with a strong biological basis. Circling back to the USR, the information presented may be useful for setting the USR, but the basis for the proposed USR could be stronger. For instance, the economics of the fishery could have been analyzed to assess whether fishing at 8 kg/trap was economically viable. The answer to this question may be obvious to those involved in the industry, but it should be documented. Also, more rigorous analyses could have been conducted to assess the level at which discard rates are kept below a desirable threshold (i.e., use a beta regression to determine the CPUE level at which there is a low probability that discards would exceed 20%). Under the analysis presented, there was no objective basis for the proposed 'breakpoint'.

Analytical Considerations

Complete reliance on CPUE is risky for several reasons. First, it is well known that CPUE is an imperfect indicator of biomass and several stocks have suffered from the "illusion of plenty" effect associated with CPUE indices (e.g., Rose and Kulka 1999; Erisman et al. 2011). Second, there is an unrealistic level of precision associated with CPUE and, as such, the status of the stock would be known with near perfect precision rendering evaluations of risk moot. Third, there is a risk that this framework would be slow to respond to important changes as the CPUE index is lagged one to two years behind the exploitable biomass index (Mullowney et al. 2020). These issues circle back to DFO policy, which clearly states that uncertainty and risk be explicitly considered in the decision-making framework. Analytical assessment models are typically used to assess uncertainty around metrics such as Spawning Stock Biomass (SSB); however, in the absence of measures of uncertainty from a model, structural uncertainties of a framework could be accounted for, to a degree, using an ensemble-like approach (e.g., the base framework).

Pragmatic Considerations

Based on the summary of the consultations, the industry expressed a desire to have a framework that included methods for anticipating and avoiding periods of low CPUE and high discard rates. The undesirable periods identified through the consultations were clear to see in the indices presented in the paper; however, the authors did not clarify how their analysis would aid the prediction of future undesirable states. I suspect the lack of clarity around this issues is related to the reliance on mean CPUE values. While means are fine for historical summaries, the ability to anticipate future conditions requires more biological and ecological considerations. Research-to-date highlights the importance of environmental variables on the trajectory of the stock and, by accounting for this, Mullowney et al. (2018) was able to predict future states of the stock and the fishery. Such projections are useful for proactively triggering actions to avoid serious harm, moreover, they facilitate a predictable business environment that fishery participants seek. By lacking any predictive methods and by focusing on CPUE, which is known to be a lagged index of biomass, decisions made under the proposed framework are bound to be reactive rather than tactical.

In summary, I believe this proposed framework has some merit and the perspectives within are valuable. However, more biological considerations are required for defining a LRP and the basis for the proposed USR could be strengthened. As is often the case, such problems can be resolved by collaboration, and I am hopeful that the eventual decision-making framework for Snow Crab will combine scientific and industry knowledge to implement management measures that encourage both a healthy fishery and stock.

REVIEW BY M. KRKOSEK, UNIVERSITY OF TORONTO

The working paper attempted to address harvester concerns of over- and under-harvesting and the stability of the fishery. However, the risks of harvesting levels were not formally characterized. For example, allowable level of softshell/undersized discards; allowable level of wastage from old and deteriorated catch; and the range of CPUE and ERI that match these thresholds. The working paper authors and the 2018 PA Framework authors do not use the same datasets and do not agree upon how to include and account for environmental variation or how to connect biomass surveys with CPUE. Models are needed to analyze uncertainty in parameter estimates, variation in risk tolerance, population biology of mate limitation and dispersal, and how to find breakpoints. A management strategy needed to be developed to analyze the models and quantify the risks in relation to the aforementioned uncertainties. The working paper used raw CPUE as a proxy for discards, but I would have rather seen a model that characterized the discard rate in relation to a threshold or target.

The concept of a ‘recovery’ LRP was problematic in relation to dispersal and panmictic population structure. In this context, local recruitment was considered to be from immigration from other ADs and was independent of local abundance or CPUE unless there was some cultivation effect. If recovery in an AD was impaired it could not be discerned whether it was the result of a broader stock failure or due to an AD-level threshold. It assumes that if other areas were healthy, local recovery would have always occurred irrespective of a temporary local low CPUE. A local recovery LRP was likely to not catch problems until later in a broader stock decline.

The working paper’s reference to recovery from 2.5 in AD 3Ps in 2016 was not reliable. The time period (two recovery points) was too short and well within natural variability of the time series to maintain recovery trajectory (e.g., AD 3K in 2011 and afterwards) and too short to measure recovery relative to the lifecycle of the crabs. The uptick seen in the data was due to recruitment from spawners at abundances preceding the 2016 low by several years.

The proposed USR was based on input from harvester surveys of desired stable fishing rate and sought to avoid wastage from softshell and aged/deteriorated catch and support sustainability and avoid low CPUE situations – 3.5 kg/trap. The idea that 12.5 kg/trap USR was unrealistically high was consistent with few CPUE levels in that range. Wastage via aging and deterioration of some individuals could be quantified with respect to ERI. The issue of hyperstability in the relationship of CPUE with biomass should be incorporated.

With regards to the proposed removal reference point, it was not clear how 0.42 was determined. This dCPUE looked at year-to-year CPUE so effects of ERI would have been on recruitment in the next year, but it should have also look at lagged dCPUE over generation timeline (if recruitment was local). It also led to the question of what the predicted size/age composition of the catch would be at different ERIs.

The proposed DMF incorporated new data from surveys of harvesters while analyzing raw CPUE and other data provided by DFO, but was missing some important data from its analyses (e.g., NAO and survey data). Models that corrected for NAO, connected to survey data, and had high prediction capacity were not used. In the context of the framework using a biological basis for assessment of the resource, egg clutch fullness was provisionally accepted as an indicator. Improvements for real-time management could have been made by including models and survey data that had high lag-correlation with CPUE and therefore provided valuable information for real-time management. The proposed alternative framework's ability to meet the requirements of the current DFO PA Framework Policy and fit within constraints of the Fisheries Act and strategic directions of DFO could not be evaluated.

Discussion

There was still some confusion about the working paper's perceived rejection of survey data, generally, and egg clutch metric specifically. Working paper authors reiterated that survey data were not rejected, and were used to develop the removal reference, which would be the basis of the HCR. As noted above, per DFO policy, HCRs are to be developed by DFO managers in consultation with stakeholders and with advice from DFO Science. The working paper authors also stated that the egg clutch metric was "provisionally accepted" in the proposed alternate PA Framework. Authors explained that they considered egg clutch fullness to be a high-level management consideration, not the basis for a reference point. However, meeting participants found these answers inconsistent with the working paper. No application of the survey data was presented in the development of reference points; however, the removal reference was based on the ERI, which was survey-based. The meeting agreed that the removal reference based on an ERI of 0.42 was an improvement on the previously recommended removal reference. The working paper argued against the relevance of the egg clutch metric based on the lack of a clear relationship between egg clutch fullness and raw CPUE, an argument that reviewers rejected. Based on the working paper, which was what the meeting was tasked with reviewing, the survey data and egg clutch metric were not included in the proposed framework in any meaningful way. Proposal authors reiterated that survey data were included in the ERI and, consequently, the target removal reference that was accepted by all reviewers.

CONCLUSIONS

REVIEW OF DATA SOURCES

The FFAW conducted consultations with Snow Crab harvesters from southern Labrador and from the southern and eastern coasts of Newfoundland to gather information on their fishery objectives and on catch rates that harvesters considered to be healthy or that should be avoided. It was agreed that this information could be useful in helping to establish an Upper Stock Reference Point (USR) and Harvest Control Rule (HCR), especially with some additional work to include an analysis that quantifies the risk tolerances and the probability of meeting or exceeding those thresholds. The meeting acknowledged the importance of these efforts and ongoing engagement of the fishing community and other stakeholders regarding the PA Framework for NL Snow Crab.

All other data sources considered in the alternate PA Framework were provided by DFO Science. The alternate PA Framework focused on the use of raw annual mean catch per unit effort (CPUE) to set operational reference points (Upper and Lower) and used the exploitation rate index (ERI) to develop a target removal reference. The ERI was calculated as annual landings divided by the survey biomass estimate of the previous year and represents the level of fisheries-induced mortality imposed on the resource each year. This estimate differs from that used in DFO Science's 2018 PA Framework, which was calculated as annual landings divided by the previous two-period moving average survey biomass estimate (Mullowney et al. 2018).

Raw annual mean CPUE was used in the alternate PA Framework because it was considered by the working paper authors the most appropriate metric for developing relationships with discarding, as it reflects annual changes in fishing practices. However, concerns were expressed by participants about using the raw CPUE in developing reference points, as this index has been demonstrated to be positively biased and lag 1–3 years behind the current survey-based biomass estimates and, therefore, represents past exploitable biomass rather than current exploitable biomass. In addition, raw CPUE does not take into account environmental factors and spatial dynamics of the resource. For example, concern was expressed that the alternate framework did not incorporate environmental factors such as the North Atlantic Oscillation (NAO) which has been shown to influence Snow Crab.

It was acknowledged that model prediction of future CPUE based on survey and environmental information, as described in DFO Science's 2018 PA Framework, would represent an appropriate index of stock status and basis for a HCR. The 2018 PA Framework's usage of predicted CPUE was considered by most meeting participants to be consistent with harvesters' emphasis on the importance of understanding incoming recruitment for management of the NL Snow Crab fishery. However, working paper authors expressed a preference for using "direct information" (i.e., raw data, not modelled values) whenever possible.

The ERI was generally considered to be an appropriate index to support the development of a proxy F- (fishing mortality) based removal reference, and there was support for the proposed approach. Moreover, because the ERI is based on survey biomass estimates, the alternate framework was not limited to information from the fishery. Concern was expressed that the ERI did not capture all sources of mortality including discard mortality.

MEETING OBJECTIVES

The reference point methodologies and proposed approaches for the identification of reference points were reviewed within the context of the following questions:

Does the alternate framework use the best available scientific information?

While the alternate PA Framework used valid information provided by DFO Science, the meeting agreed that it did not use the most appropriate CPUE series, did not make use of survey data or environmental information to determine stock status, and lacked a HCR based on predictive modelling. It also did not use appropriate analytical methods to establish the USR. The alternate PA Framework did, however, use survey data, specifically the ERI, to estimate a removal reference, which would be the basis of a HCR.

Does the alternate framework use a biological basis for assessment of the resource?

The alternate PA Framework proposed adoption of the 2018 egg clutch index and associated reference points provisionally while adjustments to reference point levels or alternative metrics (and associated reference points) are explored. However, the egg clutch index was not formally integrated into the final determination of stock status or a HCR.

Does the alternate framework enable sustainable management of the resource?

The primary concerns with the ability of the alternate PA Framework to enable sustainable management of the resource were:

- The alternate framework's assessment methods did not reflect the current status of the stock and did not take into account important predictive factors (such as environmental conditions and incoming recruitment); meeting participants felt that it better reflected the status of the fishery rather than the status of the stock.
- The alternate PA Framework's definition of recovery and recovering was unclear (i.e., it was unclear whether 3Ps Snow Crab was considered recovered in the alternative framework).
- There was concern with using a single CPUE-based LRP across all assessment divisions (ADs), given variability in the spatial dynamics of the population. Several meeting participants expressed that AD specific LRPs may be appropriate.
- The proposed LRP (3.5 kg/trap haul) may be too low to protect the stock from risk of serious and irreversible harm.

As currently proposed, the alternate framework was considered incomplete and unlikely to support sustainable management of the NL Snow Crab resource.

Does the alternate framework meet the requirements of the current DFO PA Framework Policy?

The alternative framework did not meet the requirements of the DFO PA Framework Policy.

Does the alternate framework fit within constraints of the *Fisheries Act* and strategic directions of the Department?

As discussed above, the meeting felt that the alternate PA Framework (e.g., without an explicit HCR) did not reflect the strategic direction of the Department (e.g., ecosystem considerations).

OTHER CONSIDERATIONS

Concerns were clearly expressed by the fishing industry about the current USR, which they considered to be unrealistically high for some areas, with three of five ADs having rarely been considered healthy throughout the history of the fishery.

Upon discussion, the authors agreed that the predicted CPUE model, as described in DFO Science's proposed 2018 PA Framework (and updated at subsequent stock assessments), did address some of the key considerations highlighted by harvesters during consultation meetings and should be used as the basis of a tool for implementing a HCR in a complete framework.

RECOMMENDATIONS

FRAMEWORK RECOMMENDATIONS

Participants agreed that CPUE was an important and useful metric for this stock; however, raw CPUE had some significant limitations for application to management decisions (e.g., temporal lag, hyperstability). Predicted CPUE for Snow Crab in the NL Region was based on an analytical model that incorporated survey and environmental variables. Upon discussion, the meeting agreed that future framework development should use modeled CPUE.

The meeting agreed that the proposed alternate PA Framework provided a useful removal reference that was well-supported by the data and literature, and that this reference should be carried forward to an accepted PA Framework with some minor revisions. For example, the relationship between ERI and CPUE was measured as absolute change in CPUE; reviewers and authors agreed that it would be more appropriate to measure percent change from year to year. It was also suggested that simulations should be employed to test removal rates, that other sources of mortality should be integrated into the reference value, and that authors should address the uncertainty around the contribution of adolescent crab to the subsequent year's fishery.

There was substantial discussion about the 2018 PA Framework, specifically the USR, which harvesters identified as an unrealistic threshold based on their experience with the fishery. The Chair and participants agreed that a scientific peer review was not the appropriate forum to re-evaluate the 2018 PA Framework, or to raise specific concerns regarding an USR or HCR. Unlike the LRP, the USR and HCR are not established by Science and may consider socio-economic issues as managers and stakeholders deem necessary. These issues should be addressed in a separate process that includes harvesters and managers.

A Management Strategy Evaluation (MSE) was suggested for future work to help quantify the probabilities associated with meeting targets and exceeding risk tolerance thresholds. MSE could also be used to evaluate the performance of alternative reference points and potential impacts of a changing climate.

RESEARCH RECOMMENDATIONS

It was suggested that consideration of spatially-based reference points may be warranted to account for differences in productivity, growth, and recruitment in the different areas. It was considered important to ensure the usage of spatial scales that are appropriate both in terms of the biology/ecology of Snow Crab and the decisions that the Department are trying to support. Participants believed this was worth pursuing in the future, but the absence of this should not limit the ability to provide information and advice during the annual NL Snow Crab assessment peer review process.

REFERENCES CITED

Baker, K., Mullowney, D., Pedersen, E., Coffey, W., Cyr, F., and Belanger, D. 2021. An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2018. DFO Can Sci Advis Sec Res Doc. 2021/028. vii + 180 p.

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can Sci Advis Sec Sci Advis Rep 2006/023.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach. Fisheries Management. Government of Canada.

DFO. 2018a. Assessment of Nova Scotia (4VWX) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/046.

DFO. 2018b. Assessment of snow crab (*Chionoecetes opilio*) in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F) to 2017 and advice for the 2018 fishery. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/007.

DFO. 2019a. Proceedings of the Regional Peer Review for Development of a Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region; June 6-7, 2018. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2019/016.

DFO. 2019b. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2019/041.

DFO. 2020. Proceedings of the Newfoundland and Labrador Regional Peer Review of the 4R Iceland Scallop Assessment, and the 2HJ3KLNOP4R Snow Crab Assessment; February 19-21, 2019. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2020/003

Erisman, B.E., Allen, L.G., Claisse, J.T., Pondella, D.J., Miller, E.F., and Murray, J.H. 2011. The illusion of plenty: hyperstability masks collapses in two recreational fisheries that target spawning aggregations. Can. J. Fish. Aquat. Sci. 68(10): 1705–1716.

Mullowney, D., Coffey, W., Baker, K., Evans, G., Fiander, D., Colbourne, E., Maddock Parsons, D., Koen-Alonso, M., and Wells, N. 2017. An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2016. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/081. viii + 172 p.

Mullowney, D., Baker, K., Pedersen, E., and Osborne, D. 2018. Basis for A Precautionary Approach and Decision Making Framework for the Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) Fishery. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/054. iv + 66 p.

Mullowney, R.J., Baker, K.D., and Pederson, E.J. 2020. Harvesting strategies during a forecasted decline in the Newfoundland and Labrador snow crab fishery. Fish. Res. 232: 105707.

Mullowney, D.R.J., and Baker, K.D. 2020. Size-at-maturity shift in a male-only fishery: factors affecting molt-type outcomes in Newfoundland and Labrador snow crab (*Chionoecetes opilio*). ICES J. Mar. Sci. 78(2): 516–533.

Ogburn, M.B. 2019. The effects of sex-biased fisheries on crustacean sex ratios and reproductive output. Invert. Rep. Develop. 63(3): 200–207.

Rose, G.A., and Kulka, D.W. 1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased as the northern cod (*Gadus morhua*) declined. Can. J. Fish. Aquat. Sci. 56(S1): 118–127.

Sainte-Marie, B., Sevigny, J-M., and Carpentier, M. 2002. Interannual variability of sperm reserves and fecundity of primiparous females of the snow scrab (*Chionoecetes opilio*) in relation to sex ratio. Can. J. Fish. Aquat. Sci. 59(12): 1932–1940.

Siddeek, M.S.M., Sainte-Marie, B., Boutillier, J., and Bishop, G. 2004. Comparison of reference points estimated using a size-based method for two high-latitude crab species in the United States and Canada. Can. J. Fish. Aquat. Sci. 61: 1404–1430.

APPENDIX I – TERMS OF REFERENCE

Review of an Alternate Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region

Regional Peer Review – Newfoundland and Labrador Region

September 24-25, 2020
St. John's, NL

Chairperson: Tana Worcester

Context

The Precautionary Approach (PA) is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty. The application of precaution requires increased risk avoidance where there are risks of serious harm and high uncertainty to aquatic resources. These conditions often apply in fisheries; therefore, precaution should be incorporated in fisheries management.

Canada is committed domestically and internationally to the use of PA in fishery decision-making. Over the last few years, there have been several initiatives in Canada to define the PA in context of exploited fisheries resources, to identify benchmarks that would be consistent with the approach and to apply it in fisheries management. The fundamental principles guiding this approach have been outlined in two key documents produced by Fisheries and Oceans Canada (DFO):

(i) The 2006 Science Advisory Report that identifies the minimal requirements for harvesting strategies to be compliant with the PA (DFO 2006); and

(ii) The 2009 Decision-Making Framework Incorporating the Precautionary Approach (DFO 2009) - a policy document to guide the incorporation of PA principles in the management of Canadian fisheries.

To be compliant with the PA, fisheries management plans should include harvest strategies that incorporate a science-based Limit Reference Point (LRP) along with an Upper Stock Reference (USR), reflecting stock status, and removal reference points to guide harvest rates. It is expected that the management decisions should respect the indicated actions in each of the stock status zones (i.e., Healthy, Cautious, and Critical) in relation to these points.

A 'PA Framework' combines the philosophy of precaution in resource management with identified prescriptive measures for stock health and explicit actions for stock management dependent upon stock status. At present in DFO managed fisheries resources, PA Frameworks are applied at an individual stock level. Once implemented, DFO will use the PA Framework for NL Snow Crab to maintain/revise current management approaches and to inform its decisions, including with an intended element of robust and testable harvest control rules. Advice will be shared with fish harvester committees, processors, Indigenous organizations, and the Government of Newfoundland and Labrador to make informed recommendations on the Total Allowable Catch and related fisheries management measures.

Following the peer-review and approval of the decision-making PA Framework for Snow Crab in the Newfoundland and Labrador Region developed by DFO Science in June 2018 (DFO 2019, Mullowney et al. 2018), the Fish and Food Allied Workers Union (FFAW) developed an alternate/revised framework. It has been suggested that the adoption and application of this revised framework will facilitate agreement on annual management decisions.

The September 2020 CSAS process will review the alternate framework developed by the FFAW and determine if it can be used entirely or in part to better inform the Department in terms of a way forward prior to implementing a PA Framework for the management of the Snow Crab resource. The peer review meeting will determine if the alternate FFAW framework:

(i) meets the requirements of the DFO PA Framework Policy;

(ii) uses the best available scientific information; and

(iii) provides a scientifically defensible alternative approach.

Objectives

The key objectives of this meeting are to review the proposed FFAW's framework for the Newfoundland and Labrador Snow Crab stock.

Specifically, the following objectives have been set:

- Review sources of data used in the proposed PA.
- Review reference point methodologies and proposed approaches for the identification of reference points within the context of the following questions:
    - Does the alternate framework use the best available scientific information?
    - Does the alternate framework use a biological basis for assessment of the resource?
    - Does the alternate framework enable real-time sustainable management of the resource?
    - Does the alternate framework meet the requirements of the current DFO PA Framework Policy?
    - Does the alternate framework fit within constraints of the *Fisheries Act* and strategic directions of the Department?

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Expected Participation

Consistent with the participation guidelines for Canadian Science Advisory Secretariat (CSAS) processes, attendance is by invitation only.

To contribute materials and analyses and to assist in the framework review, participation is expected from:

- DFO Science and Resource Management Branches
- Department of Fisheries and Land Resources
- Fishing Industry
- Indigenous Groups
- Academia
- Other experts as deemed necessary

References

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach.

DFO. 2019. Proceedings of the Regional Peer Review for Development of a Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region; June 6-7, 2018. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2019/016.

Mullowney, D., Baker, K., Pedersen, E., and Osborne, D. 2018. Basis for A Precautionary Approach and Decision Making Framework for the Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) Fishery. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/054. iv + 66 p.

Suggested Additional Reading

Cox, S.P., and Kronlund, A.R. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia Canada. Fish. Res. 94: 224–237.

DFO. 2021. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) Snow Crab. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/009.

APPENDIX II – AGENDA

CSAS Regional Peer Review Process: Review of an Alternate Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region

Chair: Tana Worcester, DFO Science – Maritimes Region

While the agenda is flexible, the tentative meeting schedule is as follows:

- 10:00 am - 12:00 pm
- 1:00 pm - 3:00 pm
- 3:30 pm - 5:00 pm

Day 1 - September 24, 2020

Time	Activity	Presenter
10:00 am	Introduction	Chair
-	Opening remarks and context	B. Healey and M. Henri
-	Presentation: A Modified Decision-Making Framework for the Newfoundland and Labrador Snow Crab Fishery	E. Carruthers and E. Dawe
-	Presentation: DFO Shellfish Science Review of FFAW Precautionary Approach Proposal For NL Snow Crab Management	D. Mullowney
-	Discussion	ALL
-	Reviewer Reports	P. Regular, A. Cook, Y. Chen, and M. Krkosek

Day 2 - September 25, 2020

Time	Activity	Presenter
10:00 am	Summary of Day 1	Chair
-	Follow-up on outstanding items	ALL
-	Conclusions on Terms of Reference objectives and drafting of summary bullets	ALL

Time	Activity	Presenter
-	CSAS Next Steps	E. Parrill
-	Closing remarks	Chair

APPENDIX III – LIST OF PARTICIPANTS

NAME	AFFILIATION
Dale Richards	Centre for Science Advice – NL Region
Erika Parrill	Centre for Science Advice – NL Region
Tana Worcester	Centre for Science Advice – Maritimes Region
Emilie Novaczek	DFO Science – NL Region
Rod Drover	DFO Communications – NL Region
Martin Henri	DFO Resource Management – NL Region
Brian Healey	DFO Science – NL Region
Darrell Mullowney	DFO Science – NL Region
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Derek Osborne	DFO Science – NL Region
Elizabeth Coughlan	DFO Science – NL Region
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Nancy Pond	Department of Fisheries and Land Resources

NAME	AFFILIATION
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Earl Dawe	Fish, Food and Allied Workers Union
Erin Carruthers	Fish, Food and Allied Workers Union
Alton Rumbolt	Fish, Food and Allied Workers Union r
Andrew Daley	Fish, Food and Allied Workers Union
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Dennis Chaulk	Fish, Food and Allied Workers Union
Trevor Jones	Fish, Food and Allied Workers Union
Rob Coombs	NunatuKavut Community Council
Ron Johnson	Torngat Fish Coop
Aaron Dale	Torngat Secretariat
Yong Chen	University of Maine
Marty Krkosek	University of Toronto

APPENDIX IV – WORKING PAPER

Note that the attached Working Paper is appended in its original draft form as submitted prior to the peer review process, as requested by meeting participants.

A Modified Decision-Making Framework for the Newfoundland and Labrador Snow Crab Fishery

E.G. Dawe and E.H. Carruthers

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Abstract

This paper proposes a modified decision-making framework (DMF) for Newfoundland and Labrador (NL) Snow Crab (*Chionecetes opilio*) as a more practical framework than an initially proposed (base) DMF. The current DMF is generally similar to the base framework, having been developed by building upon the strengths of the base DMF. Both DMFs include a first-level set of biological reference points (RPs) based on an egg clutch index and a primary operational framework with catch per unit effort (CPUE) as the stock index and a survey exploitation rate index (ERI) as the removal reference. One major difference is that the base DMF includes a third metric with RPs based on an index of the percentage of crabs released or 'discarded' in the fishery. This metric was not included in the current DMF, but rather the data on percent discarded were used in relation to CPUE to determine an Upper Stock Reference (USR) that minimizes wastage due to discarding. The second major difference between the DMFs relates to methods used to determine RPs and their resultant estimates; limit and upper RPs were higher in the base framework (5.0 and 12.6 kg/trap respectively) than in the current framework (3.5 and 8.0 kg/trap respectively). The base framework used a suite of generic approaches to determine RPs whereas the current framework used the most appropriate scientific data available together with information from the fishing industry. Accordingly, we conclude that the currently proposed modified DMF is the more appropriate operational framework.

Introduction

Decision Making Frameworks And The Precautionary Approach

A decision-making framework (DMF) that includes an index of stock status and pre-agreed management actions linked to stock status is a key component of sustainable fisheries management and is required by both international and Canadian fishery policies. Canada, in 2001, committed to using the Precautionary Approach (PA) in managing both straddling and domestic fishery resources as a signatory to the United Nations Agreement on Straddling and Highly Migratory Fish Stocks (DFO 2009). Fisheries and Oceans Canada (DFO), in 2006, outlined the minimal requirements, from a science perspective, for a harvest strategy to be compliant with the Precautionary Approach (DFO 2006). DFO subsequently provided more detailed guidance for the development of such a decision-making framework that incorporates the precautionary approach. (DFO 2009). The basic elements of such a DMF includes the establishment of reference points relative to some index of stock status and some removal reference as a basis for harvest control rules. The Limit Reference Point (LRP) represents a threshold below which there is potential for serious or irreversible harm to the stock, while the Upper Stock Reference (USR) represents a threshold above which the stock is considered to be in the Healthy Zone.

Reference points and associated zones are a statement of desirable (Healthy) and undesirable (Cautious and Critical) stock status (Shelton 2017), whereas the harvest control rules represent a set of pre-agreed upon management decisions meant to: 1) ensure a low risk of irreversible harm to the stock; 2) return the stock to the Healthy Zone (promote rebuilding); and, ideally, 3) maintain the stock in the Healthy Zone. When DMFs are developed based on productivity measurements appropriate for the stock (DFO 2009), reflect the history of the stock (Hilborn and Stokes 2010; Shephard et al. 2019), and account for uncertainty in both available data and implementation (DFO 2009; Cox et al. 2013), these frameworks facilitate and support successful and sustainable fisheries management. DFO policy (2009) states that "producing a workable decision framework for a fishery will require the participation of fishery interests in all aspects of the process to develop a framework". One of the challenges then is to not only develop management approaches that meet biological, conservation and fishery objectives, but to also use metrics that allow for engagement of fishery interests (e.g., Caddy et al. 2005; Cox et al. 2013).

Recent work to develop PA-compliant management plans for Canadian stocks in the Pacific Region make a distinction between biological reference points and operational control points, with biological reference points based on the biology of the species and/or theoretical considerations (e.g., Forrest et al. 2018) and operational control points based also on an understanding of data availability and stock assessment limitations, and on fishery objectives for that stock (e.g., Cox et al. 2013). Some DMFs include both types of reference points with the operational RPs representing triggers for management action above some crucial biological reference point, such as the LRP. Such an approach may facilitate addressing concerns for biological harm while also having clear pre-agreed operational RPs for fisheries managers and fishery interests.

Biological reference points are typically related to the life history of species, with the LRP identified as the point below which serious or irreversible harm may be affecting the stock (DFO 2009), with recruitment overfishing generally agreed to constitute serious harm (Shelton and Rice 2002). Stock status is often expressed relative to an index of SSB while the removal reference and harvest control rules are often based on an index of fishing mortality. However, DFO policy clearly states that the development of reference point should be appropriate for the species and stock, and could include catch rate indices, size and age profiles of the catch or empirical measurements of reproductive potential (DFO 2009). In the case of crustacean fisheries, lack of evidence of clear stock-recruit relationships and complex mating systems may mean that SSB-type reference points are not appropriate (e.g., Smith et al. 2012).

Decision-making frameworks that incorporate the Precautionary Approach, have been developed for the management of many Canadian fishery resources, including two Atlantic Snow Crab (*Chionecetes opilio*) resources. The DMF for southern Gulf of St. Lawrence (sGSL) Snow Crab includes reference points determined relative to a trawl survey index of mature male Snow Crab (DFO 2010, 2012), based on the assumption that large mature males are important to mating success, female insemination rate and ultimately maintaining reproductive capacity. The DMF for Nova Scotia (NS) Snow Crab includes reference points established in relation to estimated carrying capacity of the ecosystem (DFO 2017).

There is, as yet, no DMF in place for NL Snow Crab, but a basis for such a framework was developed by Mullowney et al. (2018a) and peer-reviewed at a science advisory meeting during June 6-7, 2018 (DFO 2019c). This base framework consisted of three components or metrices (egg clutch, catch per unit effort (CPUE) and percent discarded), each with an LRP and USR. However, we feel, in hindsight, that the peer review, including our contributions, was not sufficiently rigorous and concerns remain. There was limited participation by the fishing industry in the development and review of the base framework. Snow Crab harvesters are concerned that the base framework was impractical because it did not reflect the history of the fishery, with unnecessarily high levels of both the LRP and the USR. Harvesters were particularly concerned by the discard-based RP because high levels of discarding represent both an undesirable fishery state and an indicator of imminent increase in recruitment to the fishery. These concerns were expressed at a meeting of a working group on the Snow Crab PA in February 2019. Subsequent to that meeting, it was agreed that industry would develop a proposal for an alternative or modified framework. DFO Science Branch agreed to co-operate in this initiative by providing all required data series.

The development of a modified DMF included extensive consultation with Snow Crab harvesters, during which there was discussion of Snow Crab biology, the DFO Sustainable Fisheries Policy and the requirements of a DMF consistent with DFO's Precautionary Approach Framework, as well as discussion of sustainable fishery objectives from the fleets. In this paper, we first review Snow Crab biology, as well as the fishery and its management in the Newfoundland and Labrador region. We then outline the approach we took to develop our framework and we present the details of its parameter estimates as well as its application to all assessment divisions (ADs). We go on to provide a direct comparison between the base framework and the modified framework proposed here and we recommend research required to support sustainable fisheries management of the NL Snow Crab fishery in general and the application of a PA compliant DMF in particular.

Snow Crab Life Cycle and Biology

Snow Crab is a circumpolar species that supports commercial fisheries in the North Pacific and North Atlantic oceans. In the northwestern Atlantic, Snow Crab fisheries are prosecuted on the Newfoundland and Southern Labrador Shelf, in the Gulf of St. Lawrence, and on the eastern Nova Scotian shelf. A population genetics study showed that all northwest Atlantic Snow Crab resources constitute a single panmictic population (Puebla et al. 2008). Snow Crab is a stenothermic cold-water species (Foyle et al. 1989). On the Newfoundland-Labrador (NL) shelf and slope it inhabits waters of about -1.5 to 4°C at depths ranging about 50-1400 m (Dawe and Colbourne 2002, Dawe et al. 2012).

The Snow Crab life cycle begins when females release larvae in spring, mainly April-June in the southern Gulf of St. Lawrence (Sainte-Marie 1993). Larvae rise to the surface layer and are advected by surface currents, progressing through three larval stages until they settle in cold shallow bottom waters in the fall. (Kon 1980, Elner and Beninger 1992, Dionne et al. 2003) Following settlement crabs undergo an ontogenetic migration moving from cold shallow waters to warm deeper waters (Lovrich et al. 1995, Dawe and Colbourne 2002, Mullowney et al 2018b). As a result, largest crabs tend to be distributed mostly in the deeper warmer waters with soft mud substrate while smallest crabs are most commonly found in cold shallower areas with hard substrates on the NL shelf (Dawe and Colbourne 2002, Mullowney et al. 2018b).

Growth in Snow Crab, as in other crustaceans, is discontinuous, or step-wise, due to molting. Crabs initially molt several times per year until they attain a size of about 40 mm carapace width (CW), after which they molt once per year (Sainte-Marie et al. 1995) until the final molt of life, known as the 'terminal molt' (Conan and Comeau 1986, Dawe et al. 1991). The size at terminal molt differs between the sexes resulting in strong sexual dimorphism. The female terminal molt represents the molt to maturity, which occurs across a post-molt size range of about 35-70 mm CW at NL (Dawe et al. 2012, Dawe and Mullowney 2016). Males achieve sexual maturity at about 40 mm CW (termed 'adolescent') but they may continue to molt and grow to much larger sizes (Sainte-Marie et al. 1995). The terminal molt in males may occur across a broad post-molt size range of about 40-140 mm CW at NL (Dawe et al. 2012, Dawe and Mullowney 2016). The male terminal molt (to 'adulthood') is associated with the development of enlarged chelae which confers an advantage to these terminally-molted ‘adults’ in competing for mates (Sainte-Marie et al. 2008) as well as access to baited traps (Winger and Walsh 2011). As a result of this sexual dimorphism females do not achieve the minimum legal size of 95 mm CW for recruitment to the fishery (Dawe and Mullowney 2016).

In Canadian waters, molting of adolescent males (larger than 40-50 mm CW) occurs during March-June (Moriyasu et al. 1998; Comeau and Conan 1992; Sainte-Marie and Hazel 1992; Sainte-Marie et al. 1995; Hoenig et al. 1994, Fonseca et al. 2008). Some adolescents will continue to molt and grow to achieve the minimum legal size of 95 mm at about 9 years of age or more (Sainte-Marie et al. 1995). Some males achieve this post-molt minimum legal size as adolescents and will molt one more time to become very large adults, especially in warmest areas because size at terminal molt is directly related to temperature (Dawe et al. 2012). Adult males are soft-shelled and vulnerable for some time after the terminal molt, with shell hardening and tissue growth requiring at least 5-6 months. (Godbout et al. 2002; Hebert et al., 2002). These soft-shell crabs are not desirable in the fishery due to low meat yield and are not retained such that they actually recruit to the fishery, as hard-shelled crabs with high meat yield, the year following their terminal molt at 10 years of age or older. Capture, handling, and release (‘discarding’) of delicate recently-molted soft-shelled crabs is thought to represents a substantial source of mortality (Miller 1977; Hardy et al. 1994, Dufour et al. 1997, Grant 2003, Dawe and Mullowney 2016, Mullowney et al. 2018a). Age at recruitment may be considerably older than 10 years of age, especially in coldest areas (such as the northern Grand Bank, NAFO Division 3L), because males may fail to molt in any year (‘skip-molters’) and the frequency of skip-molting is inversely related to temperature (Dawe et al. 2012). Adult males may live for about 5-8 years following the terminal molt, depending on their physical condition, such as extent of limb loss (Fonseca et al. 2008). They remain attractive to markets for about 3-4 years before carapace ageing and fouling render them undesirable (Fonseca et al. 2008).

Snow Crab mating systems are complex, as detailed by Sainte-Marie et al. (2008). Mating takes place in winter-spring and may be highly competitive depending on sex ratio and mate availability. The mating season is separated into two spatially and temporally distinct periods associated with two stages of mature females; primiparous vs. multiparous females. Primiparous females are females that recently terminally molted to maturity and are reproducing for the first time, in soft-shelled condition. In some cases, males guard sexually mature females, assisting them in molting before mating them in post-molt soft-shelled condition. Multiparous females are hard-shelled repeat-spawners that must release larvae from their egg clutch before mating again. Primiparous females mate during December-March whereas multiparous females mate later and at greater depths (Lovrich et al. 1995; Dawe and Colbourne, 2002). initially releasing larvae in synchrony with the spring bloom (Starr et al. 1994, Sainte-Marie et al. 2008) and then mating within a few weeks while aggregated into high-density patches or mounds; Sainte-Marie et al. 2008). Therefore, the distribution of multiparous mating is concentrated in both space and time. Based on this temporal and spatial segregation it is assumed that all adult males mate with both stages of mature females such that the operational sex ratio (OSR; the ratio of receptive males to receptive females at one spawning time and location) is higher than in a scenario of a single breeding period for both female stages. Also, the broadly dispersed distribution of pubescent-primiparous females results in an OSR that is higher than that associated with the highly concentrated distribution of multiparous females. This results in strong male competition in mate selection during pubescent-primiparous mating whereas mate selection by females is more pronounced in multiparous mating (Sainte-Marie et al. 2008).

Largest adult males are most important in mating overall, especially in cases of strongly female-biased sex ratios. However, participation by smaller adult males increases when abundance of largest adults is reduced, whether due to fishing or natural causes (Ennis et al. 1990). There is little evidence of successful mating by adolescent males of any size and it remains uncertain whether these physiologically mature males are actually 'functionally mature' (Conan and Comeau 1998, Sainte-Marie et al. 2008). First-time spawning females and large adolescent and mature males undertake a seasonal migration to shallower waters in spring for molting (females and adolescent males) and mating (Mullowney et al. 2018b).

Mating is polyandrous (Sainte-Marie et al. 2008) with both sexes having multiple mates in any mating season. Under a female-biased sex ratio, males may allocate sperm among many mates such that some females may be sperm-limited, resulting in only partial fertilization of the egg clutch (Rondeau and Sainte-Marie 2001). Upon mating, sperm is delivered to an internal storage sac (spermatheca) and may be subsequently used to fertilize the egg clutch if a female goes unmated (Elner and Beninger 1992, 1995; Sainte-Marie and Sainte-Marie 1998). As many as three ejaculates have been observed in spermathecae and sperm from the most recent mating is used to fertilize the egg clutch, which accounts for post-copulatory guarding of females under highly competitive situations (Rondeau and Sainte-Marie 2001). Females may produce more than one viable egg clutch from stored sperm (Watson 1972; Sainte-Marie et al. 2008). and females probably hatch only two broods in a lifetime (Sainte-Marie 1993). This implies that females need to mate only once to ensure lifetime breeding. Embryonic development occurs over about 1 year under warm conditions versus about 2 years under cold conditions with the threshold temperature for this shift at about -0.75 C (Sainte-Marie et al. 2008). Multiparous females have higher fecundity than primiparous females, but primiparous females have larger eggs and may produce progeny of better quality (Sainte-Marie 1993).

Snow Crab Fishery: Development and Management

The Newfoundland and Labrador Region Snow Crab fishery began in the late 1960s in Trinity Bay, with harvesters landing Snow Crab caught as bycatch in their groundfish gillnet fisheries. A directed baited trap fishery then developed that expanded throughout NAFO Divisions 3L and to 3K, 3Ps, 2J, 4R and further offshore into Div.3NO (DFO 2019b). Overall landings increased to peak in at about 69,000 t 1999 (Fig. 1) due to new entrants and increased fishing effort following the collapse of groundfish stocks as well as expansion of the fishery to offshore areas.

Landings remained near 50,000 t from 2007 to 2015, while overall effort remained at approximately 3.5 to 4.5 million trap hauls per year (DFO 2019a). Landings have since steadily declined to a two-decade low of 27,700 t in 2018 and further decreased, marginally, in 2019 (Fig. 1). Overall CPUE was at a time-series low in 2018 (DFO 2019a) but increased in all ADs except 2HJ in 2019 (Pantin et al. in press).

The fishery has been broadly distributed since 1999. It is prosecuted by distinct fleet sectors, related to size classes of vessel and area fished. The harvesting sector is highly structured with elected committees established in all CMAs off southern Labrador and off the island of Newfoundland[1]. Committee chairs typically take part in the assessment and management of the resource through participation in the annual Regional Assessment Process (RAP) held each winter as well as in subsequent industry consultations (DFO 2019 a, b). Harvesters contribute to the

[1]In accordance with the Labrador Inuit Land Claims Agreement, responsibility for conservation and management of Snow Crab resources in and adjacent to the Labrador Inuit Settlement Area is shared between the Nunatsiavut Government, the Torngat Joint Fisheries Board, and the Minster of Fisheries and Oceans. In this Working Paper we detail consultations with Snow Crab harvesters from southern 2J and south. An early draft of this modified framework was provided to the Torngat Secretariat for review, with the understanding that co-management partners in Nunatsiavut have independent processes and responsibilities for dialogue, consultation, and the development of conservation and management advice.

assessment and management process through these committees and through the collaborative post-season (CPS) Snow Crab survey. The number of licensed enterprises was 2,431 in 2018 (DFO 2019b). The Snow Crab fishery remains one of the most lucrative fisheries in the Province, with landed values exceeding $200 million CAD annually since 2011, and $325 million in 2017 (DFO 2019b).

The fishery is a male-only fishery with regulations prohibiting landing of females. It is prosecuted using conical baited traps with a minimum mesh bar of 65 mm, which corresponds to a stretched mesh opening of 135 mm (5 ¼") (DFO 2019b). This mesh size allows all mature females and males smaller than about 75 mm CW to escape (Dawe and Mullowney 2016; Baker et al. in press). A minimum legal carapace width regulation of 95 mm CW requires that males smaller than 95 mm ('undersized') are returned to the sea or 'discarded'. Many harvesters now use larger meshed traps (5 ½ inch) mesh, which allows for greater escapement of undersized crabs.

The fishery is inherently selective for largest adult crabs due to strong competition for the baited traps, with largest and most aggressive adults deterring other less competitive crabs from accessing, climbing and entering traps (Miller 1977, Winger and Walsh 2011). Gear selectivity comparisons showed that traps selected for larger and large-clawed (adult) crabs, compared to trawl catches from the same area, time period and depth strata (Hoenig and Dawe 1991). Consequently, the fishery strongly selects against adolescent males, as reflected by their typical virtual absence in trap catches, such that most males are able to grow until they terminally molt to adulthood before they are subject to capture in the fishery. It is believed that maintaining a high abundance of largest, hard-shelled adult male crabs reduces the capture, discarding and wastage (through handling mortality) of less competitive undersized, adolescent, and soft-shell males (Dawe and Mullowney 2016).

The resource is assessed at the broad spatial scale of assessment division (Fig. 2). These assessment divisions are represented by NAFO division, which have no biological basis for Snow Crab. These large spatial units are further partitioned into smaller crab management areas (CMAs), the level at which consultation and management occurs.

Resource status is assessed annually by assessment division based on trends in exploitable biomass, recruitment and mortality indices, as well as fishery catch per unit of effort (CPUE). Data are derived from multi-species bottom trawl surveys in Divs. 2HJ3KLNOP, DFO inshore trap surveys in Divs. 3KLPs, fishery logbooks, at-sea observer measurements and collaborative trap surveys, with biological sampling from multiple sources (DFO 2019a).

Management is based on quota or TAC regulation, with individual quota allocations within fleets at the CMA level, which facilitates broad distribution of fishing effort. Management regulations include a minimum legal size, minimum trap mesh-size and prohibition to land females, as previously noted. Other regulations include fishing season (variable within April-July), completion of logbooks, 100% dockside monitoring of landings, trap and weekly catch limits, biodegradable twine since 2013, (to allow crab escapement from lost traps), reporting lost gear (since 2009), closed areas (to other fisheries including shrimp trawling), conservation exclusion zones and on-deck sorting of catches. Mandatory use of the electronic vessel monitoring system (VMS) was fully implemented in all offshore fleets in 2004, to ensure compliance with fishing area regulations.

Compliance with observer monitoring is mandatory. At-sea observer coverage is quite low and is unevenly distributed among Assessment Divisions (Pantin et al. in press). There have also been concerns that observer sampling is spatially and temporally biased due to several factors, including targeting areas of high soft-shelled crab occurrence (DFO 2019a).

A major management challenge for the fishery has been the capture and discarding of soft-shell crabs. A Soft-Shell Protocol was implemented in 2004, based on at-sea sampling of total (unsorted) catches by observers. The protocol has all Snow Crab assessment divisions divided into soft-shell monitoring grids (10 minutes X 10 minutes) for the offshore fleets, and quadrants (5 minutes X 5 minutes) for the inshore fleets (DFO 2019b). Within the inshore areas soft-shell grids are subdivided into 4 quadrants. The closure of grids/quadrants in Divisions 2HJ, 3K, 3Ps and 4R occurs when the incidence of soft-shell crab, in an individual grid/quadrant, is 20% or greater. In Division 3LNO individual grids close when the incidence of soft-shell crab, in an individual grid/quadrant, is 15% or greater. Grids that close due to high incidence of soft-shell crab remain closed for the remainder of the season.

There is considerable concern regarding the efficacy of the soft-shell protocol in minimizing mortality on soft-shelled crabs, in part due to the very low level of observer coverage of the fishery (DFO 2019a). Also, grid closures result in concentration of fishing effort in grids that remain open, potentially increasing handling of soft-shelled crabs in those areas. The maximum number of total grid closures was 82 in 2004, with 52 of those (63%) in Div. 3K. In that year a rapid rate of grid closures in offshore Div. 3K (CMA 3K4) reflected a very broad distribution of soft-shelled crabs, such that it was decided to close the entire offshore Div. 3K fishery. The fishery was re-opened in the fall of 2004 resulting in the landing of mostly new-hard-shelled crabs with less than optimal meat yield. Biological sampling conducted by observers showed that in 2004 the percent soft-shelled crab was even higher in Div. 2HJ (45%) than in Div. 3K (24%) (Fig. 3). However, the Div. 2HJ fishery remained open that year (with 30 grid closures throughout the season and record low CPUE, Fig. 3), which likely resulted in very high mortality on immediate pre-recruits.

High percent soft-shelled crab in Div. 2HJ3K during 2003-2005 reflects a strong incoming recruitment pulse (Fig. 3), as shown by subsequent increases in CPUE. Unfortunately, these high levels of soft-shelled crabs were associated with very low CPUE, resulting in high levels of fishing effort and considerable wastage and loss of potential yield due to handling mortality on soft-shelled crabs. Percent soft peaked very recently in 2017 in Div. 3K and SubDiv 3Ps, again associated with near record low CPUE levels, implying considerable wastage of the subsequent recruitment. Percent soft-shelled has remained low in Div. 3LNO offshore, not exceeding 4% since 2004, in association with CPUEs remaining above about 10 kg/trap haul (Fig. 3). The relationship of percent soft-shelled crab with CPUE is unclear in Inshore Div. 3L due to very low observer coverage and sampling level (Pantin et al. in press). However, a sharp decline in CPUE to record low level during 2015-2019 was associated with an increase in percent soft to about 10%, in 2018 (Fig. 3) and a further increase to near the record-high level of about 17% in 2019 (Pantin et al in press), indicating increased mortality on immediate pre-recruits.

Methodology

Consultation

Building upon the organizational structure of the NL Snow Crab fishery, we first consulted with elected Snow Crab committee chairs, many of whom have contributed to annual Snow Crab assessments or to discussions during the initial Precautionary Approach Working Group meeting (February 6-7, 2019). We then met with the crab committees from all fleets (April 3-5, 28, 2019). During each of these meetings, we presented information on the Snow Crab life cycle and biology, fishery, and data sources. Additionally, we described DFO's Precautionary Approach and the required components of management frameworks compliant with that policy, specifically reference points, stock status zones and harvest control rules. Discussion was focused first on requirements of a Precautionary Approach Framework and on desirable and undesirable fishery states prior to any discussion of the base framework for NL Snow Crab developed by DFO.

Snow Crab harvesters defined undesirable fishery states based on catch rates (CPUE) and related discard levels. They identified periods of historically low CPUE to be avoided in the future, based on their own fishing history. Harvesters defined desirable fishery states with respect to catch rates, catch composition, discard levels, and stability. These discussions then focused on fishery objectives and research needs. During these initial meetings, harvesters identified problematic aspects of the base Snow Crab framework.

Results from these discussions were used to refine research questions and our approach to the analysis of data provided by DFO. Following data analysis, crab committees and the broader crab fleets were invited to review and comment on that analysis and our draft modified framework (September 13, October 21-24, 28-November 1, 2019). In total, nineteen meetings were held in 2019 with members of the Snow Crab fishery (Appendix I).

Development of the DMF

Data Sources

All data requested for the purposes of developing a DMF for the NL region Snow Crab fishery was provided by DFO, Science Branch (D. Mullowney and K. Baker, pers. comm. 2019). These data were comprised of time series of annual values of data from the fishery, research surveys, and the observer program. In some cases, data series were also provided at the CMA level but for the purposes of developing a modified DMF we used data at the AD level, as defined and applied in the base framework to be consistent with the base framework (Mullowney et al. 2018a). Data sets provided for this work include:

Landings (kg) and fishing effort (trap hauls): Landings are accurate due to 100% dockside monitoring and effort is calculated from landings and CPUE.

Fishery Catch per unit effort (CPUE, kg/trap haul): This is the longest time series of any biomass or density index in all areas. We used annual CPUE data generated from harvesters' logbooks. The reliability of these data has been validated by both observer CPUE data and an index developed from Vessel Monitoring System (VMS) data, with tight agreement between VMS and logbook-based CPUE data series in annual, weekly and spatial comparisons (Mullowney and Dawe 2009). Two CPUE series were provided, one comprising raw annual mean CPUE values, and the other comprising standardized annual CPUE values. We used the raw means in this paper as a basis for determining relationships among CPUE and other fishery time series.

Total and soft-shelled fishery discards (percent): The percentage of the total catch discarded as soft-shelled crabs and the percentage of total crabs discarded (undersized plus soft-shelled) are derived from at-sea detailed biological sampling by at-sea fisheries observers throughout the fishing season.

DFO trawl survey exploitable biomass index (kg): These surveys are conducted in offshore areas only, in fall in Div. 2J3KLNO and in spring in Subdiv. 3Ps. Biomass and abundance indices underestimate true quantities due to low survey trawl efficiency that varies with bottom substrate type and crab size (Dawe et al. 2010). However, the trawl estimates are adjusted to near true estimates by applying catchability estimates derived from Delury depletion models (Baker et al. in press, Pantin et al. in press).

Collaborative post-season trap survey exploitable biomass index (kg): This index is derived from trap surveys, conducted by harvesters since 2005, using commercial large-meshed as well as small-meshed traps in all inshore and offshore ADs.

Ratio of Exploitable: Pre-recruit crabs: This ratio is derived from crab abundance estimates from DFO trawl surveys.

Exploitation Rate Index (ERI): This is the ratio of landings to DFO trawl survey exploitable biomass index of the previous year for each assessment area. For Subdiv. 3Ps it is the ratio of landings to DFO spring trawl survey of the same year, with an adjustment to account for crabs landed by the fishery before and during the survey of that year (Baker et al in press). For AD 3L inshore (not covered by trawl surveys) it is the ratio of landings to the Collaborative Post-Season (CPS) survey exploitable biomass index.

Egg Clutch (percent): This is the percentage of females carrying full clutches of viable eggs, based on 2-year cumulative sums, from multiple data sources including DFO offshore trawl and inshore trap surveys.

Reference Points

We determined both operational and biological reference points, as defined by Cox et al. (2013). An operational reference point is one not directly tied to the reproductive capacity or long-term productivity of the stock. It is a decision point or threshold that triggers management action. By contrast, a biological reference point is directly related to the reproductive capacity of the stock.

Biological Reference Points (LRP and USR)

We included a set of biological reference points in our framework that we adopted from the base framework (Mullowney et al. 2018a). These RPs are based on the percentage of females with full clutches of viable eggs. We consider this index to be particularly relevant for establishing an LRP because it indicates fertilization success and so is directly related to reproductive capacity. Mullowney et al.'s (2018a) egg-clutch LRP was based on the lowest percentage observed over all ADs and years from which there was subsequent recovery, whereas the USR was based on the observation that the percentage of females carrying full clutches usually exceeded 80% in all ADs.

When reviewing this biological reference point, we examined the relationship between the egg clutch index and CPUE, the latter as an approximation of the density of male crabs larger the minimum legal size.

Operational Reference Points

We developed operational reference points for both the LRP and the USR. These are intended to form the basis of the primary operational DMF. We use CPUE as the metric in developing these RPs; CPUE provides the longest time series of any biomass index in all ADs and also represents an index of density, which is particularly relevant to mating success.

Limit Reference Point (LRP). We estimated a CPUE-based LRP as the lowest CPUE level historically seen across all ADs from which the resource subsequently recovered. This was one of the approaches used in the base framework and is consistent with the approach used in determining the LRP for the egg clutch metric (Mullowney et al. 2018a).

Upper stock reference (USR). We estimated a CPUE-based USR level using two approaches. Our first approach was to solicit the advice of Snow Crab harvesters based on their knowledge of the exploitation history and resource status throughout much of the history of the fishery during the April 2019 consultative meetings. Harvesters were asked, with no information given on originally-proposed reference points, what maximum level of CPUE they would consider most likely to be sustainable in the long-term (i.e., 'good steady fishing').

Our second approach to determining a CPUE-based USR, as noted above, was to explore the relationship between the percentage discarded and CPUE toward identifying a threshold CPUE that would minimize wastage. We focused on ADs 2HJ, 3K and 3Ps because these ADs have historically lower CPUE than AD 3LNO and so any USR established for Div. 2HJ3KPs would also be appropriate for Div. 3LNO. A breakpoint in these relationships was determined as the point where the relationship changed sharply, such that the percent discarded (total or soft-shelled) increased substantially below that CPUE level. We applied simple nonlinear regression to the data from ADs 2HJ3KPs (and AD 2HJ3KLNOPs) for annual change in percent discarded (and percent soft-shelled) on CPUE toward determining a breakpoint or a threshold ERI above which there was an increased probability of a decrease in CPUE in the following year. These relationships were also shown by calculating the mean percent discarded (or percent soft-shelled) by 1 kg/trap CPUE intervals or bins.

Removal Reference

We estimated a removal reference, again using data from ADs 2HJ3KPs, based on an exploitation rate index (ERI) which was calculated as the annual landings divided by the post-season trawl survey exploitable biomass index of the previous year (same year in AD 3Ps), which was adjusted by a Delury depletion model biomass estimate (Baker et al. in press).

We estimated the ERI reference level based on determining if there was a relationship between ERI and change in CPUE (increase versus decrease) the following year, following a similar approach used in developing the base framework (Mullowney et al. 2018a). We applied simple nonlinear regression to the data from ADs 2HJ3KPs for annual change in CPUE on ERI of the previous year toward determining a breakpoint or a threshold ERI above which there was an increased probability of a decrease in CPUE in the following year.

Results and Discussion

Consultation

During the initial April meetings harvesters identified key periods in the history of their fishery that they wished to avoid in the future. 3K harvesters identified the period of 2004-2005 as a time period or fishery state that should be avoided. Harvesters reported that there may have been considerable damage done to the resource because of the mortality of soft-shell crab that was caught, handled and discarded. The 3K crab fishery in 2004 was closed partway through the year due to levels of discarding, as previously described. Thus, for 3K harvesters, a key component of a sustainable fishery management framework would include the ability to anticipate and avoid the low catch rate/high discard levels experienced during 2004-2005.

Similar low catch rate/ high discard undesirable levels were described by 3Ps and 3L inshore harvesters. They commented on the recent period of 2012-2016 in Subdiv. 3Ps and 2015-2018 in Div. 3L inshore when catch rates declined to record low levels and when incidence of soft-shell increased markedly in some areas. Additionally, 3Ps harvesters indicated that, ideally, a management framework would include methods to predict declines in CPUE, such as those that occurred between 2000 and 2004, and minimize those declines.

Despite differences among crab management areas in terms of current catch levels and fishery state, all crab committees agreed that average catch rates over a fishing season of less than 3.5 kg/trap, was an undesirable fishery state or a “no-go zone”. While some CMAs were at or below this level in 2019, they recognize that this is an unhealthy state; one which they would like to get out of and avoid in the future.

There was also broad agreement on what constitutes a healthy fishery, which was described as “steady, good fishing” over the fishing season**.** Harvesters from ADs 3K, 3L inshore and 3Ps agreed that over 17-18 lbs/ trap (about 8 kg/trap) was “steady, good fishing”. Harvesters from southern 2J, which has the lowest overall catch rates suggested a slightly lower minimum sustainable catch rates but agreed that 8 kg/trap was acceptable. 3LNO fleets, with consistently highest catch rates, indicated that they would also accept this threshold CPUE but indicated their objective is to maintain fishery catch rates well above this level.

In addition to defining desirable and undesirable fishery states and associated reference points, harvesters articulated their objectives for the NL Snow Crab fishery. Harvesters highlighted the importance of avoiding soft-shell discarding events, predicting and protecting incoming recruitment, and managing for stability.

During the October and November 2019 meetings with crab committees and fleets, harvesters again highlighted the importance of minimizing discards, predicting and protecting incoming recruitment, and managing for stability. Additionally, harvesters' comments on the determination of the removal reference highlighted risks and uncertainties associated with that metric that should be considered in a decision-making framework for this fishery (detailed below).

Reference Points

Biological Reference Points

We provisionally accepted the egg clutch reference points proposed in the base model because this is a direct index of changes in reproductive capacity that could result from size-selective removal of male crabs. Mullowney et al (2018a) proposed an LRP=60% and USR=80% of females with full egg clutches. We note, however, that there is no consistent relationship between egg clutch and CPUE, with a positive relationship between egg clutch and CPUE in 3K and 3Ps and a negative relationship in 3LNO (Fig. 4). While we recognize the importance of a reference point directly related to reproductive capacity, the lack of any consistent relationship is a concern.

Concerns regarding the egg clutch index include low sample sizes in some areas (e.g., AD 2HJ) potential subjectivity in assigning codes, and possible bias due to inconsistencies in data sources (e.g., seasons and sampling platforms). Therefore, we recommend review of possible impacts of sampling artefacts on changes to the index before taking any management action. We recommend that if no such bias is evident, measures should be taken to ensure CPUE remains in (or expediently returns to) the Healthy Zone.

Based on these concerns, we consider the egg clutch index and associated reference points to be provisional and we recommend that research be prioritized to validate this index or develop a more reliable index of reproductive capacity (see Research Recommendation 1).

Operational Reference Points

Limit Reference Point

An empirical approach for setting the lower reference point based on the lowest level from which recovery has occurred resulted in a LRP ($C_{Recovery}$) of 3.5 kg/trap. This is higher than the lowest CPUE levels from which some crab ADs have recovered; minimum catch rates of 3.3 kg/pot occurred in Div. 2J in 2004 and then recovered to 10.2 kg/trap in 2008 (Fig. 3). Also, 3Ps is currently recovering from its record low CPUE of 2.5 kg/trap in 2016 to 6.4 kg/trap in 2018 (Fig. 3).

The LRP of 3.5 kg/trap is an operational reference point for the fishery. It is a decision point below which management measures must promote stock growth (DFO 2006). This CPUE-based lower limit does not, however, represent a biological LRP because it is not tied to the reproductive capacity or long-term productivity of the stock.

Upper Stock Reference

The relationship of percent discarded with CPUE for ADs 2HJ3KPs was best described by a log function (Fig. 5; $F_{1,58}$ = 37.49, p<0.001). This relationship indicated a breakpoint at about 7.5 kg/trap haul for total discards (Fig. 5). Scatter plots showed that below that CPUE level total discards exceeded 30% in the majority of AD-by-year cases, whereas above that level total discards seldom exceeded 30%. Similarly, incidence of soft-shelled discards frequently exceeded about 12% below 7.5 kg/trap but rarely exceeded about 12% at higher CPUE levels. This is consistent with the relationships of mean percent discards with CPUE bins, which showed a breakpoint at the 7-7.9 kg CPUE bin for total discards as well as soft-shelled discards (Fig. 5).

These relationships were maintained when applied to all ADs including AD 3LNO (Fig. 6) even though percent discarded is lower in AD 3LNO due to higher CPUE relative to ADs 2HJ3KPs. These relationships were also best described by a log function (Fig.6; $F_{1,97}$ = 73.75, p<0.001).

The relatively sharp increase in percent discarded (total and soft-shelled) below about 8 kg/trap haul is consistent with increased catchability of discard components (under-sized and soft-shelled crab) at low levels of exploitable biomass. We conclude that a CPUE level of about 8 kg/trap haul represents a threshold above which discarding is minimized due to the direct effect of a relatively high proportion of exploitable crabs in the fished population as well as relatively low catchability of discard components due to competition with aggressive largest adult males.

Here we are proposing a USR of 8 kg/trap based on “broader biological considerations and social and economic objectives for the fishery” (DFO 2009). This reference point would address stakeholders’ conservation and economic goals related to minimizing wastage and maximizing long-term yield.

Removal Reference

The relationship of ERI with percent change in CPUE of the following year showed a breakpoint at about ERI=0.42 (Fig. 7). CPUE usually decreased in the next year if ERI exceeded 0.42, whereas it usually increased following an ERI that was lower than 0.42.

We propose a removal reference level of ERI=0.42. In general, exploitation rates should be maintained about 0.42, except in situations of increasing or prolonged strong recruitment, such that there is concern for an accumulation of old-shelled crab in the population. This would address harvesters’ objective of “fishing Snow Crab before they become old shell’’.

Comparison With the Base DMF

Lower Reference Point

Our proposed CPUE-based LRP (3.5 kg/trap) is based on the lowest level observed across all ADs from which the resource subsequently recovered. This is consistent with the recommendation that ‘the state from which a secure recovery has been demonstrated under similar conditions might be the best scientific basis for estimating a LRP’ (DFO 2009). It is also consistent with the approach used in determining a LRP for sGSL Snow Crab (DFO 2010), as well as for the egg clutch-based LRP in the present and the 2018 framework (Mullowney et al. 2018a) for NL Snow Crab.

Our recommended LRP of 3.5 kg/trap is lower than the LRP of 5.0 kg/trap proposed by Mullowney et al. (2018a) in the base framework. However, that originally-proposed LRP was based on an average of the estimates from five approaches, four of which were generic and provided high estimates (ranging 3.8-7.7 kg/trap haul) relative to that from the recommended recovery-based approach (3.3 kg/trap haul). The base LRP of 5.0 kg/trap is not adequately supported and is unduly high, being twice as high as the lowest level from which a resource is recovering (2.5 kg/trap in AD 3Ps in 2016).

Our recommended LRP is adequately precautious, being 1.0 kg/trap higher than the lowest level from which the resource has recovered. This level is also supported by harvesters, from an economic perspective. Features of Snow Crab biology also contribute to risk limitation associated with our proposed LRP. These include small size-at-maturity in females and some males and an elaborate mating system that includes polyandrous mating and sperm storage. These features together with fishery regulations on minimum legal body size and mesh size as well a prohibition to land females ensure that the fishery poses little risk to egg production. Furthermore, the biological LRP based on egg clutch represents a first level of protection against serious harm to reproductive potential.

A remaining potential concern is that fishery depletion of largest adult males could result in genetic selection for small adult size. The size of crabs in the exploitable biomass has historically oscillated with the recruitment cycle due to decline to minimum size by the fishery before increasing to peak size following entry of a recruitment pulse. However, there is no evidence of an overall long-term decline in mean adult size that would result from genetic selection. Such selection is unlikely due to the broad spatial scale of genetic exchange within the panmictic population (Puebla et al. 2008). Furthermore, depletion of the large male genotype would require excessive exploitation for a prolonged period, given that about 10 successive year classes comprise the unexploited population. Proper application of our framework would maintain the resource in the Healthy Zone, thereby preventing such excessive exploitation and maintaining a healthy residual biomass of large adult males.

Upper Stock Reference

Our proposed USR of 8.0 kg/trap is considerably lower than the USR proposed by Mullowney et al. (2018a) of 12.5 kg/trap. However, the 12.5 kg/trap estimate is unrealistically high relative to the history of the fishery and is not based on the 'best information available' and 'the approach most appropriate for the stock' (DFO 2009), as is our estimate.

The originally proposed USR (Mullowney et al. 2018a) was based on an average of four estimates. None of these approaches were consistent with a generic approach that has been recommended only 'in cases where insufficient stock-specific information is available' (DFO 2009). This recommended approach is to estimate the USR as 80% of B_{MSY}, where B_{MSY} may be estimated by one of three methods as follows (DFO 2009):

- The biomass corresponding to the biomass per recruit at F0.1 multiplied by the average number of recruits; or
- The average biomass (or index of biomass) over a productive period; or
- The biomass corresponding to 50% of the maximum historical biomass.

That recommended generic approach was used to develop a USR for sGSL Snow Crab (DFO 2010). However, it was not necessary for us to resort to such generic approaches because our proposed USR was based on the best information available from the NL Snow Crab population and fisheries. Furthermore, it was designed to be consistent with a guiding principle of the original base framework (Mullowney et al 2018a): to minimize wastage. By contrast, the unrealistically high USR value in the base framework would likely increase wastage. Persistent very low exploitation rates would be required to achieve and maintain such an unrealistically high catch rate especially during periods of low recruitment such that it is likely that there would be increased wastage due to carapace ageing, deterioration and loss of market value.

Removal Reference

While the methodology to determine the relationship between change in CPUE and ERI is the same as that used in Mullowney et al. (2018a), the CPUE indicators used differ in that we used raw data whereas the base framework used model predicted annual means.

Our recommended reference level agrees with results of an analysis by Mullowney et al. (2018a), based on the same approach we adopted, which we considered the most appropriate of three approaches in the original proposal. Our analyses differed in that we used raw CPUE estimates from ADs 2HJ3KPS whereas Mullowney et al. (2018a) used model-predicted CPUE values from ADs 2HJ3KLNOPs. Mullowney et al. (2018a) focused their analysis on determining minimum and maximum ERI levels for the Critical (ERI=0.24) and Healthy (ERI=0.63) Zones respectively. However, examination of their results indicates an overall breakpoint at the point of no change in CPUE associated with an ERI=0.4.

Our proposed removal reference level of 0.42 agrees generally with the results of Mullowney et al. (2018a) and is similar to that determined for the sGSL. We do not recommend maximum ERI reference levels but recommend that the ERI should not appreciably exceed the reference level except in situations of increasing or prolonged strong recruitment, such that there is concern for accumulation of old-shelled crabs in the population.

Harvest Control Rules

Our proposed CPUE-based framework represents the more appropriate framework for a practical set of reference points and harvest control rule to serve as the basis for annual management decisions involving adjustments to ERI and fishery removals. The structure of our CPUE-based framework is presented in Figure 8.

Harvesters stressed that one of their primary fishery objectives is maintaining stability through minimizing sharp year-to-year changes in TAC. They generally agreed that maintaining appropriate exploitation rates should increase stability. However, they highlighted concern that strict application of the ERI-based framework could lead to unwarranted sharp annual changes in TAC and allocations because of uncertainty in the ERI associated with the trawl survey biomass index. For example, 2J harvesters noted that the sharp drop in the 2HJ ERI in 2015 (Fig. 9) may be largely due to overestimation of biomass by the 2014 trawl survey. Strict application of the framework to increase the ERI to the target level for the Healthy Zone would have resulted in a substantial increase in TAC and removals that could have led to over-exploitation. Another example relates to AD 3Ps where the resource is in recovery (Fig. 11) and biomass has recently increased due to strong recruitment (Pantin et al. in press). Harvesters were concerned that an increased TAC level was being considered based on strict application of the HCR-based ERI. They feared that such a sharp increase could result in over-exploitation and hinder recovery, due to uncertainty in the survey biomass estimate and the magnitude of the recent recruitment pulse in particular. These examples support the view of harvesters that appropriate application of a framework should feature flexibility in applying the HCR in each zone.

There is provision for such flexibility within the scope of DFO guidance, which recommends that management actions “are within the bounds of the removal rate strategy appropriate for the status zone” (DFO 2009). That guidance further states that “in the Cautious Zone, the adjustment of the removal reference does not have to follow a linear relationship…but a progressive reduction in removals is required” (DFO 2009). Accordingly, we recommend that the primary CPUE-based HCR should be to reduce the ERI (and/or fishery removals) when in the Cautious Zone so as to arrest a decline in CPUE and reverse the trajectory.

There was also concern associated with the sharp increase in ERI in AD 2HJ in 2016 and recent high levels (well above the target) although the resource remains in the Healthy Zone (Fig. 9), which suggests either recent underestimation or spatial contraction of the exploitable biomass. The inclusion of an ERI-based HCR provides some protection against potential issues of CPUE hyperstability (Rose and Kulka 1999), The risk of overexploitation would have been minimized if removal rate guidance had been followed, with exploitation rates maintained near 0.42 in the Healthy Zone. Concerns remain regarding transition to the proposed modified framework, particularly in AD 2HJ These concerns will need to be resolved before a modified framework can be adopted. DFO guidance specifies that harvest strategies and decision rules are to be developed by fisheries management in concert with fishery stakeholders and with the advice of science.

One research and management priority consistently identified by fish harvesters was the need to predict incoming recruitment to the fishery. Longer term CPUE predictive models based on a suite of biological and environmental recruitment indices at various time lags would also be beneficial as a basis for longer term planning and decision making in the management of the fishery (see Research Recommendations 2 and 3).

Summary and Conclusions

We propose a decision-making framework for NL Snow Crab that is built upon on a base framework recently developed by Mullowney et al. (2018a). Our framework retains much of the structure of the base framework but is simpler and less restrictive, including only two of the three components (metrices) in the base model. The other major variation in our framework is the determination of reference points (LRP and USR) for the primary operational framework (based on CPUE) that are substantially lower than those of the base framework. These reference points are more realistic, practical, and consistent with the history of the fishery than those of the base framework, with a USR based on minimizing wastage and maximizing long-term yield. Our framework was developed using the most appropriate approaches and best scientific information available and with extensive participation by the fishing industry. Our framework is fully supported by Snow Crab harvesters, which is particularly important, recognizing that 'to be successful, the utilization of this decision-making framework generally and its application to the specific fisheries needs to be done in concert with the fishing participants, to which it is applied' (DFO 2009). We believe that adoption and application of our revised framework would facilitate agreement on annual management decisions and promote the development of a co-management strategy for this resource.

As indicated in this proposed framework, adjustments to the removal reference (and fishery removals) attendant falling from the Healthy Zone would be minimal if the resource remains near the target removal reference. Our analysis also showed that ERI levels higher than the target (0.42) are associated with increased wastage of incoming recruitment and increased probability of reduced CPUE the following year. Accordingly, we reiterate that ERI levels substantially above the reference level should only be allowed in exceptional circumstances, such as prolonged strong and/or increasing recruitment such that there is concern for accumulation of old-shelled crabs.

Application of the CPUE-Based Framework

We illustrate the application of our CPUE-based framework to each AD using data up to 2018 inclusive (Figs 9-13). This framework would place AD 2HJ (Fig. 9) and 3LNO (Fig 11) in the Healthy Zone in 2018 with AD 3K (Fig. 10), 3Ps (Fig. 11), and 3L Inshore (Fig 13) in the Cautious Zone. These applications illustrate how falling from the Healthy Zone during periods of weak/declining recruitment (declining CPUE) has been associated with ERI increasing above the reference level and continuing to increase to very high levels (in the Cautious Zone) until recruitment increases (increasing CPUE). Clearly, this would not happen in the future with this framework in place if annual management decisions were made consistent with this framework to maintain the ERI below or about the reference level and to immediately apply the HCR when the resource drops (or is predicted to drop) below the USR.

Recommendations

1. Prioritize research to evaluate the reliability of egg clutch as a direct indicator of reproductive capacity, by addressing issues of subjectivity in assigning codes and possible bias associated with seasons and platforms of sampling. This could also include exploring the relationship of sex ratio to percent full clutch using 3L and 3K inshore DFO survey small-mesh traps for females and large-mesh traps for males. The analysis should also be applied to CPS survey data for all ADs despite shorter time series. Regardless of a relationship the sex ratio itself could be a useful index of mating opportunity and reproductive capacity.
2. Prioritize research on developing short and long-term recruitment indices including evaluation of data from small-mesh trap catches from the relatively lengthy time series of DFO surveys in Inshore 3L and inshore 3K, as well, as from the more broadly distributed data from the CPS survey; also consider expansion of the small-mesh trap sampling in the CPS surveys.
3. Continue with the development of reliable short and long-term predictive models using landings and multiple recruitment indices (at various lags) as input variables toward improving the ability to manage the fishery over the long term.

References Cited

Baker, K., Mullowney, D., Pedersen, E., Coffey, W., Cyr, F., Belanger, D. In press. An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2018. DFO Can Sci Advis Sec Res Doc 2019/nnn. vi + xx p.

Caddy, J.F., Wade, E., Surette, T., Hebert, M., Moriyasu, M. 2005. Using an empirical traffic light procedure for monitoring and forecasting in the Gulf of St. Lawrence fishery for the Snow Crab, *Chionoecetes opilio*. Fish Res 76, 123-145.

Comeau, M. and Conan, G.Y. 1992. Morphometry and gonad maturity of male Snow Crab, *Chionoecetes opilio*. Can J Fish Aquat Sci 49: 2460–2468.

Conan, G.Y. and Comeau, M. 1986. Functional maturity and terminal molt of male Snow Crab, *Chionoecetes opilio*. Can J Fish Aquat Sci 43: 1710–1719.

Cox, S.P. and Kronlund, A.R. 2008. Practical stakeholder-driven harvest policies for groundfish fisheries in British Columbia Canada. Fish Res 94: 224-237.

Cox, S.P., Kronlund, A.R., Benson, A.J. 2013. The roles of biological reference points and operational control points in management procedures for the sablefish (*Anoplopoma fimbria*) fishery in British Columbia. Env Conser: 1-13.

Dawe, E.G. and Colbourne, E.B. 2002. Distribution and demography of Snow Crab (*Chionoecetes opilio*) males on the Newfoundland and Labrador Shelf. Pages 577–594 in Paul, A.J., Dawe, E.G., Elner, R.W., Jamieson, G.S., Kruse, G.H., Otto, R.S., Sainte-Marie, B., Shirley, T.C., Woodby, D. eds. Crabs in cold water regions: biology, management, and economics. Univ. Alaska Fairbanks, Alaska Sea Grant Coll Prog Rep 02–01.

Dawe, E.G., Taylor, D.M., Hoenig, J.M., Warren, W.G., Ennis, G.P., Hooper, W.G., Donaldson, WE., Paul, A.J., Paul, J.M. 1991. A critical look at the idea of terminal molt in male Snow Crabs (*Chionoecetes opilio*). Can J Fish Aquat Sci 48: 2266-2275.

Dawe, E.G. and Mullowney, D.R.J. 2016. Baited traps used in the Newfoundland and Labrador fishery for Snow Crab (*Chionoecetes opilio*): A precautionary approach. J Ocean Tech 11: 13-23.

Dawe, E. G., Mullowney, D.R., Moriyasu, M., Wade, E. 2012. Effects of temperature on size-at-terminal molt and molting frequency in Snow Crab *Chionoecetes opilio* from two Canadian Atlantic ecosystems. Mar Ecol Prog Ser 469: 279–296.

Dawe, E.G., Parsons, D.G., Colbourne, E.B. 2008. Relationships of sea ice extent and bottom water temperature with abundance of Snow Crab (*Chionoecetes opilio*) on the Newfoundland–Labrador Shelf. ICES CM 2008: B02

Dawe, E.G., Walsh, S.J., Hynick, E.M. 2010. Capture efficiency of a multispecies survey trawl for Snow Crab (*Chionoecetes opilio*) in the Newfoundland region. Fish Res 101: 70-79.

DFO. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis Sec Sci Advis Rep 2006/023.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach. (2009-03-23).

DFO. 2010. Reference points consistent with the precautionary approach for Snow Crab in the southern Gulf of St. Lawrence. DFO Can Sci Advis Sec Sci Advis Rep 2010/014.

DFO. 2012. Revised reference points for Snow Crab to account for the change in estimation area of the southern Gulf of St. Lawrence biological unit. DFO Can Sci Advis Sec Sci Rep 2012/002.

DFO. 2017. Assessment of Nova Scotia (4VWX) Snow Crab. DFO Can Sci Advis Sec Sci Advis. Rep 2017/033.

DFO. 2019a. Assessment of Newfoundland and Labrador (Divisions 2HJ3KLNOP4R) Snow Crab. DFO Can Sci Advis Sec Sci Advis Rep 2019/041.

DFO. 2019b. Integrated Fisheries Management Plan: Snow Crab – Newfoundland and Labrador Regions.

DFO. 2019c. Proceedings of the Regional Peer Review for Development of a Precautionary Approach Framework for Snow Crab in the Newfoundland and Labrador Region; June 6-7, 2018. DFO Can Sci Advis Sec Proceed Ser 2019/016.

Dionne, M., Sainte-Marie, B., Bourget, E., Gilbert, D. 2003. Distribution and habitat selection of early benthic stages of Snow Crab *Chionoecetes opilio*. Mar Ecol Prog Ser 259: 117–128.

Dufour, R., Bernier, D., Brêthes, J.C. 1997. Optimization of meat yield and mortality during Snow Crab (*Chionoecetes opilio* O. Fabricius) fishing operations in Eastern Canada. Can Tech Rep Fish Aquat Sci 2152 : viii + 30 p.

Elner, R.W. and Beninger, P.G. 1992. The reproductive biology of Snow Crab, *Chionoecetes opilio*: a synthesis of recent contributions. Am Zool 32: 524–533.

Elner, R.W. and Beninger, P.G. 1995. Multiple reproductive strategies in Snow Crab, *Chionoecetes opilio*: physiological pathways and behavioral plasticity. J Exp Mar Biol Ecol. 193: 93–112.

Ennis, G.P., Hooper, R.G., Taylor, D.M. 1990. Changes in the composition of Snow Crab participating in the annual breeding migration in Bonne Bay, Newfoundland. Can J Fish Aquat Sci 47: 2242–2249.

Fonseca, D.B., Sainte-Marie, B., Hazel, F. 2008. Longevity and change in shell condition of adult male Snow Crab *Chionoecetes opilio* inferred from dactyl wear and mark-recapture data. Trans Am Fish Soc 137: 1029–1043.

Forrest, R.E., Holt, K.R., Kronlund, A.R. 2018. Performance of alternative harvest control rules for two Pacific groundfish stocks with uncertain natural mortality: Bias, robustness and trade-offs. Fish Res 206: 259-286.

Foyle, T.P., O'Dor, R.K., Elner, R.W. 1989. Energetically defining the thermal limits of the Snow Crab. J Exp Biol 145: 371–393.

Godbout, G., Dutil, J.-D., Hardy, D., Munro, J. 2002. Growth and condition of post-moult male Snow Crab (*Chionoecetes opilio*) in the laboratory. Aquaculture 206: 323–340.

Grant, S.M. 2003. Mortality of Snow Crab discarded in Newfoundland and Labrador's trap fishery: At-sea experiments on the effect of drop height and air exposure duration. Can Tech Rep Fish Aquat Sci 2481: vi + 28p.

Hardy, D., Munro, J., Dutil, J.-D. 1994. Temperature and salinity tolerance of the soft-shell and hard-shell male Snow Crab, *Chionoecetes opilio*. Aquaculture, 122: 249-265.

Hebert, M., Benhalima, K., Miron, G, Moriyasu. M. 2002. Moulting and growth of male Snow Crab, *Chionoecetes opilio* (O. Fabricius, 1788) (Decapoda, Majidae), in the southern Gulf of St. Lawrence. Crustaceana 75: 671–702.

Hoenig, J.M. and Dawe, E.G. 1991. Relative selectivity of four sampling methods using traps and trawls for male Snow Crabs (*Chionoecetes opilio*). Can Atl Sci Adv Com Res Doc 91/32, 18 p.

Hoenig, J.M., Dawe, E.G., O'Keefe, P.G. 1994. Molt indicators and growth per molt for male Snow Crabs (*Chionoecetes opilio*). J. Crustacean Biol 14: 273-279.

Kon, T. 1980. Studies on the life history of Zuwai crab. Spec. Publ. Sado Mar. Biol. Sta. Niigata Univ. 2. 64 p. (Can Transl Fish Aquat Sci 5634).

Lovrich, G.A., Sainte-Marie, B., Smith, B.D. 1995. Depth distribution and seasonal movements of *Chionoecetes opilio* (Brachyura, Majidae) in Baie Sainte-Marguerite, Gulf of Saint Lawrence. Can J Zool 73: 1712–1726.

Marcello, L.A., Mueter, F.J., Dawe, E.G., Moriyasu, M. 2012. Effects of temperature and gadid predation on Snow Crab recruitment: comparisons between the Bering Sea and Atlantic Canada. Mar Ecol Prog Ser 469: 249–261.

Miller, R.J. 1977. Resource Underutilization in a Spider Crab Industry. Fisheries. 2(3): 9-13.

Moriyasu, M., Conan, G.Y., Lanteigne, C. 1998. Embryo development and reproductive cycle in the Snow Crab*, Chionoecetes opilio* (Crustacea: Majidae), in the southern Gulf of St. Lawrence, Canada. Can J Zool 76: 2040–2048.

Mullowney, D.R. and Dawe, E.G. 2009. Development of performance indices for the Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) fishery using data from a vessel monitoring system. Fish Res 100: 248-254.

Mullowney, D.R.J., Dawe, E.G., Colbourne, E.B., Rose, G.A. 2014. A review of factors contributing to the decline of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*). Rev Fish Biol Fisheries, 24: 639–657.

Mullowney, D., Baker, K., Pedersen, E., Osborne, D. 2018a. Basis for A Precautionary Approach and Decision Making Framework for the Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) Fishery. DFO Can Sci Advis Sec Res Doc 2018/054. iv + 66 p.

Mullowney, D., Morris, C., Dawe, E., Zagorsky, I., Goryanina, S. 2018b. Dynamics of Snow Crab (*Chionoecetes opilio*) movement and migration along the Newfoundland and Labrador and Eastern Barents Sea continental shelves. Rev Fish Biol Fish 28: 435-459.

Pantin, J., Baker, K., Mullowney, D., Coffey, W., Zabihi-Seissan, S., Cyr, F. In press. An Assessment of Newfoundland and Labrador Snow Crab (*Chionoecetes opilio*) in 2018. DFO Can Sci Advis Sec Res Doc.

Pardo, L.M., Riveros, M.P., Fuentes, J.P., Pinochet, R., Cardenas, C., Sainte-Marie, B. 2017. High fishing intensity reduces females' sperm reserve and brood fecundity in a eubrachyuran crab subject to sex- and size-biased harvest. ICES J Mar Sci doi:10.1093/icesjms/fsx077.

Puebla, O., Sévigny, J.M., Sainte-Marie, B., Brêthes, J.C., Burmeister, A., Dawe, E.G., Moriyasu, M. 2008. Population genetic structure of the Snow Crab (*Chionoecetes opilio*) at the Northwest Atlantic scale. Can J Fish Aquat Sci 65: 425–436.

Rondeau, A. and Sainte-Marie, B. 2001. Variable mate-guarding time and sperm allocation by male Snow Crabs (*Chionoecetes opilio*) in response to sexual competition, and their impact on the mating success of females. Biol Bull (Woods Hole) 201: 204–217.

Rose, G.A. and Kulka D.W. 1999. Hyperaggregation of fish and fisheries: how catch-per-unit-effort increased and the northern cod (*Gadus morhua*) declined. Can J Fish Aquat Sci (Suppl. 1):118-127.

Sainte-Marie, B. 1993. Reproductive cycle and fecundity of primiparous and multiparous female Snow Crab, *Chionoecetes opilio,* in the northwest Gulf of Saint Lawrence. Can J Fish Aquat Sci 50: 2147-2156.

Sainte-Marie, B., Gosselin, T., Se´vigny, J.M., Urbani, N. 2008. The Snow Crab mating system: opportunity for natural and unnatural selection in a changing environment. Bull Mar Sci 83:131–161.

Sainte-Marie, B. and Hazel, F. 1992. Moulting and mating of Snow Crabs, *Chionoecetes opilio* (O. Fabricius), in shallow waters of the northwestern Gulf of Saint Lawrence. Can J Fish Aquat Sci 49: 1282–1293.

Sainte-Marie, B., Raymond, S., Brethes, J.C. 1995. Growth and maturation of benthic stages of male Snow Crab, *Chinoecetes opilio* (Brachyura, Majidae). Can J Fish and Aquat Sci 52: 903–924.

Sainte-Marie, G. and Sainte-Marie, B. 1998. Morphology of the spermatheca, oviduct, intermediate chamber and vagina of the adult Snow Crab (*Chionoecetes opilio*). Can J Zool 76: 1589–1604.

Shelton, P.A., and Rice, J.A. 2002. Limits to overfishing: reference points in the context of the Canadian perspective on the precautionary approach. DFO Can Sci Advis Sec Res Doc 2002/084.

Shelton, P.A. 2017. Initial tests of the robustness of the provisional harvest control rule in Canada's Sustainable Fisheries Policy to process and measurement errors using simulated depleted fish populations. *J Northw Atl Fish Sci* 49: 1–21.

Smith, S.J., Bourdages, H., Choi, J., Dawe, E., Dunham, J.S., Gendron, L., Hardie, D., Moriyasu, M., Orr, D., Roddick, D., Rutherford, D., Sainte-Marie, B., Savard, L., Shelton, P., Stansbury, D., Tremblay, M.J., Zhang, Z. 2012. Technical Guidelines for the Provision of Scientific Advice on the Precautionary Approach for Canadian Fish Stocks: Section 7 – Invertebrate Species. DFO Can Sci Advis Sec Res Doc 2012/117. iv + 30 p.

Starr, M., Therriault, J.-C., Conan, G.Y., Comeau, M., Robichaud, G. 1994. Larval release in a sub-euphotic zone invertebrate triggered by sinking phytoplankton particles. J Plank Res 16: 1137–1147.

Watson, J. 1972. Mating behavior in the spider crab, *Chionoecetes opilio.* J Fish Res Board Can 29: 447–449.

Winger, P.D. and Walsh, P.J. 2011. Selectivity, efficiency, and underwater observations of modified trap designs for the Snow Crab (*Chionoecetes opilio*) fishery in Newfoundland and Labrador. Fish Res 109: 107–113.

Figures

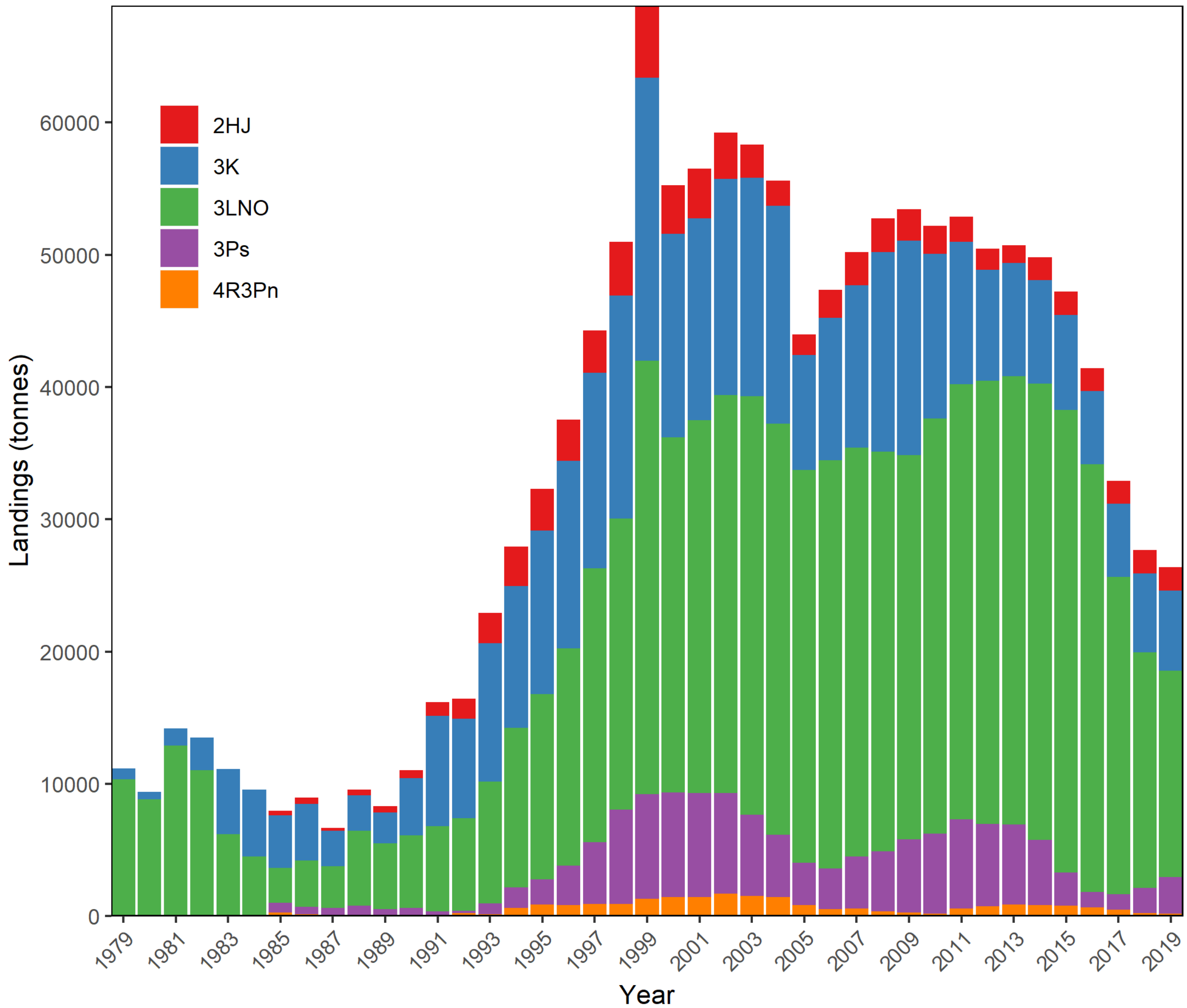


Figure 1. Annual landings by NAFO Division (1979-2019). Source Pantin et al. in press.

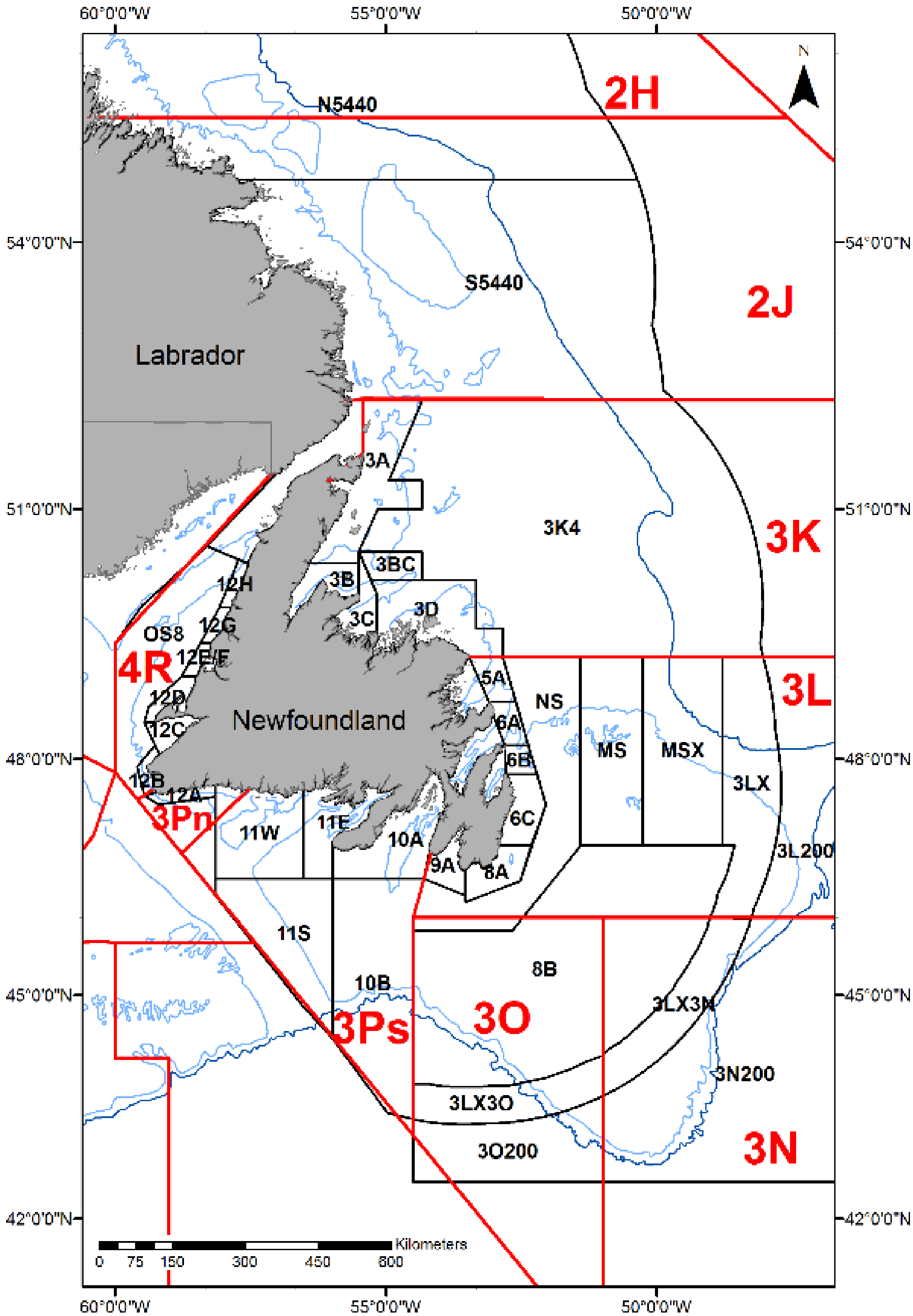


Figure 2. Map of NAFO Divisions (red) and Newfoundland and Labrador Snow Crab Management Areas (black). Source DFO 2019a.

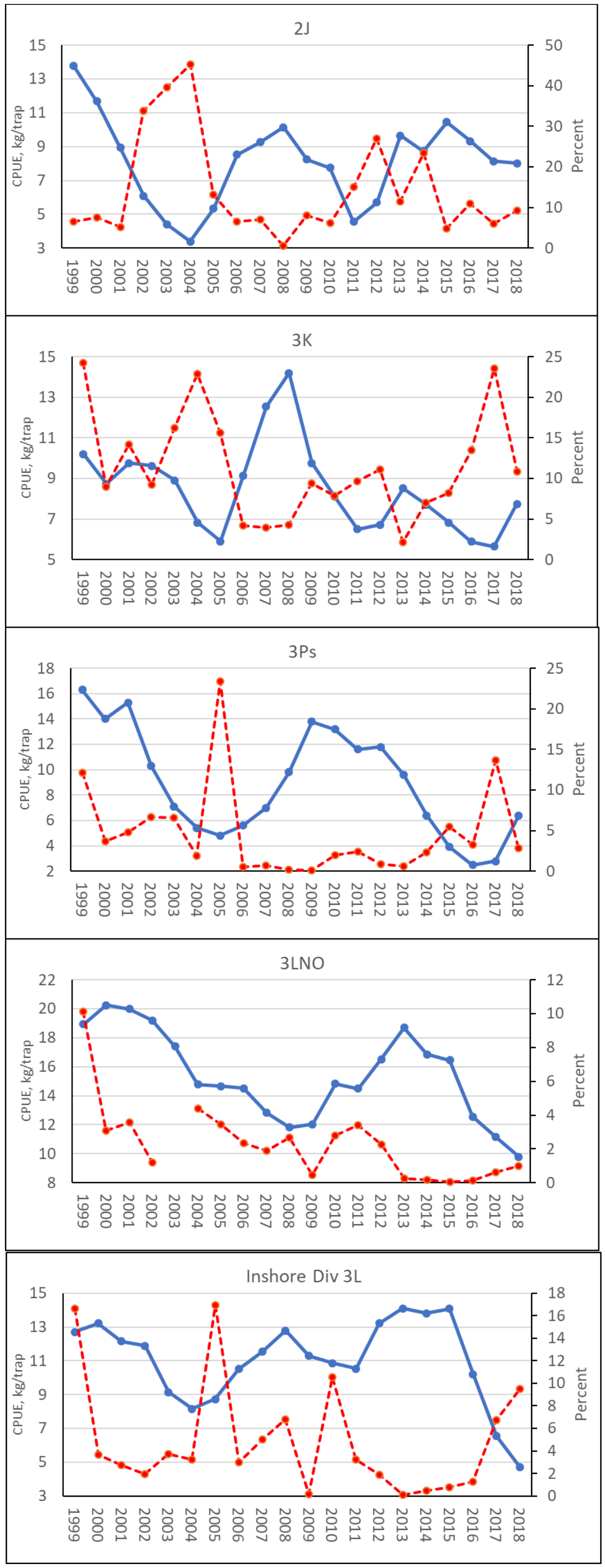


Figure 3. Trends in CPUE (blue; from harvester logbook data) and percent soft-shelled crabs (red; from biological sampling by observers) by Assessment Division.

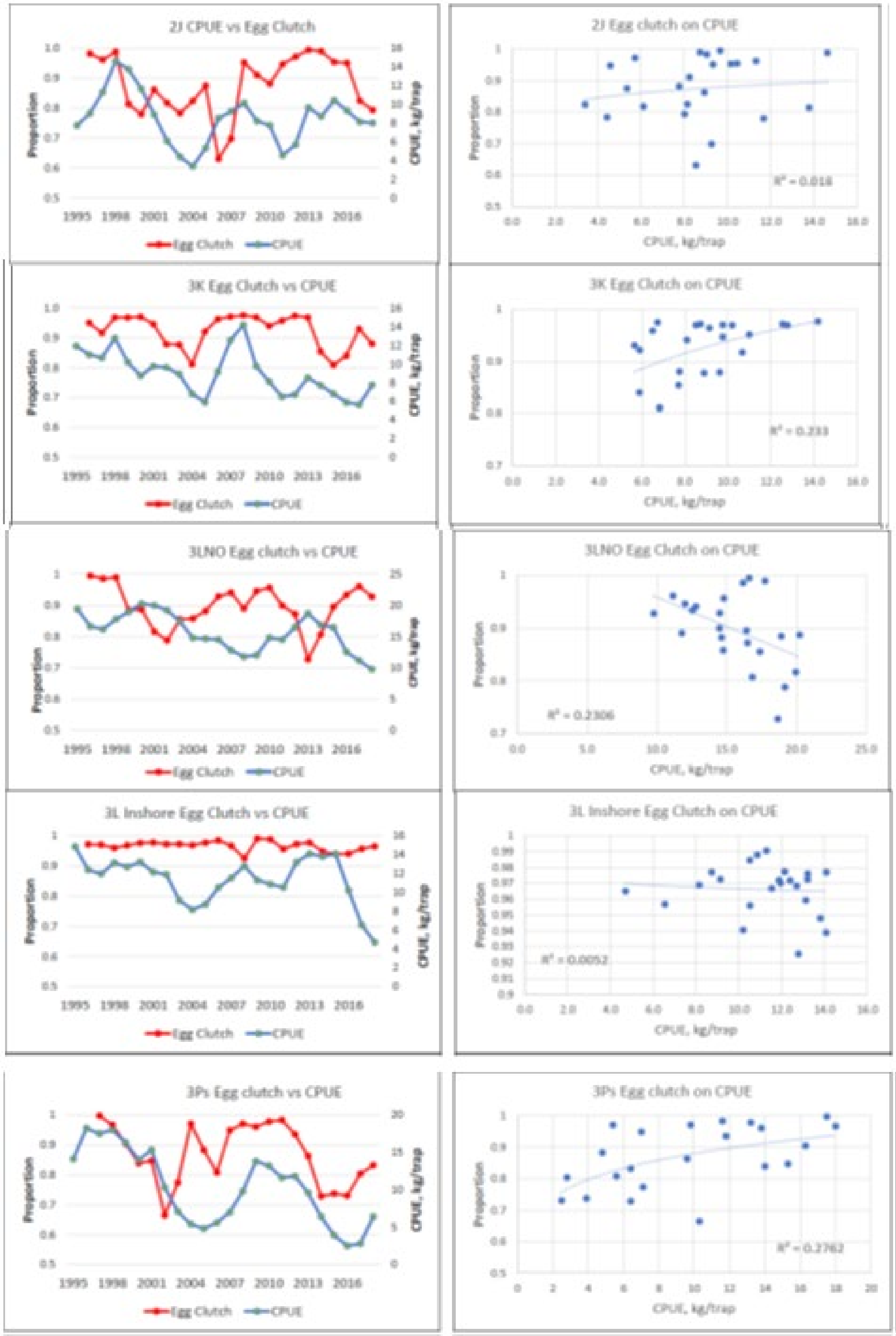


Figure 4. Relationship of proportion of females carrying full clutches of viable eggs with CPUE by assessment division.

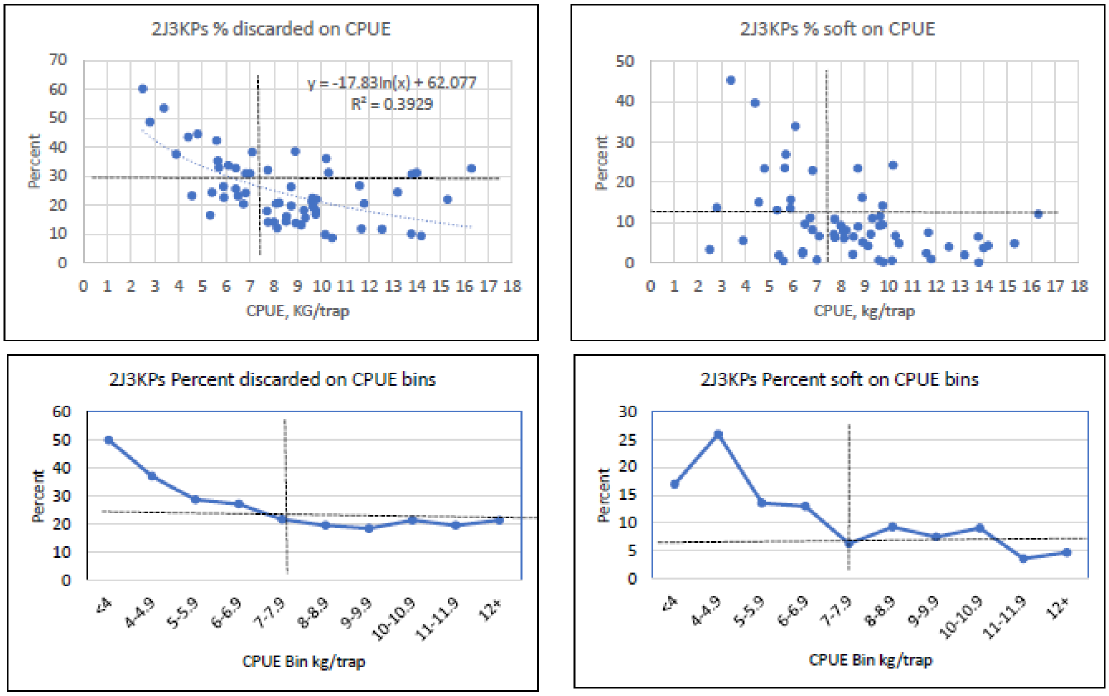


Figure 5. Relationship of CPUE with total percent discards (left) and soft-shelled discards (right) based on AD-by-year scatter plots (above) and mean percent discards by 1-kg CPUE bins (below).

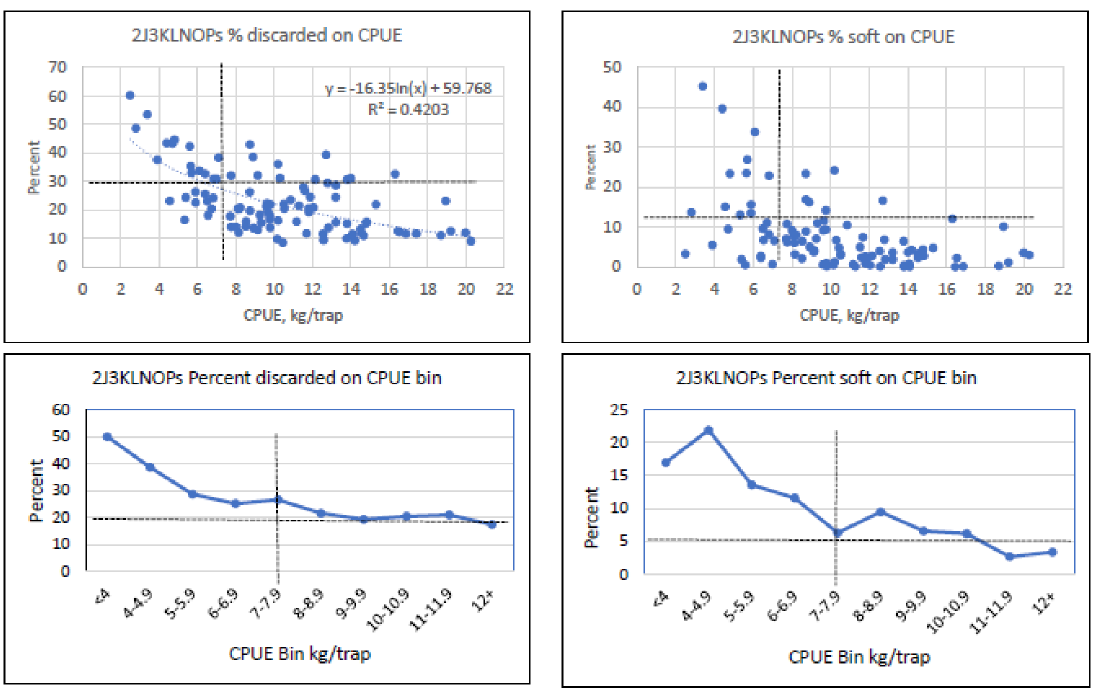


Figure 6. Relationship of AD 2HJ3KLNOPs CPUE with total percent discards (left) and soft-shelled discards (right) based on AD-by-year scatter plots (above) and mean percent discards by 1-kg CPUE bins (below).

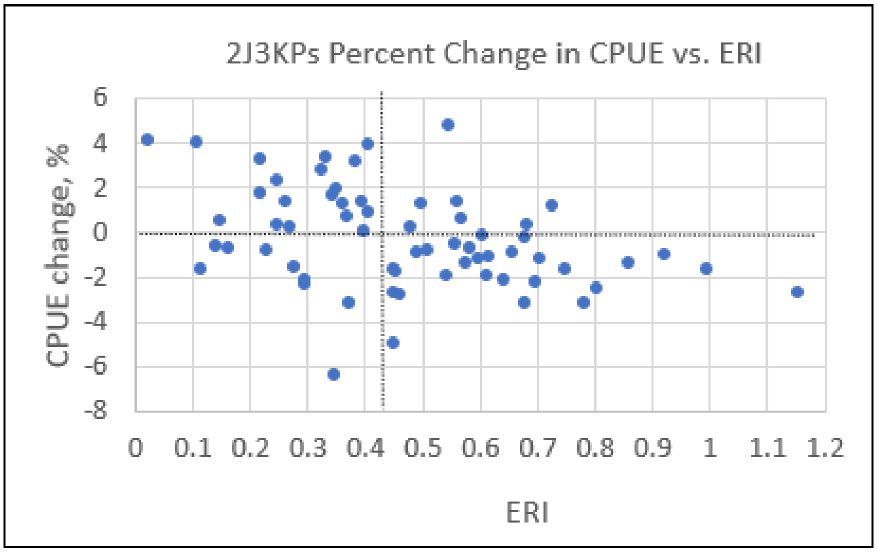


Figure 7. Percent change in CPUE on Exploitation Rate Index (ERI) for ADs 2HJ3KPs pooled.

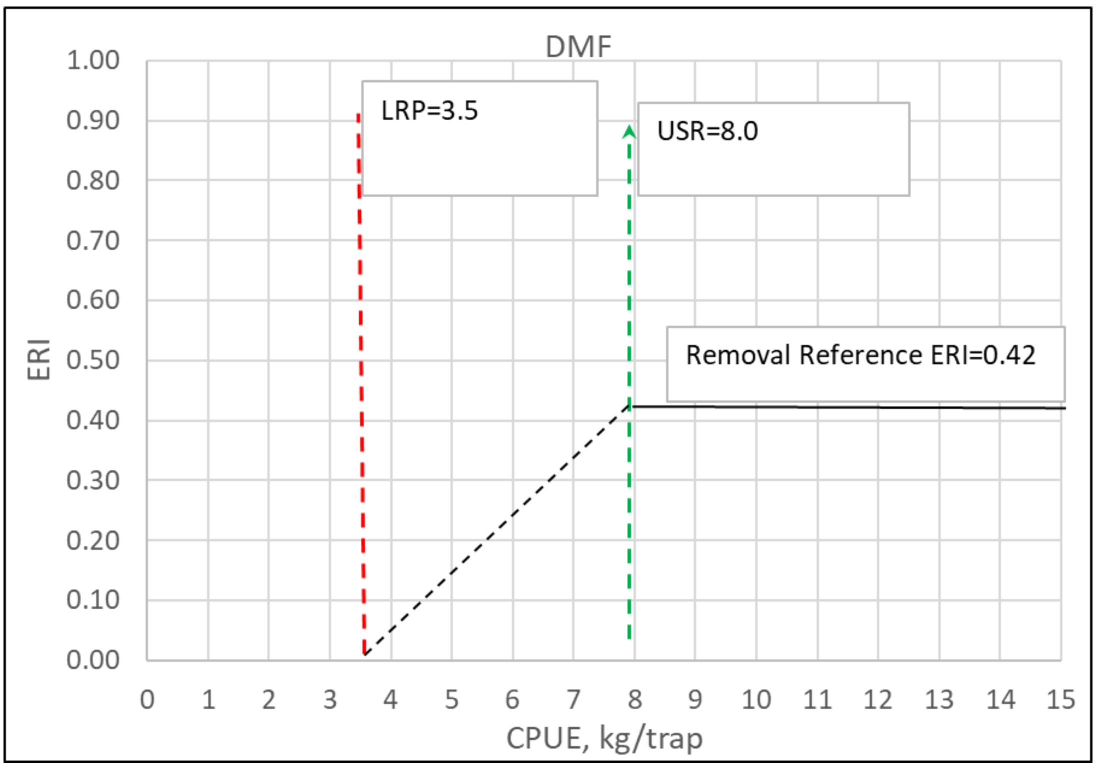


Figure 8. General form of the proposed/revised CPUE-based decision-making framework for NL Snow Crab.

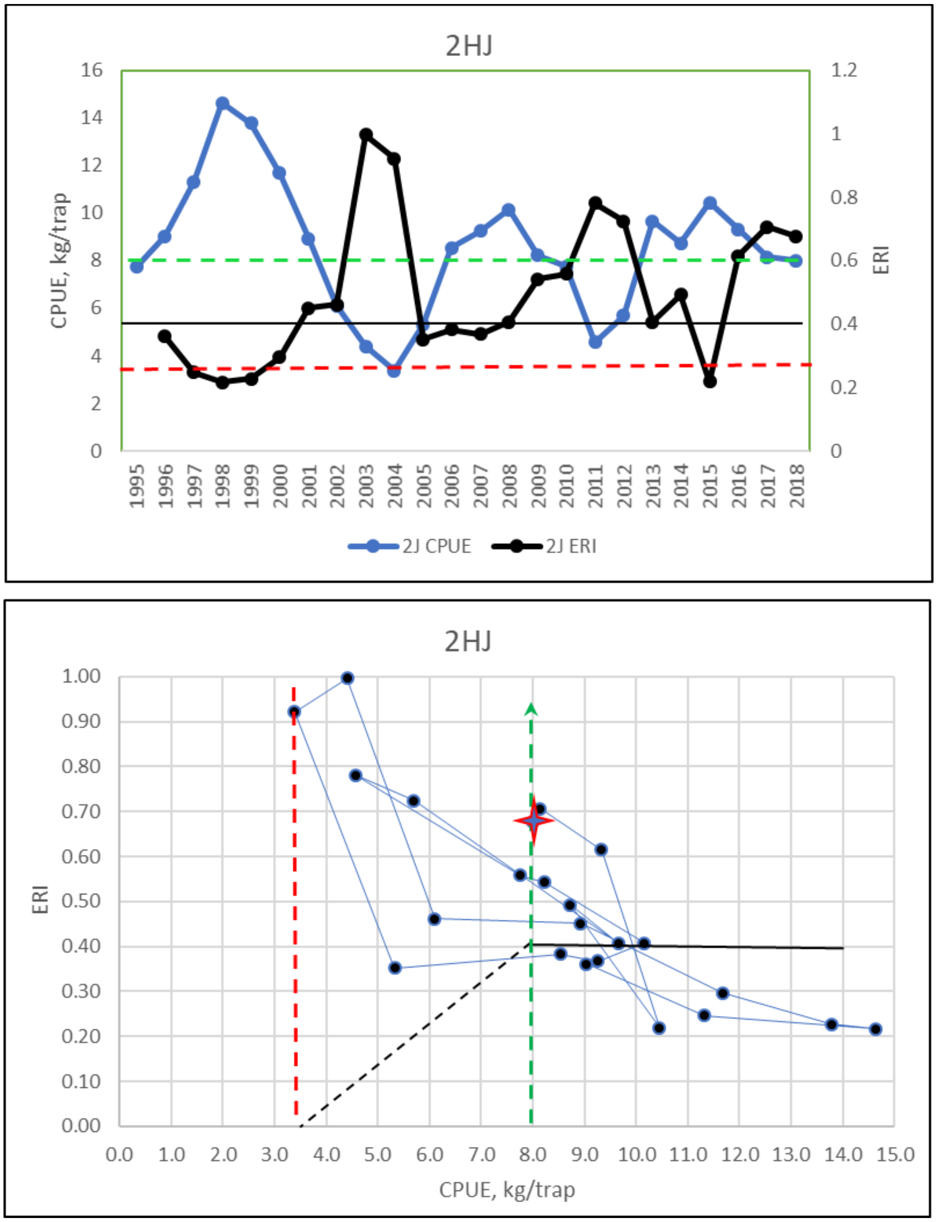


Figure 9. CPUE-based decision-making framework for AD 2HJ presented as continuous time series (above) and as phase diagram showing resource trajectory (below); red and green dashed lines represent LRP and USR respectively and horizontal solid black line represents the removal reference ERI level. Red star indicates 2018 value.

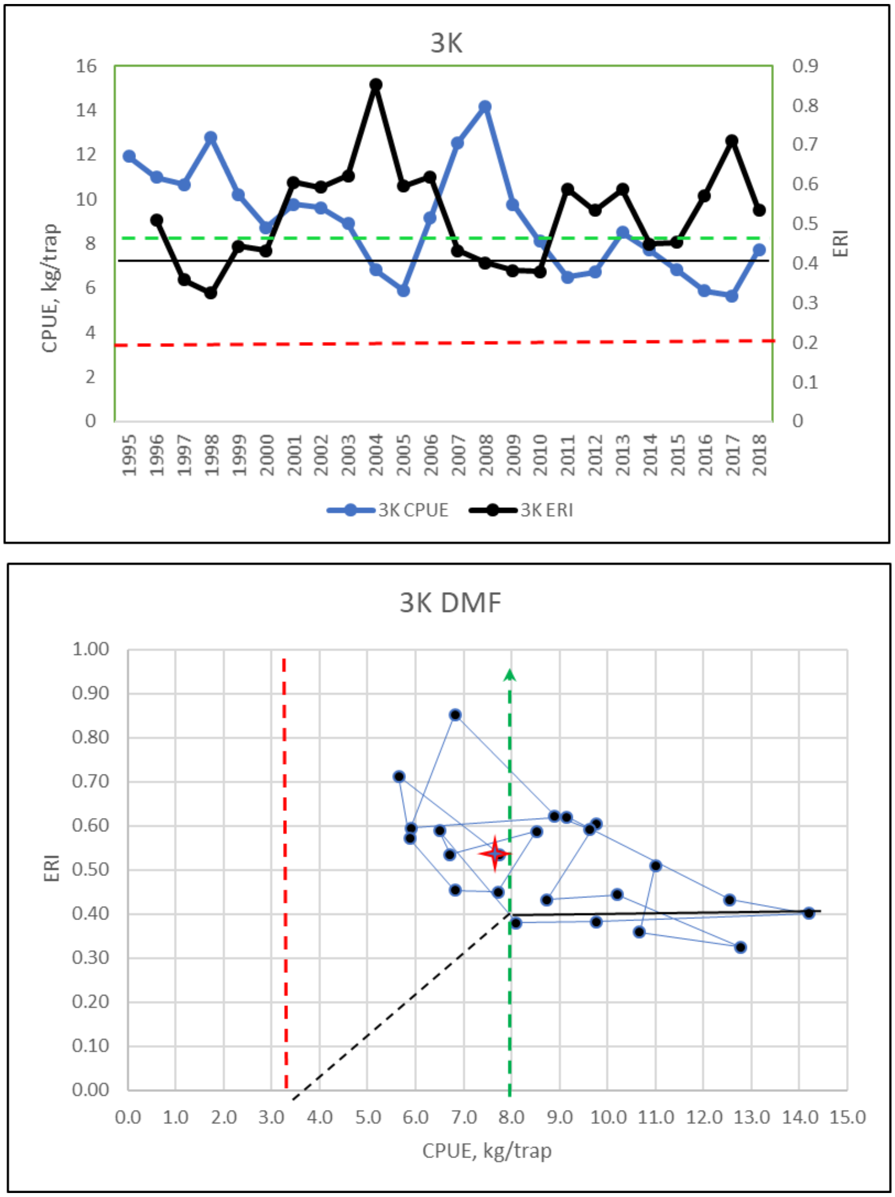
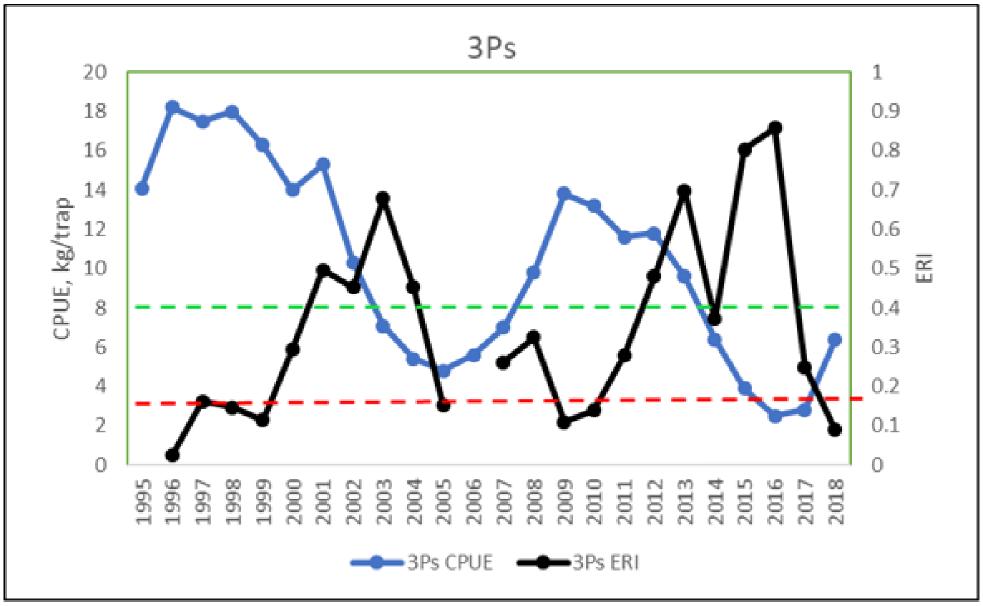


Figure 10. CPUE-based decision-making framework for AD 3K presented as continuous time series (above) and as phase diagram showing resource trajectory (below); red and green dashed lines represent LRP and USR respectively and horizontal solid black line represents the removal reference ERI level. Red star indicates 2018 value.



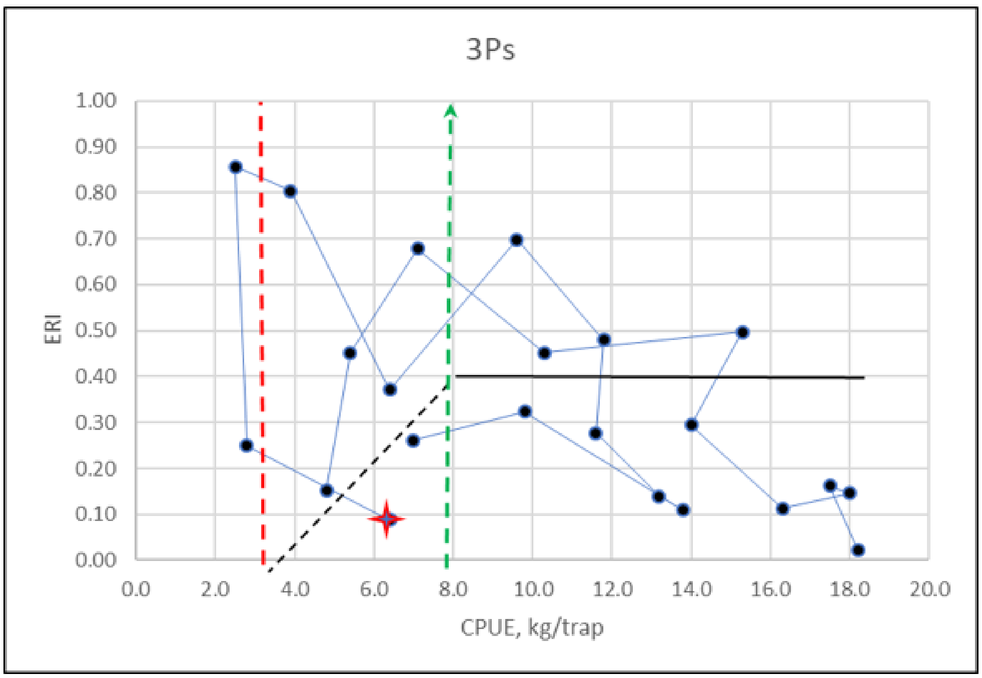


Figure 11. CPUE-based decision-making framework for AD 3Ps presented as continuous time series (above) and as phase diagram showing resource trajectory (below); red and green dashed lines represent LRP and USR respectively and horizontal solid black line represents the removal reference ERI level. Red star indicates 2018 value.

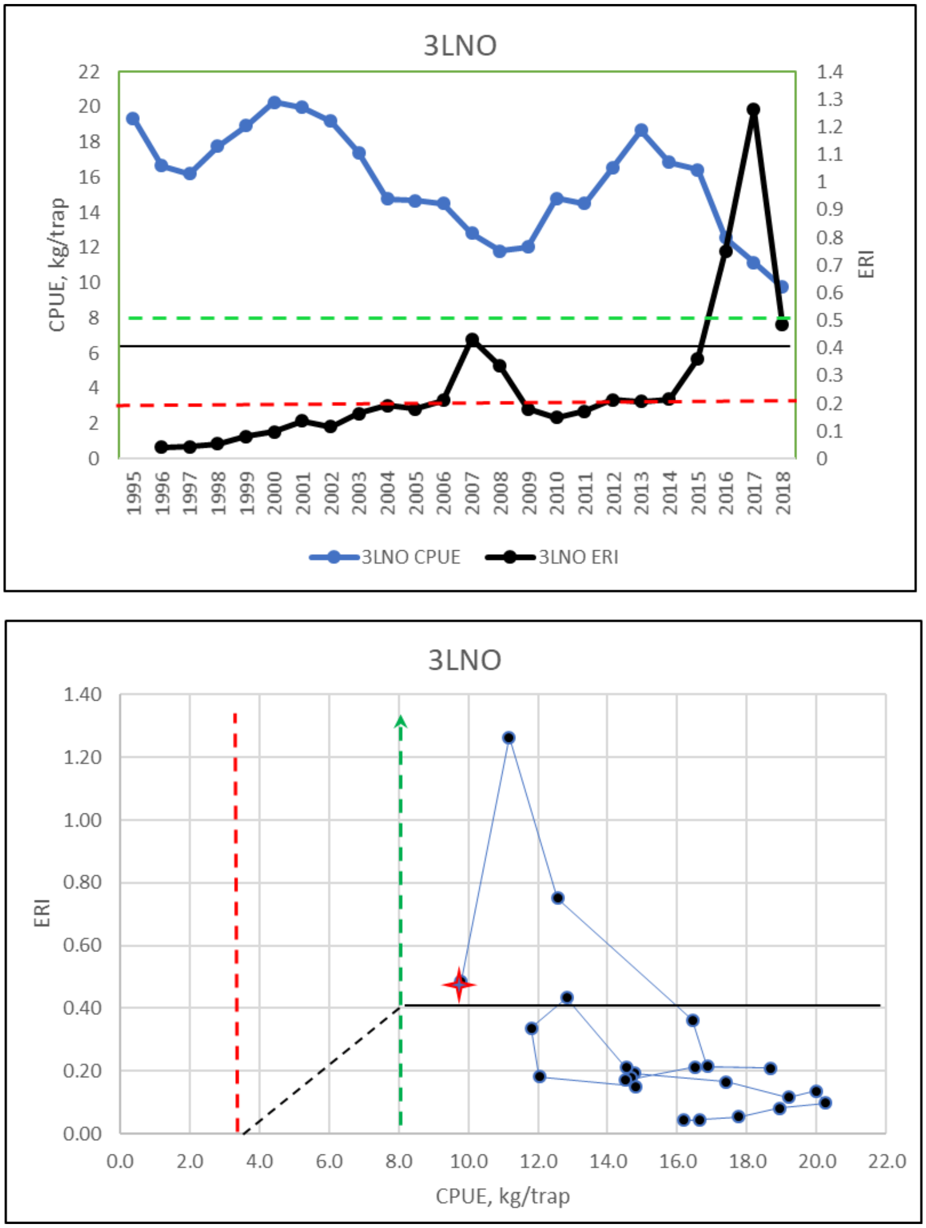
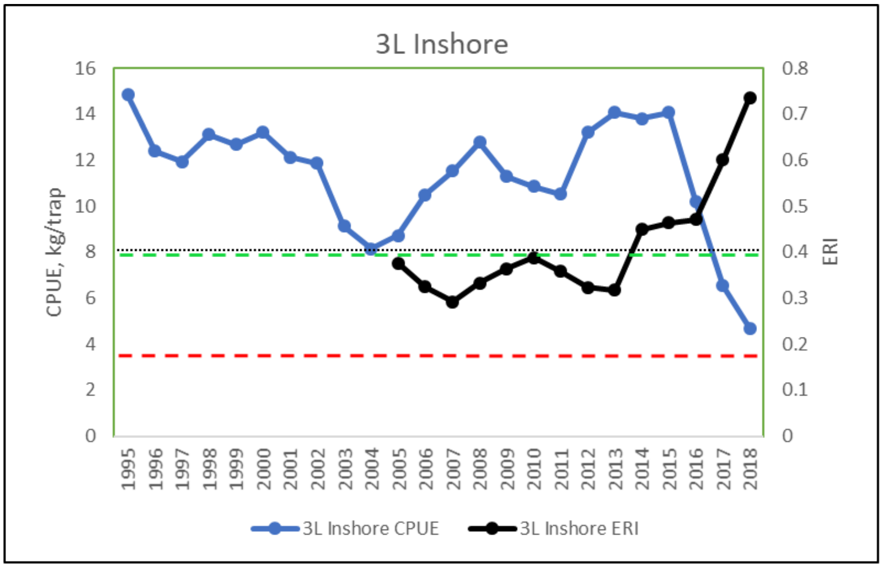


Figure 12. CPUE-based decision-making framework for AD 3LNO presented as continuous time series (above) and as phase diagram showing resource trajectory (below); red and green dashed lines represent LRP and USR respectively and horizontal solid black line represents the removal reference ERI level. Red star indicates 2018 value.



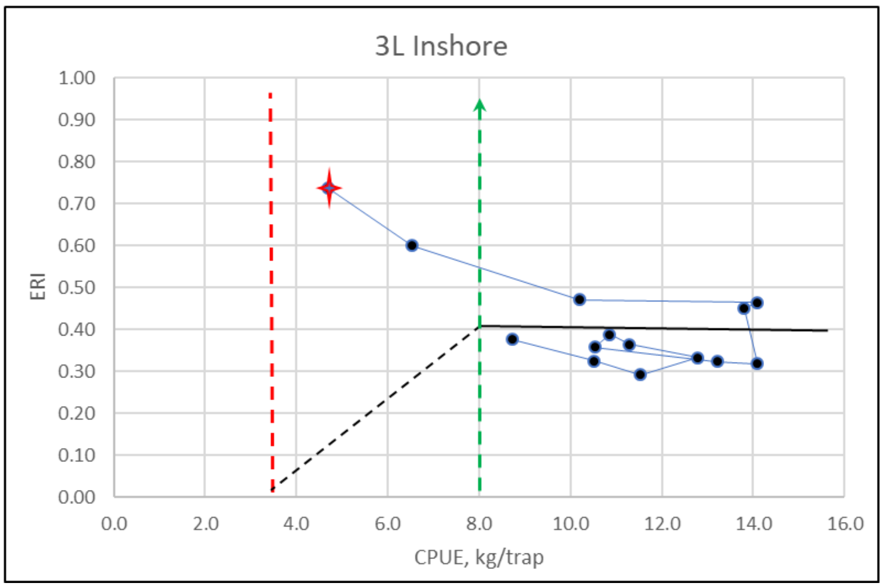


Figure 13. CPUE-based decision-making framework for AD 3L Inshore presented as continuous time series (above) and as phase diagram showing resource trajectory (below); red and green dashed lines represent LRP and USR respectively and horizontal solid black line represents the removal reference ERI level. Red star indicates 2018 value.

Appendix I

Meeting Record Submitted to DFO Management (Dec. 11, 2019)

RE: Update on the development of an alternate Decision-Making Framework Using the Precautionary Approach for Snow Crab in NAFO Divs. 2J3KLNOPs

FFAW committed to developing a PA framework for the Newfoundland and Labrador Snow Crab fisheries as an alternative to the framework previously developed by DFO Science and reviewed on June 6-7, 2018 in St. John's NL. Our alternate PA is being developed based on 1) consultations with the Snow Crab fleets, 2) based on analyses of Snow Crab data provided by DFO Science and 3) based on DFO policy regarding PA frameworks. Written documentation of our alternative NL Snow Crab PA framework will be provided to DFO Science and Fisheries Management for review.

Three sets of consultation meetings took place to date: 1) meetings with crab fleet committee chairs, 2) meetings with crab committees, and 3) meetings with crab fleets. The management structure of NL crab is complex, with multiple crab management areas (CMAs) within each NAFO Division. Fleets within each CMA elect a committee and the chairs of those committees take part in regional-level discussions of crab management. The series of consultation meetings on the Snow Crab PA was designed to reflect the structure of the crab fishery organization in NL.

FFAW held initial consultation meetings with Snow Crab chairs and committees to discuss overall fishery objectives and concerns, as well as specific components on Snow Crab precautionary approach frameworks. These meetings took place between November 2018 and April 2019. Fishery objectives and concerns that were identified during these meetings were then evaluated against the data provided by DFO Science. Crab scientist, Earl Dawe, and FFAW fisheries scientist, Erin Carruthers, presented their analyses to the crab committees and fleets for review and comment in October and November of 2019. Below is a listing of consultations with Snow Crab harvesters completed to date:

Snow Crab PA Working Group Meeting

February 6-7, 2019 (St. John’s): Participants included 11 Snow Crab fleet chairs and harvesters from 2J, 3K, 3L and 3Ps; FFAW staff; Indigenous groups representatives; processors; academia and DFO Science and Fisheries Management.

Initial Crab Committee Consultation Meetings

April 3, 2019 (Gander): 3K crab committees, with representatives from 3K4, 3BC, 3B and 3D

April 4, 2019 (Clarenville): 3Ps crab committees, with representatives from 3Ps inshore (10A, 11E, 11W) and offshore (3Ps Supplemental Fleet),

April 5, 2019 am (St. John’s): 3L inshore, with representatives from Bonavista Bay to St. Mary’s Bay (9A, 8A, 6B, 6A, and 5A)

April 5, 2019 pm (St. John’s): 3L offshore fleets, with representatives from the Small Supplemental, Large Supplemental and Full-time fleets, which fish all of the CMAs in the 3LNO offshore assessment division

April 23, 2019 (Port Hope Simpson): 2J with both participants from both the crab committee and the broader crab fleet

Review Meeting with Crab Chairs

September 13, 2019 (St. John’s)

FFAW held a review meeting with 14 Snow Crab committee chairs to discuss progress on the development of an alternative management approach and decision-making framework for NL Snow Crab.

When FFAW met with the Snow Crab committees in April 2019, the committees clearly stated that they want to manage for stability. This included keen interest in understanding and protecting incoming recruitment but also interest in keeping an eye on the amount of old shell crab in the fishery. Harvesters wanted to protect incoming recruits (minimize soft-shell discarding) and fish crab when they are in prime condition (minimizing mossy or graveyard crab).

These overall objectives were used as a starting point for the work of Fisheries Scientists Earl Dawe and Erin Carruthers in developing a management approach for NL Snow Crab. Dawe and Carruthers presented their analyses of Snow Crab data at the meeting this past Friday. Crab committee chairs then provided valuable feedback on the work including suggestions to better address harvesters' goals for the fishery and concerns about crab management.

The review meeting Friday was an important step in the process of building an alternative approach to the management of Snow Crab in the Newfoundland and Labrador, one that meets both fishing and conservation goals for NL Snow Crab. Following on from the Friday meeting, FFAW scientists will address the feedback from harvesters and will bring the revised work to Snow Crab committees and fleets throughout the province. Those meetings are planned for mid-late October. Again, feedback from those consultations will be used to further refine an alternative management approach for crab, which will then be presented to DFO for their review.

Crab Committee Review Meetings

October 21, 2019 (Port Hope-Simpson): 2J Committee and fleet

October 22, 2019 am (St. John's): 3L Inshore Committee

October 22, 2019 pm (St. John's): 3L Offshore Committee

October 23, 2019 (Clarenville): 3Ps Committee

October 24, 2019 (Grand Falls-Windsor): 3K Committee (all fleets)

October 29, 2019 am (Clarenville): Bonavista Bay and northside Trinity Bay Committees

Crab Fleet Review Meetings

October 21, 2019 (Port Hope-Simpson): 2J Committee and fleet

October 28, 2019 am (Clarenville): 3Ps Inshore Fleet

October 28, 2019 pm (Clarenville): 3Ps Inshore Fleet

October 29, 2019 pm (Clarenville): Bonavista Bay/ Trinity Bay Fleet

October 30, 2019 am (Grand Falls-Windsor): 3KBCD Fleet

October 30, 2019 pm (Grand Falls-Windsor): 3K Offshore Fleet

November 1, 2019 am (Whitbourne): Conception Bay, St, Mary's Bay and Southern Shore

November 1, 2019 pm (Whitbourne): 3L Offshore Fleets