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Maritimes Region

Proceedings of the Regional Peer Review of a Framework for the Assessment of Snow Crab (*Chionoecetes opilio*) in Maritimes Region (NAFO DIV 4VWX)

Meeting dates: February 25-26, 2020
Location: Dartmouth, NS

Chairperson: Tana Worcester
Editor: Daphne Themelis

Fisheries and Oceans Canada
Maritimes Region
PO Box 1006, 1 Challenger Drive
Dartmouth, Nova Scotia B2Y 4A2

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Canada

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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TABLE OF CONTENTS

SUMMARY

A regional peer review of a Framework for the assessment of Snow Crab in Maritimes Region (NAFO DIV 4VWX) was held on February 25-26, 2020, at the North Atlantic Fishing Organization (NAFO) Headquarters Boardroom, 2 Morris Drive, Dartmouth, NS. As set out in the Terms of Reference (ToR), the objectives were to review the proposed spatiotemporal modelling approach and demonstrate the utility of the proposed models for estimating abundance and for use in future assessments.

Participants in this meeting included DFO Science, DFO Resource Management, Province of Nova Scotia, Indigenous communities/ organizations, Fishing Industry, non-government organizations, and external experts.

This proceedings document includes a summary of the presentations and is a record of the meeting discussions and conclusions. A Research Document resulting from this meeting will be published on the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat's (CSAS) Website once it becomes available.

INTRODUCTION

This meeting provided an opportunity to review a new modelling approach for providing a stock assessment for Snow Crab (*Chionoectes opilio*) in Maritimes Region. The proposed approach is an ecosystem-based spatiotemporal approach that uses discrete (Conditional Autoregressive) models in a flexible framework to replace the previously used continuous space-time modelling approach; the latter are no longer operational due to time and computational limits. This was a technical review of the model and did not include the provision of advice on the stock status.

The objectives of this science advisory meeting were to:

- Review the proposed spatiotemporal modelling approach;
- Demonstrate the utility of the proposed models for estimating abundance and for use in future assessments.

The Terms of Reference for the meeting are shown in Appendix A. Participants in this meeting included DFO Science, DFO Resource Management, Indigenous communities/ organizations, Fishing Industry, and external experts (Appendix B). This meeting was held at the NAFO Headquarters Boardroom, Dartmouth, NS, from February 25-26, 2023 (see Appendix C for the Agenda).

DAY 1: TUESDAY, FEBRUARY 25, 2020

Rapporteurs: T. Worcester and T. McIntyre

WELCOME AND INTRODUCTION

The Chair, Tana Worcester, began the meeting by introducing herself and the reviewers Yihao Yin (DFO Science Maritimes), Joanna Mills-Flemming (Dalhousie University, Halifax, NS) and Tobie Surette (DFO Science Gulf). The Chair reviewed the Canadian Science Advisory Secretariat (CSAS) peer review process and the use of the Scientific Advice for Government Effectiveness (SAGE) Principles and Guidelines. The Terms of Reference with the specific meeting objectives and the agenda for the two days were also reviewed.

CURRENT PROBLEM

Presenter: J. Choi

Spatiotemporal modeling in the context of stock assessment of Snow Crab in Maritimes Region was discussed. There is a mismatch in scale and complexity between current assessment models and reality. Standard assumptions about the representativeness are problematic because of intrinsic factors related to Snow Crab life history and the temporal and spatial variability of the environment. Two features that have been ignored in traditional stock assessments are ecosystem variability and autocorrelation between areal units. More mechanistic models have been attempted, but parameterizing these models is difficult.

Previous approaches to sampling design and data aggregation were presented. Temporal changes in Snow Crab density and distribution caused problems with the use of kriging to estimate abundance. Moving to Bayesian approaches was helpful, but years with low densities and divergent spatial patterns made the estimation slow and problematic. Bayesian models assume stationarity. Hierarchical zero-inflated models take a long time to compute (months) and doubling of the number of parameters. The current assessment uses spatial temporal models of variability (STMV). This suite of models is very flexible and can address many issues, but the

computation speed is very slow and model performance cannot be tested. The STMV did not capture the dynamics, and biomass was very flat over time.

The proposed approach is a CAR (conditional auto-regressive spatiotemporal) model. This is a hybrid model in the sense that it combines a cartesian view as well as the interactions of the fields underneath that drive the patterns. The CAR model is closely related to models that describe ferro-magnetics in physics and chemistry. It models Snow Crab numerical abundance with environmental and biological factors as covariates. Biomass predictions by eleven model permutations were compared over the time series.

DISCUSSION

It was asked whether STMV would still be used for other purposes going forward. It could be useful for smaller spatial scales (50-100 km). STMV methods were used in the past for all covariates. Going forward, all covariates will be modeled using the CAR model on the same scale.

There have been issues throughout the survey time series, resulting in variable coverage. Survey coverage increased annually from 1996 until the year 2000. The survey vessel sank in 2004. There were major mechanical problems with the vessel in 2017. Initial survey coverage in 1996 were the core fishing grounds followed by expansion to the continental edge. The fishery has since contracted to the colder zones.

The grid size used for the continuous model is 1 km. Different grid sizes were attempted and measurement error varied with the grid sizes. There is high sampling density because crab habitat distribution is wide. The error can be controlled by averaging. The means are similar but the variance changes. Block kriging shows that survey catches are very similar at a grid size of 2-5 km.

UNCERTAINTIES

A reviewer expressed concerns about the absence of uncertainty bounds on the CAR model plots. It was explained that the figures were shown that way for simplicity. However, it is difficult to propagate uncertainty into the surplus production model; the computing is very slow and complex. Another reviewer suggested it could be done using the statistical programming package template model builder (TMB) and that there were also other methods available.

A reviewer asked whether the lack of samples in the offshore in 2000 might be causing the models to produce divergent predictions. Divergence was due in part to some models ignoring absent samples. Models employing fixed effects would assume catches in unsampled areas were zero rather than using the mean from other areas. The reviewer asked how the models would behave if the first few years were removed and suggested that the sensitivity to different survey years would be good to investigate. The presenter agreed that this could be done. It has been difficult to do this using STMV because computation was so slow.

A reviewer noted that some of the models were better at predicting observations than others and asked how the differences should be interpreted. They asked whether the Aikaike information criterion (AIC) could capture these differences well and whether the catchability parameter compensate for the differences. Because there was limited differences between posteriors and priors in the surplus production model, they were concerned about the scale of the indices going into the model. There would be less concern if the survey was effective in estimating catchability.

The response was that video gear on the sampling gear indicates catchability is high. There is limited escapement, therefore it was appropriate to assume that the catchability parameter

varies near one. The AICs indicated that the CAR model fit the data the best, based on residuals and number of parameters.

Outputs from the models were discussed and the rationale for choosing the non separable space/time model. It was jasked if there was a significant improvement using the non-spatial model rather than the simple model. It was suggested to map the residuals from each model and look for improvements in the spatial versus non-spatial models. This would show whether there was a spatial pattern. Model runs using non-separable space/time, simple and factorial crossed methods were requested for the following day, summarizing the residuals on the grid rather than every observation.

The surplus production model evaluates the temporal structure of the index; therefore, it was asked why a temporal model was used rather than allowing the surplus production model to estimate the temporal structure. The presenter answered that the data have a temporal component at the individual level that must be considered. If the survey is early one year, bias is introduced through temporal aliasing. This bias can be absorbed in the surplus production model but must be incorporated as an additional component. It was asked how seasonality is included. A cyclic pattern could be chosen, but the choice was to use autocorrelation.

The reviewers emphasized the importance of propagating error into the surplus production model.

MODEL IMPROVEMENT

Discussion continued on model improvement with a reviewer noting that the difference between the simple and complex models is small. It might be worthwhile to add more parameters. A reviewer agreed with the improvement in fit but not whether a lower AIC indicated a better prediction.

The presenter suggested that future research might include adding other co-variates, such as pH, dissolve organic carbon, alternate areal units and alternative distribution models. A reviewer questioned including some of the co-variates because they did not appear to significantly improve the model. They asked whether the model assumes a linear relationship between an ecosystem variable and biomass. No, for example, depth is a non-linear variable. It was suggested that a selection process for variables would be useful.

Principle component analyses (PCA) of the community composition was based on snow crab and groundfish biomass and not on predation. The first axis is highly correlated with temperature and the second with depth. Grain size is static. A reviewer suggested that the first two axes be removed or the inclusion of a multivariate regression to understand the PCA results.

A consideration of year and season effects indicates that the seasonal effect is not significant, but the year effect is strong. After 2005, the model outputs appear similar. Boat effects are important but have been managed, for example, the impact of the sinking boat cannot be detected.

SURVEYS

Snow Crab surveys conducted by the Gulf Region were compared to the Maritimes Region. The Gulf surveys began as a 10 by 10 minute grid and were redesigned in 2006, 2012, 2013. About 80% of the bottom appears to be uniform and trawlable. About 10-15% of the stations are moved randomly each year with a new grid structure. There has been a convergence toward more trawlable bottom with a consequent impact on the index. The Maritimes Region survey also shifts locations when bottom is not trawlable. It is a mostly fixed station survey with about

300 of the 400 stations in the same location as in 2004. Some stations have been added where there was high variance. Only about 10 stations have had to be moved or canceled because of untrawlable bottom. Post-stratification analyses indicate that the survey is biased in relation to some co-variates with some depths not explored and some stations not visited due to tear-ups.

HOMEWORK AND CONCLUSION OF DAY 1

Maps showing residuals for each observation or unit (grid) for non-separable space/time model and simple models were requested for the following day. A correlation matrix showing the relationship between variables was also requested. Conversation would continue on the PCA and the role of the first and second axes and whether to include them.

The Chair asked the reviewers to consider their concerns about the proposed model and whether there should be changes to the approach or future considerations.

DAY 2: WEDNESDAY, FEBRUARY 26, 2020

REVIEW OF PREVIOUS DAY

The Chair asked that the participants focus on whether adopting the proposed model be appropriate and then get into the details of how to implement it. Discussion points on Day 1:

- the history of the survey and comparison with the Gulf Region approach – the evolution of the survey and how the survey structure might influence model results.
- error structure and how it is or is not propagated in the model.
- The consistency in the index trend across models and the magnitude (whether there were reasons for these differences or just error)
- whether a comparison of the magnitude of the AICs was sufficient to justify model selection. Other metrics might be the fit to raw data or consistency with a precautionary approach.
- co-variates – whether depth, temperature and grain size are sufficient, and using PCAs.
- how to make best use of available data while keeping the approach simple enough to communicate and provide a robust index as input to the SPM.

A reviewer provided a summary of their views. Covariates and the PCA for species distributions must be on the same grid as the data. This could be done, for example, by using an average of the grain size and using it in the model or a preliminary CAR model could be fitted to provide predictions for each grid cell (the approach taken here). The code shows that the fishing mortalities were all smooth functions resulting from the preliminary CAR model, an approach which could be considered conducting statistics on statistics. They suggested using a rudimentary metric for each grid, rather than the CAR model. They also asserted that the sampling methodology is heavily balanced. Although it is biased toward more trawlable bottom, this is preferential sampling, and only a concern when considering Snow Crab biomass, not for covariates.

Metrics for validating the models were discussed. It was recommended that each model should have its residual plots reviewed to ensure spatial patterns were removed. It was asked how an absence of observations is was addressed and whether there was an over inflation of zeros. It was recommended that the predicted output and the observed snow crab catch be compared for each grid, as well as the zeros, and to look for spatial patterns. These are quantitative information on which to base an opinion on the best model. AICs can be used to compare nested models.

Figure 41 of the working paper showing predicted biomass trajectories by the models was discussed. The absence of uncertainty bounds on the point estimates was noted because these are necessary to determine which estimates are statistically significantly different. The pattern shown by the factorial model was concerning because predicted biomass increased when covariates were added. The model diagnostics should be available, such as using the statistical package integrated nested Laplace approximation (INLA) with just covariates and no spatial temporal variation. The requirement for robust metrics to evaluate the models was emphasized.

Industry commented that they would prefer a stable model with less intervention -- something understandable and explainable. They need to be able to manage withdrawals to protect the stock.

The final comments were an acknowledgement that these are not easy data to model because they are likely zero-inflated. There should be more focus on how the models are validated and tested. However, these data could not have been modeled at all a few years agon and methods will evolve.

CONCLUSIONS

There was a final discussion about how to use the advice from this new set of models, with a focus on the trends. The CAR model has great promise, but model validation was felt to be incomplete. It would be useful to run the model with or without a covariate to make a decision on the importance of the variable. It was decided to present Figure 41 with just the factorial crossed, mixed effects dynamic and non-separable space/time model results. The next year's review of the framework could include an exploration of the data, model formulation, diagnostics and more figures.

The surplus production model is poor at inferring catchability. There were concerns about the scale of the index now, and that the current model cannot inform the issue of catchability.

NEXT STEPS

Other co-variates that should be considered were discussed, for example, pH. The working group could link to the process used during Marine Spatial Planning to ensure data quality. The two most important co-variates are temperature and depth. Spatial autocorrelation should not be ignored because these cause bias and incorrect precision. Ecosystem variability has been mostly ignored in previous assessments. The ability to run a CAR model on a laptop was an impressive achievement. Bayesian analysis enables us to ask questions in different ways and incorporate into INLA. Running it as a template model builder process (maximum likelihood) would be faster but that level of programming is not yet available.

APPENDIX A: TERMS OF REFERENCE

A FRAMEWORK FOR THE ASSESSMENT OF SNOW CRAB (CHIONOECETES OPILIO) IN MARITIMES REGION (NAFO DIV 4VWX)

Regional Science Advisory Process – Maritimes Region
February 25-26, 2020
Dartmouth, NS

Meeting Chair: Tana Worcester

Context

Snow Crab (*Chionoecetes opilio*, O. Fabricius) is a subarctic species with a distribution from northern Labrador to near the Gulf of Maine. Snow Crab has been a dominant macro-invertebrate in the Scotian Shelf ecosystem since the decline of the groundfish during the late 1980s to early 1990s. They are observed in large numbers in deep, soft-bottom substrates ranging from 60-280 m water depths and at temperatures generally less than 6 ˚C. Scotian Shelf Snow Crab are in the southern-most extreme of its spatial distribution in the Northwest Atlantic.

The Snow Crab fishery on the Scotian Shelf has been in existence since the early 1970s. It occurs annually throughout the year dependent upon the Crab Fishing Area (CFA). In 2005, many CFAs and subareas were merged with the resulting divisions being North-Eastern Nova Scotia (N-ENS; formerly CFAs 20-22), South-Eastern Nova Scotia, S-ENS; formerly CFAs 23, 24), and Northwest Atlantic Fisheries Organization (NAFO) Area 4X.

This meeting will provide an introduction to an operationally viable way of providing a stock assessment for Snow Crab in Maritimes Region. The proposed approach is an ecosystem-based spatiotemporal one that uses discrete (Conditional Autoregressive) models in a flexible framework to replace the previously used continuous space-time modelling approaches; the latter are no longer operational due to time and computational limits.

Objectives

The objectives of this science advisory meeting are to:

- Review the proposed spatiotemporal modelling approach
- Demonstrate the utility of the proposed models for estimating abundance and for use in future assessments

Expected Publications

- Research Document
- Proceedings

Participation

- DFO Science
- DFO Resource Management
- Aboriginal Communities/Organizations
- Fishing Industry
- Provincial representative

- Non-government organizations
- Other invited experts

APPENDIX B: LIST OF PARTICIPANTS

Name	Affiliation
Anderson, Bob	CFA 24 (S-ENS)
Brickman, David	DFO Science, Maritimes Region
Cameron, Brent	DFO Science, Maritimes Region
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Choi, Jae	DFO Science, Maritimes Region
Cook, Adam	DFO Science, Maritimes Region
Couture, John	Unama'ki Institute of Natural Resources (UINR)
Denny, Leonard	Eskasoni Fish & Wildlife Commission / Crane Cove Seafoods
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Glass, Amy	DFO Science, Maritimes Region
Gould, Bobby	Waycobah Fisheries
Harris, Lei	DFO Science, Maritimes Region
Hayman, Timothy	DFO Maritimes Resource Management
Keith, David	DFO Science, Maritimes Region
Keyser, Freya	DFO Science, Maritimes Region
MacDonald, Gordon	CFA 23 (S-ENS) / Traditional Fleet / LFA 30 Fishermen's Association
Martin, Tim	Native Council of Nova Scotia (NCNS)
McIntyre, Tara	DFO Science, Maritimes Region
Mills-Flemming, Joanna	Dalhousie University, Department of Biology
Mitchell, Vanessa	Maritime Aboriginal Peoples Council (MAPC) - MAARS
Nicholas, Hubert	Membertou First Nation / Fisheries
Penny, Lorne	DFO Maritimes / Resource Management, ENS
Sameoto, Jessica	DFO Science, Maritimes Region
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Worcester, Tana	DFO Science, Maritimes Region
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APPENDIX C: AGENDA

NAFO Headquarters Boardroom
2 Morris Drive
Dartmouth, Nova Scotia

Chair: Tana Worcester

Day 1 – Tuesday, February 25th

1:00 PM Welcome and Introduction (Chair)

- Context
- Current Problem
- Snow Crab Life History
- Previous Approaches
- Proposed Approach

4:30 PM Wrap Up Discussions

Day 2 – Wednesday, February 26th

09:00 AM Review of Previous Day

- Data Considerations
- Management Implications
- Recommendations and Future Considerations

4:00 PM Closing Remarks

* Hospitality will be provided at breaks during the day. Lunch on Day 2 will not be provided.