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Proceedings of the Regional Peer Review for the Evaluation of the Limit Reference Point (LRP) for 2J3KL Atlantic Cod

January 22-24, 2019
St. John's, NL

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Editor: Danny Ings

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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 meeting of the Newfoundland and Labrador (NL) Regional Peer Review Process was held January 22–24, 2019, in St. John's, NL, to evaluate the biomass reference point for Northern Cod (*Gadus morhua*) in Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J3KL. This Proceedings Report includes an abstract and summary of discussion for each presentation and a list of research recommendations. The meeting's terms of reference, agenda, list of participants, and reviewer reports of the working papers are appended.

Participants at the meeting included staff from Fisheries and Oceans Canada (DFO) Science and Fisheries Management Branches; Institut Français de Recherche pour l'exploitation de la mer; and representatives from the Newfoundland and Labrador Department of Fisheries and Land Resources, Memorial University, non-governmental organizations, and the fishing industry. External review was provided by Dr. Alexander Kempf, Thunen Institute, Germany and Dr. Carmen Fernandez, Instituto Espanol de Oceanografia, Spain. Additional review was provided by Dr. Daniel Duplisea (DFO, Quebec Region).

In addition to these Proceedings, publications to be produced from the meeting include a Science Advisory Report and a comprehensive Research Document, which will be available online on the DFO Canadian Science Advisory Secretariat's Website.

INTRODUCTION

In 2010, Limit Reference Points (LRPs) were adopted for several Atlantic cod stocks, including the Northern cod stock (NAFO Divs. 2J3KL; Fisheries and Oceans Canada 2011). At that time, it was noted that the LRP should be re-evaluated once more data, particularly at higher stock sizes, are available. Since then, there have been increases in Spawning Stock Biomass (SSB). Fisheries Management requested the current LRP be re-evaluated in accordance with the DFO Precautionary Approach (PA) Framework to determine whether the previous approach to adopting the LRP (as well as the LRP itself) remain valid.

PRESENTATIONS

ENVIRONMENTAL CYCLES AND TRENDS ON NEWFOUNDLAND AND LABRADOR SHELVES

Presenter: F. Cyr

Abstract

An overview of the marine environment variability off Newfoundland and Labrador (NL) is presented in relation to decadal and multi-decadal climate cycles. A look at historical data going as far back as 1948 suggests that 1960–75 stands as the warmest period over the last 70 years (1–1.5°C warmer than the cooler 1948–55 and 1985–95 periods). There was a recent warming period that lasted from the late-1990s to the early-2010s. Since about 2012, the system is marked by a new cooling trend that has some similarities with the 1985–95 cold period. These cycles follow the low-pass filtered winter North Atlantic Oscillation (NAO), with the cold and saltier periods generally associated with a predominance of positive NAO anomalies. Biogeochemical oceanographic conditions were also presented and discussed.

Discussion

Clarification was sought on the widely held perception that the Newfoundland Region has been in a warming period that was predicted to continue for some time, but this was inconsistent with information provided in the presentation. It was explained that on a global scale there is a warming trend, but this affects circulation patterns which could result in cooling in some locations. Further, it was noted that over the last five years, data suggest a decoupling of the local area with the entire North Atlantic, so Newfoundland is actually in a cooling phase at this time.

There was a brief discussion on the trends in nutrients over time with particular reference to the period since 2010. The presenter acknowledged that there was inter-annual variability in the values but concluded that the overall trend was negative.

A participant asked if there was an explanation for declines in zooplankton biomass over time. It was noted that the decline in zooplankton was a broad-scale phenomenon and a cause for concern. The discussion expanded to how the composition of the zooplankton community had also changed over time, so it was mainly the large lipid-rich species that had declined, and these were higher energy prey sources.

There was discussion on linking environmental variables and the recovery of the cod stock. It was agreed that this topic should be covered in the research recommendations with specific areas of research listed, including relationships between the plankton/environmental variables and cod stock dynamics. It was explained that the resources to fully evaluate all the aspects of

the environment on cod are not currently available within DFO but there are some data available from existing surveys. It was also noted that the limited timeframe of some of the environmental data presented challenges for these analyses.

REVIEW OF THE DFO PA AND CURRENT LRP FOR NORTHERN COD

Presenter: K. Dwyer

Abstract

This presentation and the associated working paper provide a review of the Canadian DFO Precautionary Approach (PA) Framework, as it applies to LRP for Northern cod (NAFO Divs. 2J3KL). Generalities of the 2009 report on the PA Framework are given, discussing key features of the framework, including the Critical Zone of the PA. In addition, a review of outcomes from the 2012 workshop relating LRP under varying productivity is considered. A review of the 2010 Regional meeting framework that set the current reference point for Northern cod is given as well as the current LRP and the rationale for choosing the LRP.

Discussion

There was a question of whether the LRP was set independent of the model or approach, or if it was meant to remain the survey index value at the time. This question referenced the 2010 LRP meeting. It was explained that the LRP was defined as the average SSB of the 1980s and the value was only included for the benefit of management. A number of parameters were considered but the LRP was ultimately based on recruitment-below the 1980s level of SSB, recruitment was impaired and hence this was the approach taken. It was acknowledged that there was a gap in the spawner per recruit plots that received a lot of attention during the 2010 meeting, and that meeting concluded that the LRP should be reassessed when SSB/recruit values in the gap were observed. A number of those attending the 2010 LRP meeting agreed that the method rather than the absolute value was selected as the LRP.

Clarification was sought on what data were available for the 1960s and why the Healthy Zone wasn't shown on PA plots for the stock. It was explained that data are available for that period, but there were unresolved issues with some of it that prevented its use at this time.

There was a comment about confidence in the high level of recruitment estimated for the 1960s. Another participant noted that given the level of catches and the spawner per recruit analyses conducted for the current meeting, all evidence suggests that recruitment was high in the 1960s.

A participant asked for details on values provided in the 2003 Stock Status Report (SSR) (DFO 2003) *("When the spawner biomass in the stock as a whole approaches 150,000 t, the available data will be reviewed to determine appropriate spawner biomass limit reference points … it is anticipated that appropriate conservation limit reference levels will be set at levels greater than 300,000 t for the stock as a whole.*") and whether the 300,000 t value was meant to be considered a milestone or actually a LRP for the stock. It was explained that the value from that meeting was not meant to be a LRP, and the text in the SSR was just setting the stage for developing a reference point in the future.

There was a discussion on how to determine whether high productivity conditions will not occur again, with respect to changing a LRP when conditions were not expected to improve appreciably. It was noted there wasn't much insight available from documentation of meetings on the PA Framework that would assist with using this practically. Comments highlighted that there was no guidance on how to adjust to the best information available on whether it is likely that higher productivity will reoccur or the appropriate time framework for reoccurrence. A

participant suggested that a probability could be assigned to the likelihood of higher productivity returning. It was noted that currently, the burden of proof is high that high productivity will not occur again. A participant explained that management actions would be very different at low versus high productivity conditions so it was not considered advisable to change a LRP without a high standard and there should be caution in making changes to LRPs. Also, it was noted that F-based reference points could be established (which may be considered targets rather than limits) and they would be important in low productivity periods. It was concluded that in the current form of the PA, there were issues with interpreting guidance on changing LRPs based on changing productivity.

NCAM VS. XTENCAM AND STOCK RECRUIT SCATTER

Presenter: P. Regular

Abstract

The Northern cod Assessment Model (NCAM; Cadigan 2016a, 2016b) was supplemented with data that extend from 1982 back to 1962. While the time series in base case NCAM begins at the start of the research vessel (RV) survey series for 2J3KL in 1983, older data used in previous assessment models for Northern cod, such as reported landings and catch-at-age, have gone unused. Though limited in quantity, there are also historical data from the tagging program that have yet to be utilized in a formal assessment model. Here we document the process and assumptions behind the inclusion of reported landings, catch-at-age, and tagging data collected between 1962–82 into NCAM. Stock-recruitment relationships are evaluated using estimates from the extended model and implications for the setting of LRP were discussed.

Discussion on NCAM vs. xteNCAM

The meeting agreed that extending modeling back in time was a worthwhile exercise especially for evaluating the LRP. It was noted that various assumptions were necessary for this exercise; most important were the assumptions around natural mortality (M), but the general agreement between NCAM and the extended models during the period of overlap was thought to be reassuring.

A participant commented that baseline M is set for the first year in both NCAM and xteNCAM and pondered whether this could have effects in the recent period. It was explained that confidence intervals are wider and more variable as a result of this setting. Also, it was explained that the spike in mortality estimated for the early-1990s by NCAM is reduced in the xteNCAM model and the change has reduced the process error. There was further discussion on the implications of setting the M to the base case in the first year.

There was a comment that the main concern for different assumptions/settings between the two models was that stock recruit (SR) relationships may be impacted because recruitment estimates may differ between models. It was agreed that these issues are relevant to more than evaluating the LRP and it would be discussed further during a subsequent presentation at the meeting on SR relationships.

A participant commented that additional survey data were available for portions of the stock prior to 1982 that were not included in xteNCAM. There were M and some catch data, although no additional catch-at-age data, available that could potentially be utilized by xteNCAM. Nevertheless, this run was thought to be useful by the commenter and it was noted to be consistent with the Virtual Population Analysis (VPA) results obtained previously for the stock. These VPA analyses are available in Baird (1991), and these were also shown at the meeting.

There was a question about how the models estimate M in the recent period, and if there were implications for not having estimates of removals from the recreational fishery in most years. It was explained that there were multiple sources of information used to tease fishing mortality (F) and M apart and that the tagging data were particularly informative. Also, it was noted that even when the catch bounds were widened, there were a number of things keeping the catch estimates similar between runs.

A participant commented on the bounds test, noting that the wide bounds in the early period resulted in more recruitment, as would be expected, but the result implies that the historic period is more driven by assumptions than the recent period. The presenter explained that he had conducted runs with various wide bounds and the results didn't change all that much. Another comment focused on using the same catch bounds before and after the introduction of Total Allowable Catches (TAC) in 1978. A participant thought that there would be no reason to misreport prior to TACs when there were no quotas, although it was acknowledged that record keeping may have been an issue then. The participant thought that there was some confidence in landings back in time and that discarding might not be all that significant, especially prior to 1978. However, it was noted that there was no observer program in the 1970s and each country would simply submit landings estimates to the International Commission for the Northwest Atlantic (ICNAF)/NAFO. There was a follow-up question about a comment in an early proceedings document that suggested that landings were inflated during the pre-TAC period. There was a perception that some landings were overestimated when countries were jockeying for position prior to the development of quota keys. It was concluded that this may not have been much of an issue for Northern cod and likely more important for 3Ps cod.

More documentation was requested on the differences in tagging data used in the two models (minimum of 70 tags per experiment in NCAM vs 30 in xteNCAM). There was a request that in the future, more detailed data be made available on the number of fish tagged per experiment and the spatial distribution of early tagging relative to that of the commercial fishery.

A reviewer asked whether any attempts were made to estimate unfished biomass (B_0) with xteNCAM. It was explained that this was not attempted because a number of assumptions would have to be made in projecting the population backward or forward until B_0 is reached; in particular, all outcomes would likely be sensitive to the assumptions about M in the future.

There was a discussion on whether using xteNCAM for the SR analysis was the best possible approach. The meeting concluded that the current formulation was likely not the best possible and that a formal process would be necessary to evaluate it thoroughly before it could be used as an assessment model. It was noted that the current formulation was meant to provide information on the period prior to NCAM that captures more of the stock history, so it was more of an illustrative exercise rather than an attempt to develop a new assessment model for the stock. Also, it was noted that xteNCAM was developed to evaluate whether the SR patterns were consistent between NCAM and the extended model. Other options for improving xteNCAM were offered (using standardized catch rates although issues were noted with this approach, partial survey data, etc.). The meeting concluded that xtenNCAM would be useful for considering SR relationships to inform the LRP, keeping the caveats in mind.

Discussion on SR Scatter

A participant commented that the history of the fishery should be considered when interpreting the analysis and suggested that high levels of SSB in the 1960s might be considered virgin stock. The participant noted that many areas were not fished offshore until the 1960s so F should not have been especially high during that period. There was also a brief discussion on discard levels during that time.

There was a discussion on applying International Council for the Exploration of the Sea (ICES) guidelines to develop a biological limit reference point (B_{lim}) for the stock. Participants commented that because the SR relationship appeared linear, this could result in selecting the highest observed SSB as B_{lim}, but this was not an approach the meeting was comfortable with adopting. Discussions circled back to this point later and more details were presented on landings prior to 1962. A plot of catch estimates from Rose (2004) was shown and catch levels over time were discussed relative to model (xteNCAM) estimates of F.

There was a brief discussion on NCAM, specifically on the range of age classes that were incorporated in modeling. It was noted that there was no plus group in NCAM, and this would have implications for estimating recruitment. Also, there were comments on how Z would affect the plus group in NCAM.

One of the external reviewers commented that there was no evidence of an asymptote in the SR scatter and that they liked the resampling approach taken to generate confidence intervals. There was a suggestion to run the model (xteNCAM) forward to determine how the population produces biomass in the future and whether this analysis could inform selection of a LRP. However, it was pointed out that the confidence limits broaden quickly in forecasting with NCAM, and this exercise may have limited utility.

There was a discussion on how the SR scatter was consistent with the idea that SSB levels lower than those observed during the 1990s resulted in only low levels of recruitment.

There was a discussion on how recruitment was treated in NCAM. Comments centered around using a time-varying recruitment relationship versus estimating average recruitment values for various periods, which is the current method employed. It was explained that a time-varying relationship had been explored previously, but this resulted in some technical issues and the model fits were reduced. Further, it was noted that this approach wouldn't change the overall conclusion that the best SR relationship was linear. There was a comment that there were limited data in some areas of the graph and this presented challenges in evaluating whether some potential LRPs should be considered acceptable. It was agreed that some of the proposed work would be outside of the scope of the meeting and it was an ongoing academic exercise anyway.

A participant asked whether NCAM could be fit with an internal SR relationship. It was explained that it was possible and may be explored in the future but hasn't been attempted yet.

CHANGES IN PRODUCTIVITY OF NORTHERN COD (GADUS MORHUA) STOCK IN NAFO DIVISIONS 2J3KL

Presenter: J. Morgan

Abstract

An extended period of low productivity could be a signal that a population may not return to productivity conditions that would allow it to grow to historic levels used to set a biomass LRP. Length-at-age, weight-at-age, condition, spawner per recruit, recruits per spawner, potential population growth rate, and surplus production were all examined for evidence that Div. 2J3KL cod has been in an extended period of low productivity. All metrics of productivity showed variation over the time series. Short periods of low (and high) productivity are evident, particularly a low productivity period from the mid-1980s to mid-1990s, including four consecutive years with the lowest productivity in the time series. Since the mid-1990s there have been years of both high and low productivity. Overall, there is no evidence that Div. 2J3KL

cod is experiencing a prolonged period of low productivity that would indicate that historic levels of biomass cannot be reached in the future under environmental conditions similar to the past.

Discussion

A participant asked why the mean weight-at-age and length-at-age calculations used only ages 3–7 and suggested that it might be useful to look at percentages of these ages in the catch because recently there are no fish older than age seven in the survey. The presenter explained this range was used to be consistent over time because some older ages were missing in some years.

There was a conversation about the use of M from NCAM for the productivity analyses. A participant noted that after 15 years of low F (~0.02) there is no increase in the number of older fish in the survey data and pondered whether that means something about productivity. It was clarified that analyses presented were based on the output from NCAM, which is the accepted assessment model for the stock, and if you look at the surplus production rate even with the high M, productivity has been rather high recently. Another participant commented that the stock has increased from 3%–35% of B_{lim} recently. A participant also described preliminary analyses that showed higher stock levels in recent years if there had been no fishery removals. A research recommendation was suggested to examine how NCAM teases out F and M.

There was a discussion about the importance of Capelin and the environment on cod productivity and the difficulty in predicting Capelin biomass in the future. Recent trends in the Capelin stock were described. The meeting recognized that it could not determine what information on the Capelin stock meant for future cod productivity at this time.

There was a comment that the decrease in recruits per spawner around 2010 was large and whether this represents a decrease in productivity in the recent period. It was responded that possibly, this could be related to the levels of M estimated by the model as there would have to be a lot of recruits estimated that will subsequently die. It was suggested that the large increase in recruitment prior to 2010 may be unrealistic, so the model may be just correcting this. Participants noted that a number of metrics (i.e., mean weight-at-age) dropped around 2010 as well. The presenter emphasized the goal of the analysis was to look for long periods of low productivity and these were not observed. A participant commented that while a number of stocks declined around the same time as cod, other stocks and many biological indicators did not decline at that time. He concluded that despite variability in the recent period there was no evidence of any long-term reduction in productivity in the system.

An alternate approach to setting the LRP based on recovery during the 1970s was proposed. It was noted that further development of xteNCAM may help evaluate this approach, but older formulations of VPA (with constant M=0.2) and xteNCAM results were very similar, giving some comfort with the model. The rationale for the proposed level of 1970s as a LRP was that the stock recovered after that period. A participant commented that an average of the SSB from 1975–78 (approximately) might be useful for a LRP and pointed out that this was not based on a single year like the $B_{recover}$ is for 3Ps cod. To develop xteNCAM further, there was a suggestion to add fishery-dependent data (standard catch rates) and partial research survey data from the fall, and that spring research data could be added. There was a suggestion that xteNCAM could be vetted and used for the assessment model and then used to evaluate the 1970s period as a basis for B_{lim}.

There were a number of responses to this proposal. One participant commented that looking back and knowing the current high levels of M, taking the 1970 period as the basis for a LRP would be problematic because it was the time following the extension of Canadian jurisdiction which led to the implementation of restricted quotas in 1978. F and M were thought to be among

the lowest in the time-series at that time. Given that M is estimated to be much higher for the recent period, the participant expressed concerns about basing a LRP derived from the lowest level from which there has been stock recovery on a period with low M because stock growth under current high M might not be supported. Further comments were provided around the difficulty of selecting the late-1970s period as the basis for the LRP with respect to fitting within the Canadian PA, although there were opposing views presented on this. The presenter responded that the LRP should be based on productivity, not on any management regime.

A participant responded that during the 1970s trough, recruitment was very low for two years and moderate for the other two years and this low productivity was not ideal for selecting a recovery period. It was acknowledged that there was no definitive analysis to determine LRPs, but recruitment-based approaches work well because it permits identification of periods of impairment and unlike other approaches, assumptions about mortality are not required. Issues with interpreting the Canadian PA were commented on, especially terms such as “serious harm”. It was also noted that in other PA Frameworks, objectives are defined (such as impaired recruitment in ICES), unlike the Canadian PA.

Another participant commented that the proposed period in the 1970s was an anomaly from environmental point of view.

A participant provided their perspective that the current LRP is not attainable. They commented on what this means for upper stock limits estimates (typically 2 x LRP) and that the resultant value would be rather high.

An external reviewer described the ICES approach to setting LRPs and stepped through it with the SR plot for Northern cod. It was noted that an argument could be made for a LRP anywhere between 500,000 t and 800,000 t, but taking into account the uncertainty, the current LRP could be supported. This reviewer thought the current LRP was a good compromise between different views.

There was a comment that the baseline value for M of 0.4 in xteNCAM may not be appropriate for the 1960s and 1970s. The participant suggested that this should be evaluated further because we are uncertain about this level, and further work on the model fit was required. It was proposed to use a range of values of M for the 1962-82 period to see how the model responds.

A participant showed surplus production plots from working papers that have the current LRP and considered periods when the stock had shown growth. A plot of surplus production estimates showed a scatter that included the late 1970s and the 1980s (LRP basis) so if an average SSB for these two periods was taken, the estimate of the LRP wouldn’t change much from the current value. There were no questions.

There was a comment that in the 2010 LRP meeting, there was a lot of analysis of different periods with varying productivity that wasn’t presented to this meeting and there may be value in presenting this in future considerations of the LRP.

A participant proposed to keep the current LRP as an interim measure, until additional work is completed on the xteNCAM model. This would allow time to address some of the issues noted during the meeting. This proposal was ultimately accepted by the meeting. Timeframes of months to a couple of years were proposed to complete the work, but there was no agreement on a definitive time period. There was general agreement that an assessment model with a longer time series would be desirable for the stock and further work to explore the diagnostics of xteNCAM would have utility.

REVIEWER REPORTS

Discussion of Report Summary by Dr. Alexander Kempf

Reference was made to the ICES approach to setting LRPs and further details were provided to the meeting describing differences between the ICES and DFO approach. In particular, there were questions on how the DFO approach considers changes in productivity metrics. It was explained that ICES was also conservative in changing LRPs.

There was a comment on how to consider uncertainty in the early period (pre-1982) when making decisions around changing the LRP. The response stressed that there wasn't much evidence to support changing the LRP and there should be attention given to evaluating what will happen in the future, (i.e., what is the probability of further increases in the stock?). It was noted that the cloud of points in plots that indicated periods with high surplus production included both the 1970s and 1980s, but surplus production was estimated to be lower in recent years.

The reviewer commented that within the DFO PA Framework, there is no clear guidance on the procedures for changing a LRP and that interpreting the term "serious harm" was also open for interpretation. It was noted that a benefit of using the term serious harm is that it is general enough to apply to invertebrate stocks and stocks that don't have estimates for a SR relationship.

Discussion of Report Summary by Dr. Carmen Fernandez.

There was a discussion on ways to fill the gap in the stock-recruit plot (500,000 t to 800,000 t) which is immediately below the current LRP. It was agreed that filling the gap is important for reevaluating the LRP and that the two options of waiting for the gap to be filled in the future and completing work on xteNCAM to help fill the gap were not mutually exclusive processes. Participants noted, however, that xteNCAM is not thoroughly vetted. Also noted was that filling the gap with only a few points would not be advisable because of the high variability and low power. A timeframe of around four years was discussed, but there was no commitment to completing the work within a specific period.

Discussion of Report Summary by Dr. Daniel Duplisea

There was a comment that DFO Science should bring in the ecosystem considerations as an area of research. It was noted that there has been some work on prey effects on the stock and that this work should be expanded. The discussion covered the data limitations in doing this type of analyses, especially the paucity of data in early years (e.g., Atlantic Zonal Monitoring Program [AZMP] started in 1999). It was concluded that modeling could take things only so far because of data limitations.

There was a discussion on the reviewer's comment that having an estimate of B_0 could assist with determining an LRP. The proposal was that projecting the stock forward would give an idea of the stock's potential productivity in the future and this exercise could be a diagnostic tool recognizing that estimates, for example, 20 years out, should not be considered as valuable. It was noted that some work had been done on the long-term projections but there were difficulties in settling on the appropriate assumptions to be used. It was concluded that there were a number of issues in estimating B_0, but ongoing work on it should continue being cognizant that pressure to change/reevaluate the LRP will be high as the stock approaches it.

There was a comment that some type of analytical approach to setting reference points is preferred to more arbitrary methods that can be debated between the stakeholders. It was

stressed that the approach involved much more than just looking at stock-recruit plots because many aspects of the models that provide the estimates for these plots should be considered in detail (i.e., assumptions about recruitment).

A participant noted that the current LRP could be considered at the upper limit for the LRP because there are no data in the gap in the SR plot. They suggested that qualifications (e.g., periodic reevaluation of the LRP) from the meeting in 2010 that set the LRP should still hold, and it was agreed that this would be repeated in text for the current meeting.

RESEARCH RECOMMENDATIONS

DISCUSSION

There was a comment that broad statements about research priorities are good but for wording of research recommendations it would be most helpful for the managers allocating resources if rather specific areas of research were identified.

A participant noted that the SAR should address the issues with applying the definitions of LRPs implementing the PA that were discussed during the meeting.

RESEARCH RECOMMENDATIONS

- Continue broad scale research into linking the environmental and lower trophic dynamics with cod population dynamics. Specifically, natural climatic cycles, predator-prey relationships, consolidation of previous relationships, understanding how recruitment has changed over SSB levels, and spatial migration are the primary areas for research.
- Other potential issues to explore with respect to influences on the results of xteNCAM/NCAM include temporal changes in weights/length-at-age and alternative methods to estimating recruitment (e.g., estimate time-varying values) as only mean values are used currently.
- Conduct further investigations to better understand how NCAM (and xteNCAM) estimates F versus M, and how assumptions about F and M relate to the historical impressions on recruitment and stock structure.
- Add other available data to xteNCAM and conduct further testing with different levels of mortality. Potential data to incorporate/evaluate include research survey data from 1971–81 (mostly 2J and 3K), spring research survey data (3L), and standardized commercial catch rates series.
- Conduct a framework process to determine whether a model incorporating pre-1982 data (e.g., xteNCAM) could be adopted as the accepted assessment model. Timeframes of a couple years were emphasized.
- Conduct a new process that evaluates multiple approaches to developing LRP for Northern cod. Compare approaches among Canada and other jurisdictions (e.g., ICES) to developing and changing reference points and consider a variety of options for Northern cod. If at all possible, derive an analytical approach to developing a reference point.

BULLETS

DISCUSSION

There was discussion whether reference to 'serious harm' should be included in the bullets. This wording was used in 2010 so a participant thought that there should be consistency among meetings. Others disagreed that serious harm was demonstrated. It was pointed out that serious harm is in the definition from the PA and another participant also noted that poor recruitment would be indicative of harm. The meeting decided to include reference to serious harm in the bullet.

A bullet was requested on using a five-year period in the 1970s as the basis for LRP. It was agreed that this topic was incorporated into a bullet on xteNCAM, but years weren't specified because they may change with different model formulations. As no working paper or full analysis of the proposal was available at the meeting, this request was rejected. It was agreed that the proposal would be presented in the proceedings and the SAR, although it shouldn't be the basis for a bullet.

A bullet specifically on the physical environment in the 1980s relative to present conditions was proposed, but this was not accepted. Participants noted that other aspects of ecosystem were not covered in the bullets, and this topic would be covered in the text of the SAR and it was referenced in first bullet.

A bullet on prolonged productivity periods was suggested but not accepted. It was agreed that this would be included in the body of the SAR, and since it was not related to the objectives of the meeting it shouldn't form a bullet.

The timelines and work required for reevaluating the LRP was discussed as a potential bullet. It was agreed that this would not be included in the bullets, but it would be included in the SAR, proceedings and referred to in the research recommendations. Participants noted that even without a specific timeline, any new analysis would be presented when available, for example at an annual RAP. Participants noted that there were a large number of priorities for work by scientists and committing to specific timeframes is difficult because of shifting priorities. Someone also commented that the modeling attempts are not guaranteed to be successful so it might not be useful to specify timelines.

BULLETS

- Re-evaluation of the Limit Reference Point (LRP) was based on biological and environmental information available for the stock area, 2018 stock assessment (1983–2018), and an exploratory population model that extended over a longer period (xteNCAM; 1962–2018).
- The previous approach to adopting the LRP, as well as the LRP itself, remains valid, with B_{lim} as the average of spawning stock biomass (SSB) of the 1980s.
- The low SSB levels since the 1980s have only produced poor recruitment, indicative of serious harm occurring on the stock. However, a gap remains in the stock-recruit relationship at SSB levels between those of the 1980s and currently observed.
- The LRP will be re-evaluated with further information on the productivity of the stock within this range, either through refinement of xteNCAM and/or future years with higher SSB.
- Several metrics of productivity were examined and although variable, there is currently no evidence that Northern cod is experiencing a prolonged period of lower stock productivity.

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APPENDIX I: TERMS OF REFERENCE

Evaluation of the Limit Reference Point (LRP) for 2J3KL Atlantic Cod

Regional Peer Review Process-Newfoundland and Labrador Region

January 22-24, 2019
St. John's, NL

Chairperson: Ben Davis, Division Manager - Aquatic Resources, Science Branch

Context

In 2010, Limit Reference Points (LRPs) were adopted for several Atlantic cod stocks, including the Northern cod stock (Northwest Atlantic Fisheries Organization Divisions 2J3KL; Fisheries and Oceans Canada [DFO] 2011). At that time, it was noted that the LRP should be re-evaluated once more data, particularly at higher stock sizes, are available. Since then, there have been general increases in spawning stock biomass (SSB) and a decline in 2018. Fisheries Management requested the current LRP be re-evaluated in accordance with the DFO PA to determine whether the previous approach to adopting the LRP (as well as the LRP itself) remain valid.

Objectives

Determine whether the previous approach to adopting the LRP (as well as the LRP itself) remains valid.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- DFO Science and Fisheries Management Braches
- Province of Newfoundland and Labrador Department of Fisheries and Land Resources
- Industry
- Academia
- Non-Governmental Organizations
- Other Invited Experts

References

DFO. 2011. Proceedings of the Newfoundland and Labrador Regional Atlantic Cod Framework Meeting: Reference Points and Projection Methods for Newfoundland cod stocks; November 22-26, 2010. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2010/053.

APPENDIX II: AGENDA

Tuesday, January 22

Time	Topic	Presenter
09:00	Opening remarks and overview of Regional Peer Review Process	B. Davis
-	Presentation: Environmental Cycles	F. Cyr
-	Presentation: Review of the DFO PA, and current LRP for Northern Cod	K. Dwyer
-	Presentation: NCAM vs. XtendCAM	P. Regular
-	Presentation: Stock Recruit Scatter (Beverton-Holt and Segmented Regression models)	P. Regular
-	Presentation: Productivity over time in Northern Cod	J. Morgan
-	Discussion on LRP	All

Wednesday, January 23

Time	Topic	Presenter
09:00	Discussions and Conclusions	All
-	Drafting of Summary Bullets	All
-	Drafting of Research Recommendations	All
-	Upgrade of Working Papers to Research Documents	All
-	External Reviewers' Reports	C. Fernandez and A. Kempf
-	Additional Reviewer's Report	D. Duplisea

Thursday, January 24

Time	Topic	Presenter
09:00	Discussion	All
-	Closing Remarks and ADJOURN	B. Davis

Notes:

- Coffee, tea and lunch can be purchased from the cafeteria.
- Agenda remains fluid-breaks to be determined as meeting progresses.
- This agenda may change.

A third day (**January 24th**) has been added in the event of winter weather related delays, NAFC storm closures and/or extra time is required for discussion.

APPENDIX III: LIST OF PARTICIPANTS

Name	Affiliation
Alexander Kempf	Thunen Institute Germany
Ben Davis	DFO Science, NL Region
Bob Rogers	DFO Science, NL Region
Brian Healey	DFO Science, NL Region
Carmen Fernandez	Instituto Espanol de Oceanografia Spain
Chelsey Karbowski	Oceans North
Connie Korchoski	DFO CSA, NL Region
Dale Richards	DFO CSA, NL Region
Dan Dulpisea	DFO Science, Quebec Region
Danny Ings	DFO Science, NL Region
David Belanger	DFO Science, NL Region
Devan Archibald	Oceana Canada
Eric Pedersen	DFO Science, NL Region
Erika Parrill	DFO CSA, NL Region
Erin Carruthers	Fish, Food and Allied Workers Union
Frédéric Cyr	DFO Science, NL Region
Gilbert Penney	Harvester
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Hannah Murphy	DFO Science, NL Region
Heather Penney	DFO Science, NL Region
Hilary Rockwood	DFO Science, NL Region
James Baird	NL Groundfish Industry Development Council
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Name	Affiliation
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Keith Lewis	DFO Science, NL Region
Laura Wheeland	DFO Science, NL Region
Martha Krohn	DFO Science, National Capital Region
Noel Cadigan	Marine Institute
Paul Regular	DFO Science, NL Region
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Pierre Pepin	DFO Science, NL Region
Rick Rideout	DFO Science, NL Region
Steve Devitt	Atlantic Groundfish Council
Tom Dooley	Department of Fisheries and Land Resources

APPENDIX IV: REVIEWER REPORTS

DR. ALEXANDER KEMPF

Working Document: Environmental Cycles and Trends

A comprehensive overview is provided in this document about hydrodynamic and climatic conditions in 2017 and further back in time. There are several cycles and trends of hydrodynamic and climatic variables that could have influenced the dynamics of the cod stock. The cycles and trends reach from few years (colder and warmer periods) up to decadal scales. The environmental conditions have likely influenced the ecosystem around the cod stock in many ways. Unfortunately, there were hardly any links presented between the hydrodynamic properties and the biology of the stock and the ecosystem. This could be an important topic for future research.

Working Document: PA Framework in General

A working document has been provided explaining the current PA framework applied by DFO in Canada as background information for the reference point workshop. The PA framework is to some extent based on difficult to define expressions (e.g., serious harm to stock productivity) leaving room for interpretations. A specific focus in the WD is on how to deal with changes in stock productivity over time. This is especially relevant for setting the LRP for the Northern cod stock.

The PA Framework states: "… the only circumstances when reference points should be estimated using only information from a period of low productivity is when there is no expectation that the conditions consistent with higher productivity will ever recur naturally or be achievable through management.".

It is extremely difficult to predict whether a change in productivity is irreversible and in practice, it can hardly be proofed that a shift is permanent (or at least will last for the next decade(s)). In addition, management can only impact F, and therefore as long as fishing is kept at a decent level (e.g., below F_{MSY}) the outcome in terms of SSB trajectories is mainly a consequence of environmental factors. Given the current assessment, F has been very low in recent years and was never in a range that could seriously harm the stock after 1982 (highest median values around 0.2, which is half the assumed base M). Therefore, according to the current assessment the stock has been mainly driven by environmental factors. Whether the F estimates in the current assessment are unbiased, however, is unclear and more research may be needed.

The guidelines on the derivation of maximum sustainable yield (MSY) and PA reference points for stocks with varying productivity conditions or regimes are partly inconclusive (at least according to the description in the WD). On the one side it is stated that reference points may be changed:

1. Only when certain (there is a high probability) that a regime shift has occurred should a reference point be changed, and
2. Only when the mechanisms of this shift are understood.
3. This shift cannot be reversed (longer than a decade or a generation, whichever is longer) and
4. There has to have been a change in the capacity of the environment to support the stock (DFO 2012).

On the other side, DFO states that a reference point should not be lowered because there is a less productive regime (DFO 2012). Changes in recruitment rates, M, fecundity, or growth rates

are not considered suitable reasons to change biomass LRPs. The question following from this is what other metrics can indicate a regime shift and are suitable enough to trigger changes in reference points?

Working Document: Extension of the Northern Cod (*Gadus morhua*) State-Space Integrated Assessment Model back to 1962

This working document describes the approach to extend the NCAM model back to 1962. The official assessment only goes back to 1982. The extended time series allows to investigate a wider range of stock and recruit estimates and potential changes in productivity. The Canadian DFO PA Framework also suggests that a time-series as long as possible should be used when defining limit reference points (DFO 2009).

The extension comes at the cost of extrapolating data (length and weight-at-age, age distribution from length data) and using more tagging data when only a few fish were tagged. Also, catch data are less certain than in the period after 1982. The additional usage of tagging experiments with less fish (compared to the official assessment) had only a very limited influence on the time series after 1982. Overall, the estimates for the years before 1982 are more uncertain as also indicated by the model. The M test predicts much lower recruitment in the early period compared to the base run while the time series after 1980 is hardly impacted. Therefore, the perception of recruitment in the period when the stock was high also depends on the assumption of baseline M. A lower M in a period where the stock was high is not unrealistic as according to the current assessment the decline and recovery of the stock are largely driven by increasing and decreasing M.

M is a major driver of the assessment. It is unusual that M is increasing with age in many years (especially during the collapse). For older and larger fish only starvation can cause this high mortality or an extreme top- predator outbreak. The influence of harp seals was analysed and was found not to be an important driver of the stock. Mean weight is going down especially for older fish before and during the collapse. It is less clear whether the effect is strong enough to explain why most individuals died in this period. Cod is an opportunistic feeder. This makes extreme starvation events less likely. The observed gutted condition and liver condition (see WD3) do not show drastic changes during the collapse. But maybe only the survivors could be sampled and therefore the values are biased upwards.

The runs with a base M of 0.4 and 0.2 show an increasing trend with increasing SSB. A linear model explains the stock-recruitment relationship best. Lower R/SSB was mainly observed during the collapse (see WD3) and in the SRR the outliers in recruitment strength are obvious. Figure 11 and Figure 13 suggest that the current recruitment is within the expected range but in general lower than around 1980 at similar SSBs. The yellow points are below the blue points in most cases. However, more data points are needed to judge whether this is by chance or whether the stock will likely produce less recruits per SSB compared to earlier periods in the future.

Overall, the results and diagnostics of the current version XteNCAM highlight larger uncertainties that need to be resolved first before it is a reliable model for assessing long-term trends in the status and productivity of the stock. However, the extension provides already now interesting information to get a general idea about trends in stock dynamics and productivity over a longer time period.

There is some indication that the current recruitment is lower than around 1980 at similar SSB values. But more data points are needed to judge whether the few year classes which have entered the stock after the partly recovery are by chance lower compared to similar SSBs around 1980 or whether indeed lower recruitment has to be expected in the future. To set B_{lim}

near the highest observed SSB as discussed in the document is questionable until it is clear that indeed the SSB is the main driver that determines recruitment and historically observed recruitment levels can be expected after further recovery. There are many indications from literature that the ecosystem drastically changed, and it first needs to be understood what this means for the future recovery potential of the stock. In addition, it seems that Figure 13 suggests a breakpoint of a segmented regression around the current LRP (B_{lim}) when taking into account the uncertainty in estimates. Overall, there is not much evidence to change the current LRP until more information becomes available and the likely stock development under a MSY or PA approach can be predicted with more certainty.

Working Document: Changes in Productivity of Northern Cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL

The objective of this study was to examine variation in some of the components of productivity, as well as potential population growth rate, in Div. 2J3KL cod. Specifically, the objective was to determine if the population is in an extended low productivity period.

The conclusions regarding mean weight-at-age, mean length-at-age, relative gutted condition and liver condition are based on observed data. There are clear trends over time (i.e., during the collapse) with a decline again in recent years (i.e., 2011-16). But the reasons for the changes in mean weight are less clear. It remains unclear to what extent density-dependent effects play a role (e.g., high mean weights-at-age during the 90ies when the stock was collapsed) and when changes in mean weight were more related to prey availability (i.e., Capelin and shrimp) and the carrying capacity of the ecosystem. For example, it could be tested whether an index: (Capelin and shrimp abundance or biomass)/(biomass of cod) is correlated with the mean weight. The question what is a suitable ratio between food available and cod biomass is interesting and seems to be relevant for this stock.

The calculations of recruits, SPR, RPS and G are influenced by the estimates of M in the assessment. Is there any external information that the time series of M can be related to predator and/or prey fields? Assuming that the M estimates are representative, it can be seen that the metrics are in recent years back to levels similar to those observed before the collapse. Also, the surplus production does not show negative anomalies in recent years. The main conclusions hold true regardless whether the shorter or longer assessment time series is used.

Overall, based on the information available and assuming that the assessment and M estimates are representative, I agree to the final conclusion that there is currently no strong evidence that Div. 2J3KL cod is experiencing a prolonged period of low productivity (at least compared to the period during and after the collapse). However, it is premature to conclude that the biomass levels before the collapse can be reached. For this the carrying capacity of the ecosystem is important. It is not clear yet whether there is still enough food available (and can be expected to be available in the future) to sustain a much larger cod stock. Also, the loss of previous spawning grounds could play an important role. Not much is known from this working paper about potential predators and competitors for (juvenile) cod that could have taken over the ecological niche after the collapse (any predator outbreaks after the collapse?). Mean weight-at-age is declining again and M is increasing in 2017 according to the latest assessment. The question is whether this is just by chance and further recovery will take place in the next years or whether the biomass will level off even under the current low F (at least according to the assessment). More data points are needed to answer this with more certainty. Additional analyses (e.g., on density-dependent effects and prey availability) could potentially give indications what can be expected in the coming years.

Overall Conclusions

There is not enough evidence to change the current LRP reference point for northern cod now. The mechanisms are not enough understood to predict what will likely happen in the next decade(s) and there are not enough data points from the current period to judge whether the recovery potential of the stock is still similar or lower compared to the period before the collapse. The current LRP constitutes a compromise between different views on the recovery potential of Northern cod and ensures SSB levels that were able to produce higher recruitment. It is in line with the current PA framework. However, the framework itself is open to interpretation and would benefit from clearer objectives and streamlining. A $B_{recover}$ was proposed during the meeting that could be also in line with the PA framework after further research. But also, here a clear understanding of the processes determining the recovery potential are key to judge on whether biomasses observed in the late-70s are a suitable biomass limit.

The assessment is key for answering the question of what drives the dynamics of the cod stock. Especially the split of Z in F and M is critical and could potentially lead to biased management decisions. Given the agreed assessment, the stock is currently driven by environmental factors and fisheries management is not able to influence the SSB that can be reached in the next years. Current management can only do its best to avoid negative impacts on the recovery potential of the stock. When more data points and knowledge under the current low fishing regime become available, a realistic target for SSB that can be reached has to be agreed upon. Therefore, a re-evaluation of the LRP after 5 years may be considered. Dependent on the agreed objectives in a (re-evaluated) PA framework a new LRP may be set.

Reviewer Recommendations:

The estimated M values are absolutely central to understand the dynamics of the stock. More research is needed to understand the processes driving M (mainly starvation?). The split between F and M in the model, associated correlations between model parameters and the reliability of tagging data need to be evaluated further to exclude the possibility that the current perception of the influence of F is biased.

The processes from hydrography over the dynamics of main predator and prey stocks up to the dynamics of the cod stock itself need to be understood to increase the predictive power regarding the recovery potential of the stock under future climatic conditions.

An analysis of density-dependent effects and prey availability could give important indications on the carrying capacity of the current ecosystem and the likely recovery potential of the cod stock. It needs to be understood how important prey stocks will likely develop in the next decade(s) to set realistic LRP levels.

A re-evaluation of the PA framework could be considered. Especially the formulation of clearer objectives could be beneficial in applying the framework for management.

The guidelines for setting reference points taking into account changes in stock productivity need to be streamlined and made more conclusive. Metrics indicating a shift in productivity need to be agreed. It is also important to have realistic expectations on how well it can be predicted that a shift will last the next decade(s).

DR. CARMEN FERNANDEZ

The objective of the meeting was stated in the Terms of Reference as follows:

“In 2010, Limit Reference Points (LRPs) were adopted for several Atlantic cod stocks, including the Northern cod stock (Northwest Atlantic Fisheries Organization Divisions 2J3KL; Fisheries

and Oceans Canada [DFO] 2011). At that time it was noted that the LRP should be re-evaluated once more data, particularly at higher stock sizes, are available. Since then, there have been general increases in spawning stock biomass (SSB) and a decline in 2018. Fisheries Management requested the current LRP be re-evaluated in accordance with the DFO PA to determine whether the previous approach to adopting the LRP (as well as the LRP itself) remains valid.

Objective: Determine whether the previous approach to adopting the LRP (as well as the LRP itself) remains valid."

Four documents were made available in advance of the review meeting (I call these documents Doc1, Doc2, Doc3, and Doc4 in my report). Doc1 was an overview of the DFO PA as it relates to setting the current LRP for Northern cod. Doc2 was an extension of the current stock assessment model currently agreed for this stock, NCAM, which starts in the year 1983, back in time to 1962 (note: the extended model is called XteNCAM in Doc2, though it was referred to as xteNCAM during the meeting). Doc3 was an examination of several productivity metrics of this stock over time to try and ascertain if the stock is experiencing a prolonged period of low productivity. Doc4 was on physical oceanographic conditions on the Newfoundland and Labrador Shelf. These documents were presented during the first day of the meeting and formed the basis of the discussions held during the meeting.

My comments here pertain to these documents and also take into account the discussions that took place at the meeting and the meeting's conclusions. I participated in the meeting by WebEx. While preparing for this review, I also consulted the proceedings of the 2010 workshop where the current LRP was established for Northern cod (CSAS Proceedings Series 2010/053) and the stock assessment agreed in 2018 (CSAS SAR 2018/038).

Reading through the 2010 proceedings document, two main methods appear to have been examined at that time to decide on the LRP for this stock: Stock-recruitment estimates from a previously accepted VPA-based going back to the early 1960s and stock-recruitment estimates from a survey-based assessment (SURBA+) starting in the early-1980s. The 2010 meeting concluded that:

"The 2J+3KL cod spawner biomass and recruitment remain at extremely low levels compared to the 1960s. SSBs in the 1980s was the last to produce medium levels of recruitment. After the 1980's SSB has been low and recruitment poor, indicating that the stock has been below a level where serious harm occurs.

The average SSB during the 1980s is considered as the limit reference point for 2J+3KL cod.

The stock is currently estimated to be at 10% of this LRP. The model spawning stock during the 1980s' was 55 Kg per tow or 660 000 t. Recent estimates of total mortality have been lower than the very high levels experienced by 2J+3KL cod from 1996-2003, thus establishing an LRP based on the low productivity period is not appropriate for this stock. This LRP should be reevaluated once more data, particularly at higher stock sizes, are available."

By the time of the stock assessment in 2018 (CSAS SAR 2018/038), a new stock assessment methodology had been agreed upon. The new method is a state-space model (NCAM) that includes M and F as stochastic processes whose values change from year to year; the natural and F values are estimated within the stock assessment model. The assessment starts in 1983 and includes the following data: fishery catches (treated as intervals of values instead of as single known values, in order to account for expected biases in these data), proportions-at-age in the fishery catches, various indices of stock abundance, and tagging data. According to this assessment, M has fluctuated over time, was extremely high in 1992-94, and has experienced a

big increase in 2017 relative to 2016; M has often been considerably higher than F (certainly in the last decade) and, hence, appears to be a main driver of the dynamics of this stock.

Doc1 explains that the LRP in the DFO PA is defined as the “stock status below which serious harm is being done to the stock”. No definition of what constitutes “serious harm to the stock” seems to be provided in the PA; for Northern cod, it seems to have been generally interpreted as impaired productivity or impaired recruitment, which seems in line with NAFO and ICES PA frameworks. Despite available general guidance, the actual determination of LRPs in PA frameworks is, in my experience, very often difficult and the case of Northern cod is no exception.

Doc1 also displays the stock-recruitment plot based on the SSB and recruitment estimates from the 2018 assessment (I reproduce the figure here below). The document notes that although the SSB has increased since 2010 (when the meeting that set the current LRP was held), there is no evidence of increased recruitment at these higher SSB values and that, as a consequence, the 2018 assessment meeting agreed that the current LRP should be maintained. Doc1 says that, considering that the current SSB values are higher than all others in the collapsed period, the 2018 assessment meeting also agreed that new information would be frequently reviewed to see if there was improved productivity, potentially leading to a revision of the current LRP.

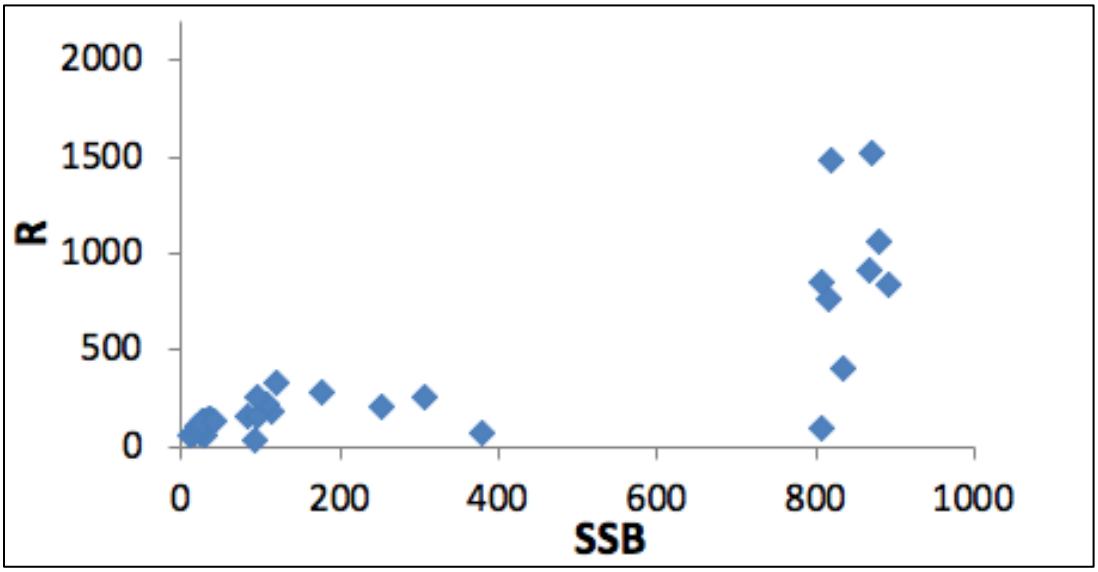

Figure 1 (from Doc1): SSB and Recruitment (age 2) estimates from the 2018 stock assessment.

A difficulty I see with Figure 1 is the SSB gap between 400 and 800 kt (where the values above 800 kt correspond to the years 1983-91 and the values below 400 kt to the years 1992-2015: note that the SSB estimates for 2016-18 are not shown in Figure 1, as there is no corresponding recruitment (age 2) estimate yet available for those SSB years). Therefore, I think it is very helpful to be able to extend the stock assessment back in time, to try and gain a better understanding of the stock dynamics and possible relationships between stock size and recruitment; this is what Doc2 has done. It should be noted that the extended assessment in Doc2 is considered as an exploratory tool (not as an approved or even necessarily a “valid” stock assessment at this point), to provide some indication of likely stock dynamics before 1983.

For the years before 1983, only catch data from the fishery (total catches and proportions-at-age, treated as in NCAM) and some tagging data were used in the extended assessment, although in discussions at the review meeting it emerged that some survey, and possibly some fishery catch rate, indices existed and could possibly be used in the further development of this

extended model. Doc2 compares assessment results from the extended model (XteNCAM, starting in 1962) with the approved assessment in 2018 (NCAM, starting in 1983). The results are quite similar for the common years (since 1983), although recruitment until the mid-1990s appears to be higher in the NCAM model.

The extended assessment indicates that both SSB and recruitment were higher during the 1960s than afterwards, and that the SSB experienced a continuous decrease from the early-1960s until about 1977, with some subsequent SSB increase to reach a rather constant plateau during the 1980s, after which both recruitment and SSB dropped to very low values. The extended assessment contains some SSB values (corresponding to the late-1970s) which fall in the SSB gap observed in Figure 1. A sensitivity test indicated that changing the baseline M value in the assessment can substantially impact on the recruitment estimates before 1980, and this can, in turn, impact the shape of the SSB and recruitment scatter plot.

Under the two assumptions on baseline M explored in Doc2, statistically fitting a segmented-regression relationship to the log (SSB)-log(recruitment) scatter plot suggests that recruitment increases continuously with SSB over the range of observed SSB. As the document notes, a situation where recruitment continuously increases with SSB would correspond to what ICES guidelines on reference points call a Type 3 SSB-recruitment scatter plot. The ICES guidelines say that “in such cases, it may be suspected that F has been high before the historical time-series started and that all historical data are within the range of impaired recruitment. B_{lim} may be at higher SSB values than observed. This decision should be based on evaluations of other data, especially the historical data on F.” This was discussed at the meeting and some participants commented that, based on their knowledge of the fishery, they thought it unlikely that the stock would have been experiencing overfishing before the 1960s. It was suggested that in future development of the XteNCAM assessment, efforts should be made to incorporate available survey indices and catch rate data. I agree that it would be useful to include further sources of information in future development of the XteNCAM assessment (note: if fishery catch rate data were to be considered for inclusion in the stock assessment, they should be appropriately standardized).

As I noted above, the XteNCAM assessment estimates some SSB values (from the late-1970s) that fall in the gap in Figure 1. If instead of aiming to fit a stock-recruit function statistically, one simply explored the XteNCAM SSB-recruitment scatter plot by eye, there might be some debate as to whether it would be possible to identify by eye an SSB value below which recruitment is observed to be impaired. If this was attempted, it seems to me that one might end up with SSB values between the average SSB of the late-1970s (which is below the current B_{lim}) and the average SSB of the 1980s (which is the current B_{lim}).

I found the examination of different productivity metrics in Doc3 very useful. The metrics examined were length-at-age, weight-at-age, fish condition, spawners per recruit (under no fishing conditions), recruits per spawner, potential SSB growth rate (under no fishing conditions), surplus production, and surplus production rate. I agree with the overall conclusion of this document that, despite variation of these productivity metrics over the time series (with particularly low productivity from the mid-1980s to the mid-1990s), there is no evidence that the stock is experiencing a prolonged period of low productivity that would indicate that historic levels of biomass cannot be reached in the future.

A summary of my conclusions follows:

- All things taken together; I do not think there is presently clear evidence indicating that B_{lim} should be changed from its current value.

- According to the agreed stock assessment, M plays a very significant role in the dynamics of this stock. Therefore, further understanding of the environment (physical and biological) inhabited by this stock, and the interplay between the environment and the stock dynamics, would be useful.
- Given that the SSB has been increasing in recent years, hence potentially being able to fill the SSB gap in Figure 1 with current SSB values in the reasonably near future, I think it would be useful to re-examine B_{lim} after some years (such as 4 or 5 years from now) in order to include the latest SSB and recruitment values.
- I agree that in further development of the XteNCAM model, which extends the stock assessment back to 1962, it would be useful to include available additional sources of data (survey indices and catch rates, if appropriately standardized). I also think that some aspects of the way M is treated in the model should be further explored (e.g., the impact that assuming that M in the first assessment year is exactly equal to the baseline M can have on the assessment results and whether it is possible to soften this assumption).
- I agree with the bullet point summary and research recommendations agreed by the meeting participants and stated in the review meeting report.

DR. DANIEL DUPLISEA

A Few General Comments

The tool provided by Paul Regular to look at the assessment results interactively is a great step forward for transparency and utility. This is a highly commendable piece of work and an example for the Department.

The NCAM - XteNCAM comparisons are very informative and useful and the extension back in time has been really informative for show the stock biomass potential in the past as well as stock productivity. This is essential for assessing the suitability of the reference points.

The papers by Cyr, Dwyer and Morgan and very informative and essential for the evaluation.

There was a notable lack of papers before the meeting on biological characteristics of the ecosystem and more information about cod that was not a model input or derived from the model.

Questions and short points relevant for assessing the reference point and if it should change

On what should B_{lim} be based?

There is not strong evidence for a stock recruitment relationship that is not linear or even at all. Without inflections in the SR relationship, it is difficult to justify a reference point based on it. A biomass proxy is probably best and the 2010 B_{lim} fits into that category. Eventually, a simulation approach may be a good way to address this.

How does a 2010 B_{lim} work with a new model approach? Does it scale properly?

The reference point is presently defined as a period rather than a biomass level (i.e., Regular has adjusted it to mean of 1980-90 SSB – 832 kt, contrast with the 540 kt from SURBA in 2010). By doing this, the reference point is a function of a period and not a level and thus, given that all approaches so far essentially show a similar biomass history from 1962-present, the approach automatically scales to the modelling approach developed and is robust.

When do we change reference points?

There is not a well-defined practice for this. Newer approaches would suggest that reference points should change every time the model is refitted and while this can present the problem of moving points that are difficult to manage , the reality is that most robust approaches tend to scale the reference points roughly to the equivalent of changes in recent biomass. (i.e., the relative stock state does not change much). This is presently true with the mean biomass in a period approach and Regular has shown how current biomass is relative to that and it scales properly. In terms of absolute biomass level, there are implicitly assumptions about the stability of the overall productivity conditions of the stock (stock production, ecosystem impacts, and environmental impacts). It would be unwise to change reference points when these appear to be showing just standard variance and not directional changes. It also would be difficult to justify changes when productivity conditions are showing directional change, but different components of that productivity may be going in different directions and we may not know what the ensemble of those changes means. Finally, when they are in flux and do not show variance characteristics that suggest some kind of stability, it would not be wise to follow those conditions down, up, or wherever.

Do present conditions reflect reference conditions?

Because the B_{lim} is a period and not a biomass, the B_{lim} has an implicitly assumption that the present climate 1980s productivity climate for the stock, ecosystem, and environment. The question then becomes if the productivity conditions of the present are similar or different from those of the reference period? The physical oceanographic conditions would appear to be similar to the 1980s (e.g., present temperatures are approaching long term average) (Cyr, Figure 42); summer CIL is more like 1980s now than in years since moratorium (Cyr, Figure 38). It is difficult to visually interpret figures like Figure 71 in Cyr for anything other than broad pictures but to my eye the 2014-18 composite is more similar to the productive early-1980s period than it has been in many years. (i.e., subjectively, it would seem that present conditions are like those in the reference period).

I am not sure about the biological conditions for the stock (e.g., AZMP plankton, Chlorophyll a analysis could be interesting). Also a characterization of the predator and prey environment. Other interesting aspects to explore would be spatial and migratory characteristics of the population and how that might compare to the 1980s (probably a lot of speculation required). During the meeting, the presentations of AZMP data and nutrients suggested that there is worry recent changes in these variables and it may not bode well for cod production. Similarly, they seem to suggest a declining production from 1980s level.

Given this are there grounds for changing B_{lim}?

One could argue that because B_{lim} should represent a point of serious harm and because biomass in the 1980s had good fisheries (although it would appear it could not support these fisheries) that it would be very conservative to consider this B_{lim} a point of serious harm. NCAM emphasized this criticism because it did not go back into the very high biomass historical period of the 1960s, XteNCAM solves this. Even in the early-1960s the stock had been exploited heavily for hundreds of years and industrialized in the post-war period (i.e., the stock biomass was potentially even higher than peak biomass in the 1960s). An argument might be made that the 1980s biomass is a B_{MSY} proxy and not a B_{lim} proxy. The 1980s biomass is about 1/3 1962 biomass which is less than B_{MSY} for a symmetrical density-dependent function (B_{MSY} = 1/2 K). This is simple biomass production model thinking but that is the kind of thinking that underlies much of the Canadian PA approach. A symmetrical density-dependent function is the Schaefer model. Some would consider an asymmetrical density-dependent function to be more appropriate and that is most stable. Several simple calculations can be made with these assumptions (paste into R window):

```
status= function(years=1:5){
B1962= 2912
Brecover= mean(c(587,447,455,621))
#years: #1=2018, 2=2017 ...
B5yr.med= rev(c(245,301,366,418,315))
B5yr.low= rev(c(114,123,143,156,104))
B5yr.high= rev(c(287,352,434,516,438))
Bmsy.sch= B1962*0.5
Bmsy.fox= B1962*0.36
Blim.sch= Bmsy.sch*0.4
Blim.fox= Bmsy.fox*0.4
s.l= round(mean(B5yr.low[years])/Blim.sch,2)
s.m= round(mean(B5yr.med[years])/Blim.sch,2)
s.h= round(mean(B5yr.high[years])/Blim.sch,2)
f.l= round(mean(B5yr.low[years])/Blim.fox,2)
f.m= round(mean(B5yr.med[years])/Blim.fox,2)
f.h= round(mean(B5yr.high[years])/Blim.fox,2)
b.l= round(mean(B5yr.low[years])/Brecover,2)
b.m= round(mean(B5yr.med[years])/Brecover,2)
b.h= round(mean(B5yr.high[years])/Brecover,2)
Bstatus.sch= paste(c(s.l,s.m,s.h),collapse="<")
Bstatus.fox= paste(c(f.l,f.m,f.h),collapse="<")
Bstatus.baird= paste(c(b.l,b.m,b.h),collapse="<")
out= list(schaefer=Bstatus.sch,fox=Bstatus.fox,baird=Bstatus.baird)
out
}
status(years=1) #1=2018
status(years=1:5) #1:5= mean of 2014-2018, inclusive
```

This function calculates the B/B_{lim} status given Schaefer (symmetrical) and fox (asymmetrical) production vs biomass dynamics and the choice from only one to all over the last 5 years. This was also modified to include a $B_{lim}=B_{recover}$ (1976-79) based on meeting discussions during Day 1.

In no case is there a good reason to believe stock status is above a limit reference point. In the best case, the median relative stock status is 78% and given model uncertainty the very best that could be possible would be 104% of B_{lim} under an asymmetrical density-dependent stock production function but only with the top 2.5 or 5% of all estimates. It absolutely must be noted that these simple calculations do not capture the full uncertainty in both the recent SSB estimate and those of the B_{lim} at the same time. Those ratios ideally would be calculated as part of the model taking into account the full uncertainty.

Point by Point Recap

1. The physical conditions of the current stock state are perhaps more towards those of the 1980s than any time since. So, this supports that a 1980s based reference point is relevant in the current conditions. The biological conditions however are worse and appear to be worsening.
2. The current method of estimating the limit reference point is a function of a time period and not a fixed biomass from one model therefore it scales with the model used. This supports the idea that a reference point from a previous process can still be valid under these new modelling approaches because the point scales properly with the model.
3. SR dynamics are not and have not in the past been well captured by parametric SR curves and there appears to be little basis for estimating a reference point based on these. This supports the B_{proxy} method of B_{lim} linked to mean B in stable periods of healthy biomass.
4. The productivity measured as R/S for example, show some recent decline since 2010 (when the current reference point was decided) but to levels in the past 5 years (1.01) similar to those in the 1980s (1.22); surplus production is positive although somewhat lower than the 1980s and potential population growth rate is near the long term average and around 1980s level; there seems to be little reason to change things. It should be noted, however, that there are some declines in recent population productivity parameters that should be watched closely. The system may be in a period of movement towards lower production, but I would be hesitant to say that it has shifted and it does not appear to be stable.
5. It could be argued that B_{lim} as mean biomass in the 1980s is a better estimate of B_{MSY} than B_{lim}. However, when we approximate these ideas in the above calculations, there seems to be no reasonable assumption that could make stock status larger than the limit reference point (i.e., practically, any way you cut it, the stock in presently in the Critical Zone).
6. If the stock's productive capacity is declining but still just part of a naturally varying cycle, decreasing a limit reference point to follow could potentially lead to exploitation decisions that would increase F and this could be like lopping off potential SSB building. If there has been a real change in productivity that is not just part of the productivity short-term variance, then there could be greater grounds for considering a decline in B_{lim}. Defining stability of the productivity is not straight-forward, however.

Reviewer D. Duplisea Advice:

1. Do not change the limit present reference point presently from the time-period based method;
2. Watch stock productivity parameters closely over the next few years for signs of continuing decline and/or stability in productivity to a new level;
3. If there is a continued decline, it would not be prudent to chase the decline with increased F but if there appears to be some stability in a new productivity level (I am not sure how to best evaluate and justify this) then it could be grounds for considering a new reference point;
4. Ecosystem conditions for the stock should be examined particularly for predator-induced F on prerecruits and adults. Also, bottom-up process should be examined to see how that is affecting the recruitment success in particular. Condition factor suggests that the overall health of individuals is somewhere around expected levels, but condition factor of individuals may not reflect recruitment potential. Reproductive dynamics (e.g., behaviour and migration), population sub-structure, physical and biological conditions at and during spawning may have impacts that we are not measuring well and these could be part of the recent declines in R/S.

5. Work on spatial dynamics of the populations may reveal something about the populations that are not present in the research papers.
6. There are known issues with recreational catch, and it would be interesting to see how this affects not just historical biomass estimate but how that affects M and F estimates in the most recent period;
7. There is a weakness in using 1980s biomass as a limit (i.e., it can be argued that it does not have the characteristics associated with B_{lim}). Given that other approaches (e.g., like the calculations above) suggest that there is very little chance it affects current PA zone designation for the stock it does not matter presently. It will matter someday, and it could be difficult to justify the current B_{lim} when/if B begins to get closer to B_{lim}. Simulation may be a tool that could inform this in the future.
8. If an MSE for N cod is conducted, passes peer review, and is accepted, reference points could be derived from the MSE operating models. Alternatively simply having a management procedure that met objectives (many of which would necessarily derive from PA reference points), then could be sufficient in itself to meet conditions of good management and PA compliance.