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Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/058

EVALUATION OF THE BIOMASS LIMIT REFERENCE POINT FOR NORTHERN COD (NAFO DIVISIONS 2J3KL)

Image: Atlantic Cod (Gadus morhua).

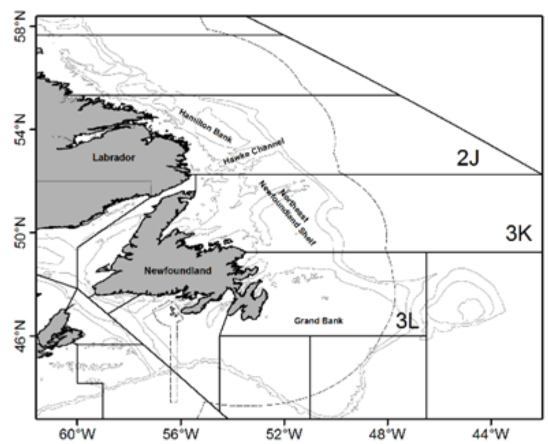

Figure 1: Stock area of Northern (2J3KL) cod. The dashed line indicates Canada's 200 nautical mile Exclusive Economic Zone (EEZ).

Context:

A conservation Limit Reference Point (LRP) was established for Northern cod (Div. 2J3KL; Figure 1) in 2010 (DFO 2010) and was defined as the average spawning stock biomass (SSB) during the 1980s. SSB since then has been lower and produced only poor recruitment. This reference point defines the boundary between the critical and cautious zones within the Precautionary Approach (PA) Framework (DFO 2009) and defines the stock level below which serious harm is occurring. At these levels the stock is considered to have suffered serious harm and the ability to produce good recruitment is impaired.

At that time it was noted that the LRP should be re-evaluated once more data, particularly at higher levels of SSB, were available. Since then, there have been general increases in SSB from 2012 to 2017. Fisheries Management requested the current LRP be re-evaluated in accordance with the DFO PA Framework to determine whether the previous approach to adopting the LRP (as well as the LRP itself) remain valid.

This Science Advisory Report is from the January 22-24, 2019 Evaluation of the Limit Reference Point (LRP) for 2J3KL Atlantic Cod. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Reevaluation 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.

BACKGROUND

Canadian Precautionary Approach Framework and Limit Reference Points

Canada's Precautionary Approach Framework (DFO 2009) is divided into three stock status zones: the Healthy, Cautious and Critical Zones (Figure 2). The Upper Stock Reference (USR) divides the Healthy Zone from the Cautious Zone and the Limit Reference Point divides the Cautious Zone from the Critical Zone. Associated with these zones are general removal rates and management actions to be taken. Uncertainty and risk are to be taken into account when developing these reference points.

The Limit Reference Point is defined as the stock status *below which serious harm is being done to the stock*. However, a challenge in setting LRPs is determining what constitutes *'serious harm'* to the stock. LRPs are based on biological criteria and are established by DFO Science through a peer review process. In the Critical Zone, conservation/biological considerations are meant to be the primary drivers for management decision-making (as opposed to socio-economic factors) and there is to be no tolerance for preventable declines as the primary goal is to get the stock out of the critical zone. Therefore, the management actions pertaining to this Zone are to promote stock growth and removals are to be kept to the lowest possible level regardless of the stock trajectory.

When establishing an LRP, the guidelines advise choosing a stock metric that can account for changing productivity; generally, the spawning stock biomass in the case of stocks with age-based analytical assessments. As long a time series as possible should be used in determining the LRP, as periods of high and low productivity should be taken into account. 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."* While reference points should be reviewed periodically, the timeframe for review has not been established and no triggers for reevaluation have been determined. However, given recent increases in SSB for Northern cod, and that the current LRP has been in place since 2010, Fisheries Management requested that a review of the rationale for, and level of, the LRP be carried out for this stock. Generally, guidelines indicate that reference points should not be lowered unless the change in productivity is well understood, irreversible, and the capacity of the environment to support the stock has changed (DFO 2013).

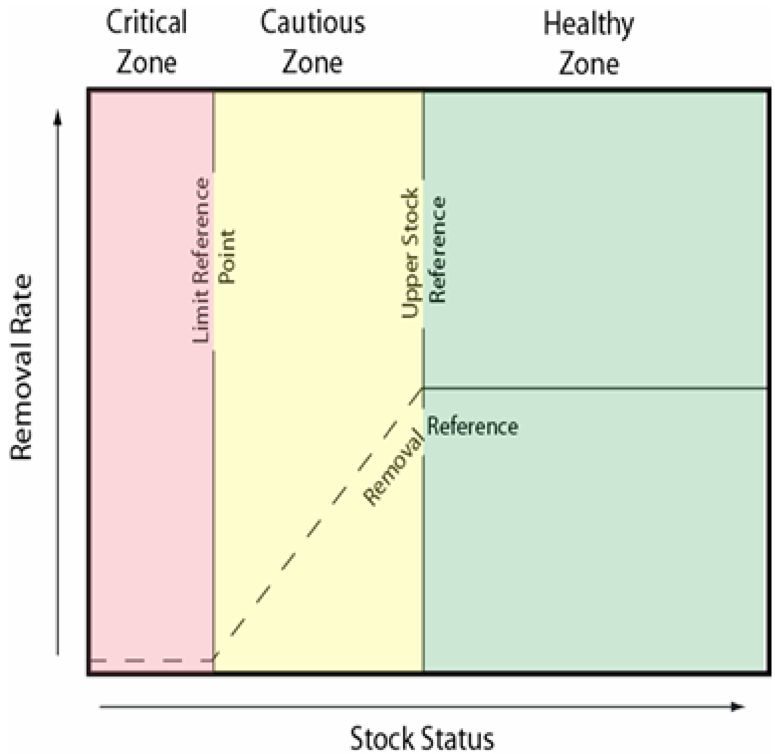

Figure 2. The different elements of Canada's PA framework (from DFO 2009).

ECOSYSTEM INFORMATION

Physical Environment/Ocean Productivity

The marine environment off Newfoundland and Labrador (NL) experiences considerable variability on decadal to multi-decadal timescales (e.g., Cyr et al. 2019). The cold intermediate layer (CIL) – a sub-surface layer that is formed during the winter by atmospheric cooling and fills a large portion of the NL shelves with waters <0°C the rest of the year – is a good proxy of these changes. This is generally because the conditions of a certain year partly depends on the previous years' conditions (i.e., preconditioning). As a consequence, slowly evolving changes on the shelf are well represented by the CIL core temperature (minimum temperature in the monthly profiles). Data back to 1948 (Figure 3) suggest that the period 1960-75 stands as the warmest period on the NL shelves over the last 70 years (1 to 1.5°C warmer than the cooler 1948-55 and 1985-95 periods). After a recent warming period that lasted from the late 1990s to the early 2010s, the CIL core is now exhibiting a marked cooling trend since 2012. Colder CIL core temperatures have generally been associated with saltier water column over the shelf (0-200 m depth range), while warmer CIL core temperatures have been fresher, except since about 2010 where fresher and colder conditions trends are emerging. The bottom temperatures in NAFO Divs. 2J3KLNO are also well correlated with the CIL evolution since the beginning of the bottom multi-species surveys in 1980. These temperature cycles follow the winter North Atlantic Oscillation (winter NAO), with the cold and saltier periods generally associated with a predominance of positive NAO anomalies. In recent years, a predominance of positive winter NAO have caused a marked cooling of the CIL.

A regular collection of biogeochemical data was initiated in 1999 as part of Atlantic Zone Monitoring Program (see Pepin et al. 2015 for the most recent updates). These data show that the deep nutrients (50-150 m) generally exhibit decreasing concentrations over the entire NL region since 1999. Phytoplankton blooms magnitude and amplitude (total and peak production as determined by satellite-derived ocean color) have been decreasing since about 2011 and zooplankton biomass remains low after a drastic decrease that occurred in 2014. These changes observed in lower trophic levels and community composition of zooplankton indicate reduced primary and secondary inputs that may impact transfer of energy to higher trophic levels.

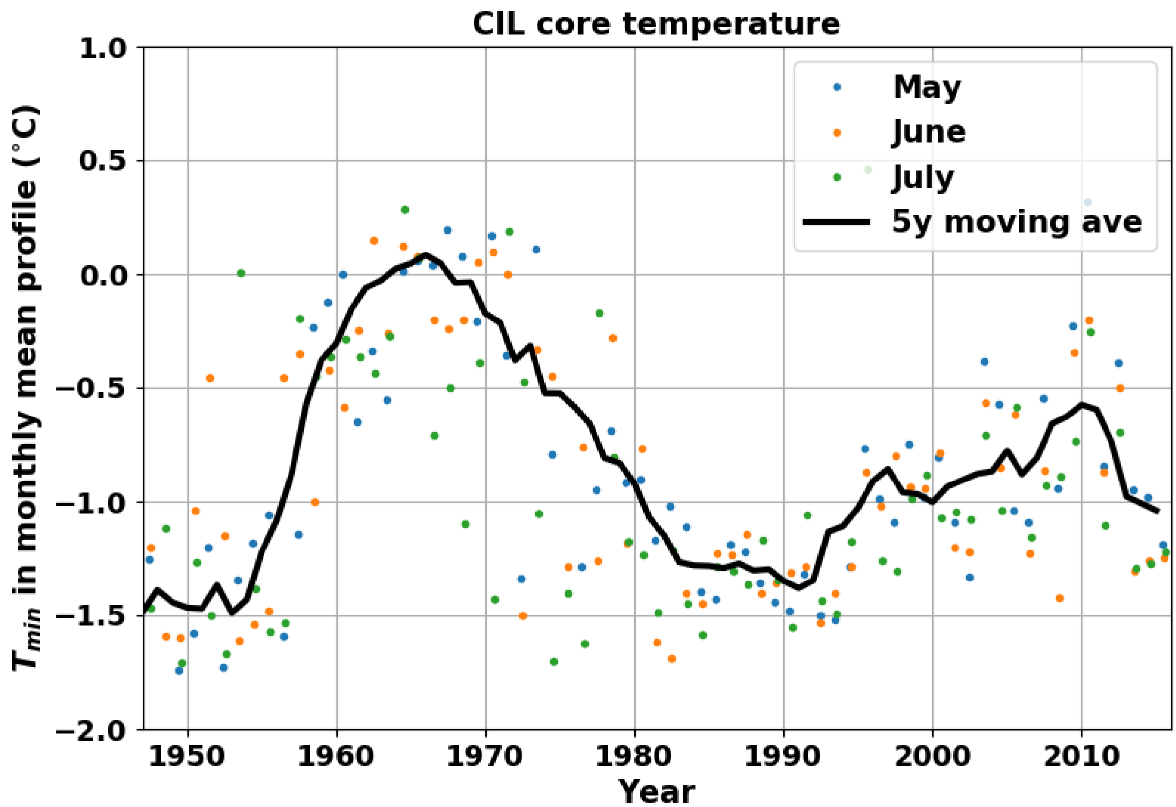

Figure 3. CIL core temperature (minimum temperature of the monthly mean profile) for May (blue), June (orange) and July (green) over the area 45-50N and 50-55W. The five-year moving average is plotted in solid black.

Regulation of Northern Cod Dynamics

Studies have shown that dynamics of the Northern cod stock are driven by an interplay between fisheries removals and bottom-up forces, such as availability of food, especially capelin. Top-down forces, particularly predation of cod by seals, are not considered to be a substantial driver (Drinkwater 2005, Halliday and Pinhorn 2009, Shelton et al. 2006, Buren et al. 2014, Morgan et al. 2017, Sherwood et al. 2007, Rose and O'Driscoll 2002). Small cod tend to feed on small crustaceans, with diet shifting towards larger crustaceans and fish as cod increase in size. Capelin (*Mallotus villosus*) in particular has historically been an important part of cod diet. It has been suggested that capelin availability may limit the ability of the stock to reach the LRP (DFO 2010).

ANALYSIS

Stock-Recruit Scatter (NCAM and xteNCAM)

The current assessment is based on an integrated state-space population dynamics model developed specifically for Northern cod (Northern Cod Assessment Model; NCAM). NCAM models the dynamics of the northern cod stock from 1983 to 2018 and integrates much of the existing information about the productivity of the stock (details in Cadigan 2015, Cadigan 2016, Brattey et al. 2018; Dwyer et al. *unpublished report*[1]). The current model includes information from the DFO RV autumn trawl survey (1983-2017), Sentinel fishery survey (1995-2017), Smith Sound acoustic survey (1995-2009), tagging program (1983-2017), and the fishery (reported landings and catch at age; 1983-2017). An exploratory population model was carried out in order to provide a longer-term perspective on the history of the stock, which extended the time series back to 1962 using landings, catch-at-age and tagging data from the 1962-82 period. (xteNCAM; Regular *unpublished report*[2]). xteNCAM allowed for an examination of a wider range of years, and therefore a wider range of stock and recruit estimates, to facilitate testing of stock recruitment relationships that assume compensation and help define reference points (e.g. Beverton-Holt, segmented regression). A longer time-series was also thought to be useful for identifying potential changes in productivity.

Several models were applied to the stock-recruit estimates generated by the xteNCAM model. However, in all cases, and similar to the results from the 2010 framework, model fit was poor and a clear breakpoint where recruitment is impaired by reductions in SSB was not identified. As a result of the lack of a model to identify a clear breakpoint the relationship between SSB and recruitment (age 2), the stock-recruit (S-R) scatter from NCAM was examined visually (Figure 4; top panels) and compared to S-R scatter from xteNCAM (Figure 4; bottom panels). The S-R scatter from NCAM indicates a cloud of “moderate” level recruitment during the 1980s when SSB was about 850 kT and lower levels of recruitment at SSB < 400 kT. SSB between 400-800 kT have not been observed across this time period and therefore it is unknown what the level of recruitment would or will be at this level. An examination of the S-R scatter from xteNCAM, however, revealed that there are four years observed at this level from the 1970s, two points with low levels of recruitment and two with moderate levels of recruitment. Levels of SSB and recruits from the 1960s were much higher (Figure 4; lower right).

Results and diagnostics from the xteNCAM model suggest that it may be an acceptable model for assessing long-term trends in the status and productivity of the stock. However, sensitivity to assumptions regarding natural mortality and the bounds around catch during the 1962-82 period, as well as the possible inclusion of other available datasets (eg. survey series, increased tagging information, etc.), indicated that more work should be done on xteNCAM in order to further refine and develop this model before it could be utilized as an assessment model. Therefore, numbers as presented at this meeting were discussed only as relative levels to provide context to the absolute values within the shorter time series provided by NCAM. The

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[1] Dwyer, K.D., Brattey, J., Cadigan, N., Healey, B.P., Ings, D.W., Lee, E.M., Mello, L., Morgan, M.J., Regular, P., Rideout. R.M., Rogers, R., and L. Wheeland. 2019. Assessment of the Northern cod (*Gadus morhua*) stock in NAFO Divisions 2J3KL in 2018. DFO unpublished report.

[2] Regular, P. 2019. Extension of the Northern Cod (*Gadus morhua*) State-Space Integrated Assessment Model back to 1962. DFO unpublished report.

further development of xteNCAM is recommended, and may further inform stock productivity in the gap of stock-recruit scatter at SSB levels between 400-800 kT.

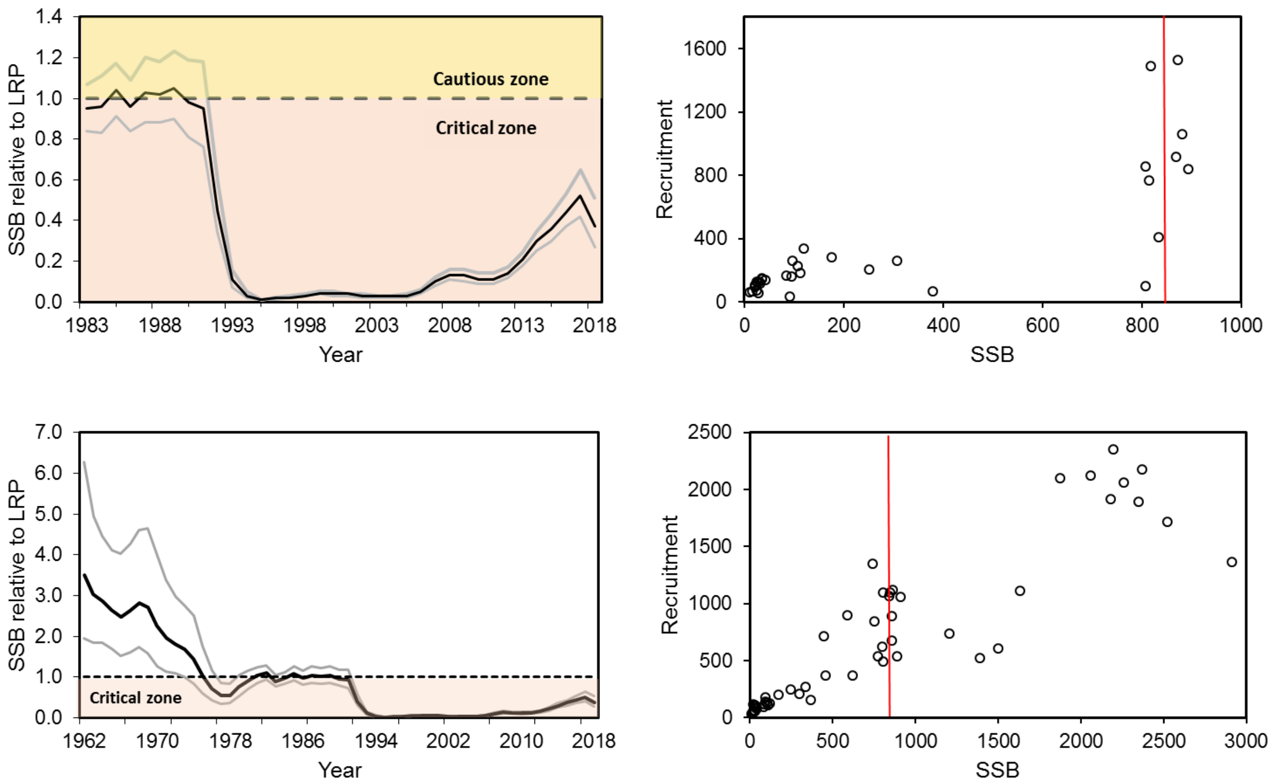

Figure 4. Top panels indicate the SSB relative to the LRP (average SSB from 1983-89) 1982-2018 from NCAM (left) and the associated stock-recruit scatter (right). Bottom panels indicate the SSB relative to the LRP (average SSB 1980-89) from an exploratory population model, xteNCAM (left) and the associated stock-recruit scatter (right). Dashed line and red lines indicate B_{lim} in left and right panels respectively.

Productivity of the Stock

Under the PA guidelines, it is recommended that as long of a time period be used as possible when setting reference points as to take into account periods of both low and high productivity. 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 limit reference point.

Various metrics of productivity, such as 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 Divs. 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 (Figure 5 for potential population growth). 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 similar environmental conditions.

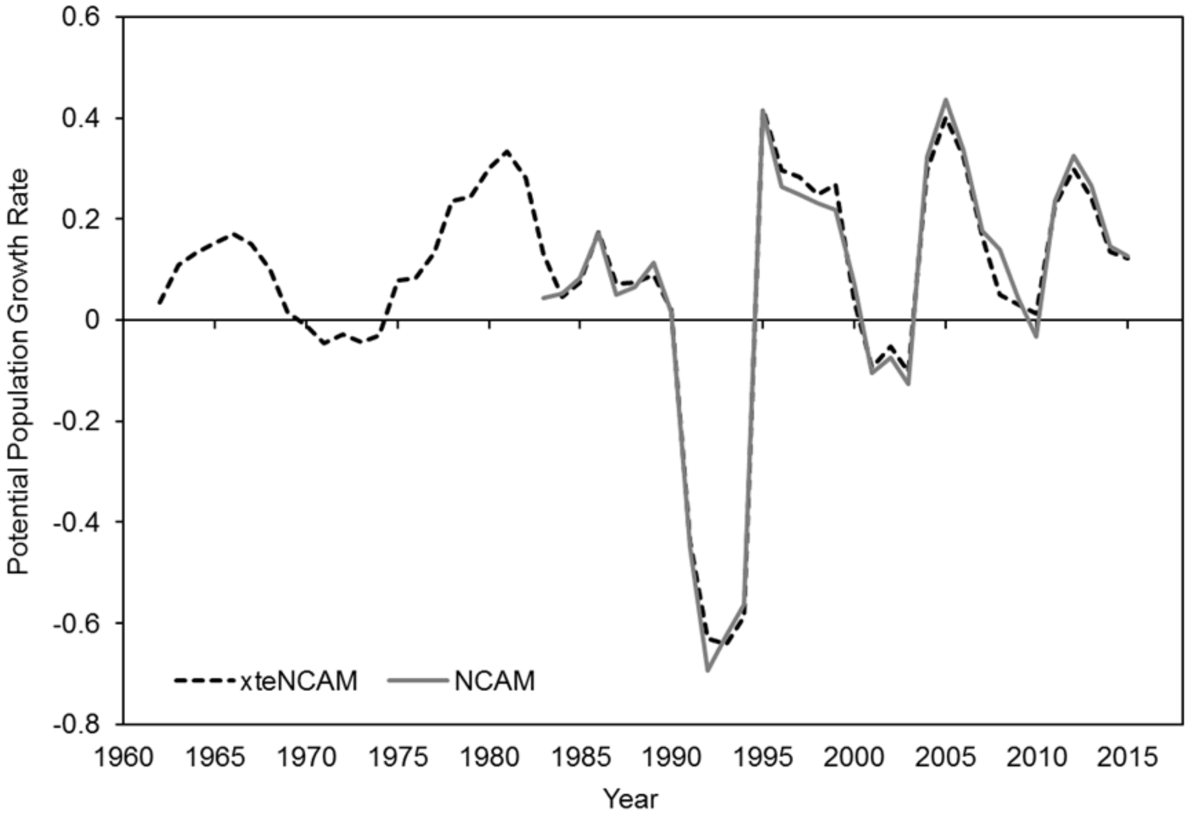

Figure 5. Potential population growth rate as proportion growth in SSB for Divs. 2J3KL cod using results of NCAM starting in 1983 (grey solid line) and xteNCAM starting in 1962 (dashed black line).

Other Methods

As mentioned above, a clear breakpoint where recruitment is impaired by decreases in SSB was not identified. This is because the relationship between SSB and recruitment appears to be linear over the time period, with an overall trend of increasing recruitment with increasing SSB. In such a situation the LRP is sometimes considered to be the highest observed SSB (e.g. ICES 2017). This is potentially supported by other modelling results which indicate that the stock was already collapsing through the 1960s (Rose 2004, Lilly 2008), so it is possible that the stock was already in a depressed state in 1962, therefore suggesting the true breakpoint for the S-R relation of this stock has not yet been observed or pre-dates the period covered by xteNCAM.

The possibility of using $B_{recover}$ (the lowest historical biomass level from which the stock recovered readily or produced good recruitment; DFO 2004) as an LRP was discussed, as the stock increased from a lower population size in the late-1970s. However, the earlier part of the time series could not be considered at this time as the data inputs and model diagnostics for the 1962-82 period have not been fully reviewed and more work on the extended model is necessary. Additionally, the recovery of the population in the late-1970s was in spite of poor recruitment and that period also showed low natural mortality. At least two other factors complicate this approach: ocean temperatures were warm at that time and Canada extended its jurisdiction (to 200 miles) in 1977 (presumably fishing mortality decreased on the stock at this time; Lilly *et al.* 2008). Nonetheless it was agreed that this period of apparent recovery in the late 1970s would be examined further in future work.

Another method suggested was the use of the SSB in the first year of xteNCAM, 1962, as B_0 (i.e. unfished, virgin biomass). Thus, 50% of this value would be B_{msy} and then, as suggested by Canada's PA guidelines, 40% B_{msy} could be the potential limit reference point. Again, because the xteNCAM model and associated inputs have not yet been fully reviewed and accepted, the time period prior to 1983 could not be used to set reference points, and, as previously mentioned, there is debate around the amount of fishing that had already occurred on the stock by 1962. Thus it was questionable whether the SSB estimated in 1962 was an appropriate estimate of B_0.

Sources of Uncertainty

There are several uncertainties to consider when examining the longer time series used for xteNCAM. Although xteNCAM generally captured trends from 1962 to 1982 and was comparable to previous population model outputs from that time period (Virtual Population Analysis; for example, Baird et al. 1992, Shelton et al. 2006, Lilly et al. 2008), the model was found to be sensitive to assumptions regarding natural mortality and the bounds around catch from 1962 to 1982. Therefore, this model formulation should be considered provisional and further work must be done before it can be considered an accepted reconstruction of population dynamics.

There is a clear gap in the stock-recruit scatter from NCAM between 400-800 kT of SSB. As more data become available, from continued stock growth and/or the refinement of the population modelling approach incorporating earlier time series, the LRP will have to be re-evaluated again for evidence that the level of SSB giving only poor recruitment is different than the current LRP. Based on the currently available modeled SSBs and recruitment estimates, there is no clear evidence of compensation in this stock.

Finally although there is no evidence that Divs. 2J3KL cod stock is experiencing a prolonged period of low productivity, the capacity of the environment has to be considered, and levels of adequate prey must be available for the stock to reach the LRP. It is unknown how current low levels of nutrients and zooplankton will impact higher trophic levels (e.g. capelin stock size, cod condition, larval survival) on the NL Shelf. In addition, the time series for primary and secondary producers only goes back to 1999; therefore there is limited knowledge of long-term trends in productivity.

For sources of uncertainty associated with the accepted model, NCAM, see the Science Advisory Report for the Northern Cod Assessment (DFO 2018). Various aspects of the NCAM formulation should be considered when interpreting the results of the spawner per recruit analysis. First, there is no explicit link in the model between recruitment and spawning stock biomass and if a stock-recruitment relationship were to be used in the model it may change the recruitment estimates. Also, there is no plus group currently used in NCAM and the influence of considering contributions of fish older than age 14 on SSB estimates is unknown.

CONCLUSIONS AND ADVICE

The previous approach to adopting the LRP, as well as the LRP itself, remains valid; which set B_{LIM} as the average of spawning stock biomass (SSB) of the 1980s. The LRP will be re-evaluated with further information on the productivity of the stock, either through refinement of xteNCAM and/or future years with higher SSB.

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SOURCES OF INFORMATION

This Science Advisory Report is from the January 22-24, 2019 Evaluation of the Limit Reference Point (LRP) for 2J3KL Atlantic Cod. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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