Fisheries and Oceans Canada
Pêches et Océans Canada

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Canadian Science Advisory Secretariat (CSAS)

Research Document 2025/019

Newfoundland and Labrador Region

Extending the Northern Cod (*Gadus morhua*) Assessment Model - Part III: Revisiting the Limit Reference Point

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June 2025

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-76354-5   Cat. No. Fs70-5/2025-019E-PDF

Correct citation for this publication:

Regular, P.M. 2025. Extending the Northern Cod (*Gadus morhua*) Assessment Model - Part III: Revisiting the Limit Reference Point. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/019. iv + 5 p.

Aussi disponible en français :

*Regular, P.M. 2025. Extension du modèle d'évaluation du stock de morue du Nord (*Gadus morhua*) - Partie III : Révision du point de référence limite. Secr. can. des avis sci. du MPO. Doc. de rech. 2025/019. iv + 5 p.*

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ABSTRACT

Under the Canadian Precautionary Approach (PA) to fisheries management, a Limit Reference Point (LRP) is defined as the stock status below which serious harm is occurring. Since 2010, the LRP for Northern cod has been defined as the average spawning stock biomass (SSB) from the 1980s as this was the last time medium levels of recruitment were observed. This definition has been formally revisited using the Beverton-Holt stock-recruitment relationship by calculating the level of SSB that produces 50% of maximum predicted recruitment. Potential maximum sustainable yield (MSY) based alternatives are also considered and the limitations of both recruitment-based and MSY-based reference points are discussed in this perspective piece. In short, the suitability of an MSY-based LRP is called into question for Northern cod as estimates are sensitive to changes in vital rates and fisheries selectivity, both of which have exhibited substantive changes through time since 1954. I suggest that estimates of MSY may be more suitable for the provision of tactical, ecosystem-informed advice. Ultimately, continued use of the recruitment-based LRP is recommended since it should be above the point at which recruitment rates are impaired and depensation or extirpation is a concern.

DISCUSSION

Canada's Precautionary Approach (PA) policy defines a Limit Reference Point (LRP) as "the stock status below which serious harm is occurring to the stock" (DFO 2009). The specific meaning of serious harm is, however, left undefined. It has been frequently interpreted as the point below which recruitment is severely impaired, and the action of fishing a stock below this limit is often deemed recruitment overfishing (DFO 2015). The current LRP for Northern cod is grounded in this concept, as it is defined as the average spawning stock biomass (SSB) from the 1980s, which is the last time good recruitment was observed (DFO 2010, DFO 2019). Good or medium is a relative statement based on comparisons to recruitment estimates from the 1960s, which were deemed high and near maximum levels of recruitment. The assessment model described in Part I (Regular et al. 2025a) and Part II (Regular et al. 2025b) estimates SSB and recruitment back to 1954 and, as such, provides an opportunity to revisit the LRP for Northern cod.

The application of a Beverton-Holt stock recruitment relationship is specifically recommended in Part I. This relationship enables the estimation of the level of SSB that produces medium levels of recruitment (i.e., SSB that produces 50% of the maximum predicted recruitment, which is simply the inverse of the Beverton-Holt β parameter; Myers et al. 1994). The proposed assessment model, therefore, provides a more formal calculation of the current LRP for Northern cod. That said, the application of a Beverton-Holt relationship also enables the estimation of maximum sustainable yield (MSY)-based reference points, which may be deemed superior to recruitment-based reference points since they account for both sources of productivity: recruits-per-spawners and spawners-per-recruit (DFO 2010). As such, it is worth considering the most common LRP applied in Canada, which is the 40% B_{MSY} proxy recommended in Canadian PA policy (Marentette et al. 2021).

The estimation of MSY does, however, require important technical and theoretical considerations since the concept is built on the premise of steady-state dynamics. Leaning on these theoretical foundations, stationary levels of SSB can be calculated for a given snapshot of a stock (natural mortality, maturity-at-age, stock weights-at-age) and a fishery (selectivity, catch weights-at-age; Albertsen and Trijoulet 2020). MSY estimates are known to be sensitive to changes in these metrics (e.g., Scott and Sampson 2011, Punt et al. 2021), and all of these variables have changed through time for Northern cod. This leaves the question: which MSY should be calculated? Should it be MSY for the current fishery under contemporary productivity and fishery conditions, or should it be MSY for the long-term average stock and fishery? Fish stock provision guidelines suggest that MSY should represent sustainable levels of catch under prevailing conditions (DFO 2022), and prevailing conditions for Northern cod could be argued to be post-collapse conditions. In contrast, the PA policy suggests that "as long as a time series as possible should be used in establishing reference points for a stock" (DFO 2009), which implies that MSY-based reference points should be based on averages across the whole time series. Given the changes that have occurred in the stock and fishery since 1954, the choice of the period over which to average key metrics has a significant impact on resultant estimates of MSY and B_{MSY}, causing an absolute difference of approximately 250 thousand tonnes for MSY and 1 million tonnes for B_{MSY} under model **M12** (utilizes a Beverton-Holt relationship and assumes allometric M; Part I). Estimates of 40% B_{MSY} also differed by approximately 260 thousand tonnes across models with different baseline M assumptions (**M11** to **M13**). In contrast, estimates of the SSB that produces 50% of maximum recruitment differed by 48 thousand tonnes across these models. On one hand, this level of sensitivity calls into question the suitability of the 40% B_{MSY} proxy for defining the point below which serious harm is occurring to the stock. One might also argue that the range of change in the biology and the fishery over time means that these values should not be compared. This leaves the question: should MSY based reference points be static or dynamic? For Northern cod, MSY calculations may be more suitable for providing tactical advice, and this advice could be adjusted using ecosystem indicators of productivity (*sensu* F_{eco}; Howell et al. 2021).

I, therefore, contend that the recruitment-based LRP remains the more appropriate LRP for this stock given its more reliable and straightforward estimation. Still, it may be argued that the recruitment-based LRP is an oversimplification that overlooks important sources of serious harm. First, the Beverton-Holt relationship ignores depensation. Second, the focus on recruitment ignores changes in spawners-per-recruit, an important component of productivity. Third, loss of resilience through loss of genetic diversity is not accounted for by a recruitment-based LRP. With this in mind, the question remains: is the recruitment-based reference point suitable and sufficiently precautionary?

At the very least, an LRP is supposed to represent a stock state before extirpation is a concern (DFO 2004, DFO 2023). A well-known path to extirpation and even extinction is the phenomenon known as depensation (aka Allee effects), which is, for example, what is thought to have led to the demise of the overexploited Great Auk (Courchamp et al. 2006). However, we found no evidence of depensatory dynamics for Northern cod; there is no obvious deterioration of recruits-per-spawner, even at the lowest observed levels of SSB, and there was no clear support for depensation when using a sigmoidal Beverton-Holt relationship (Part I). In reality, this likely means the Allee-effect zone has not been observed yet. Avoiding the point below which recruitment is expected to be below average is, therefore, a precautionary level to set an LRP as it should be well above a stock state where depensation may be occurring. Previous meta-analyses support this contention (Myers et al. 1994).

Depensation can also arise from the impacts of predators as levels of consumption can, in some cases, force a species into what’s called a predator pit (Bakun 2006). Concerns persist that Harp seals are imposing such an effect on Northern cod; however, despite extensive analyses, we lack evidence of such an effect (Part II, Buren et al. 2014). While it is true that seals have an impact on the population, it appears to be primarily isolated to the juvenile component of the population, and presumed impacts have dwindled in recent years (Part II). In short, growth of cod SSB does not appear to be impaired by seals.

The availability of prey, especially Capelin, appears to be the biggest impediment to the continued growth of Northern cod (Part II, Buren et al. 2014, Koen-Alonso et al. 2021, Regular et al. 2022). Simply put, increases in Capelin are expected to result in increases in cod SSB, which will in turn promote increases in recruitment towards maximum expected levels. While Capelin continue to exhibit low productivity (Buren et al. 2019), and this appears to be contributing to the relatively high rates of natural mortality expressed by Northern cod since the collapse, there is a lack of evidence that current levels of Capelin place cod at an increased risk of extirpation. That said, it could be argued that current levels of Capelin are causing serious harm to Northern cod given the slow reversal towards previous levels.

Finally, fisheries-induced evolution is often flagged as a concern as such a phenomenon may reduce resilience and inhibit recovery even if fishing mortality is reduced (Enberg et al. 2009). Northern cod have shown a dramatic shift in maturity at age, and if this shift was caused by genetic change in response to fishing pressure, then the stock may be locked into its current state for an extended period of time (Olsen et al. 2004). A recent genome-wide study has, however, demonstrated “genomic stability through time despite decades of exploitation” of Northern cod (Pinsky et al. 2021). This suggests that the observed changes in maturity-at-age are phenotypic and, therefore, reversible.

In conclusion, the determination of an LRP for Northern cod is a complex endeavor. Given analyses conducted to date, we have two options to consider:

1. continue to apply a recruitment-based LRP, or
2. switch to an MSY-based LRP.

While the recruitment-based LRP remains a reasonable choice due to its historical stability, it does overlook important sources of harm such as depensation, changes in spawners-per-recruit, and genetic diversity loss. The MSY-based option is potentially more robust as it accounts for spawners-per-recruit, but it is potentially less consistent given its sensitivity to life history parameters. Following the structure of tables presented in DFO (2023), I have outlined the pros and cons of each option in Table 1. My recommendation is to continue to rely on the recruitment-based LRP to strategically safeguard against recruitment overfishing while utilizing dynamic estimates of MSY for tactical, ecosystem-informed advice.

Table 1: Overview of the pros and cons of a recruitment-based vs. MSY-based LRP for Northern cod.

	Recruitment-based LRP	**MSY-based LRP**
Link to Serious Harm	Impaired recruitment	Impaired surplus production
Pros	Provides relatively stable estimates	Accounts for recruits-per-spawners and spawners-per-recruit
	Expected to be above Allee-effect zone	Expected to be above the Allee-effect zone
	Based on the whole time series	-
	Simple and easy to interpret	-
Cons	50% is subjective	40% is subjective
	Requires assumption of constant stock-recruitment relationship	Whole time series estimate requires averages of time-varying metrics
	Ignores production from spawners-per-recruit	Averages are not stochastic and may provide a false sense of precision
	Sensitive to stock-recruitment relationship	Sensitive to stock-recruitment relationship, selectivity, natural mortality, weights-at-age, and maturity-at-age

ACKNOWLEDGEMENTS

The author thanks Mariano Koen-Alonso, Divya Varkey, and Brian Healey for their valuable feedback on an earlier version of this perspective piece. Their input encouraged a more balanced perspective.

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