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NORTHERN SHRIMP (*PANDALUS BOREALIS*) IN THE NORTH AND SOUTH STOCK ASSESSMENT REGIONS - REVIEW OF MANAGEMENT STRATEGY EVALUATION (MSE) OPERATING MODEL AND CANDIDATE MANAGEMENT PROCEDURES



Northern Shrimp (*Pandalus borealis*) Photo: Fisheries and Oceans Canada.

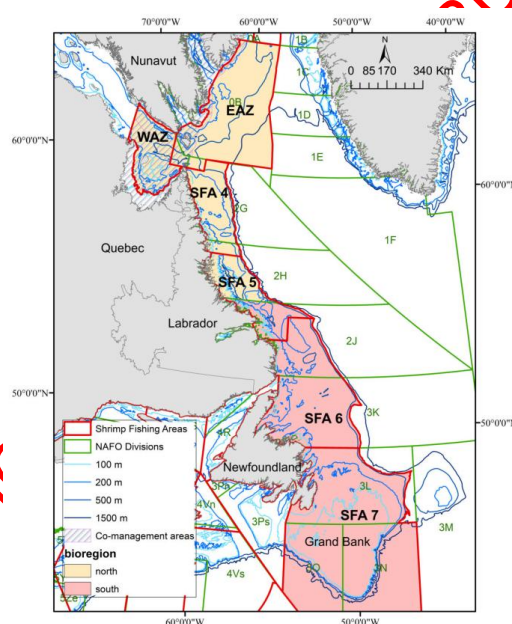


Figure 1. The spatial management areas for Canadian Northern Shrimp, including North (yellow) and South (red) Stock Assessment Regions.

CONTEXT

This Science Advisory Report is from the national peer review of December 2-5, 2025 on the Northern Shrimp - Review of Management Strategy Evaluation (MSE) Operating Model and Candidate Management Procedures. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada \(DFO\) Science Advisory Schedule](#) as they become available.

SUMMARY

- The spatially integrated statistical catch-at-length / size (SISCALS) assessment model, developed as part of the [December 2024 Northern Shrimp assessment framework](#), was adopted as the foundation for the operating models used in the Management Strategy Evaluation (MSE).

- For the North Stock Assessment Region, length composition data used in the operating models only includes years 2007-2024. Years prior to 2007 were removed to address the lack of Eastern Assessment Zone survey coverage in these early years.
- Operating models were developed to represent plausible stock dynamics and incorporate uncertainty in recruitment, growth, natural mortality, maturity, and survey indices.
- Two distinct recruitment regimes were identified during the 1996-2019 period and were used to form the two operating model recruitment scenarios used in this MSE:
 - A short time-series of recent low recruitments (the same period used in the [March 2025 assessment projections](#)); and,
 - The full time-series that had higher average recruitment with greater variability.
- MSE performance statistics were calculated using a weighted combination of results from each of the two operating models. In the North Stock Assessment Region, operating models were similar and therefore equally weighted (50% each). In the South Stock Assessment Region, the recent low recruitment regime was considered more plausible in the near-term and received a higher weighting (90%) than the full time-series (10%).
- Validation tests confirmed that the 28 harvest decision rules (HDRs) specified based on combinations of harvest control rule types, exploitation rate values, HDR phase-in periods, and maximum allowable Total Allowable Catch changes produced outputs as intended.
- All HDRs are constructed to be run annually using the previous year's Total Allowable Catch, fishable biomass index and spawning stock biomass index. At these annual time-steps, exceptional circumstances (to be developed) would also be examined.
- Twelve (12) performance metrics were used that fall into 3 categories (conservation, yield and stability). Metrics were calculated and applied across all HDRs; trade-off plots demonstrate conservation–yield–stability relationships, indicating that performance metrics are appropriate indicators of performance in relation to objectives.
- Operating model structure and performance metrics were reviewed to support the MSE process; the performance of HDRs for meeting management objectives was not reviewed. Nevertheless, the example HDRs displayed a wide range of performance across conservation, yield and stability metrics as well as stock assessment regions.
- Other uncertainties were identified that should be explored in the future for incorporation in the operating models. It is recommended that the expected performance of any adopted HDR be reviewed periodically (e.g., 3-4 years) as new operating models and performance measures arise unless a formal review is otherwise triggered by exceptional circumstances.

INTRODUCTION (OR BACKGROUND)

The provision of science advice for Northern Shrimp (*Pandalus borealis*) changed fundamentally following the adoption of a statistical model-based assessment framework for the species in December 2024 and a revised population structure from six stock assessment areas (Western Assessment Zone (WAZ), Eastern Assessment Zone (EAZ), Shrimp Fishing Areas (SFAs) 4-6, NAFO Divisions 3LNO) to two stock assessment regions (North Stock Assessment Region (NSAR) and South Stock Assessment Regions (SSAR)). Historically, science advice was provided at the same spatial scale as the management of the fishery; however, with the revised population structure, science advice is now provided for two stocks (NSAR and SSAR) that span six management areas.

Earlier in 2024, a two-step harvest decision rule (2SHDR) using survey data specific to each management area was adopted to calculate the total allowable catch (TAC) in the WAZ, EAZ and SFAs 4-6. The potential effectiveness of the 2SHDR was not tested in simulations because a model-based assessment framework did not yet exist for Northern Shrimp.

The new framework adopted in December 2024 uses a specially designed model for Northern Shrimp called the spatially integrated statistical catch-at-length / size (SISCALS) model. The framework provides model-based estimates of biomass, productivity and stock status with respect to biological reference points for the NSAR and SSAR. Further, alternative formulations of SISCALS are the basis of the operating model(s) used in simulation testing the potential effectiveness of candidate harvest decision rules (HDRs) within the management strategy evaluation (MSE) process for Northern Shrimp.

A Northern Shrimp Advisory Committee MSE Working Group comprised of DFO fishery managers, Northern Shrimp harvesters, provincial and co-management partner representatives, and scientists developed the context, preliminary objectives, and candidate HDRs of the MSE. The science advice herein supports this work by:

1. Ensuring that the operating model(s) used in the MSE align(s) with the modeling framework for Northern Shrimp that was adopted in December 2024 and used in the March 2025 assessment (i.e. the spatially integrated statistical catch-at-length / size (SISCALS) model);
2. Reviewing any changes or deviations in the framework adopted in December 2024 and providing a rationale for these changes;
3. Reviewing all candidate management procedures to ensure their code/design aligns with their intended function in the real world; and,
4. Reviewing the performance metrics calculations to ensure they are the most appropriate calculations to align with the MSE's objectives.

MSE Objectives

Seven (7) preliminary MSE objectives (3 primary and 4 secondary) are under consideration by the MSE Working Group.

ANALYSIS

Operating models

The statistical model used in the Northern Shrimp stock assessment framework (i.e., SISCALS, adopted in December 2024 and used in the March 2025 assessment) was incorporated as the basis for developing the operating model(s) for closed-loop simulations related to the MSE process.

Changes in data or structure from March 2025 assessment

The operating model(s)'s historical period (conditioning) was developed using an updated dataset compared to that used in the March 2025 assessment (Le Corre et al. *in prep.*¹). This updated dataset excludes NSAR shrimp length composition data before 2007, whereas the dataset used in March 2025 covered 1996-1999 and 2005-2024. This change is viewed as an improvement to the model and was made to address a lack of sampling across the full range of Northern Shrimp size classes before 2007 in the NSAR. In particular, before 2007 there were no usable survey data available in the EAZ (Figure 2), which created a potential bias in shrimp size and mortality because Northern Shrimp in the EAZ are larger than shrimp in the WAZ and SFA 4. This bias (*i.e.*, using the pre-2007 data, without EAZ representation) could skew the model(s)'s estimates of shrimp growth and mortality. While the data from 2007 onwards also has spatial gaps, those gaps were viewed as less problematic (*e.g.*, there is some missing survey coverage in the WAZ, but Northern Shrimp sizes in the WAZ span those observed in SFA 4 and the EAZ, thus this gap is unlikely to introduce bias). In the future, it may be possible to re-incorporate pre-2007 data for the NSAR within a standardization model to address incomplete spatial and temporal coverage across years. However, a standardization model for length composition data was not available at the time of this meeting.

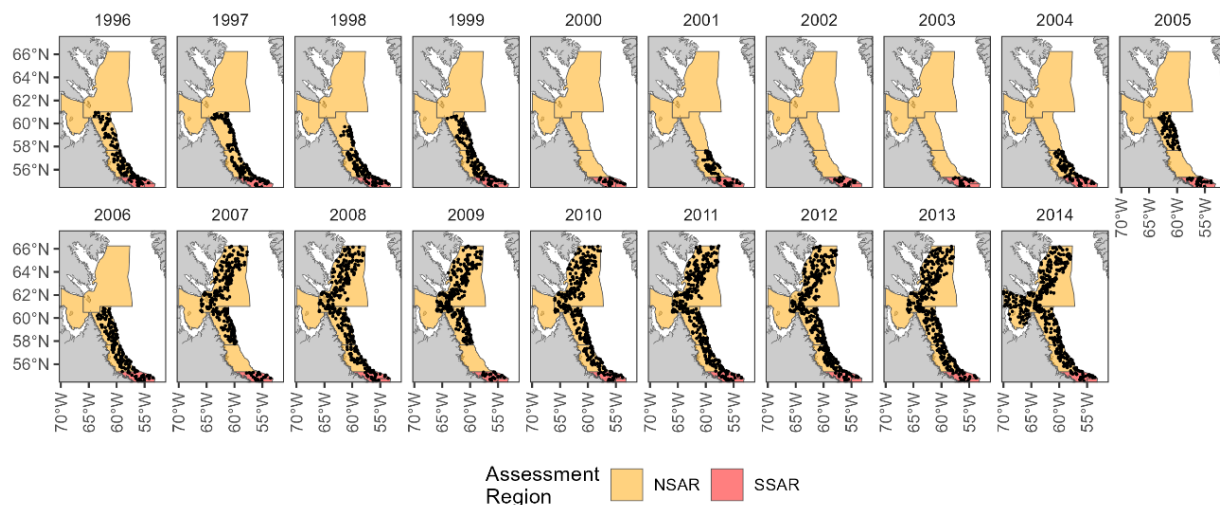


Figure 2. Survey coverage in the NSAR from 1996 to 2014, combining DFO and Northern Shrimp Research Foundation (NSRF) surveys, with each survey set represented by a black dot. In later years (2015 to 2024), survey coverage was complete, similar to 2014.

Operating Model Scenarios

Operating model (OM) scenarios in an MSE context represent plausible hypotheses about fishery and stock dynamics used to test HDRs. In general, OM's are designed to represent both

¹ Le Corre N., Baker K.D., Coffey W., Enright D., Walkusz W., Munro H., Belanger D., Coyne J., Koen-Alonso M., Malainy C., Sullivan D., and Atchison S. (*in preparation*). Assessment of Northern Shrimp (*Pandalus borealis*) in North and South Stock Assessment Regions in 2024. DFO Can. Sci. Advis. Sec. Res. Doc. 2026/nnn. iv + 81 p.

parameter uncertainty and structural uncertainty within stock assessments and management procedure simulations. Parameter uncertainty arises because the true values of model parameters are not known exactly and may include uncertainty in growth rates, natural mortality, maturity schedules, survey catchability, and stock–recruitment parameters such as unfished spawning biomass or spawner productivity in the stock–recruitment relationships. Structural uncertainty, by contrast, arises from uncertainty about the underlying processes and model assumptions used to represent the system. This may include uncertainty in stock–recruitment functional form (e.g., Beverton–Holt versus Ricker), spatial structure of the stock and connectivity between different components of the stock, time-varying productivity, or conflicting data sources.

For Northern Shrimp, future recruitment dynamics currently represent the primary structural uncertainty. Two alternative operating models are therefore used to represent plausible future productivity scenarios. Both are based on Beverton–Holt stock–recruitment relationships fitted to different periods of estimated recruitment:

1. A short time series (2009-2019), consistent with the recruitment regime underlying the March 2025 assessment projections; and,
2. The full estimated recruitment time series (1996-2019).

These alternative OMs are defined as follows:

1. BH-Long (long time-series; 1996-2019): SRR estimated from spawning biomass and recruitment estimates over the full assessment period (excluding 2020-2024). Captures the average productivity over multiple ecosystem states (i.e., higher and lower productivity periods).
2. BH-Short (short time-series; 2009-2019): SRR estimated over the most recent 10-year period (excluding 2020-2024). Captures recent lower productivity, particularly for the SSAR.

The BH-Long and BH-Short scenarios bracket the range of productivity observed during the assessment period, but both include overly precise steepness estimates because the post-fitting approach ignores uncertainty in spawning biomass and recruitment estimates. This issue may be addressed in future assessments and OMs.

Note that recruitment estimates for 2020-2024 are not estimable from the data, so these are simulated from the BH-Short model (DFO 2025, [Le Corre et al., in prep.](#)).

Operating model weighting

The two operating model recruitment scenarios defined above aimed to represent possible future productivity states for Northern Shrimp. In the SSAR, the BH-Long and BH-Short scenarios implied very different recruitment regimes, mostly due to the change in productivity regime observed within the BH-Long period. The environment for shrimp is ever changing, however predation and the ecosystem are continuing to change and have clear directional movements that are thought to be continuing. Both operating models were retained but were assigned plausibility weights based on expert knowledge. In the SSAR, results from the two operating model scenarios were weighted at 90% for BH-Short and 10% for BH-Long when combining operating model results to generate the set of performance metrics for each HDR.

In the NSAR, recruitment productivity was mostly comparable under the BH-Long and BH-Short scenarios, therefore the contributions of the two operating models were given equal weighting (50%/50% weighting).

Performance Metrics

Performance metrics are statistics that summarize the expected behaviour of a candidate HDR over a specified period of time. They allow different candidate HDRs to be compared and to ascertain how well a candidate HDR aligns with the MSE's objectives. Performance metrics are particularly important in understanding the trade-offs between different dimensions of performance such as the trade-off between higher potential yield and lower probability of avoiding the limit reference point (LRP). Table 1 lists the performance metrics reviewed during the meeting along with their definition and how each metric is calculated.

Table 1. Performance metrics used in the Northern Shrimp MSE with definitions and more detailed information on how the statistics are calculated.

Performance Metrics	Objective Category	Definition	How it is Calculated
pLRP30	Conservation	Probability that spawning biomass remains above limit reference point over 30-year projection period.	- Count the number of years the spawning biomass is above the LRP over each 30-year projection. - Sum these counts across the 200 replicates. - pLRP30 is the sum from (b) divided by 6,000 (the total number of years across the 200 replicates; 30 years multiplied by 200 replicates = 6,000).
pLRP10	Conservation	Probability that spawning biomass remains above limit reference point over first 10 projection years.	- Count the number of years the spawning biomass is above the LRP over the first 10 years of each projection. - Sum these counts across the 200 replicates. - pLRP10 is the sum from (b) divided by 2,000 (the total number of years across the 200 replicates; 10 years multiplied by 200 replicates = 2,000).
pUSR30	Conservation	Probability that spawning biomass remains above upper stock reference over 30-year projection period.	- Count the number of years the spawning biomass is above the USR over each 30-year projection. - Sum these counts across the 200 replicates.

Performance Metrics	Objective Category	Definition	How it is Calculated
			c. pUSR30 is the sum from (b) divided by 6,000 (the total number of years across the 200 replicates; 30 years multiplied by 200 replicates = 6,000).
pUSR10	Conservation	Probability that spawning biomass remains above upper stock reference over first 10 projection years.	a. Count the number of years the spawning biomass is above the USR over the first 10 years of each projection. b. Sum these counts across the 200 replicates. c. pUSR10 is the sum from (b) divided by 2,000 (the total number of years across the 200 replicates; 10 years multiplied by 200 replicates = 2,000).
MAC10	Fishery Yield	Median of the average annual catch over first 10 projection years (short-term yield, kt).	a. Calculate the average annual catch over the first 10 years of the projection for each of the 200 replicates. b. List the 200 values from lowest to highest. c. MAC10 is the median, or number in the middle of the list.
MAC30	Fishery Yield	Median of the average annual catch over final 10 projection years (2045-2054; long-term yield, kt).	a. Calculate the average annual catch over the final 10 years of the projection for each of the 200 replicates. b. List the 200 values from lowest to highest. c. MAC30 is the median, or number in the middle of the list.
AAV10	Catch Stability	Median average annual variation in catch over first 10 projection years.	a. Calculate the absolute annual percentage change in catch for each of the first 10 projection years in a

Performance Metrics	Objective Category	Definition	How it is Calculated
			replicate (<i>i.e.</i>, the percent increase or decrease in catch compared to the previous year). b. Calculate the average of (a). c. List the 200 replicate averages from (b) lowest to highest. d. AAV10 is the median, or number in the middle of the list.
AAV95th	Catch Stability	95th percentile of average annual variation in the first 10 years or 95% of all values are smaller than this. Represents a relatively rare outcome, but indicates the range of possible average annual variations.	a. Calculate the absolute annual percentage change in catch for each of the first 10 projection years in a replicate (<i>i.e.</i>, the percent increase or decrease in catch compared to the previous year). b. Calculate the average of (a). c. List the 200 replicate averages from (b) lowest to highest. d. AAV95th is the 95th percentile of the list from (c) (<i>i.e.</i>, the 190th value).
C5th	Risk of low Catch	5th percentile of annual catches in first 10 projection years (lower bound of short-term yield, kt).	a. List the annual catch (lowest to highest) for all 200 replicates over first 10 projection years (2,000 values). b. C5th is the 5th percentile of the list from (a) (<i>i.e.</i>, the 100th value).

Candidate Management Procedures

Stock Status and Control Points

The assessment framework in December 2024 adopted limit reference points (LRPs) for both the NSAR and SSAR, and upper stock reference points (USR) were also recommended for both regions (DFO 2025). These LRPs and proposed USRs are based on the unfished spawning

biomass (SB) calculated within the stock assessment model (Figure 3A). These biological reference points are specifically used in the Performance Metrics calculations described above (e.g., pLRP and pUSR), and therefore play a role in comparing candidate HDRs. These are also the only reference points used to determine and report on stock status.

Biological reference points (LRPs and USRs) should not be confused with the control points used in candidate HDRs even though they share some similarities. The LRPs and USRs are operating model biological reference points derived from SISCALS estimates of unfished spawning biomass and stock productivity. Because these quantities depend on estimated model states and parameters, they are not directly observable. Control points, by contrast, are specified values of the survey spawning biomass index (SB^* ; read “SB-star”), where the “*” denotes that these are actual observable indices used operationally within the HDR.

Within the operating model simulations, TACs in each year are determined by the HDR using simulated spawning biomass indices (SB^*) relative to predefined operational control points. The resulting catches influence future stock dynamics and subsequent SB^* levels, thereby creating the feedback mechanism used to evaluate HDR performance over time. Control points therefore define the SB^* thresholds where changes occur in the harvest control rule slope (Figure 3B).

Biomass indices for the fishable (FB^*) and spawning (SB^*) stocks are derived from the spatio-temporal model of annual survey data (DFO 2025) and are the main inputs to candidate HDRs.

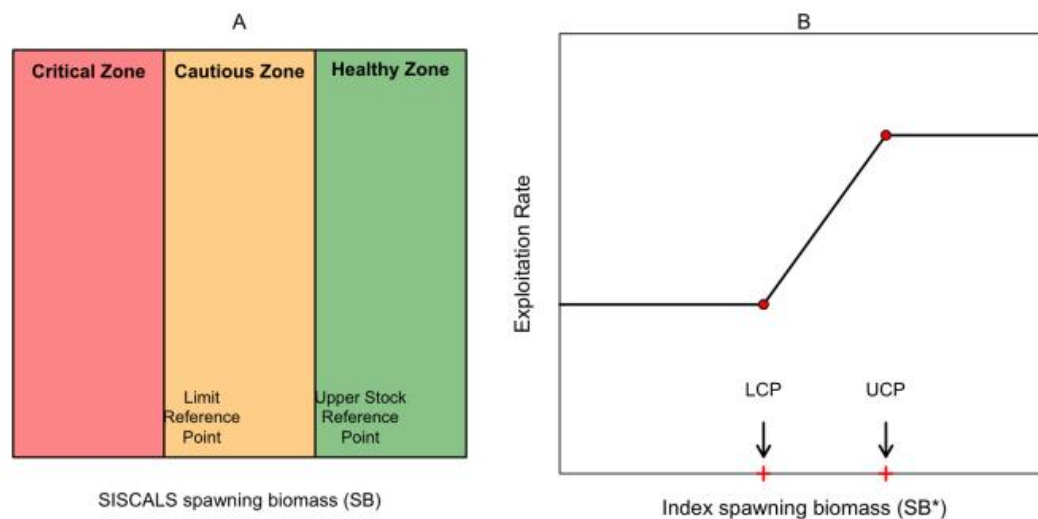


Figure 3. (A) Stock status zones (Critical, Cautious, and Healthy Zones) defined by the Limit Reference Point (LRP) and Upper Stock Reference (USR). These status zones are determined using the spawning biomass (SB) derived by the SISCALS assessment model (referred to as absolute values). (B) An example management procedure (HDR) showing the lower control point (LCP) and upper control point (UCP), which define thresholds where the HDR slope changes. The LCP and UCP are calculated based on the spawning biomass index (SB^*) derived from survey indices (referred to as relative indices).

Candidate Management Procedures

Three general forms of HDR were tested based on variations in control points and exploitation rates (Figure 3B). All three forms include two initial stages:

1. The HDR determines the exploitation rate based on SB^* (reminder: SB^* and FB^* are indices derived from the spatio-temporal modeling of survey data) relative to the lower and upper control points; and,

2. The resulting exploitation rate is multiplied by the fishable biomass index derived from survey indices (FB^*) to produce an initial catch limit or total allowable catch (TAC).

The “default DFO HDR” (also labelled defHDR in tables and figures) has a constant exploitation rate when above the upper control point. Below the upper control point, the exploitation rate linearly decreases with SB^* until reaching the lower control point, at which the exploitation rate is 0%. No exploitation occurs when SB^* is below the lower control point (Figure 4: top row).

The “base HDR” (labelled baseHDR in tables and figures) has a constant exploitation rate when above the upper control point. Below the upper control point, the exploitation rate linearly decreases with SB^* until reaching the lower control point, at which exploitation rate is 50% of the initial exploitation rate used when above the upper control point. Below the lower control point, the exploitation rate is 50% of the initial exploitation rate (Figure 4: middle row).

The “Half Leaf HDR” (labelled halfLeafLRP in tables and figures), which looks similar to half of a leaf torn in two along its midline, implements the half leaf design below the lower control point (Figure 4: bottom row). This HDR is implemented the same way as the baseHDR when SB^* is above the lower control point. When the SB^* is below the lower control point, and trending downwards, exploitation rates decline rapidly to zero by following the curve of the leaf. When the SB^* is trending upwards exploitation rates increase linearly until the lower control point is reached (Figure 4: bottom row).

Several adjustment mechanisms were layered on top of the baseHDR to control variability in TACs produced by the HDRs. The “2-stage HDR” (2SHDR) mimics the currently adopted HDR used in EAZ, WAZ, and SFAs 4-6. After generating an initial catch limit using the baseHDR the 2SHDR component smooths inter-annual TAC variation based on the direction of the fishable biomass index trend. When fishable biomass is increasing, the TAC is the maximum of (a) the average of the previous TAC and current initial catch limit (50% rule) or (b) the previous year’s initial catch limit (finish rule). When biomass is decreasing, the TAC is the minimum of these values. This provides balance between the TAC responding to short-term survey index trends and stable TACs.

Another adjustment to the HDRs, added to reduce the extent of inter-annual changes to the TACs, applies a flat 25% maximum inter-annual change in the TAC. This constrains year-to-year variation. This “25% maximum change in TAC” was an added option to the 2SHDR procedure.

A third type of adjustment included “phase-in periods” to provide gradual transitions from the current TAC to TACs determined solely by the HDR. Both three-year (3YrPhz) and four-year phase-in (4YrPhz) periods were tested. These are implemented by computing the final TAC as a weighted average of the 2024 TAC and the one derived from the HDR in that year. By the third year (or fourth year) the TAC is solely based on that calculated by the HDR. These phase-ins were added options to the 2SHDR procedure. The following are the weightings used for each phase-in length:

- 3YrPhz
 - Year 1 TAC = 66.7% 2024 TAC + 33.3% HDR TAC calculation
 - Year 2 TAC = 33.3% 2024 TAC + 66.7% HDR TAC calculation
 - Year 3 TAC = 0% 2024 TAC + 100% HDR TAC calculation
- 4YrPhz
 - Year 1 TAC = 75% 2024 TAC + 25% HDR TAC calculation
 - Year 2 TAC = 50% 2024 TAC + 50% HDR TAC calculation

- Year 3 TAC = 25% 2024 TAC + 75% HDR TAC calculation
- Year 4 TAC = 0% 2024 TAC + 100% HDR TAC calculation

All of these HDRs were reviewed and tested within the MS3 simulation package and via an independent MSE Excel spreadsheet to ensure that they were coded correctly, their mathematical formulae aligned with how they were being described, and that they were behaving as expected and described. A review of their particular performance with respect to fishery objectives was not within the terms of reference for this process.

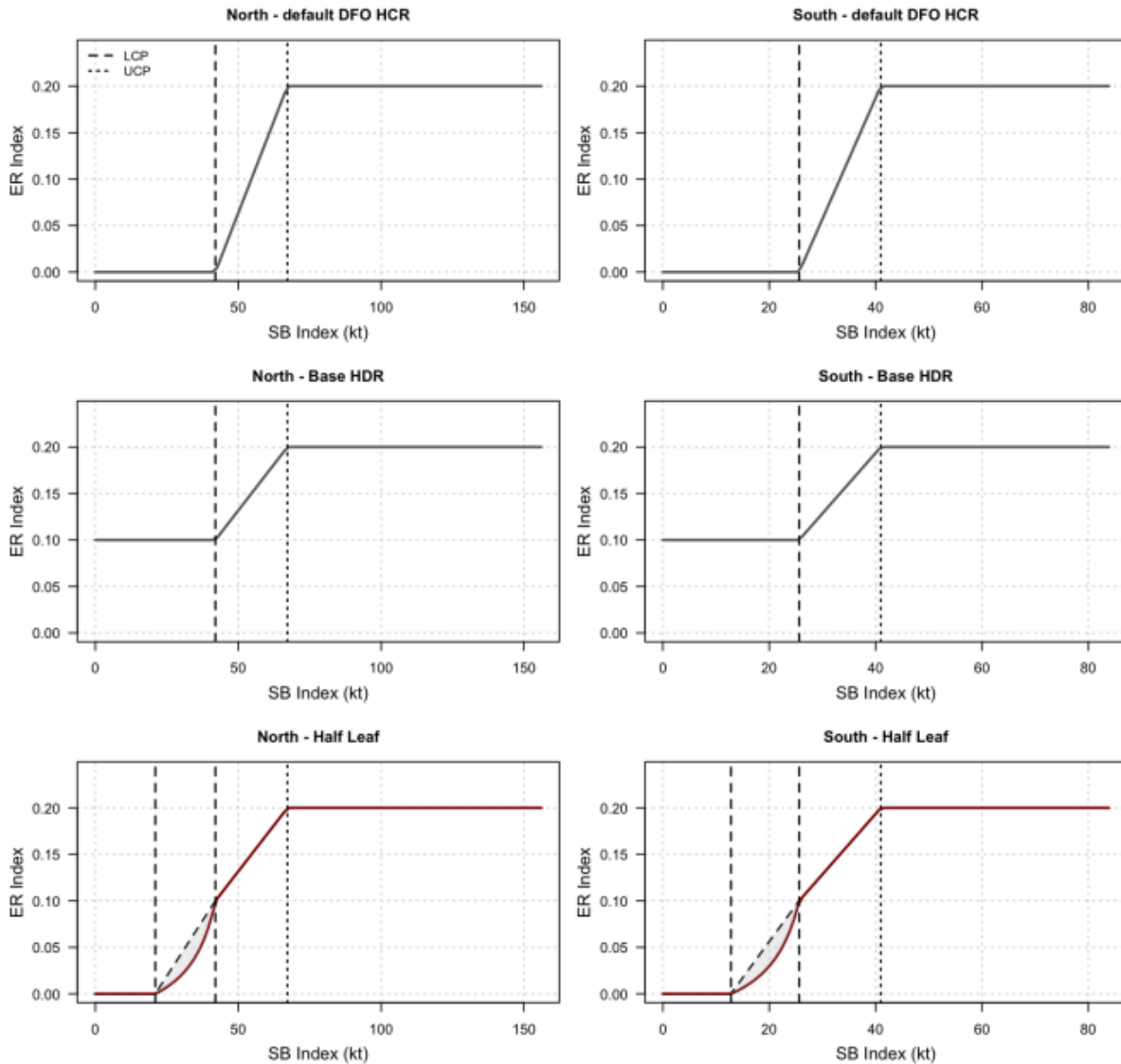


Figure 4. Harvest decision rules (HDRs) for Northern Shrimp management procedures showing the relationship between spawning biomass index (SB^* , x-axis) and exploitation rates (y-axis; above the upper control point exploitation rates between 10% and 25% were tested; 20% is shown for illustrative purposes only). Columns show North SAR (left) and South SAR (right). Rows show three HDR types: Default DFO HDR (top), Base HDR (middle), and Half-Leaf HDR (bottom). Vertical reference lines indicate control points: dashed line for the lower control point ($LCP = 0.5 \times SB^*_{Maximum Sustainable Yield (MSY)}$), dotted line for the upper control point ($UCP = 0.8 \times SB^*_{MSY}$), and lowest dashed line in half-leaf HDR as $0.25 \times SB^*_{MSY}$.

TAC Utilization in the Operating Models versus in Reality

The HDR simulations assume that the full TAC calculated by an HDR is removed each fishing season. This is no different from stock assessment projections where a fixed catch scenario is projected into the future, with each year removing the entire fixed value. It is clear from historical catch records that not all the Northern Shrimp management areas have their full TAC removed each year. While the entire TAC is regularly caught and removed each year in some areas, TACs are underutilized in other areas. Under-utilization arises for various reasons including for example, adverse weather, less favourable catch rates, targeting for quality and/or size, or logistical issues related to trip length and location.

The 5-year average utilization (i.e., proportion of TAC actually caught) rates calculated for each region using reported catch in 2017, 2018, 2019, 2022 and 2023 fishing years (2020 and 2021 were not used due to impacts from COVID-19) were 91% for the NSAR and 95% for the SSAR.

Sources of Uncertainty

Data Inputs in SISCALS

This section outlines key uncertainties associated with the data inputs used in SISCALS, which may in turn affect the operating models (OMs) derived from it. These uncertainties are not directly transferred in MSE outcomes, but may influence some of the inputs used within the MSE framework (e.g., catchability).

- **Survey Length Composition Data:** Survey biomass index data are standardized using spatiotemporal models to account for variability across space and time, but survey length composition data are not. Without standardization, regions not covered by surveys may be underrepresented, which can bias length-based indicators (e.g., size at 50% transition to female, growth estimates). Standardizing survey length composition data could also allow inclusion of pre-2007 observations in the North SAR time series for SISCALS and OM conditioning.
- **Commercial Length Composition Data:** Commercial length data can be biased by differences in fleet behavior, gear type (catchability), and uneven seasonal or spatial coverage, making them less representative of the true population structure. Spatiotemporal standardization of commercial length data would help correct these biases and improve the robustness of length-based indicators used in the stock assessment framework and OMs.
- **Additional Survey Data:**
 - Incorporating other survey data (e.g. European Union survey data covering NAFO Divisions 3LNO outside Canadian waters), which use slightly different protocols and provide limited coverage of the assessment region, could be beneficial. Testing robustness with and without these data would help clarify their potential benefit for improving survey index estimates.
 - The NSAR currently lacks key ecosystem and environmental data, including predation mortality indices, oceanographic information, and pelagic production metrics. These gaps limit the ability to include ecological drivers in assessments and hinder progress toward ecosystem-based fisheries management.

Catchability Parameter for Projections

Uncertainty in survey catchability is taken into account in the HDR projection by sampling from the joint posterior distribution of all estimated parameters from SISCALS. Therefore, although the survey catchability in each region is assumed known and constant for the lower control

point, upper control point, and FB calculations, the operating models simulate a very wide range of alternative values over the 200 simulation replicates. This range of catchability in the posterior samples provides some protection against mis-scaled TACs if true catchability differs from the median estimate. It is possible that survey catchability could vary over time via protocol adjustments or environmental factors but these were not considered in this work. Violation of catchability assumptions primarily affect the absolute scale of operating model biomass and catch projections, which should not affect the relative performance of HDRs against one another – the more important problem would be that performance of all HDRs would be biased with actual risk being more or less than projected depending on the direction of bias. Future MSE iterations could examine catchability in more detail via retrospective analysis and other techniques aimed at evaluating persistent bias in stock assessment model estimates.

Biological and Model Assumptions

Uncertainty also arises from assumptions about biological processes and how they are represented in the model. These include recruitment, growth, sex transition, and natural mortality, all of which are influenced by environmental conditions and biological complexity. Because these factors are difficult to estimate precisely, they introduce variability into HDR projections.

- **Recruitment:**

- **Trans-boundary Larval Connectivity:** Current assessments do not directly account for larval imports from West Greenland stocks, which may affect recruitment. Expanding the SISCALS framework to include Greenland spawning indices or developing a trans-boundary meta-population model would better reflect potential connectivity via larval dispersal patterns. SISCALS estimates annual deviations from the expected recruitment based on SB, which means that imports from West Greenland stocks could already be accounted for in the recruitment estimates; however, the future role of West Greenland stocks is treated as random around a constant average in projections.
- **Stock-Recruitment Relationships:** The SISCALS model used to estimate stock dynamics, catchability, recruitment, natural mortality and other parameters assumes constant average recruitment with annual deviations that are independent over years but correlated between NSAR and SSAR shrimp. This assumption helped make the original estimation more tractable as SISCALS was being developed. However, constant average recruitment is inappropriate for projecting stock dynamics for risk assessment. The stock-recruitment models BH-Long and BH-Short were estimated from SISCALS SB and recruitment estimates to better reflect potential future over-fishing risk. While these recruitment scenarios are sufficient for initial MSE screening, a revised SISCALS model should incorporate a Beverton–Holt stock–recruitment relationship within the model structure to better integrate uncertainty in model parameter estimates, recruitment dynamics, and associated biological reference points.

- **Growth and Transition:** Projected spawning biomass dynamics were sensitive to growth and the length at 50% transition (L50), particularly the latter as it directly affects SB. These are modelled independently in SISCALS, so future research could develop biologically plausible scenarios for projections of size-at-transition and growth parameters that would help explore a broader range of uncertainties and strengthen the science advice derived from HDR simulations.

- **Mortality:** Future natural mortality was simulated using a zero-trend random walk, maintaining the recent average and variability without persistent increases or decreases. This approach reflects the absence of reliable information on future ecosystem-driven

mortality shifts, as well as lack of a direct mechanistic link between ecosystem factors and mortality. Future research could develop methods to link mortality to predation, in particular, since there is a relatively high correlation between some predators on Northern Shrimp mortality in the SSAR.

CONCLUSIONS

Operating models

Two operating models were endorsed for use in this initial phase of the Northern Shrimp MSE; one based on the estimated stock recruitment relationship using the whole data-series (1996-2019) and the other using a shorter time period to estimate the stock recruitment relationship (2009-2019). Based on expert opinion the two operating models in the NSAR are equally weighted when calculating performance metrics because the two scenarios imply similar productivity over time. In the SSAR the operating model using the short time-series was given 90% weighting and the operating model using the whole time-series was given 10% weighting, because of the perception that the more recent recruitment levels were more likely to be persistent in the near term. Performance metrics calculated for each HDR represent the weighted combination of outputs from these two scenarios.

Performance Metrics

All performance metrics computations were reviewed and determined to be 100% accurate and consistent with their descriptions and intended use. A full list of these performance metrics including clear descriptions of what they represent can be found in Table 1.

Management Procedures

The reviews of the HDRs were conducted to ensure that they had been coded correctly, their mathematical formulae aligned with how they were being described, and that they were behaving as expected and described. They were not reviewed to consider how they performed compared to any MSE objectives for conservation, yield nor variability in catch.

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SOURCES OF INFORMATION

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