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Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2024/014

ASSESSMENT OF NORTHERN SHRIMP (*PANDALUS BOREALIS*) AND STRIPED SHRIMP (*PANDALUS MONTAGUI*) IN SHRIMP FISHING AREA (SFA) 4 IN 2022 AND EVALUATION OF A PROPOSED LIMIT REFERENCE POINT (LRP) FOR STRIPED SHRIMP IN SFA 4

*Figure 1. Top: Northern Shrimp (*Pandalus borealis*) Bottom: Striped Shrimp (*Pandalus montagui*) Photo: Fisheries Oceans Canada, Newfoundland and Labrador (NL) Region.*

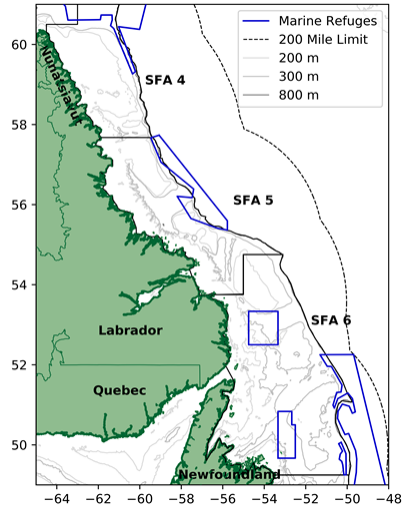

Figure 2. Map of Shrimp Fishing Areas 4–6. Blue polygons identify Marine Refuges (Hatton Basin, Hopedale Saddle, Hawke Box, Funk Island Deep Box, and Northeast Newfoundland Slope from North to South) in which bottom-contact fishing (i.e., shrimp trawling) is not permitted.

Context:

Fisheries and Oceans Canada (DFO) Resource Management (RM) has requested Science advice on the status of the two species of shrimp, Northern Shrimp (Pandalus borealis) and Striped Shrimp (Pandalus montagui) in Shrimp Fisheries Area (SFA) 4, and the establishment of a limit reference point (LPR) consistent with the Precautionary Approach (PA) Framework for SFA 4 Striped Shrimp. This assessment follows the framework developed in 2007 for Northern Shrimp off Labrador and the northeastern coast of Newfoundland (DFO 2007). Striped Shrimp in SFA 4 are primarily taken as by-catch during the Northern Shrimp fishery in that area.

The last full stock assessment of Northern Shrimp in SFA 4 took place in February 2022 (DFO unpublished). The last full stock assessment of Striped Shrimp in SFA 4 took place in February 2021 (DFO 2021), and a stock status update was held in 2022 (DFO 2022a).

This Science Advisory Report (SAR) is from the March 14–16 2023 Regional Peer Review meeting, Assessment of Northern Shrimp and Striped Shrimp in Shrimp Fishing Area (SFA) 4 and the Development of a Limit Reference Point (LRP) for Striped Shrimp in SFA 4. Additional publications from

this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Resource status of Northern Shrimp (also known as Pink Shrimp) and Striped Shrimp were assessed based on Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (SFA 4) and commercial catch data.
- It is recognized that Northern Shrimp are distributed broadly over the Northwest Atlantic Ocean, including SFA 4, and all of these areas are connected through larval dispersal. Rates of exchange of adults are less understood. Preliminary research demonstrates localized genetically distinct pools that may be linked to smaller-scale oceanographic profiles (i.e., gyres). These linkages need to be considered to interpret dynamics within and among assessment areas.
- There is a spatial scale mismatch between the assessment unit and the dynamics of the wider population.
- Northern Shrimp in SFA 4 is currently assessed relative to a Limit Reference Point (LRP) and Upper Stock Reference point (USR) in accordance with DFO's Precautionary Approach (PA) Framework.
- The majority of the population of Striped Shrimp spans the Eastern Assessment Zone (EAZ), Western Assessment Zone (WAZ) and SFA 4. The extent of movement between these zones are unknown; therefore, understanding resource dynamics as a whole requires integrating information from across the entire range.

Environment & Ecosystem

- Environmental conditions in the Northwest Atlantic experience fluctuations at decadal time scales, with potential impacts on availability of optimal Pandalid habitat. A composite climate index remained high and indicated that 2022 was the ninth warmest of the time series (1950-present), continuing the ongoing warming trend since 2018.
- The Spring phytoplankton bloom in SFA 4 in 2021 was the earliest in the time series but returned to more normal timing in 2022.
- Multiple analyses suggest that thermal habitat available to Pandalid Shrimp in SFA 4 has been favorable since the late-2010s.

Limit Reference Point for SFA 4 Striped Shrimp

- In accordance with DFO's PA Framework, an LRP for Striped Shrimp based on the combined survey data time series (2005–22) of SFA 4, EAZ, and WAZ was developed from a spatiotemporal model that created a new fishable biomass index (FB_{pop}) to determine the stock status in SFA 4.
- The adopted LRP is based on FB_{pop} and was calculated as the average of
  - the lowest fishable biomass at which the stock increased and remained above the geometric mean for a period of at least 3 years,
  - the lowest observed fishable biomass in the time series, and
  - 40% of the geometric mean of the fishable biomass index throughout the time series.

SFA 4 Northern Shrimp

- Northern Shrimp Fishable Biomass (FB) and female spawning stock biomass (SSB) indices were unusually high in 2021. Despite a year-over-year decrease in 2022 (by 47% to 79,500 t for FB, and by 55% to 51,300 t for SSB), the recent trend suggests continued increases from a historic low in 2018.
- The Exploitation Rate Index (ERI) ranged between 5.8% and 36.7% from 2005/06 to 2021/22 and was 15.3% in 2022/23. If the Total Allowable Catch (TAC) is taken in 2022/23, the ERI will be 16.3%.
- In 2022, Northern Shrimp in SFA 4 was in the Healthy Zone within the PA Framework, just above the USR, with a 53% probability of being in the Cautious Zone.

SFA 4 Striped Shrimp

- In SFA 4, Striped Shrimp Fishable biomass and SSB indices have increased since 2021, by 25% (to 38,800 t) and 37% (to 30,600 t) respectively and are above the long-term means (2005–21) of the survey time series.
- The ERI ranged between 0.8% and 23.3% from 2005/06 to 2021/22 and was 9.0% in 2022/23. If the TAC is taken in 2022/23, the ERI will be 10.4%.
- In 2022, Striped Shrimp biomass (FB_{pop}) was estimated to be 5 times the LRP. Other indices of stock health, including the potential predator index, total egg production index, and SFA 4 specific fishable biomass index showed no cause for concern. Striped Shrimp in SFA 4 is considered in a healthy state in the PA Framework.

BACKGROUND

Species Distribution and Stock Boundaries

Northern Shrimp (*Pandalus borealis*) are found in the Northwest Atlantic from Baffin Bay south to the Gulf of Maine while Striped Shrimp (*Pandalus montagui*) are found in the Northwest Atlantic from Davis Strait south to the Bay of Fundy (Figure 1). Northern Shrimp are typically found on soft and muddy substrates and in bottom temperatures ranging from 1°C to 6°C. However, the majority of Northern Shrimp are caught in waters from 2°C to 4°C. These conditions typically occur at depths of 150–600 m and exist throughout the Newfoundland and Labrador offshore area. In contrast, Striped Shrimp are typically found on hard substrates, with higher concentrations in colder waters, from -0.3 to 2.7°C and shallower depths (100–300 m) (Baker et al. 2021); however, as there are no shrimp survey data at depths less than 100 m, they may have a shallower preference. Although the temperature, depth, and bottom type preferences differ slightly between species, their distributions overlap; the extent of the overlap has not been examined. Northern Shrimp represents the dominant shrimp resource in the North Atlantic.

While shrimp management boundaries are, to some extent, arbitrary and selected based on factors other than species population structure, the northern boundary of SFA 4 leads to more questions/uncertainties than the boundaries between other SFAs, and a strategy of applying similar harvest control rules across areas mitigates potential consequences of connectivity interference via management of arbitrary boundary units. In addition to being found in SFA 4, both Northern and Striped Shrimp are found in the EAZ and WAZ, directly north of SFA 4 (DFO 2022b). Hudson Strait is a highly dynamic system with strong currents and mixing

(Drinkwater 1986). Shrimp could be transported a great distance in a relatively short period of time, resulting in rapid shifts of shrimp into and out of SFA 4.

Further to the issues of transport across the northern boundary of SFA 4, the Labrador Current runs southward from SFA 4, through SFAs 5 and 6. Larval dispersal simulation modeling within SFAs 4–6 indicated strong downstream larval connectivity and that a majority of recruits in a particular SFA may come from SFAs farther north (Le Corre et al. 2019). Northern Shrimp larvae may travel several hundreds of kilometers before settlement. Further larval simulation modelling has demonstrated that larvae originating in the Arctic also show high settlement in SFAs 4–6 (Le Corre et al. 2020). This research indicates low larval shrimp retention in SFAs 4 and 5, and higher larval retention in SFA 6. Release location, ocean circulation, and larval behaviours were identified as important variables affecting simulated larval dispersal in the study area.

It is recognized that Northern Shrimp are distributed broadly over the Northwest Atlantic Ocean, including SFAs 4–6, and that these areas are connected through larval dispersal. Rates of exchange of adults are less understood. While early genetic studies demonstrated that Northern Shrimp in SFAs 4–6 are largely genetically homogenous (Jorde et al. 2014), more recent preliminary research identified localized genetically-distinct pools that may be linked to smaller-scale oceanographic profiles (i.e., gyres). These linkages need to be considered to interpret dynamics within and among assessment areas. Currently the rates of exchange (export/import) between these zones are unknown; therefore, understanding resource dynamics as a whole requires integrating information from all assessment areas. This assessment is conducted at spatial scales reflecting management units to accommodate management/industry preferences and historic practices. The biological stock unit is recognized to be larger than management scales and caution in interpreting and applying stock status information at sub-stock scales is warranted.

Species Biology

Both Northern and Striped Shrimp are protandrous hermaphrodites. Most are born and first mature as males, mate as males for several years beginning in their second year, and then spend the rest of their lives as mature females. Individuals of both species are thought to live for more than eight years. Some northern populations of both species exhibit slower rates of growth and maturation, but greater longevity results in larger maximum size. Females generally produce eggs in the late summer-fall and carry the eggs on their pleopods until they hatch in the spring. Shrimp are thought to begin to recruit to the fishery around age three. Most of the fishable biomass is female; however, the proportion of females in the fishable survey catch varies by SFA and year.

During the daytime, shrimp rest and feed on or near the ocean floor. At night, substantial numbers migrate vertically into the water column, feeding on zooplankton. They are prey for many species such as American Plaice (*Hippoglossoides platessoides*), Atlantic Cod (*Gadus morhua*), Greenland Halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes spp.*), Roughhead Grenadier (*Macrourus berglax*), skates (*Raja radiata, R. spinicauda*), wolffish (*Anarhichas spp.*), and Harp Seal (*Phoca groenlandica*).

Fishery

The fishery for Northern Shrimp off the coast of Labrador began in SFA 5 (Figure 2) in the mid-1970s, primarily in the Hopedale and Cartwright Channels. Soon after, concentrations of Northern Shrimp were located within SFAs 4 and 6, leading to an expansion of the fishery into

those areas. The fishery expanded to Hawke Channel, St. Anthony Basin, Funk Island Deep, and slope edges of the continental shelf in SFAs 4–6 during the early-1990s, with associated TACs periodically increased over the next two decades.

In 2003, the management year was changed from a calendar (January 1-December 31) to a fiscal (April 1-March 31) year. A seasonal “bridging” program was established that allows each license holder in the large-vessel fleet (starting in 2007) and each license holder in the small-vessel fleet (in 2012–15) to carry over some unused quota from the previous year, or borrow from next year’s quota.

Despite linkages between Shrimp populations in SFAs 4–6, EAZ, and WAZ, they are managed independently from one another (i.e., TACs are allocated only with consideration for that particular SFA). After a decrease from 2018/19 to 2020/21 as a result of declines in survey biomass indices, TACs in SFA 4 have been increasing from 8,658 t in 2020/21 (Figure 3) to 12,944 t in 2022/23 all vessels combined.

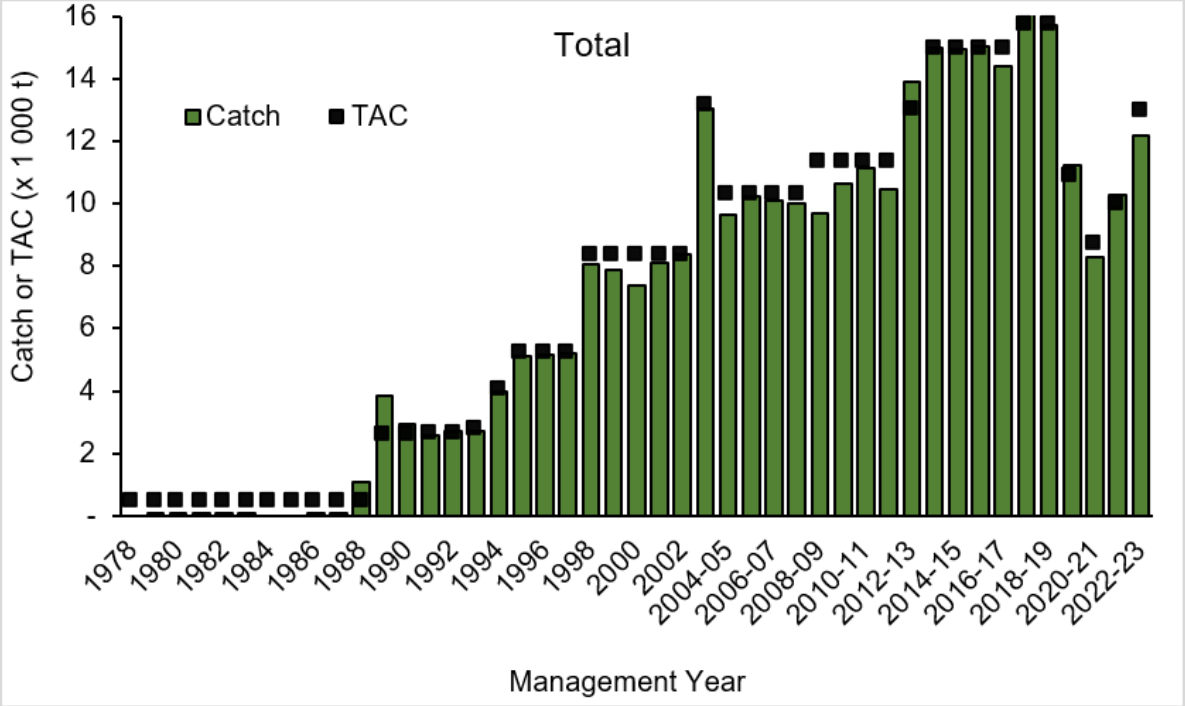

Figure 3. Historical Northern Shrimp catches and TACs in SFA 4 (large and small vessels combined) for the period 1978–2022/23. Catches for 2022/23 are preliminary and from the Atlantic Quota Monitoring System (AQMS) as of February 17, 2023. The management year changed from a calendar to a fiscal year in 2003 such that the values for 2003/04 are based upon a 15 month fishing season.

Commercial catch of Striped Shrimp is taken as by-catch in the SFA 4 Northern Shrimp fishery. Until 2012, the sole source of catch information for Striped Shrimp was logbooks; however, by-catch was recorded in the AQMS beginning in 2013. A by-catch limit of 4,033 t was implemented in 2013/14 and has remained unchanged since.

All Northern Shrimp fisheries in eastern Canada are subject to the Atlantic Fisheries Regulations, established under the Fisheries Act. Pertinent regulations apply to by-catch, discards, vessel logs, etc., and include a minimum mesh size of 40 mm and mandatory use of sorting grates to minimize by-catch of non-target species. Grate size is dependent upon the

area fished. In SFA 4, the maximum bar spacing is 28 mm. At-sea observers are required on all trips by the large-vessel fleet. A target of 10% observer coverage has been established for the small-vessel fleet, although coverage has been well below 10% over the last ten years.

ASSESSMENT

The assessment of Northern and Striped Shrimp was based on NSRF-DFO summer trawl survey data (SFA 4) and commercial catch data (landings). Data on ecosystem status in SFA 4 are limited.

NSRF-DFO trawl survey data provided information on shrimp distribution, length composition, and biomass. Fishable biomass is defined as the weight of all males and females with a carapace length >17 mm and female SSB is defined as the weight of all female shrimp. It has not been possible to infer recruitment (first-time available to the fishery) from observations of pre-recruits; no correlation between numbers of small 'pre-recruit' sized shrimp and subsequent changes in fishable biomass has been observed (Orr and Sullivan 2013). Trends in fishery performance were inferred from TAC, commercial catch-to-date, fishery catch per unit effort (CPUE), and fishing patterns.

Exploitation rate index was determined by dividing the commercial catch from a fishing season by the survey fishable biomass index from the same year (summer survey in SFA 4).

Northern Shrimp

Biomass indices were derived from ogive mapping methods (Ogmap) (Evans et al. 2000).

The initial framework for the assessment of Northern Shrimp off Labrador and the northeastern coast of Newfoundland followed a traffic light approach (DFO 2007). In 2008, a workshop was held with the objective of establishing a PA framework for Canadian shrimp and prawn stocks (DFO 2009). During that meeting, reference points based on proxies were introduced for Northern Shrimp resources in SFAs 4–6. The PA framework (which this assessment follows) is described in the Integrated Fisheries Management Plan (IFMP) which was updated in 2018 (DFO 2018a). This framework was first developed in 2008–10, based on a 2008 framework workshop where the Marine Stewardship Council (MSC) working group, DFO Science, DFO Fisheries Management, and industry stakeholders were represented.

Northern Shrimp reference points in the IFMP PA Framework were developed using proxies, relatively consistent with guidance in the DFO PA Framework (DFO 2009). The upper stock reference (USR) was defined as 80%, and limit reference point (LRP) as 30%, of the geometric mean of female SSB index over a productive period. The reference period was 2005–09 for SFA 4. The values of the reference points were revised slightly in 2016 and again in 2018, in accordance with refinements in the biomass estimation method. In 2019, the reference points for SFA 4 Northern Shrimp were modified to exclude the Hatton Basin Marine Refuge which was not surveyed beginning in 2018. The PA framework itself has not changed since its implementation.

Striped Shrimp

In accordance with DFO's PA Framework, during this Canadian Science Advisory Secretariat (CSAS) peer review meeting, an LRP for SFA 4 Striped Shrimp based on the combined survey data time series (2005–22) of SFA 4, EAZ, and WAZ was developed from a spatiotemporal model that created a new fishable biomass index for the Striped Shrimp population as a whole (FB_{pop}) (Baker et al. 2024). The spatiotemporal model was used to hindcast density estimates

for the entire time series and survey area, despite lack survey coverage in some SFAs in some years (Baker et al. 2024). FB_{pop} was used to determine the stock status in SFA 4 only; there are no current or anticipated changes to the reference points associated with EAZ and WAZ. The adopted LRP was based on FB_{pop} which was calculated as the average of:

1. the lowest fishable biomass at which the stock increased and remained above the geometric mean for a period of at least 3 years,
2. the lowest observed fishable biomass in the time series, and
3. 40% of the geometric mean of the fishable biomass index throughout the time series.

The methodology forms the basis for this LRP, rather than a precise estimate of FB_{pop}, to allow for future model refinements. In addition to reporting on the status of the stock in relation to the LRP, three additional indicators of stock health will be reported during each assessment: ecosystem outlook – potential predator index, reproductive outlook – total egg production index, and the Ogmap-derived SFA 4-specific fishable biomass index. The ecosystem outlook is based on the 3-year moving average of a population-wide (i.e., SFA 4, EAZ, and WAZ combined) potential predator index incorporating available predator data from the NSRF survey (large redfish, Greenland Halibut, skates, and grenadiers) in a spatiotemporal model (Baker et al. 2024). Similarly, the reproductive outlook is based on the 3-year moving average of a population-wide total egg production index taking into consideration both the abundance and size distribution of females at each NSRF set location in a spatiotemporal model (Baker et al. 2024). The SFA 4-specific fishable biomass index represents the biomass estimates calculated using Ogmap on NSRF survey data in SFA 4 only (Orr and Sullivan 2013). Those three indicators were assessed against historical values (i.e., long-term average) to identify potential concerns in the stock health.

Environment and Ecosystem

It is believed that the shrimp available habitat is influenced, to a great extent, by the oceanographic conditions present in the area. Environmental conditions in the Northwest Atlantic experience fluctuations at decadal time scales, with potential impacts on availability of optimal Pandalid habitat and/or predator-prey interactions. A composite climate index remained high and indicated that 2022 was the ninth warmest of the time series (1950-present), continuing the ongoing warming trend since 2018. Multiple analyses suggest that thermal habitat available to Pandalid Shrimp in SFA 4 has been favorable since the late-2010s. The Spring phytoplankton bloom in SFA 4 in 2021 was the earliest in the time series but returned to more normal timing in 2022.

Additionally, other drivers of stock variability are poorly understood, and research is needed on foraging (e.g., water column productivity estimates), predation (e.g., gut contents of shrimp predators), and ecosystem tracers (e.g., stable isotopes and fatty acids to connect various food chain elements). The emergence of a large biomass of juvenile redfish in the SFA 4, EAZ and WAZ over the last three years has been identified as one such driver that may have indirect (competition) and/or direct (future predation) impacts on the shrimp population. The magnitude and duration of these impacts are currently not fully known. Quantification of *P. montagui* and *P. borealis* as a prey species in the SFA 4, EAZ and WAZ is ongoing. A qualitative overview of stomach content from six predator taxa collected between 2018 and 2021 provided a preliminary look at potential trends in predator size and species that may consume higher proportions of Pandalid shrimp. This information can be used to inform ongoing data collection in order to target specific questions instead of the current broad approach.

SFA 4 Northern Shrimp (*P. borealis*)

Fishery

TAC was increased from 8,658 t in 2020/21 to 9,957 t in 2021/22, and increased, by 30%, to 12,944 t in 2022/23. Large-vessel standardized CPUE varied without trend over 1989–2021/22 but has been at or above the long term mean for the past 5 years (Figure 4). Several factors including changes in management measures (i.e., different allocation tables) and species composition of catches (i.e., catches of both Northern and Striped Shrimp in the same area such that less Northern Shrimp catch might be recorded for equivalent effort) confound the interpretation of large-vessel fishery performance in SFA 4.

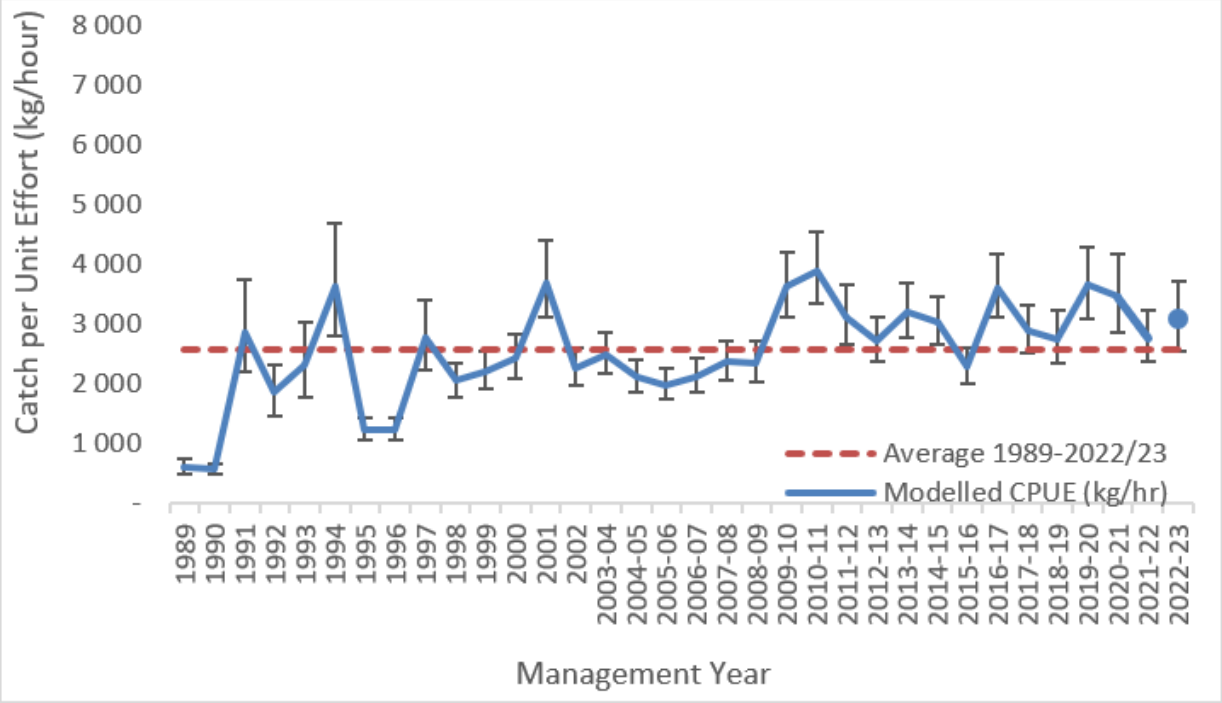

Figure 4. SFA 4 Northern Shrimp large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series.

Biomass

The NSRF-DFO shrimp survey in 2022 indicated a decrease in biomass estimates. Fishable biomass and female SSB indices have decreased since 2021, by 47% (to 79,500 t) and 55% (to 51,300 t) respectively. However, the 2021 estimates and confidence intervals were unusually high and were influenced by two large, localized sets that could be categorized as outliers in view of biomass estimates in contiguous years (i.e., 2020 and 2022). Despite this year-over-year decrease in 2022, the recent trend suggests continued increases from historic lows in 2018 (Figure 5).

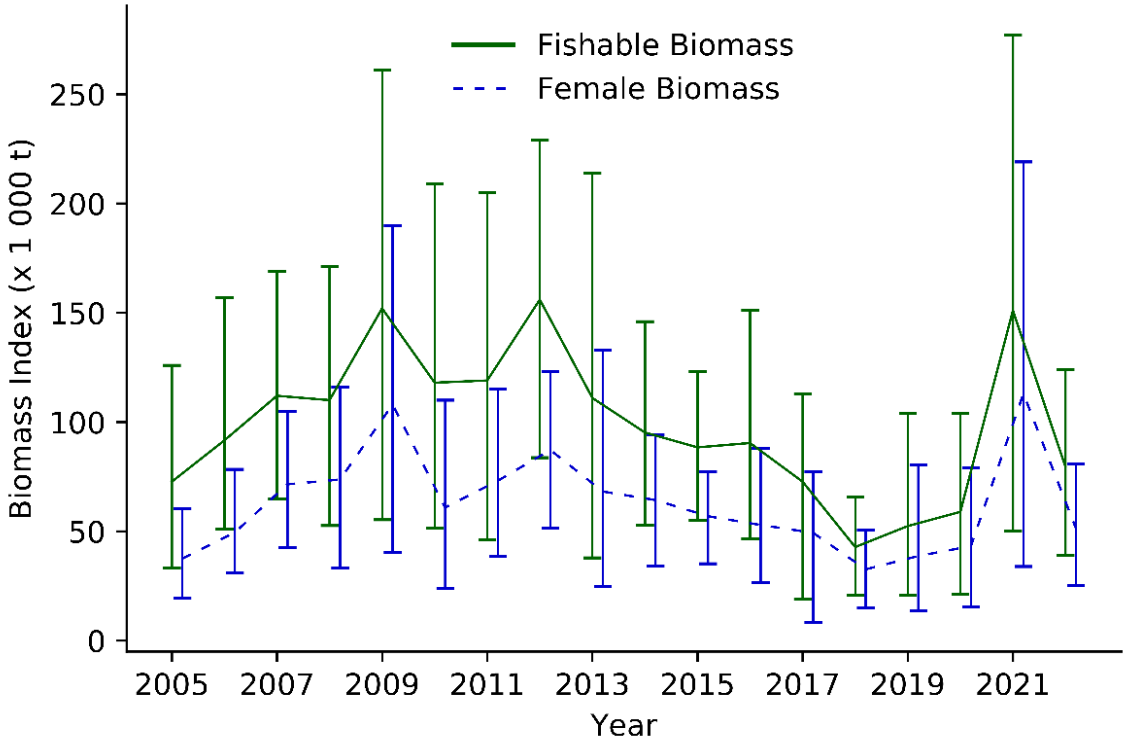

Figure 5. SFA 4 Northern Shrimp fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index ranged between 5.8% and 36.7% from 2005/06 to 2021/22 and preliminary data, based on total catch as of the February 17, 2023 AQMS, result in a ERI of 15.3% in 2022/23. If the total TAC is taken in 2022/23, the exploitation rate index will be 16.3% (Figure 6). The TAC is set for SFA 4 Northern Shrimp using the best available information, the most recent survey year, as the best estimate of the biomass that will be available in the next year. There is no ability to calculate the actual exploitation rate index one year in advance in SFA 4 as it requires the data from the DFO-NSRF summer survey, which happens halfway through the fishing year.

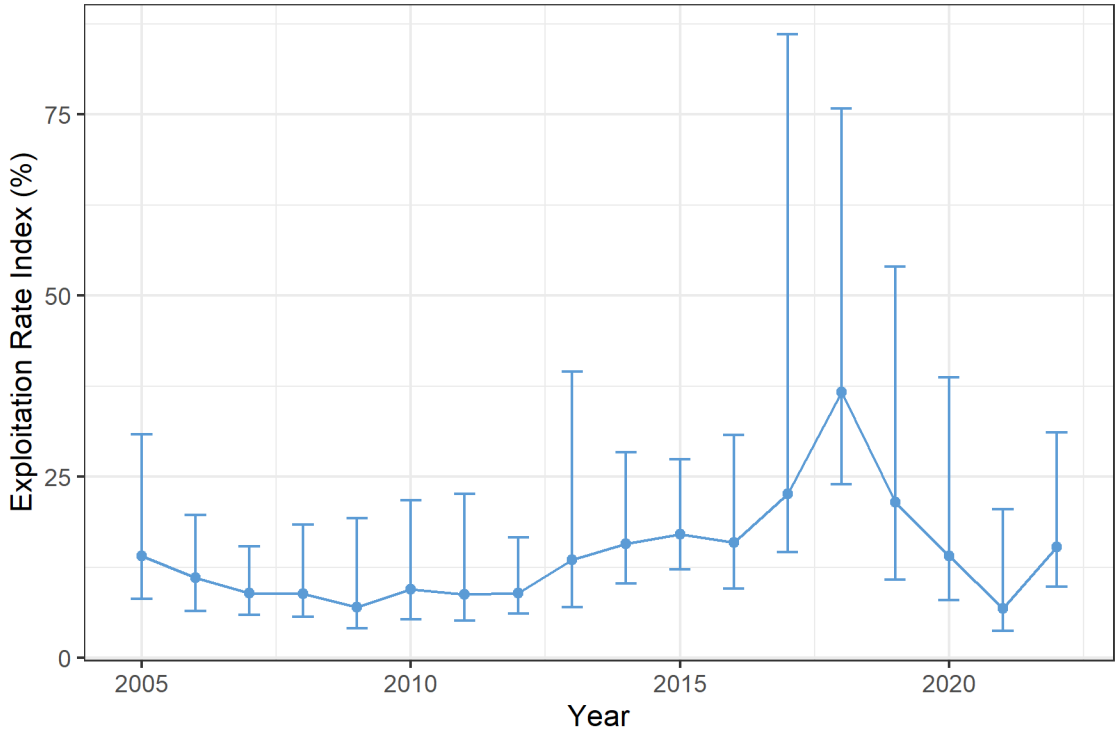

Figure 6. SFA 4 Northern Shrimp exploitation rate index, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Horizontal axis labels denote beginning-year of the fishery (i.e., 2022 indicates 2022/23). The 2022/23 point is preliminary and based on total catch as of the February 17 2023 AQMS. Error bars indicate 95% confidence intervals.

Current Outlook

In 2022, the female SSB index for Northern Shrimp in SFA 4 was in the Healthy Zone, just above the LRP, with a 53% probability of being in the Cautious Zone (Figure 7). Given the relatively wide and asymmetric confidence intervals, there is a >50% chance the current SSB index is not in the Healthy Zone (i.e., in the Cautious Zone). The point estimate, however, falls just above the boundary between the Cautious and Healthy Zones (i.e., the USR).

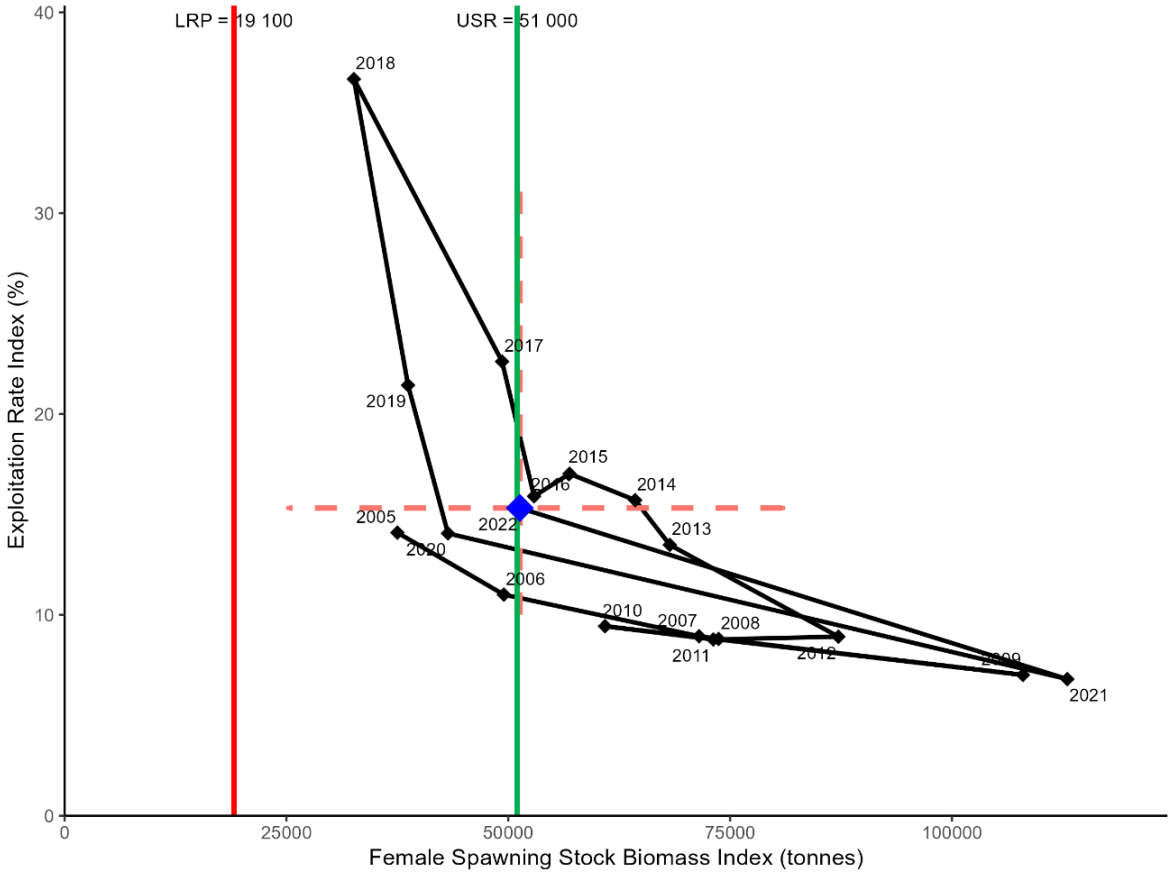

Figure 7. SFA 4 Northern Shrimp PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote beginning-year of the fishery (i.e., 2022 indicates 2022/23). The red cross on the 2022/23 point indicates 95% confidence intervals for the 2022 female SSB index (horizontal) and the 2022/23 exploitation rate index (vertical).

SFA 4 Striped Shrimp (*P. montagui*)

Fishery

The by-catch limit of 4,033 t has not been taken in the past ten years, with the commercial catch ranging between 1,113 t (2016/17) and 3,498 t (2022/23) (Figure 8).

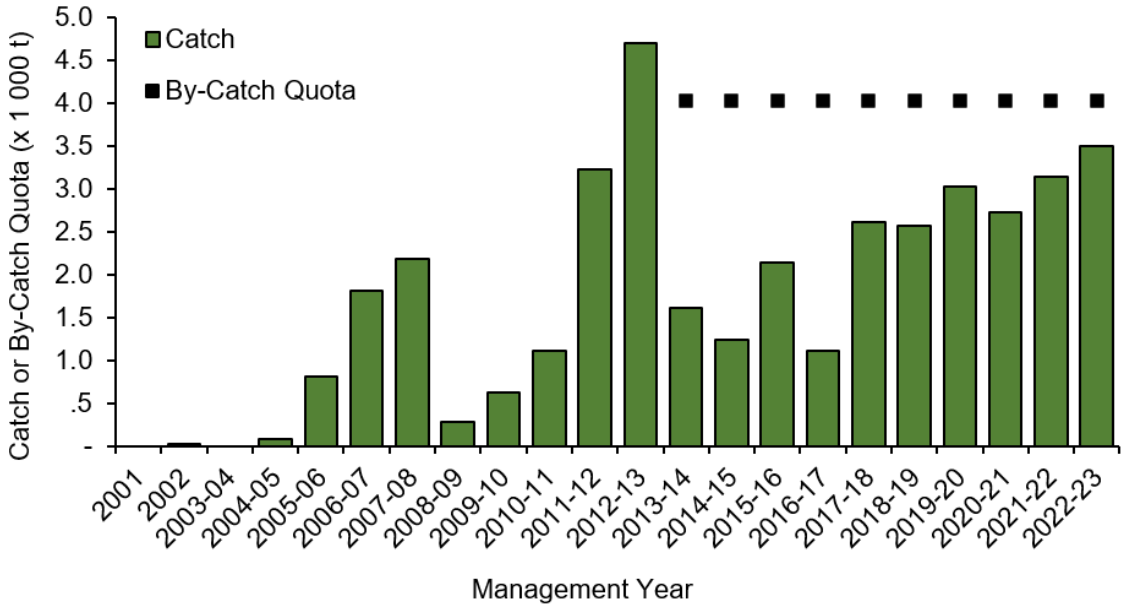

Figure 8. SFA 4 Striped Shrimp commercial catches and by-catch quotas from 2001 to 2022/23. Catches for 2022/23 are preliminary as of the February 17 2023, AQMS. Management year was changed from a calendar year to a fiscal year (April 1 to March 31) in 2003.

Biomass

Over 2005 to 2021 the fishable biomass index averaged 28,600 t. It was 38,800 t in 2022, a 25% increase from 2021. Over 2005 to 2021 the female biomass index averaged 21,900 t. It was 30,600 t in 2022, a 37% increase from 2021 (Figure 9).

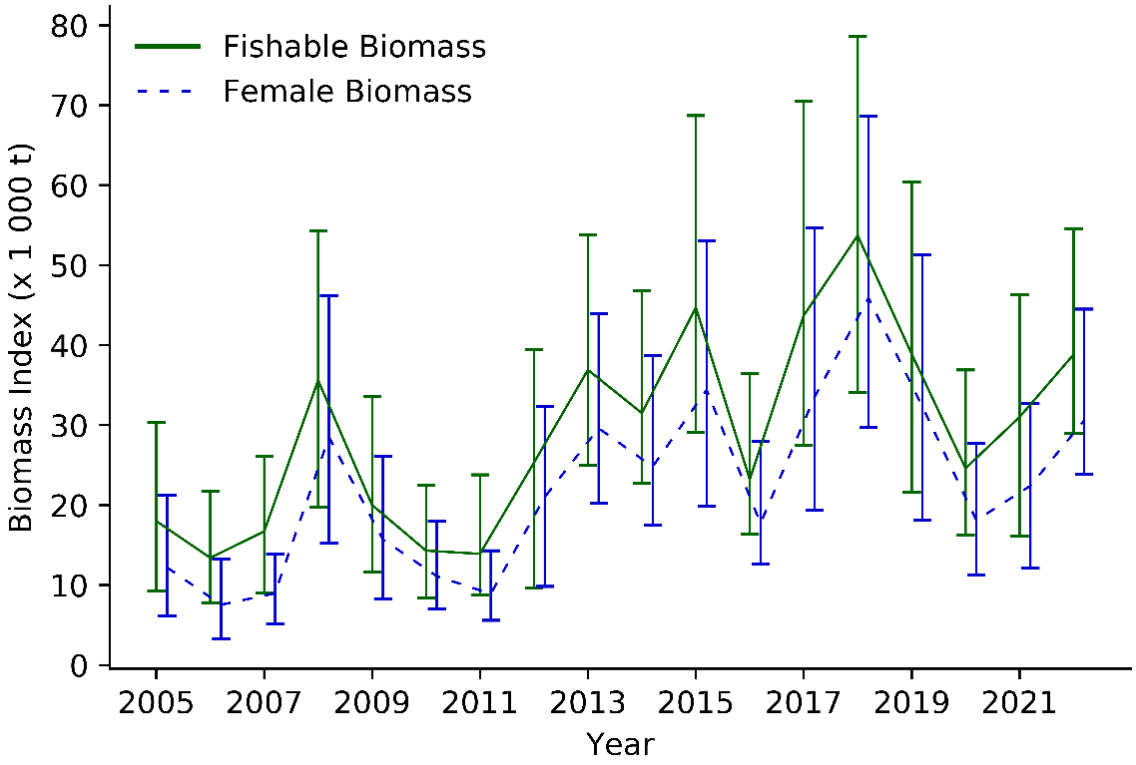

Figure 9. SFA 4 Striped Shrimp fishable and female biomass indices from 2005 to 2022. Biomass indices were calculated using Ogmap on NSRF survey data and error bars reflect 95% CIs.

Exploitation

The ERI ranged between 0.8% and 23.3% from 2005/06 to 2021/22 and using preliminary data, based on total catch as of the February 17 2023 AQMS, result in a ERI of 9.0% in 2022/23 (Figure 10). If the total TAC was taken in 2022/23, the ERI will be 10.4%.

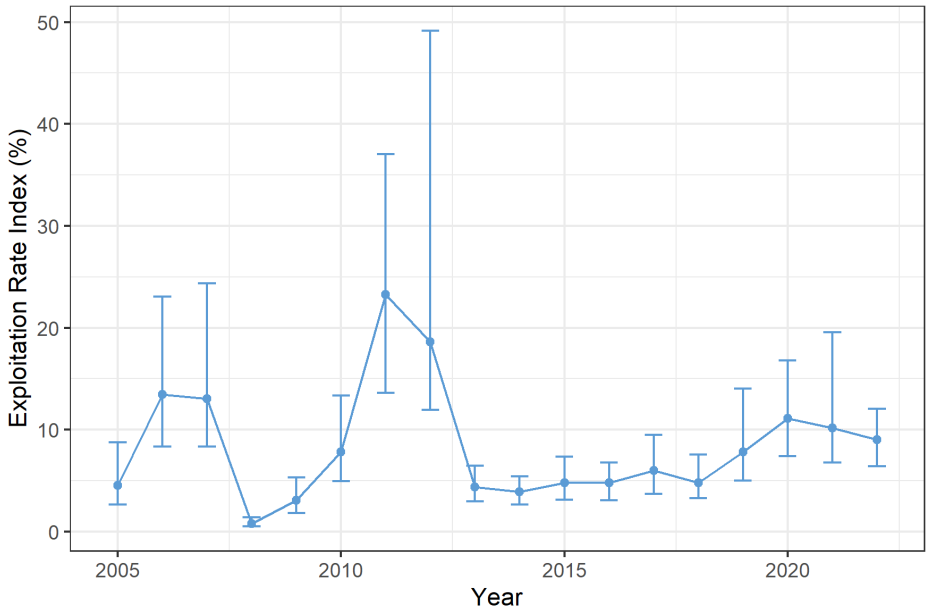

Figure 10. SFA 4 Striped Shrimp ERIs from 2005 to 2022/23. The ERI for 2022/23 is preliminary and based on catches from the February 17, 2023, AQMS. Error bars reflect 95% CIs.

Current Outlook

In 2022, Striped Shrimp biomass (FB_{pop}) was estimated to be 5 times the LRP (Figure 11). The stock has remained above the LRP since 2007. Other indices of stock health, including the potential predator index (Figure 12), total egg production index (Figure 13), and SFA 4 specific fishable biomass index (Figure 9) showed no cause for concern. Striped Shrimp in SFA 4 is considered in a healthy state in the PA framework.

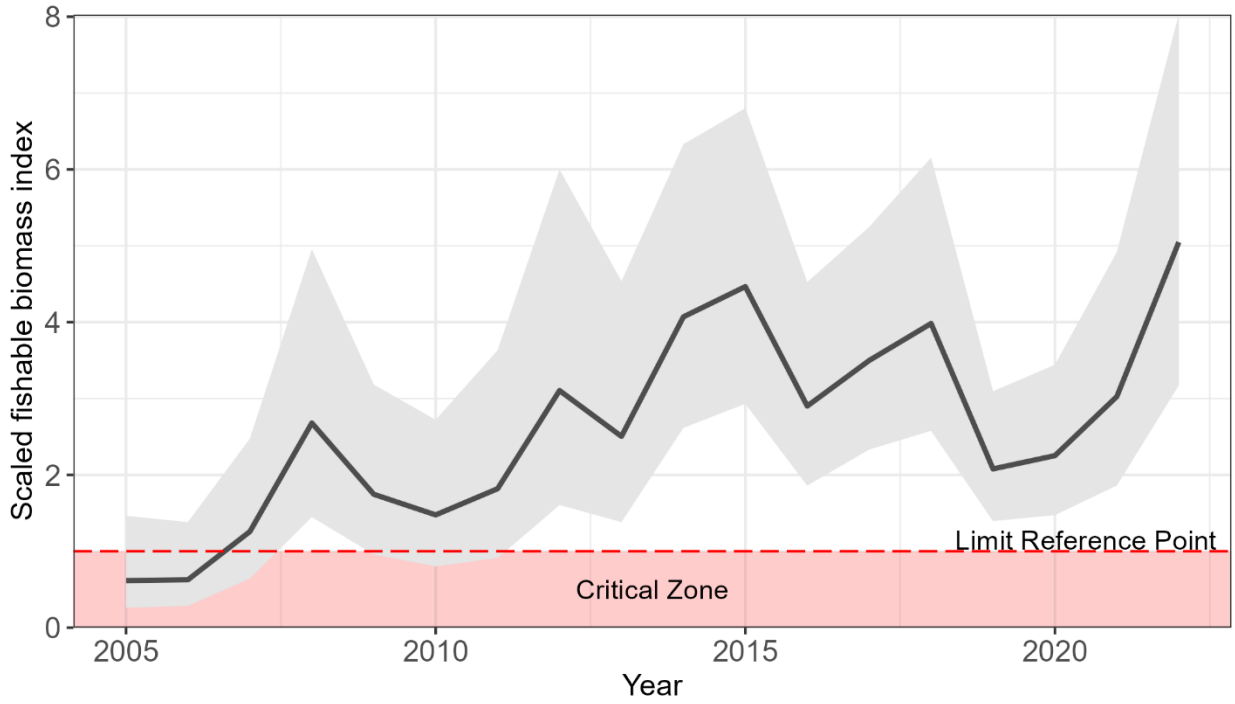

Figure 11. SFA 4 Striped Shrimp Precautionary Approach Framework: modelled striped shrimp fishable biomass index in the Western Assessment Zone (WAZ), Eastern Assessment Zone (EAZ), and shrimp fishing area (SFA) 4 combined (solid line) based on Northern Shrimp Research Foundation surveys, 2005 to 2022 with 95% confidence limits (Grey shading) (values scaled to LRP).

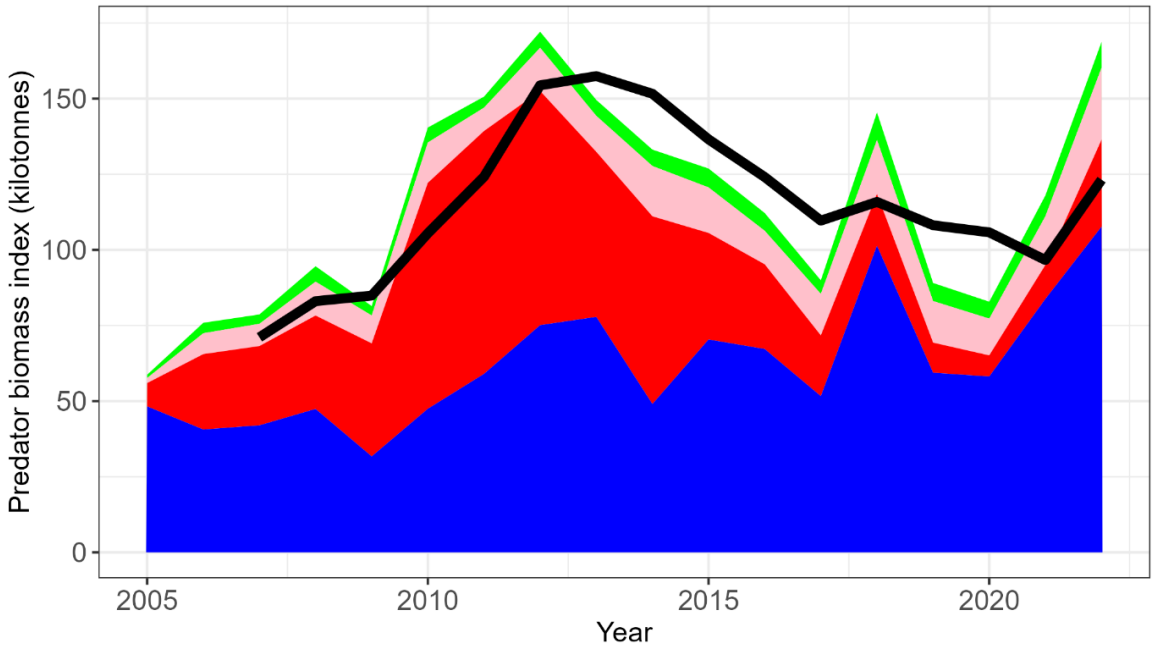

Figure 12. Modelled annual biomass indices (stacked shaded areas) and 3-year moving average (black solid line) of potential predator indices (kilotonnes). Blue area – annual Greenland halibut biomass index, red area – annual large redfish biomass index, pink – annual skate biomass index, green – annual grenadier biomass index.

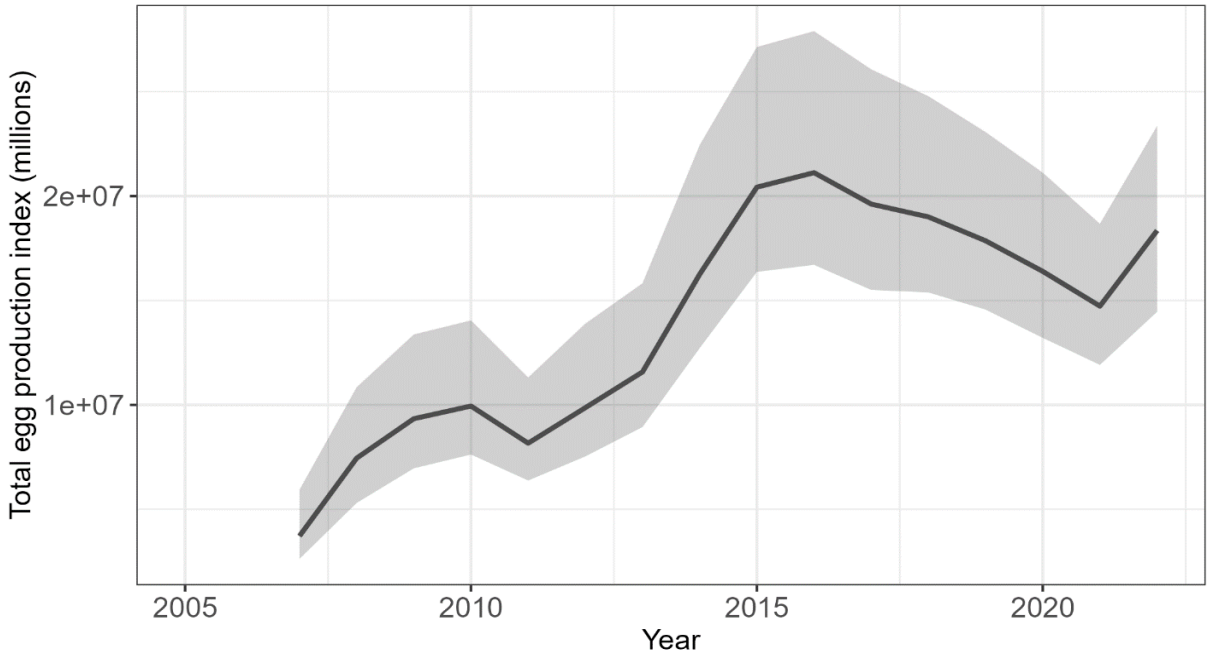

Figure 13. Three-year moving average of modelled total egg production index (millions) of striped shrimp in the Western Assessment Zone (WAZ), Eastern Assessment Zone (EAZ), and shrimp fishing area (SFA) 4 combined, based on Northern Shrimp Research Foundation surveys, 2005 to 2022, with 95% confidence limits (Grey shading).

Sources of Uncertainty

The survey in SFA 4 was conducted by four research vessels (*Cape Ballard*, *Aqviq*, *Kinguk*, *Katsheshuk II*) from 2005 to 2022. Expert opinion was that, given the commonality of the ships' dimensions, the relative catchability would be consistent among vessels. However, no among-vessel calibration was conducted. Research has demonstrated that there are catchability effects resulting from vessel changes (Benoît 2006, Pérez-Rodriquez and Koen-Alonso 2010, Thorson and Ward 2014) despite survey gear and protocols being equal. Frequent vessel changes are undesirable and lead to uncertainty in interpreting survey results due to the likely violation of an assumed constant survey catchability (q=1).

The degree to which the vertical distribution of Northern and Striped Shrimp changes within years, among years, or between spatial locations at a given time, is currently unknown. As biomass estimates are based on bottom trawl surveys (which will not sample shrimp that are not immediately adjacent to the benthos), an unquantified amount of observed biomass fluctuations may be due to changes in vertical distribution rather than the size of the shrimp population.

The SFA 4 Northern Shrimp SSB index and fishable biomass index showed highest historical levels in the survey time series in 2021. However, as indicated by wide confidence intervals, these unusually high estimates were influenced by two large, localized sets that could be considered as potential outliers in view of the biomass estimates in contiguous years (i.e., 2020 and 2022).

Given the relatively wide and asymmetric confidence intervals, there is a >50% chance the 2022 SFA 4 Northern Shrimp SSB index is not in the Healthy Zone. In certain years (e.g., 2017 and 2022, DFO 2018b), the biomass index was primarily influenced by a low number of large survey catches such that the uncertainty (i.e., error bars) around estimates was higher and

asymmetrical. Those large and asymmetrical confidence intervals could lead to Ogmap female SSB point estimates to be into the Healthy Zone, with a higher probability of being in the Cautious Zone (e.g., 2022).

The female SSB that is relevant to the PA for an area consists of the animals whose spawning products will ultimately be caught in that area (as opposed to the animals that spawn in the area). The strong currents that likely affect all sizes of shrimp, especially larvae, into an area create especially severe problems with estimating female SSB, for SFA 4 in particular. Accordingly, the true female SSB differs from the females observed by the survey alone. The existing management areas do not represent biological units. Changes in one management area quite likely produce effects in other management areas.

Because of limited data, research on Northern Shrimp larval dispersal did not consider potentially important factors such as temperature-dependent development or mortality (e.g., predation and post-settlement). Additionally, while there are survey indices of small shrimp, there was no recruitment data for Northern Shrimp to validate the simulated dispersal patterns. The degree of adult and larval striped shrimp transfer throughout the area has not been quantified and is assumed to vary through time. Larval studies in West Greenland waters concluded that Striped Shrimp likely have an earlier hatch and slower development time than Northern Shrimp based on sizes of the different larvae sampled (Pedersen et al. 2002). Given this information, recent larval drift modelling of Northern Shrimp (Le Corre et al. 2020, 2019) is unlikely to apply to striped shrimp on the same scale.

For the exploitation rate index calculation, both the numerator (catch) and denominator (fishable biomass) are uncertain. Trawls used in the surveys have shrimp catchability less than one, but the true value is unknown. Therefore, the survey underestimates biomass by an unknown percentage which may vary annually. Although the commercial catch is asserted to be known without error, the total fishery-induced mortality (i.e., landed catch plus incidental mortality from trawling) is unknown. Therefore, the exploitation rate index is likely underestimated by an unknown percentage.

Exploitation rate is far from being spatially uniform in all fisheries, areas, and time; it is a source of uncertainty if one attempts to use commercial catch rates (e.g., CPUE) as an index of stock status. Commercial effort is impacted by a variety of factors, including but not limited to ice cover, bycatch, and market conditions. Additionally, changing fishing practices impact CPUE in unknown ways.

CONCLUSIONS AND ADVICE

During the assessment in 2023, data were presented including shrimp biomass/abundance indices from NSRF survey, survey catch rates of known shrimp predators, commercial fishery CPUEs, exploitation rate indices, bottom temperatures, sea surface temperatures, and spring phytoplankton bloom dynamics for SFA 4. These data were incorporated into a new model and used to estimate a limit reference point (LPR) consistent with DFO's PA Framework for SFA 4 Striped Shrimp. Northern Shrimp was assessed relative to a LRP and USR following the IFMP PA Framework, which was last revised in 2019. While there are likely several contributing factors to shrimp production (e.g., North Atlantic Oscillation, predation), the specific causes of changing trends in SFA 4 are not fully understood and the requirement for further research is advised.

SFA 4 Northern Shrimp

Despite a year-over-year decrease of biomass indices in 2022, the recent trend suggests continued increases from a historic low in 2018. In 2022, Northern Shrimp in SFA 4 was in the Healthy Zone within the PA Framework, just above the USR, with a 53% probability of being in the Cautious Zone. If the TAC is fully taken in 2022/23, the ERI will be 16.3%.

SFA 4 Striped Shrimp

The fishable biomass index and female biomass index are above the long-term mean and on an increasing trend since 2020. In 2022, the SFA 4 Striped Shrimp stock was 5 times higher than the adopted LRP, and was considered in a healthy state in the PA Framework. If the by-catch limit is taken, the ERI will be 10.4% in 2022/23.

MANAGEMENT CONSIDERATIONS

It is recognized that Northern Shrimp are distributed broadly over the Northwest Atlantic Ocean, including SFA 4–6, EAZ, and WAZ, and that these areas are connected through larval dispersal, but rates of exchange of adults are less understood. These linkages need to be considered to interpret dynamics within and among assessment areas. It is also recognized that the population of *Pandalus montagui* spans the area of EAZ, WAZ, and SFA 4, as well as farther south. Currently the rates of exchange (export/import) between these zones are unknown. Therefore, understanding resource dynamics as a whole requires integrating information from all assessment areas. This assessment is conducted at spatial scales reflecting management units to accommodate management/industry preferences and historic practices. The biological stock unit is recognized to be larger than management units and caution in interpreting and applying stock status information at sub-stock scales is warranted. Although Northern and Striped shrimp are managed on a single-species basis, management of key forage species such as shrimp, under an ecosystem approach, requires adoption of a conservative approach with lower fishing mortality reference points and higher biomass reference points than those that would be adopted under a regular single-species management approach. The dependence on shrimp as prey is related to availability of alternate prey sources; however, a better understanding of ecosystem demands on shrimp as a forage species is required.

There is strong connectivity between the Canadian Arctic areas (EAZ and WAZ) and SFAs 4–6; much of the recruitment to the pre-recruit biomass likely originates north of SFAs 5 and 6 (Le Corre et al. 2019, 2020). Research on larval dispersal modeling shows highest potential settlement rates and highest rates of self-settlement (retention) consistently observed in SFA 6 and 7, often in association with weaker currents in those areas. On the Canadian shelves, biophysical larval dispersal simulations suggest that Northern Shrimp larvae originating in the north (source: Arctic, SFA 4 and 5) provide most of the potential settlers to southern populations (mostly directed towards SFA 6), and show higher settlement success than larvae released from the south (SFA 6 and 7). Larvae may travel several hundreds of kilometers prior to settlement, connecting all the different areas along the northeastern shelves of Canada (SFAs 1–7) and western Greenland consistently over the years.

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This Science Advisory Report is from the March 14–16, 2023 Assessment of Northern and Striped shrimp in Shrimp Fishing Area (SFA) 4 in 2022 and Development of a Limit Reference Point (LRP) for Striped Shrimp in SFA 4 Regional Peer Review meeting. 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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Aussi disponible en français :

*MPO 2024. Évaluation de la crevette nordique (*Pandalus borealis*) et de la crevette ésope (*Pandalus montagui*) dans la zone de pêche de la crevette (ZPC) 4 en 2022 et évaluation d'un point de référence limite (PRL) proposé pour la crevette ésope dans la ZPC 4. Secr. can. des avis sci. du MPO. Avis sci. 2024/014.*