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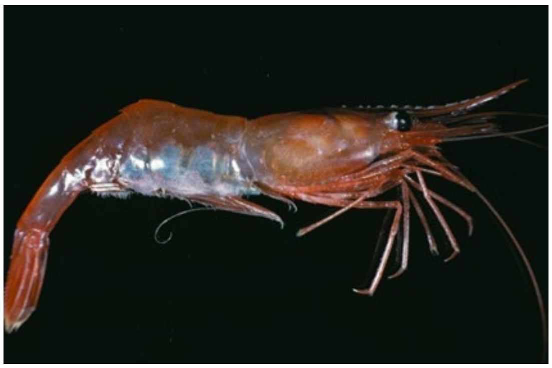
Newfoundland and Labrador Region

Canadian Science Advisory Secretariat
Science Advisory Report 2023/038

ASSESSMENT OF NORTHERN SHRIMP (*PANDALUS BOREALIS*) IN SHRIMP FISHING AREAS 4-6 IN 2021



Northern Shrimp (Pandalus borealis)

Photo: Fisheries and Oceans Canada

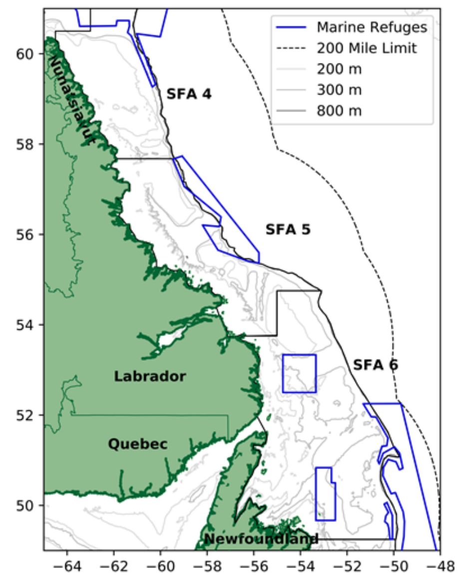


Figure 1. Map of Shrimp Fishing Areas 4-6. Blue polygons identify Marine Refuges (Hatton Basin, Hopedale Saddle, Hawke Box, Funk Island Deep Box, and Northeast Newfoundland Slope from North to South) in which bottom-contact fishing (i.e., shrimp trawling) is not permitted.

Context:

*The bottom trawl fishery for Northern Shrimp (*Pandalus borealis*) off the coast of Labrador began in the mid-1970s, primarily in the Hopedale and Cartwright Channels (Shrimp Fishing Area [SFA] 5), before expanding north to SFA 4 and south to SFA 6 through the 1980s.*

The last Zonal Peer Review Process that assessed Northern Shrimp in SFAs 4-6 was held in February 2021 (DFO 2021). Stock status updates for Striped Shrimp in SFA 4 and for shrimp in the Eastern Assessment Zone (EAZ) and Western Assessment Zone (WAZ) (north of SFA 4) were held in January 2022 (DFO 2022a and 2022b, respectively).

This assessment made use of fishery data from observer and logbook datasets and from the Atlantic Quota Monitoring System (AQMS), along with survey data from fall and summer bottom trawl surveys and from the Atlantic Zonal Monitoring Program (AZMP). Together these provided information on biomass, potential environmental drivers, exploitation rate, distribution, and catch rates.

This Science Advisory Report is from the February 15-17, 2022 regional peer review on the Assessment of Northern Shrimp in SFAs 4-6. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

September 2023

Canada

SUMMARY

- Resource status of Northern Shrimp was assessed based on DFO fall multi-species trawl survey data (Shrimp Fishing Areas [SFAs] 5-6), Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (SFA 4), and commercial catch data (exploitation rate index).
- Ecosystem status in 2J3K and 2H (SFAs 5-6) was considered by examination of available oceanographic conditions, biological community structure, predator-prey interactions, genetic composition of shrimp components, and some human impacts (including trends in fishery performance). Data on ecosystem status in SFA 4 are limited.
- 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. 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.

Environment & Ecosystem

- The NL Climate Index indicated that 2021 was one of the warmest years on record, continuing the ongoing warming trend since 2018.
- The spring phytoplankton bloom was earlier than average in 2021, continuing a trend towards earlier blooms since the mid-2010s. The zooplankton community structure in recent years has returned to a state of higher proportion of larger copepod species (*Calanus finmarchicus)* which could potentially have a positive impact on energy transfer to upper trophic levels.
- Under current ecosystem conditions (i.e., low shrimp stock sizes, low ecosystem productivity, shifting back to finfish dominated structure, low shrimp per capita net production, and generally high predation pressure in SFA 6 and southern SFA 5) fishing is unlikely to be a dominant driver of shrimp stocks in SFA 6 and southern SFA 5, but it is likely a dominant driver in northern SFA 5. Ecosystem conditions in SFA 4 could not be determined.
- Given the relative impact of predation in recent years in SFA 6 and southern SFA 5, small changes in catches have the potential to be more influential on stock trajectory than they may have been in the mid-2000s. Similar analyses for northern SFA 5 do not show a consistent increase in relative impact of predation, but indicate the likely impacts from fishing have been more important than predation in recent years. There is no information on the relative impact of predation in SFA 4.

SFA 6 *Pandalus borealis*

- The annual commercial catch per unit effort (CPUE) declined considerably between 2015/16 and 2017/18 to the lowest levels in two decades and has increased since 2019/20, but remains below the long-term mean.
- The number of stations sampled by the DFO multi-species survey in 2021 had significant reductions. Simulated resampling of historic survey data, using 2021 survey coverage, suggest that the 2021 biomass estimates may slightly overestimate the stock status in SFA 6.

- Fishable biomass and female spawning stock biomass (SSB) indices have declined since 2020, by 20% (to 94,300 t) and 3% (to 72,900 t) respectively, and remain amongst the lowest levels in the survey time series.
- The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2021/22 and was 6.0% in 2021/22. If the total allowable catch (TAC) is fully taken in 2021/22, then the exploitation rate index will be 8.1%.
- The female SSB index is in the critical zone of the Integrated Fisheries Management Plan (IFMP) Precautionary Approach (PA) Framework for the sixth consecutive year, with a 22% probability of being in the cautious zone.
- The rebuilding plan states a maximum exploitation rate of 10% while the stock is in the critical zone. If the 2021/22 TAC of 9,534 t is maintained and taken in 2022/23, the exploitation rate index would be 10.1%.

SFA 5 *Pandalus borealis*

- Standardized large-vessel CPUE had varied without trend at relatively high levels for more than a decade but has been near the long-term mean since 2017/18.
- The number of stations sampled by the DFO multi-species survey in 2021 had significant reductions. Simulated resampling of historic survey data, using 2021 survey coverage, suggest that the biomass estimates in SFA 5 in 2021 show no consistent bias.
- Fishable biomass and female SSB indices have declined since 2020, by 12% (to 71,000 t) and 17% (to 42,800 t) respectively, and are amongst the lowest levels in the survey time series.
- The exploitation rate index ranged between 7.8% and 29.3% from 1997 to 2021/22 and was 11.1% in 2021/22. If the TAC is fully taken in 2021/22, then the exploitation rate index will be 20%.
- Female SSB index is in the healthy zone within the IFMP PA Framework, with 42% probability of being in the cautious zone. If the 16,080 t TAC is maintained and taken in 2022/23, then the exploitation rate index will be 22.7%.

SFA 4 *Pandalus borealis*

- Large-vessel standardized CPUE varied without trend over 1989–2020/21 but has been at or above the long term mean for the past 5 years.
- The NSRF-DFO shrimp survey in 2021 survey indicated an increase in biomass estimates, but the large magnitude of the increase is influenced by two large, localized sets. It is uncertain how much of this estimated increase from 2020 is due to changes in local shrimp productivity, sampling variation, or movement of shrimp into SFA 4 from neighbouring areas.
- Fishable biomass and female SSB indices have increased significantly since 2020, by 156% (to 151,000 t) and 162% (to 113,000 t) respectively, and are amongst the highest levels in the survey time series.
- The exploitation rate index ranged between 7.0% and 36.7% from 2005/06 to 2020/21 and was 5.8% in 2021/22. If the TAC had been taken, the exploitation rate index would have been 6.6%.

- In 2021, the female SSB index was in the healthy zone within the IFMP PA Framework, after four years in the cautious zone, with 8% probability of being in the cautious zone.

BACKGROUND

Species Distribution and Stock Boundaries

Northern or Pink Shrimp (*Pandalus borealis*) are found in the Northwest Atlantic from Baffin Bay south to the Gulf of Maine. 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. 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, *P. borealis* 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 behaviour were identified as important variables affecting simulated larval dispersal in the study area. Simulations on larval dispersal indicated that larvae released from inshore populations showed higher potential settlement success than larvae released from offshore sites (shelf edge).

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

Northern Shrimp are protandrous hermaphrodites; they are born and first mature as males, mate as males for one or more years, and then change sex to spend the rest of their lives as mature females. Individuals are thought to live for more than eight years. Some northern populations exhibit slower rates of growth and maturation, but greater longevity results in larger maximum size. Females produce eggs in the late summer-fall and carry the eggs on their pleopods until they hatch in the spring.

Northern 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-sized survey catch varies by SFA and year.

During the daytime, Northern 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 important prey for many species such as Atlantic Cod (*Gadus morhua*), Greenland Halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes spp*.), 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 1) 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.

Until 1996, the Northern Shrimp fishery in SFA 6 was executed solely by a large-vessel (tonnage >500 t) fleet, which currently consists of 17 licenses. Commercial catch of Northern Shrimp increased rapidly from the mid-1990s into the early-2000s within SFA 6, where the resource was considered to be healthy and fisheries exploitation low. The majority of TAC increases in this period were allocated to a small-vessel (<100 feet) fleet, which has since grown to include about 250 license holders. The number of active licenses varies by year and has been less than 250 for the past several years.

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. Each large-vessel license can bridge up to 750 t in each SFA and each small-vessel license can bridge up to 5% of their quota, up to 1,500 t combined, in SFA 6. Bridging had not been permitted in SFA 6 since about 3,200 t was bridged in 2015/16. However, some exceptions were made in SFA 6 in 2020/21 due to impacts (i.e., a high portion of unfished quota due to market conditions) of the COVID-19 pandemic.

Despite linkages between Northern Shrimp populations in SFAs 4-6, they are managed independently from one another (i.e., TACs are allocated only with consideration for that particular SFA). TACs in SFAs 4-6 combined have been decreasing since the 2008/09 management year (Figure 2), mainly due to TAC reductions in SFA 6 which were implemented as a result of declines in survey biomass indices. The combined SFA 4-6 TAC was 120,345 t in 2009/10 and 35,572 t in 2021/22.

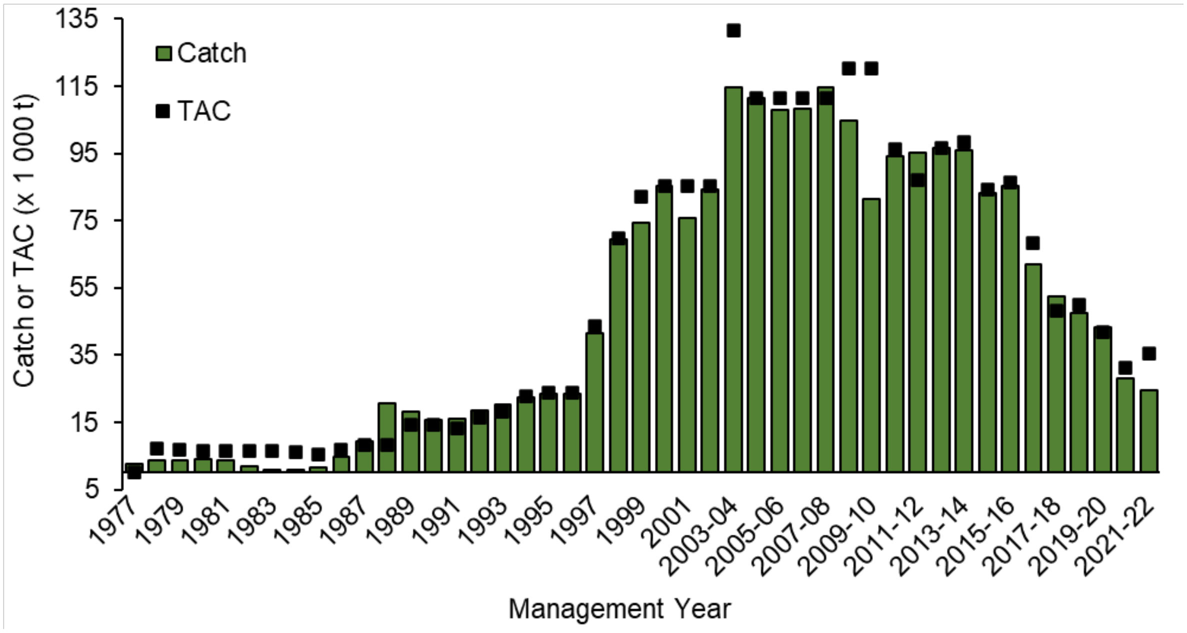


Figure 2. Historical Northern Shrimp catches and TACs (SFAs 4-6 combined) for the period 1977–2021/22. Catches for 2021/22 are preliminary and from the AQMS as of February 11, 2022. The management year changed from a calendar to a fiscal year in 2003 such that the values for 2003/04 are based upon a 15 month fishing season.

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 6, the maximum bar spacing is 22 mm and in SFAs 4-5 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 addresses general key considerations inherent in biological measurement of any renewable resource including how fast the resource is renewing itself, how renewal rates might change, and how human activity can affect renewal rates. In management terms, the rate at which a resource renews itself informs decisions on harvest rates that are sustainable.

Resource status of Northern Shrimp was assessed based on DFO fall multi-species trawl survey data (SFAs 5-6), NSRF-DFO summer trawl survey data (SFA 4), and commercial catch data (exploitation rate index). Ecosystem status in Northwest Atlantic Fisheries Organization (NAFO) divisions 2J3K and 2H (SFAs 5-6) was considered by examination of available oceanographic conditions, biological community structure, predator-prey interactions, genetic composition of shrimp components, and some human impacts (including trends in fishery performance). Data on ecosystem status in SFA 4 are limited.

Trawl survey data for SFAs 4-6 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. For these SFAs, 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, fisher CPUE, and fishing patterns.

Exploitation rate index was determined by dividing the commercial catch from the fishing season by the survey fishable biomass index from the previous year (for fall surveys in SFAs 5 and 6) or the current year (for summer surveys in SFA 4).

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 2007a). 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 IFMP which was first published in 2007 (DFO 2007b) and updated in 2018 (DFO 2018a). This framework was developed in 2008–10 following the 2008 framework workshop attended by a Marine Stewardship Council (MSC) working group and including representation from DFO Science, DFO Fisheries Management, and industry stakeholders.

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. Because of differences in survey history, the reference periods were taken to be 1996–2003 for SFA 6, 1996–2001 for SFA 5, and 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.

In order to demonstrate historic changes in SFAs 5 and 6 Northern Shrimp biomass, time-series analyses of three metrics (biomass from pre-1995 shrimp-specific fishery-independent surveys, CPUE from commercial offshore vessels, and the fraction of analyzed cod stomachs that contained shrimp) were initially presented during the 2018 Canadian Science Advisory Secretariat (CSAS) Regional Peer Review Process (RPR, DFO 2018a). They were again presented at the CSAS framework meeting in May 2019 and at the CSAS RPR in 2020. Fisheries-independent survey data and commercial CPUE data came from two areas in SFA 5 (the Cartwright and Hopedale Channels) and one area in northern SFA 6 (the Hawke Channel). Diet indices were based on the frequency of shrimp in cod diets from the entirety of SFA 6. These analyses indicate that Northern Shrimp biomass in SFA 6 is currently similar to the 1980–90 period (substantially lower than its peak in the mid-2000s), but this is occurring in a context of a much reduced fish biomass relative to the 1980–90 period.

A Northern Shrimp production model incorporating environmental and ecosystem drivers was developed and peer reviewed during a CSAS framework meeting in May 2019 (Pedersen et. al. 2022). The model utilizes North Atlantic Oscillation (NAO) and predation by Atlantic Cod, Greenland Halibut, and Redfish to predict productivity changes within each SFA, permitting a prediction of total biomass in the following year. While the model was tentatively accepted, the consensus from the external reviewers and meeting participants determined that model testing and refinements should take place prior to utilizing biomass projections for management decisions. It is anticipated that this process will take several years. Both the shrimp model and consumption analyses indicated that predation is a major driver of the stock. While ecosystem analyses are typically conducted on NAFO Divs. 2J3KL combined, there were no NAFO Div. 3L survey data available for 2021 so the analyses was completed only on NAFO Divs. 2J3K. In 2021, the shrimp predation mortality rate (calculated by dividing the total shrimp consumption by predators by the estimated integrated availability) in NAFO Divs. 2J3K (SFA 6 and southern part of SFA 5) had increased to the highest level on record (Figure 5 and Figure 10).

Additionally, the 2019 framework meeting was presented with a proposed PA framework based on the model results. This approach was not accepted by external reviewers or meeting participants. Subsequently, the PA approach currently in use will remain in place until a new PA framework can be developed for these stocks.

Environment

The NL Climate Index indicated that 2021 was one of the warmest years on record, continuing the ongoing warming trend since 2018. The spring phytoplankton bloom was earlier than average in 2021, continuing a trend towards earlier blooms since the mid-2010s. The zooplankton community structure in recent years has returned to a state of higher proportion of larger copepod species (*Calanus finmarchicus*) which could potentially have a positive impact on energy transfer to upper trophic levels.

SFA 6 *Pandalus borealis*

Ecosystem

Ecosystem conditions in the Newfoundland Shelf and Northern Grand Bank NAFO Divs. 2J3K; SFA 6, and southern part of SFA 5 remain indicative of overall limited productivity of the fish community. While total biomass levels remain much lower than prior to the fish community collapse in the early-1990s, it showed some recovery up to the mid-2010s, when some declines where observed. Current total biomass (i.e., biomass of all fish functional groups combined) remains below the early-2010s level. Since the mid-2000s this fish community has shifted back to a finfish-dominated structure, but has shown small increases in shellfish dominance since 2018.

Fishery

TAC reductions have been applied periodically since 2009/10 due to stock declines. Subsequently, catches follow the same trend. TAC was decreased from 8,961 t in 2019/20 to 8,290 in 2020/21 and increased, by 15%, to 9.535 t in 2021/22. As of the February 11, 2022, AQMS, 75% of the 2021/22 TAC had been taken. The annual commercial CPUE declined considerably between 2015/16 and 2017/18 to the lowest levels in two decades and has increased since 2019/20, but remains below the long-term mean (Figure 3).

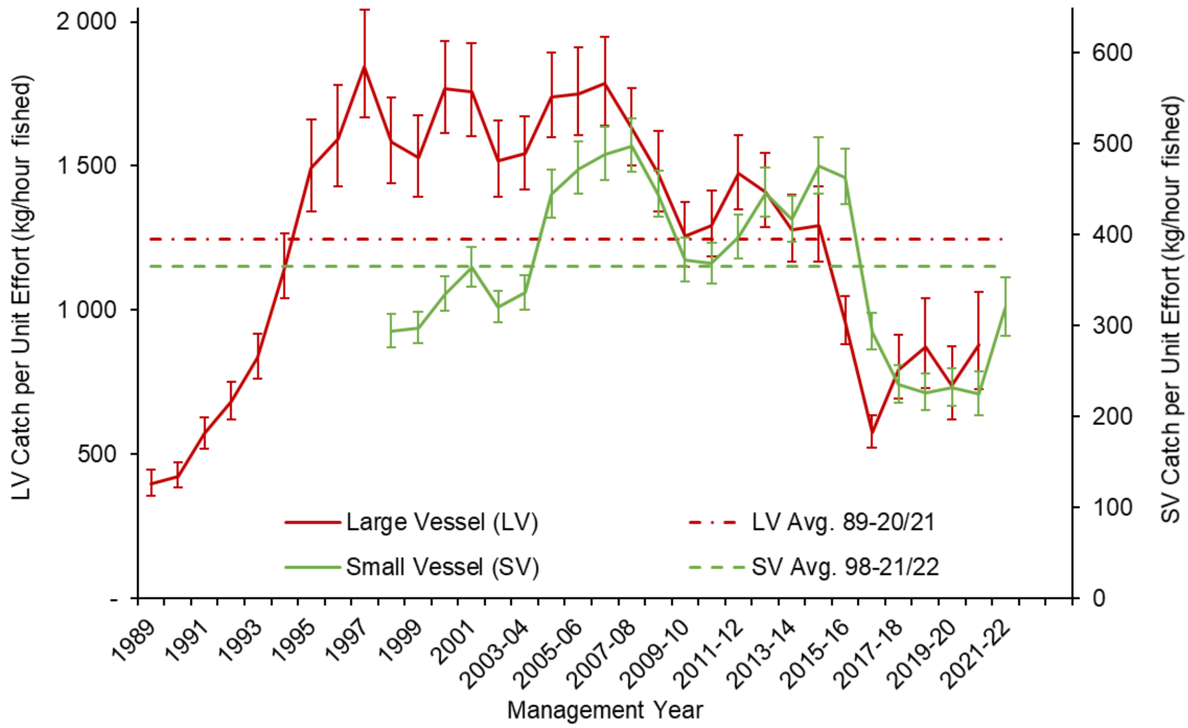


Figure 3. SFA 6 large-vessel (LV, red solid line beginning in 1989) and small-vessel (SV, green solid line beginning in 1998) annual standardized CPUE. Error bars indicate 95% confidence intervals and dashed horizontal lines indicate long-term mean of CPUE series. The 2021/22 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

The number of stations sampled by the DFO multi-species survey in 2021 was significantly reduced. Simulated resampling of historic survey data, using 2021 survey coverage, suggest that the 2021 biomass estimates may slightly overestimate the stock status in SFA 6.

Fishable biomass and female SSB indices have declined since 2020, by 20% (to 94,300 t) and 3% (to 72,900 t) respectively, and remain amongst the lowest levels in the survey time series (Figure 4).

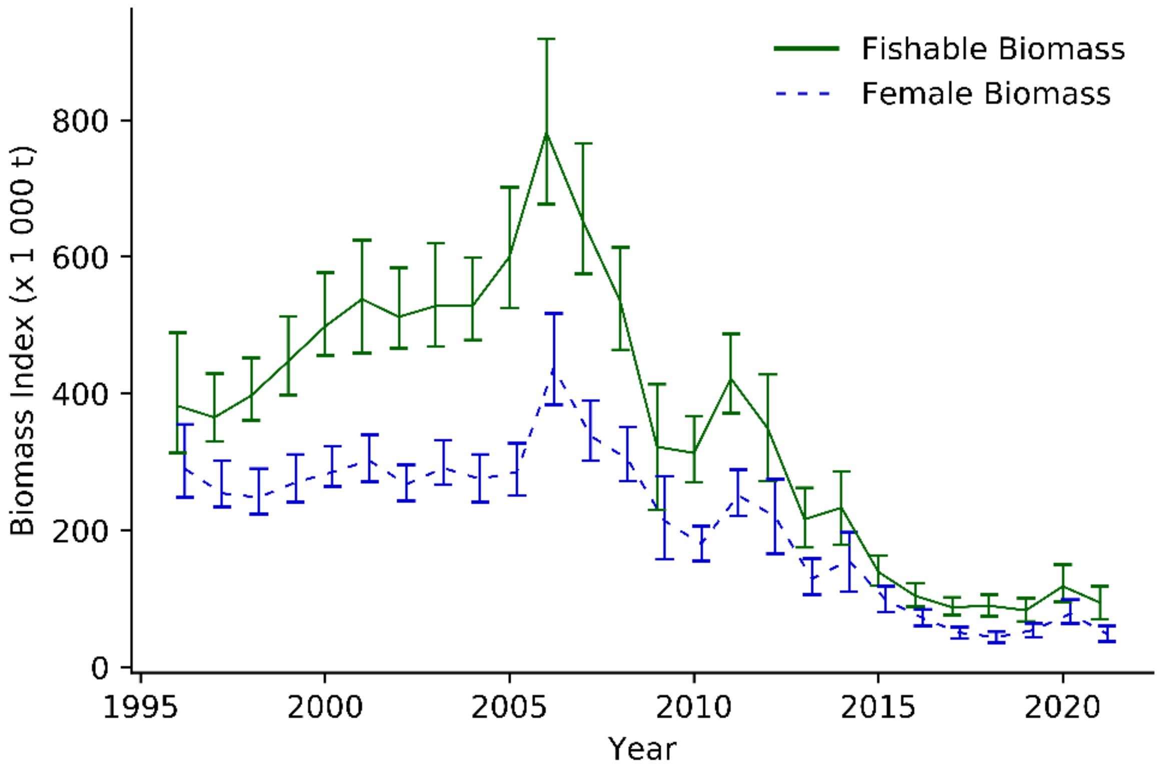


Figure 4. SFA 6 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Renewal

Renewal is the difference between the increase due to production, and removal largely due to predators and fishing. The build-up of shrimp until the mid-2000s occurred during a period of favourable environmental conditions and reduced predation. Shrimp per-capita net production has declined since the mid-2000s, but the trend has shown some signals of reversal in 2019–20. Shrimp per-capita net production is expected to remain around current values, or show modest improvement in the next 1–3 years (Figure 5). Predation, fishing pressure, and warm climate conditions remain negatively correlated with subsequent shrimp per-capita net production (DFO 2018b) in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5). Fishing in NAFO Divs. 2GH (SFA 4 and northern part of SFA 5) also shows a negative correlation with shrimp per-capita net production in NAFO Divs. 2J3KL, suggesting that shrimp productivity may be impacted by fishing in upstream areas. Under current ecosystem conditions (i.e., low shrimp stock sizes, low ecosystem productivity, shifting back to finfish dominated structure, low shrimp per capita net production, and generally high predation pressure in SFA 6 and southern SFA 5) fishing is unlikely to be a dominant driver of shrimp stocks in SFA 6 and southern SFA 5, but it is likely a dominant driver in northern SFA 5. Ecosystem conditions in SFA 4 could not be determined. Given the relative impact of predation in recent years in SFA 6 and southern SFA 5, small changes in catches have the potential to be more influential on stock trajectory than they may have been in the mid-2000s (Figure 5). Similar analyses for northern SFA 5 do not show a consistent increase in relative impact of predation, but indicate the likely impacts from fishing have been more important than predation in recent years. There is no information on the relative impact of predation in SFA 4.

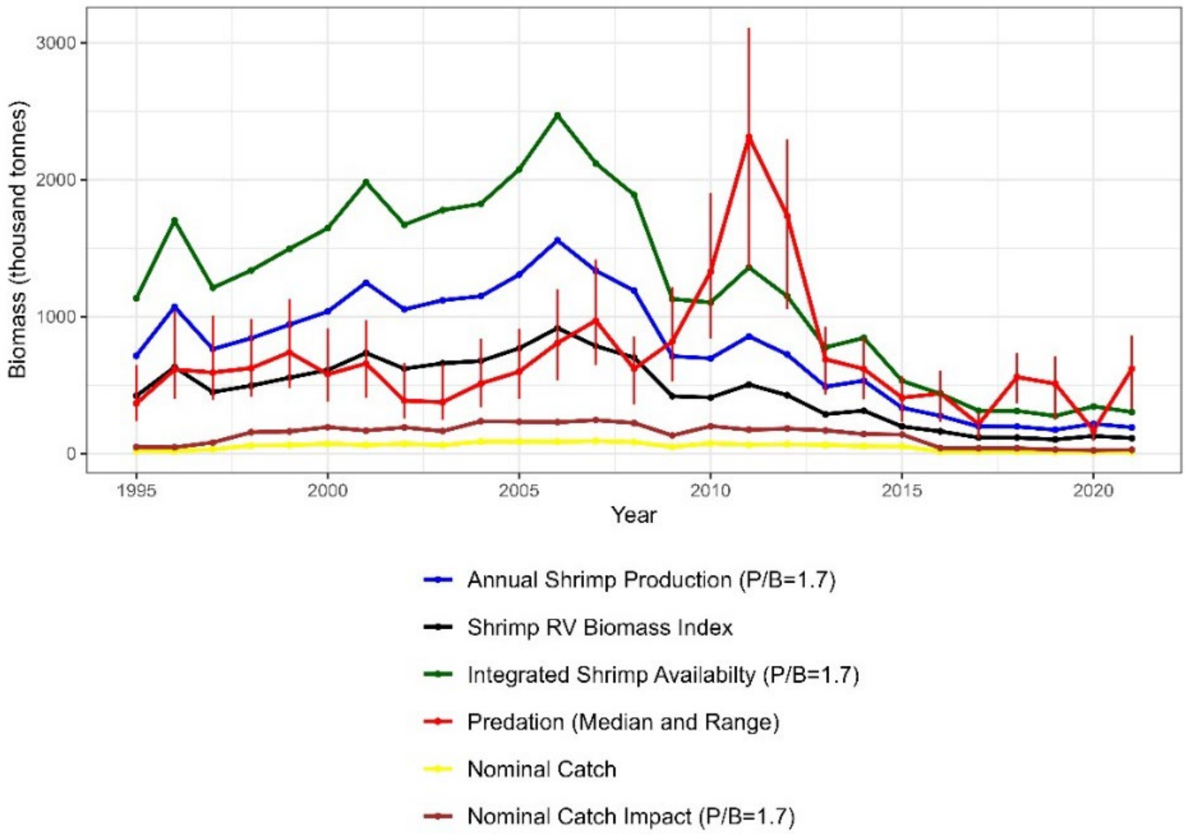


Figure 5. Comparison of predation and fisheries catches in NAFO Divs. 2J3K (SFA 7, 6, and southern part of SFA 5) with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a production over biomass (P/B) ratio of 1.7.

Exploitation

The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2021/22 and was 6.0% in 2021/22. If the TAC is fully taken in 2021/22, then the exploitation rate index will be 8.1% (Figure 6).

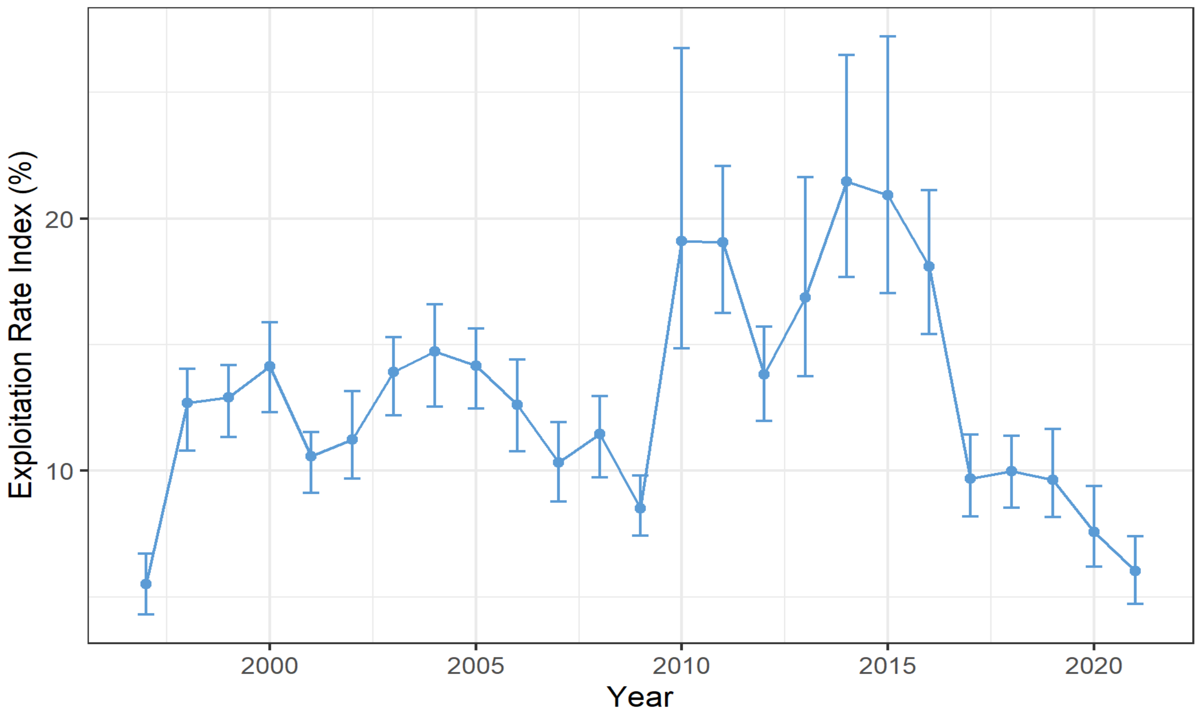


Figure 6. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. Horizontal axis labels denote beginning-year of the fishery (i.e., 2021 indicates 2021/22). The 2021/22 point is preliminary and based on total catch as of the February 11, 2022, AQMS. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

The female SSB index is in the critical zone of the IFMP PA Framework for the sixth consecutive year, with a 22% probability of being in the cautious zone. The rebuilding plan states a maximum exploitation rate index of 10% while the stock is in the critical zone. If the 2021/22 TAC of 9,534 t is maintained and taken in 2022/23, the exploitation rate index would be 10.1%. (Figure 7).

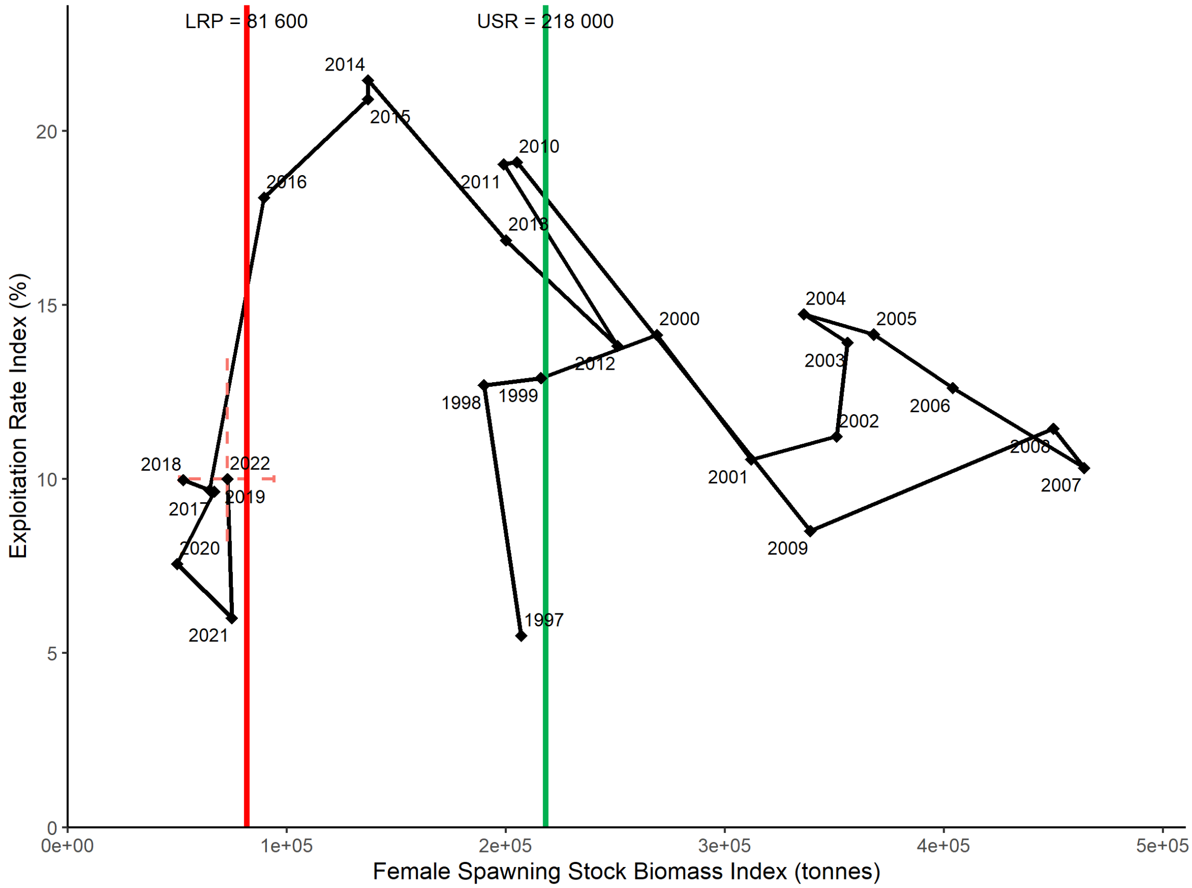


Figure 7. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote beginning-year of the fishery (i.e., 2022 indicates 2022/23). The 2021/22 fishery was ongoing and based on reported catch as of February 11, 2022. The red cross on the 2022/23 point indicates 95% confidence intervals for the 2021 female SSB index (horizontal) and the 2022/23 exploitation rate index (vertical), assuming that the 9,534 t TAC is maintained and taken in the 2022/23 fishery.

SFA 5 *Pandalus borealis*

Ecosystem

The available information for the Labrador Shelf (NAFO Div. 2H, northern part of SFA 5) shows declines in total biomass of the fish community from the levels observed in the early-2010s, but the 2021 survey suggests a potential reversal of this trend. The structure of the fish community is also changing, showing reductions in the dominance of shellfish. This suggests that this ecosystem could be shifting to a finfish-dominated community, as observed in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5).

Fishery

TAC was reduced from 22,100 t in 2019/20 to 14,450 t in 2020/21 and increased, by 11%, to 16,080 t in 2021/22. Standardized large-vessel CPUE had varied without trend at relatively high levels for more than a decade but has been near the long-term mean since 2017/18 (Figure 8).

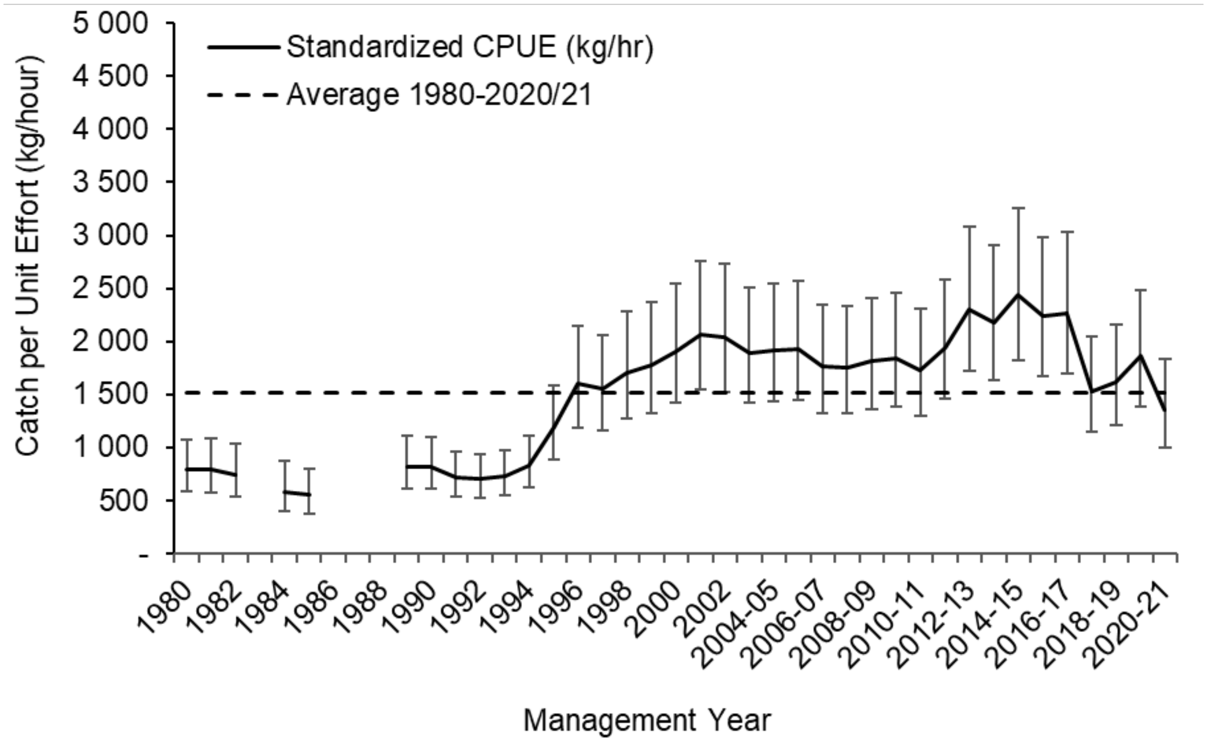


Figure 8. SFA 5 large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long-term mean of CPUE series. The 2021/22 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

The number of stations sampled by the DFO multi-species survey in 2021 was significantly reduced. Simulated resampling of historic survey data, using 2021 survey coverage, suggest that the biomass estimates in SFA 5 in 2021 show no consistent bias. Fishable biomass and female SSB indices have declined since 2020, by 12% (to 71,000 t) and 17% (to 42,800 t) respectively, and are amongst the lowest levels in the survey time series (Figure 9).

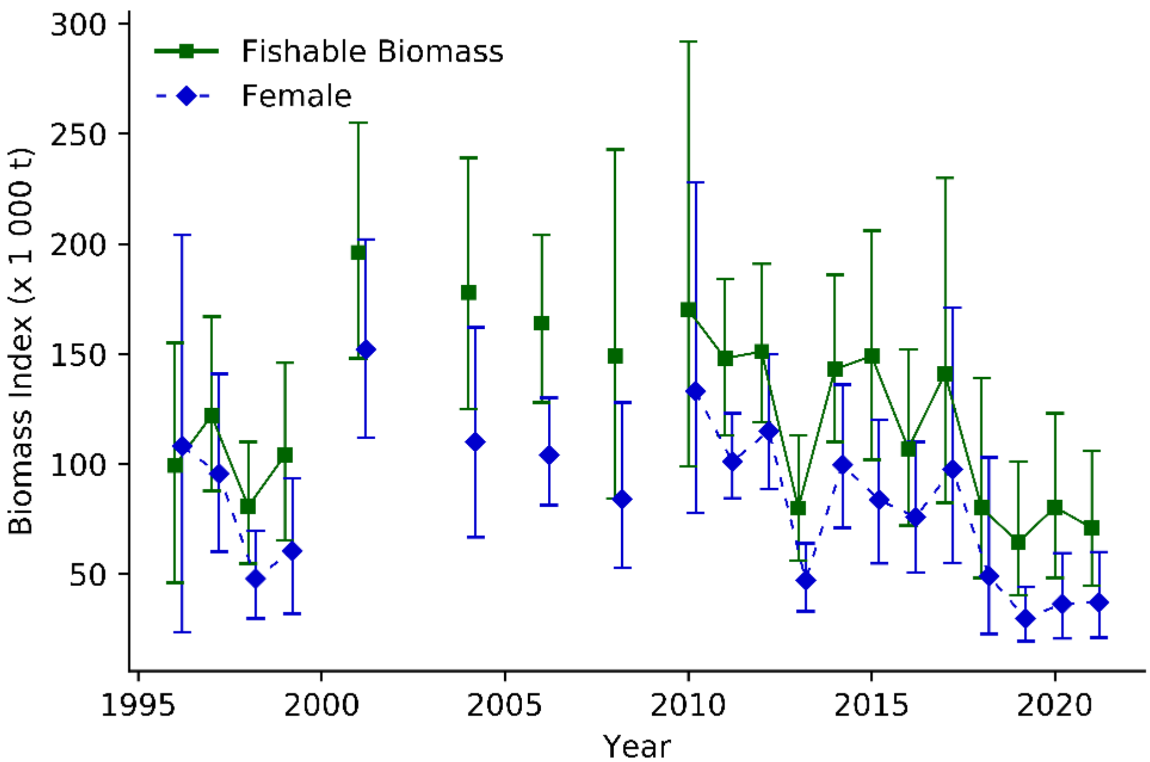


Figure 9. SFA 5 fishable biomass (green solid line and squares) and female SSB (blue dashed line and diamonds) indices. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. Error bars indicate 95% confidence intervals.

Renewal

Similar analyses, to that of NAFO Divs. 2J3KL, on the relative impacts of predation and fishing for the Labrador Shelf (NAFO Div. 2H, northern part of SFA 5) suggest that fishing is likely a dominant driver in northern SFA 5 and analyses indicate impacts from fishing have been more important than predation in recent years (Figure 10).

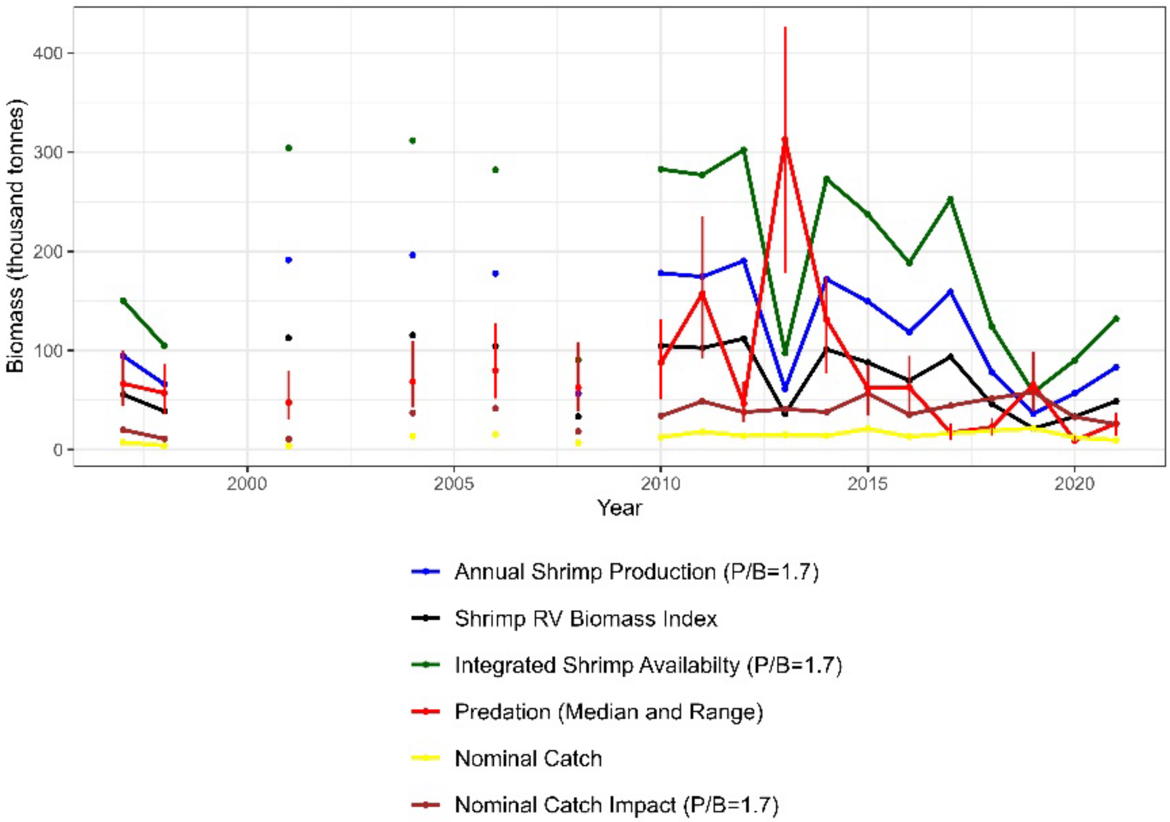


Figure 10. Comparison of predation and fisheries catches in NAFO Div. 2H (northern part of SFA 5) with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a production over biomass (P/B) ratio of 1.7.

Exploitation

The exploitation rate index ranged between 7.8% and 29.3% from 1997 to 2021/22 and was 11.1% in 2021/22. If the TAC is fully taken in 2021/22, then the exploitation rate index will be 20% (Figure 11), however this could be higher if season bridging is permitted. For example, in 2017/18 the TAC was 22,000 t (an anticipated 20.6% exploitation rate) but the catch was 26,100 t (an actual 24.4% exploitation rate) due to season bridging.

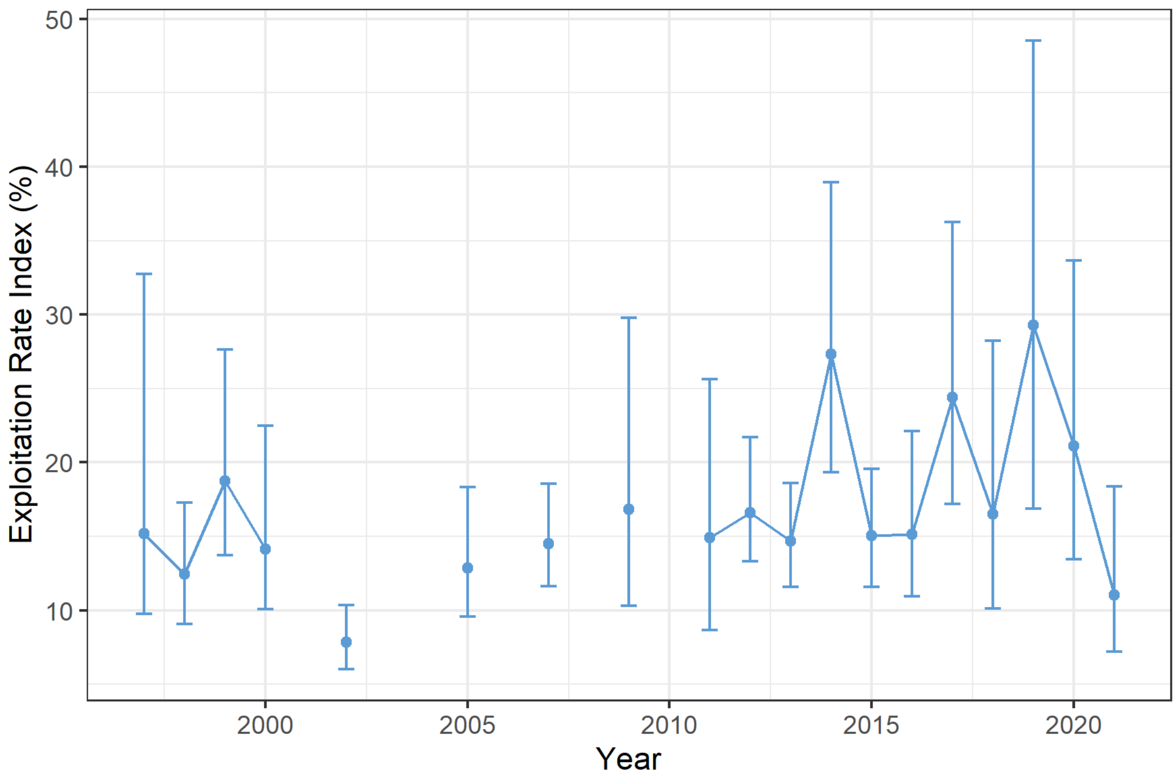


Figure 11. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. Horizontal axis labels denote beginning-year of the fishery (i.e., 2021 indicates 2021/22). Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. The 2021/22 point is preliminary and based on total catch as of the February 11, 2022, AQMS. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index is in the healthy zone within the IFMP PA Framework, with 42% probability of being in the cautious zone. If the 16,080 t TAC is maintained and taken in 2022/23, then the exploitation rate index will be 22.7% (Figure 12).

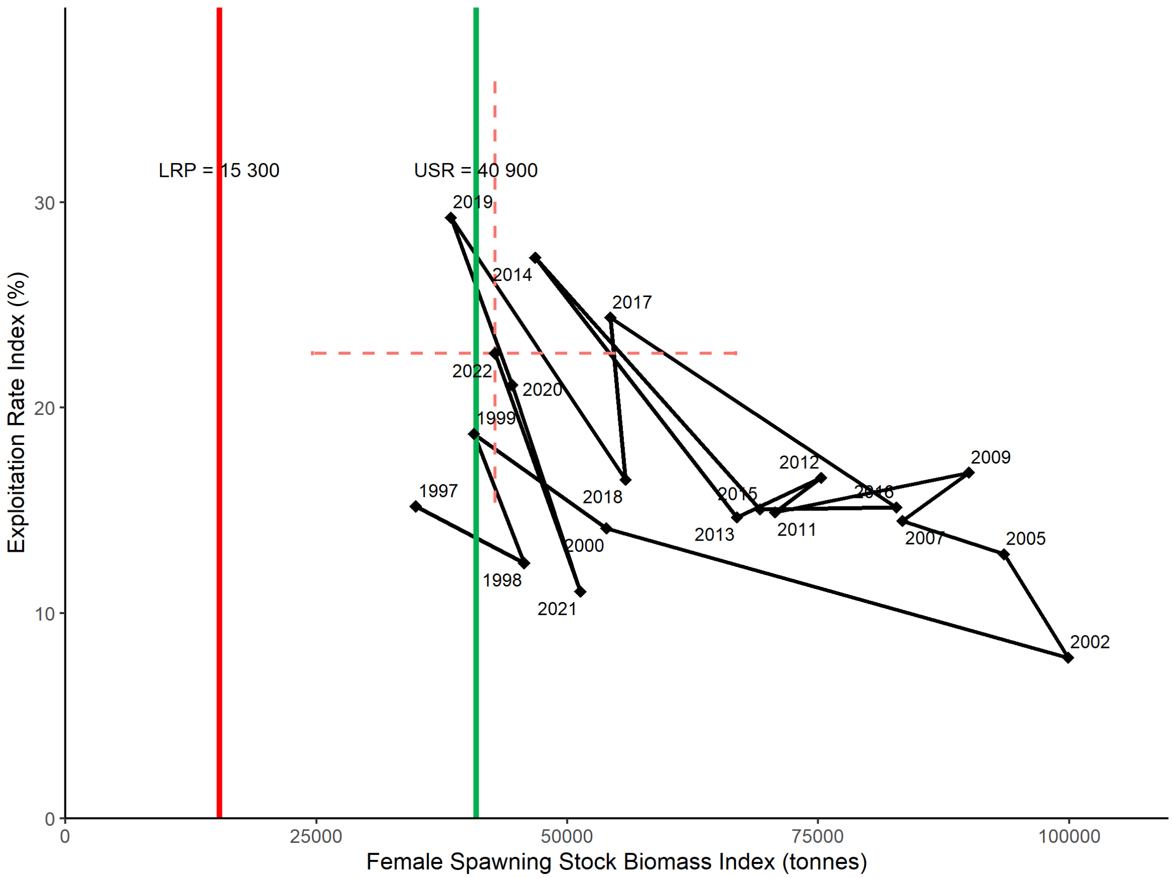


Figure 12. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote beginning-year of the fishery (i.e., 2022 indicates 2022/23). The 2021/22 fishery was ongoing and based on reported catch as of February 11, 2022. The red cross on the 2022/23 point indicates 95% confidence intervals for the 2021 female SSB index (horizontal) and the 2022/23 exploitation rate index (vertical), assuming that the 16,080 t TAC is maintained and taken in the 2022/23 fishery.

SFA 4 *Pandalus borealis*

Ecosystem

Ecosystem conditions in SFA 4 could not be determined at the meeting and there is no information on the relative impact of predation in this area.

Fishery

TAC was reduced from 10,845 t in 2019/20 to 8,658 t in 2020/21 and increased, by 15%, to 9,957 t in 2021/22. Large-vessel standardized CPUE varied without trend over 1989–2020/21 but has been at or above the long term mean for the past 5 years (Figure 13). 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 this area.

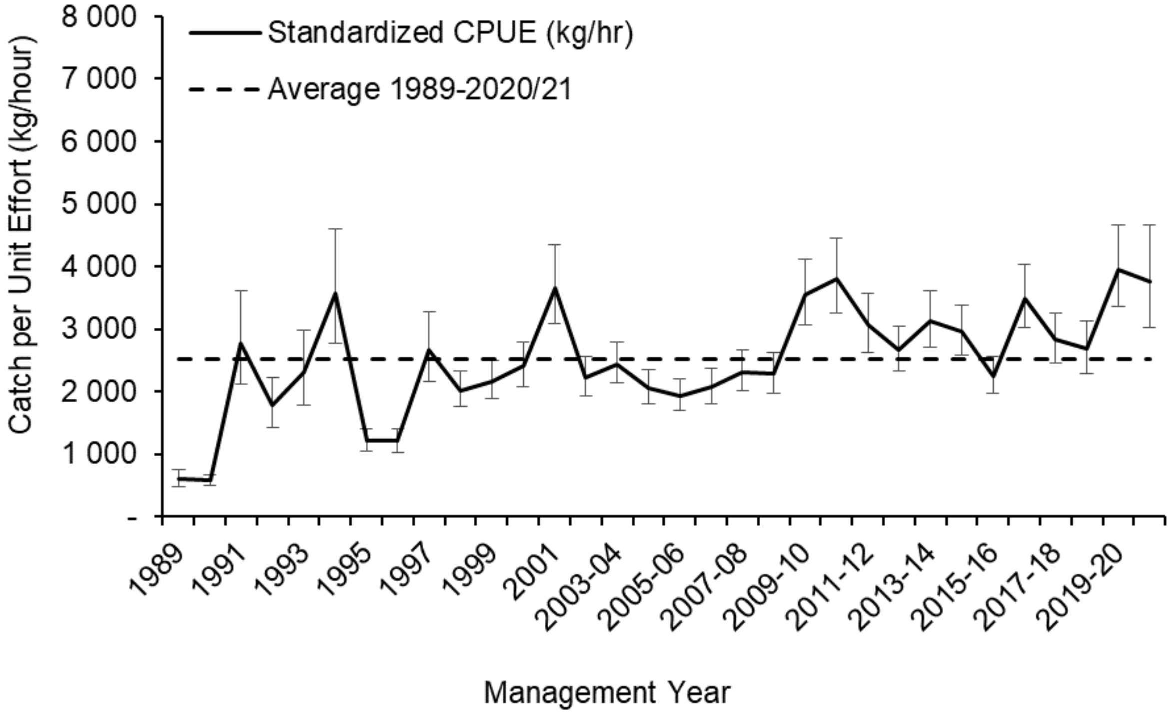


Figure 13. SFA 4 Northern Shrimp large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series. The 2021/22 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

The NSRF-DFO shrimp survey in 2021 survey indicated an increase in biomass estimates, but the large magnitude of the increase is influenced by two large, localized sets. It is uncertain how much of this estimated increase from 2020 is due to changes in local shrimp productivity, sampling variation, or movement of shrimp into SFA 4 from neighbouring areas. Fishable biomass and female SSB indices have increased significantly since 2020, by 156% (to 151,000 t) and 162% (to 113,000 t) respectively, and are amongst the highest levels in the survey time series. However, there is a notable, large degree of uncertainty associated with these biomass estimates (Figure 14).

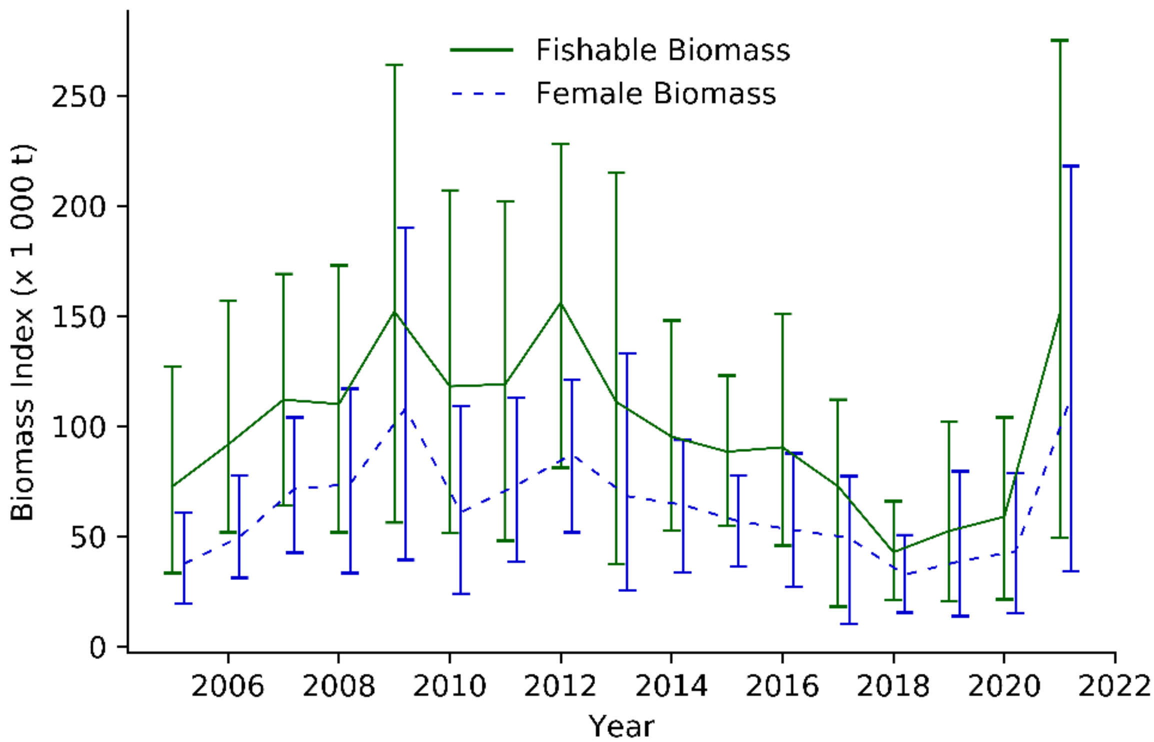


Figure 14. SFA 4 Northern Shrimp fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index ranged between 7.0% and 36.7% from 2005/06 to 2020/21 and was 5.8% in 2021/22. If the TAC had been taken, the exploitation rate index would have been 6.6%. (Figure 15). The TAC is set for SFA 4 Northern Shrimp under the assumption that biomass indices will not change from the most recent survey year to the next survey year. There is no ability to calculate the exploitation rate index one year in advance in SFA 4 due to the survey timing (summer). The exploitation rate index had been increasing from 2012/13 to 2018/19, corresponding to a period of declining biomass indices. The exploitation rate index was high in 2018 due to the significant decrease in fishable biomass index from 2017 to 2018.

The confidence intervals surrounding the 2017/18–2020/21 exploitation rate indices are wide, particularly the upper interval. The upper confidence interval for the exploitation rate index is based on the lower confidence interval of the fishable biomass index, which are the lowest values in the survey time series in 2017–20. For this reason, the upper confidence intervals of the 2017/18–2020/21 exploitation rate indices are very high.

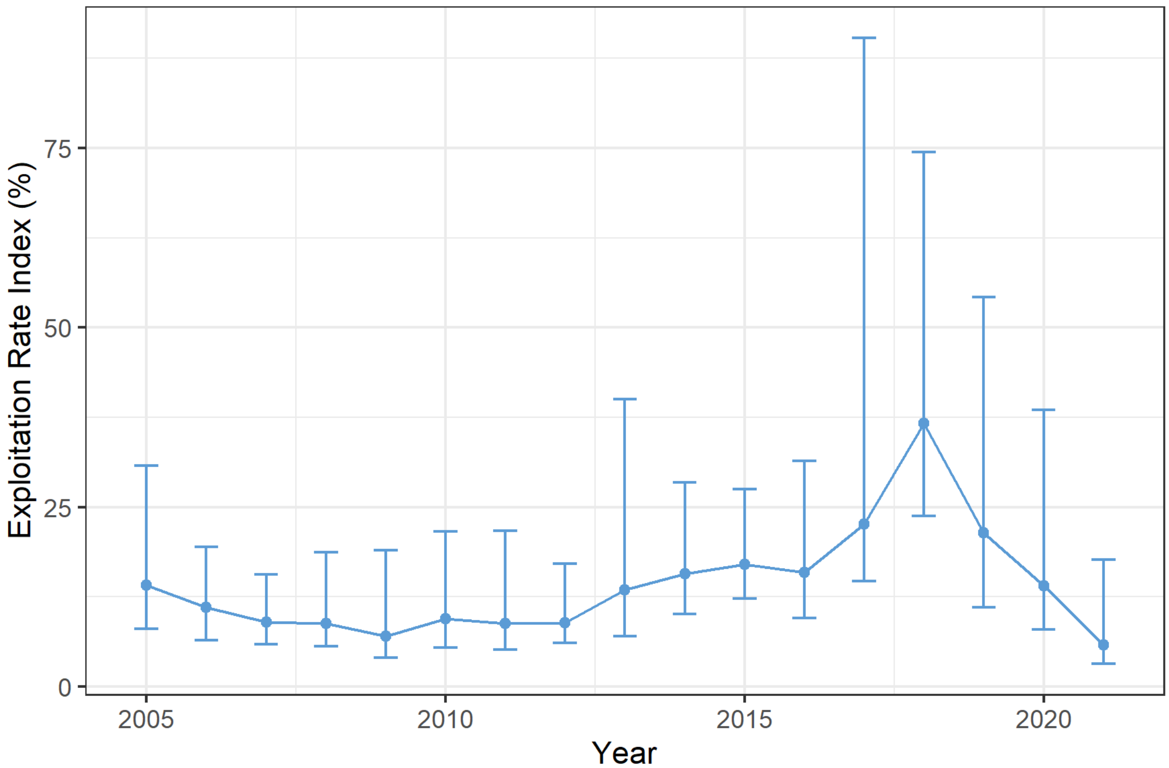


Figure 15. SFA 4 Northern Shrimp exploitation rate index, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Horizontal axis labels denote beginning-year of the fishery (i.e., 2021 indicates 2021/22). The 2021/22 point is preliminary and based on total catch as of the February 11, 2022, AQMS. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

In 2021, the female SSB index was in the healthy zone within the IFMP PA Framework, after four years in the cautious zone, with 8% probability of being in the cautious zone. (Figure 16).

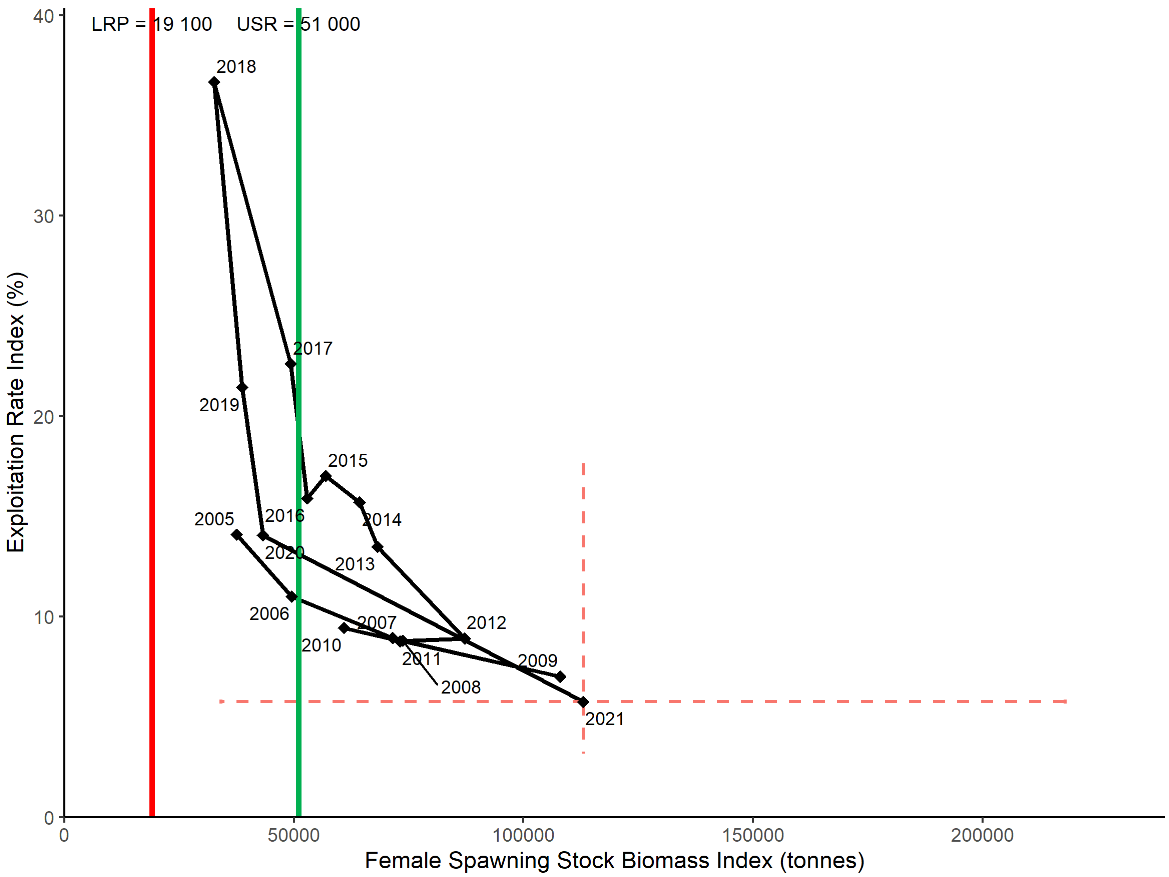


Figure 16. SFA 4 Northern Shrimp PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote beginning-year of the fishery (i.e., 2021 indicates 2021/22). The red cross on the 2021/22 point indicates 95% confidence intervals for the 2021 female SSB index (horizontal) and the 2021/22 exploitation rate index (vertical).

Sources of Uncertainty

Spatiotemporal variation in survey efficiency among three DFO research vessels (CCGS *Teleost*, CCGS *Wilfred Templeman* and CCGS *Alfred Needler*), particularly in NAFO Division 3K (SFA 6), is a source of uncertainty and the implications are unknown. The NAFO Division 3K portion of SFA 6 is the last area surveyed and was typically undertaken by two survey vessels annually, which begin the area at different times and survey at different rates depending on weather, mechanical issues, remaining area to cover, etc. Though the timing of the survey and proportion of sets performed by different research vessels may change slightly from year to year, it is assumed that the effects are minimal. In some years survey coverage may be more impacted than others, for example in 2019–21 survey coverage was reduced. Analyses presented at the assessment tested previous survey years by removing sets from 1996 to 2020 to imitate the same reduced coverage in affected SFAs. These analyses demonstrated that estimates are representative of the stock status (although likely a slight overestimate in SFA 6 and showing no bias in SFA 5) and usually fall within the error bars of past accepted biomass estimates.

The survey in SFA 4 was conducted by the *Cape Ballard* from 2005 to 2011. Beginning in 2012, the *Aqviq* was used and is the primary survey vessel for this area. However, there have been some exceptions due to mechanical issues (*Kinguk* was used in 2014, *Katsheshuk II* was used in 2015 and 2020). The *Cape Ballard*, *Aqviq* and *Kinguk* had similar specifications, but the *Katsheshuk II* was a larger, more powerful vessel. There was no change in the survey gear or design, and it was assumed that any effect of this change in the survey vessel would be minimal. 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).

It is unknown if the increase in biomass from 2020 to 2021 is biologically possible. The SSB index increased by 162% and the fishable biomass index increased by 156%, both to the highest levels in the survey time series. The large increase in biomass was attributed mostly to two large survey sets and the confidence intervals are wide and extend to the cautious zone.

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 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.

Research at Memorial University indicated that there might have been reductions in sizes at sexual maturity (i.e., the size at which 50% of females are sexually mature). Additionally, there have been reductions in fecundity at size (i.e., egg production by shrimp size) compared to previously available research from the 1980s (Beita 2021).

There is no risk analysis for this resource.

There is uncertainty in the appropriateness of the reference points as it is unknown how the time periods selected to generate proxies (which differ by SFA) relate to the biomass of maximum sustainable yield (B_{MSY}). While a Northern Shrimp forecast production model was preliminarily accepted during a peer-review meeting, it is not yet ready for use in management decisions, nor were the reference points from the model output accepted for use. Subsequently, there is no accepted scientific basis on which to change the current reference points.

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 imprecisely estimates the exploitation rate by an unknown percentage.

The degree to which the vertical distribution of Northern 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.

Physical changes in the environment (e.g., temperature) may affect the distribution and hence the availability of shrimp to commercial and survey trawls.

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 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.

In trawl surveys, year effects can occur when estimating biomass. These effects are apparent when future surveys are added to the time series. For example, in 2013 multi-species survey data for other species captured were analyzed to determine if a year effect had been evident across all species. Given that there was no indication that the catch rates for other species were reduced it was determined at that time that there was no year effect. However, the sharp reduction in survey biomass indices in 2013 were attributed to a year effect at the subsequent assessment.

Differences in the spatial and seasonal distribution in catch rates from the small- and large-vessel fisheries and the DFO or NSRF surveys have not been resolved. In areas such as SFA 6 it took two to three years for commercial catch rates to reflect declines in survey biomass indices.

CONCLUSIONS AND ADVICE

During the assessment in 2022, data were presented including shrimp biomass/abundance indices from surveys, survey catch rates of known shrimp predators, commercial fishery CPUEs, exploitation rate indices, bottom temperatures, sea surface temperatures, spring phytoplankton bloom dynamics for SFAs 4-6, and zooplankton biomass and community structure for SFA 6 and part of SFA 5. Preliminary ecosystem analyses had demonstrated correlations between exploitation rate, predation, shrimp consumption, composite environmental index, and dynamics of the spring phytoplankton bloom with subsequent shrimp per capita net production (DFO 2018a). Similarly, the 2019 CSAS Shrimp Framework Meeting presented research demonstrating that changes in NAO and biomass of predators (Atlantic Cod, Redfish and Greenland Halibut) are significant drivers of subsequent shrimp production on a smaller spatial scale (i.e., Voroni polygons). While there are likely several contributing factors, the specific causes of changing trends in SFAs 4-6 are not fully understood and the requirement for further research is recognized.

SFA 6 *Pandalus borealis*

There is concern for the current status of this resource. The female SSB index remains in the critical zone for the sixth consecutive year, based on the PA Framework. This follows three consecutive years (2014–18) of the female SSB index declining while in the cautious zone. The IFMP and rebuilding plan state that the exploitation rate index should not exceed 10% while the female SSB index is in the critical zone.

Under current ecosystem conditions (i.e., low shrimp biomass, but potentially declining predation pressure), fishing at the current exploitation rate is unlikely to be a dominant driver for shrimp in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5) as most available shrimp are likely consumed by predators. However, fishing, predation and warm climate conditions are all drivers of shrimp dynamics in this area and fishing pressure could now be more influential on stock trajectories than it may have been when the stock was large (i.e., in the mid-2000s).

SFA 5 *Pandalus borealis*

Biomass indices in SFA 5 have been declining since 2010, although with some annual variability. The SSB and fishable biomass indices are amongst lowest levels of the survey time series. Female SSB index is in the healthy zone within the PA Framework with 42% probability of being in the cautious zone. If the 16,080 t is maintained and taken in 2022/23 then the exploitation rate index will be 23%.

SFA 4 *Pandalus borealis*

Biomass indices in SFA 4 had been declining from 2012–20, although with some annual variability. The SSB and fishable biomass indices increased substantially in 2021, however they were largely influenced by two large, localized sets and it is unknown if the increase is due to shrimp productivity, sampling variation, or movement of shrimp into SFA 4 from neighbouring areas. Exploitation rate indices had been increasing from 2012/13 to 2018/19 before beginning to decline, corresponding to reduced TACs in 2019/20–2020/21 and a high fishable biomass estimate in 2021/22. Female SSB index in 2021 was in the healthy zone with an 8% probability of having been in the cautious zone.

MANAGEMENT CONSIDERATIONS

It is recognized that Northern Shrimp are distributed broadly over the Northwest Atlantic Ocean, including SFA 4–6, 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. 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. Although shrimp is 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.

If predator biomass increases or remains stable and shrimp biomass decreases or remains low, fishery removals may become a large fraction of the net difference between shrimp production and total predation. This ecosystem change was evident from the mid-2000s to 2017 in SFA 6 and Southern SFA 5 and also in Northern SFA 5 from 2018 to 2020. Thus, fishing mortality can be important for determining whether gains (production) exceed losses (predation) and hence whether the stock increases or decreases.

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 to 7) and western Greenland consistently over the years.

A CSAS Science Response Process was held in January 2017 to review the reference points used in the PA Framework for Northern Shrimp in SFA 6 (DFO 2017). Since the PA reference points were developed, there have been changes in environment, ecosystem and predation; factors that can have negative impacts on Northern Shrimp. Despite the decline in shrimp per-capita net production as a result of these changing factors, there was insufficient evidence of a change in shrimp productivity regime, how it might change in the short-term, or how changing the reference points would affect the resource. An alternate PA approach was proposed at the May 2019 peer review framework meeting, however it was not accepted by external reviewers nor meeting participants.

Because of the high level of uncertainties, lowering the current biomass reference points would involve a high amount of risk to the ecosystem and to the resource. It was concluded that the current biomass reference points used in the Northern Shrimp PA for SFA 4-6 would remain unchanged until a new approach is developed in the next two to three years.

LIST OF MEETING PARTICIPANTS

NAME	AFFILIATION
Luiz Mello	DFO-NL – Science
Dawn Maddock Parsons	DFO-NL – Science
Katherine Skanes	DFO-NL – Science
Sanaollah Zabihi-Seissan	DFO-NL – Science
Eugene Lee	DFO-NL – Centre for Science Advice
Ryan Critch	DFO-NL – Communications
Erika Parrill	DFO-NL – Science
Dale Richards	DFO-NL – Centre for Science Advice
Martin Henri	DFO-NL – Resource Management
Mark Simms	DFO-NL – C&P
Krista Baker	DFO-NL – Science
Darrell Mullowney	DFO-NL – Science
Will Coffey	DFO-NL – Science
Darren Sullivan	DFO-NL – Science
Julia Pantin	DFO-NL – Science
Mariano Koen-Alonso	DFO-NL – Science
Jessica Desforges	DFO-NL – Science
Steven Snook	DFO-NL – Science
Frédéric Cyr	DFO-NL – Science

NAME	AFFILIATION
David Belanger	DFO-NL – Science
Mark Simpson	DFO-NL – Science
Pierre Pepin	DFO-NL – Science
Robert Deering	DFO-NL – Science
Vonda Hayes	DFO-NL – Science
Elizabeth Coughlan	DFO-NL – Science
Brian Healey	DFO-NL – Science
Elaine Hynick	DFO-NL – Science
Jennifer Duff	DFO-NL – Communications
Wojciech Walkusz	DFO-O&P – Science
Nicholas Duprey	DFO-NCR – Science
Genevieve Parent	DFO-QC – Science
Gregory Neils Puncher	DFO-QC – Science
Kailey Noonan	DFO-NCR – Resource Management
Nicholas Le Corre	DFO-QC – Science
Sheila Atchinson	DFO-O&P – Science
Manon Cassista-Da Ros	DFO-Maritimes – Science
Audrey Bourret	DFO-QC – Science
Nicole Rowsell	Gov NL – Fisheries and Land Resources
Anna Tilley	Gov NL – Fisheries and Land Resources
Derrick Dalley	Innu Nation, NL
George Russell	Nunavut Community Council, NL
Todd Broomfield	Nunatsiavut Government, NL
Keith Watts	Torngat Fisheries COOP
Rob Coombs	NunatuKavut Community Council
Craig Taylor	Torngat, Wildlife, Plants & Fisheries Secretariat
Tony Wright	Makivik Corp
Bruce Chapman	Canadian Association of Prawn Producers
Brian McNamara	Newfoundland Resources Ltd.
Alastair O'Rielly	Northern Coalition
Erin Carruthers	Fish, Food and Allied Workers Union (FFAW)
Nelson Bussey	FFAW Harvester
Chris Rose	FFAW Harvester
Allister Russell	FFAW Harvester
Keith Watts	Torngat Fisheries COOP
Ron Johnson	Torngat Fisheries COOP
Derek Butler	Association of Seafood Producers
Renae Butler	Association of Seafood Producers
Brian Burke	Executive Director – Nunavut Fisheries Association
Patrice Element	Mobile Gear Fishers Rep. (France-St. Pierre & Miquelon)
Arnault LeBris	Academia – Memorial University of Newfoundland / Marine Institute
Eric Pedersen	Academia – Concordia University
Gemma Rayner	Ocean’s North

SOURCES OF INFORMATION

This Science Advisory Report is from the February 15-17, 2022 regional peer review on the Assessment of Northern Shrimp in SFAs 4-6. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Beita Jiménez, A. 2021. Spatiotemporal variability in northern shrimp (*Pandalus borealis*) life-history traits in Newfoundland and Labrador. Masters of Sci. thesis, Memorial University of Newfoundland. St. John's, NL.

Benoît, H.P. 2006. Standardizing the southern Gulf of St. Lawrence bottom trawl survey time series: Results of the 2004-2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/008. iii + 127 p.

DFO. 2007a. Assessment Framework for Northern Shrimp (*Pandalus borealis*) off Labrador and the northeastern coast of Newfoundland; 28-30 May 2007. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2007/034.

DFO. 2007b. Northern Shrimp (SFAs) 0-7 and the Flemish Cap. Integrated Fisheries Management Plans (IFMP). Resource Management Operations – Fisheries and Oceans Canada.

DFO. 2009. Proceedings of the Precautionary Approach Workshop on Shrimp and Prawn Stocks and Fisheries; November 26-27, 2008. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/031.

DFO. 2017. Review of Reference Points used in the Precautionary Approach for Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Area 6. DFO Can. Sci. Advis. Sec. Sci. Resp. 2017/009.

DFO. 2018a. An assessment of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Areas 4-6 in 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/018.

DFO. 2018b. Northern shrimp and striped shrimp - Shrimp fishing areas 0, 1, 4-7, the Eastern and Western Assessment Zones and North Atlantic Fisheries Organization (NAFO) Division 3M. Integrated Fisheries Management Plans (IFMP). Fisheries Resource Management, Fisheries and Oceans Canada.

DFO. 2021. An Assessment of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Areas 4–6 and of Striped Shrimp (*Pandalus montagui*) in Shrimp Fishing Area 4 in 2020. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2021/049.

DFO. 2022a. Stock Status Update of Shrimp Fishing Area 4 Striped Shrimp (*Pandalus montagui*) in 2021. DFO Can. Sci. Advis. Sec. Sci. Resp. 2022/012.

DFO. 2022b. Update of stock status indicators for Northern Shrimp, *Pandalus borealis*, and Striped Shrimp, *Pandalus montagui*, in the Western and Eastern Assessment Zones, January 2022. DFO Can. Sci. Advis. Sec. Sci. Resp. 2022/013. (Erratum: February 2022).

Drinkwater, K. F. 1986. Chapter 13 Physical Oceanography of Hudson Strait and Ungava Bay. In: I.P. Martini (Ed.). Canadian Inland Seas. Elsevier Oceanogr. Ser. 44: 237–264.

Evans, G.T., Parsons, D.G., Veitch, P.J., and Orr, D.C. 2000. A Local-Influence Method of Estimating Biomass from Trawl Surveys, with Monte Carlo Confidence Intervals. J. Northw. Atl. Fish. Sci. 27: 133–138.

Jorde, P.E., Søvik, G., Westgaard, J.I., Orr, D., Han, G., Stansbury, D., and Jørstad, K.E. 2014. Genetic population structure of northern shrimp, *Pandalus borealis*, in the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 3046: iv + 27 p.

Le Corre, N., Pepin, P., Han, G., Ma., Z., and Snelgrove, P.V.R. 2019. Assessing connectivity patterns among management units of the Newfoundland and Labrador shrimp population. Fish. Oceanogr. 28(2): 183–202.

Le Corre, N., Pepin P., Burmeister A., Walkusz W., Skanes K., Wang Z., Brickman D., Snelgrove P.V.R. 2020. Larval connectivity of northern shrimp (*Pandalus borealis*) in the Northwest Atlantic. Can. J. Fish. Aquat. Sci. 77(8): 1332–1347.

Orr, D., and Sullivan, D. 2013. The February 2013 assessment of Northern Shrimp *(Pandalus borealis*) off Labrador and Northeastern Newfoundland. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/055. vii + 144 p.

Pedersen, E.J., Skanes, K., le Corre, N., Koen Alonso, M., and Baker, K.D. 2022. A New Spatial Ecosystem-Based Surplus Production Model for Northern Shrimp in Shrimp Fishing Areas 4 to 6. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/062. v + 64 p.

Pérez-Rodriquez, A., and Koen-Alonso, M. 2010. Standardization of time series for the EU bottom trawl Flemish Cap survey: Estimation of conversion factors between RV Cornide de Saavedra and RV Vizconde de Eza. Serial No. N5780. NAFO SCR Doc. 10/22.

Thorson, J.T., and Ward, E.J. 2014. Accounting for vessel effects when standardizing catch rates from cooperative surveys. Fish. Res. 155: 168–176.

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