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Newfoundland and Labrador Region

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Science Advisory Report 2019/027

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 2018

*Top: Northern Shrimp (*Pandalus borealis*)*
*Bottom: Striped Shrimp (*Pandalus montagui*)*
Photo: Fisheries and Oceans Canada

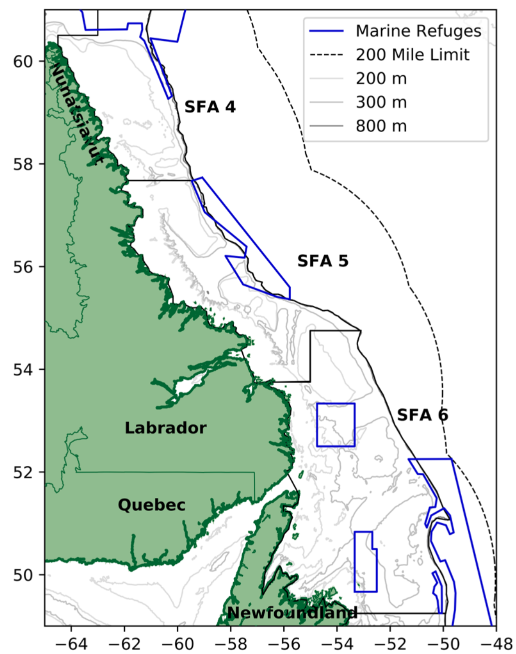

Figure 1. Map of Shrimp Fishing Areas (SFAs) 4-6. Blue polygons identify Marine Refuges (Hatton Basin, Hopedale Saddle, Hawke Box, Funk Island Deep Box and Northeast Newfoundland Slope from North to South) in which bottom-contact fishing (i.e., shrimp trawling) is not permitted.

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), expanding north to SFA 4 and south to SFA 6 through the 1980s. Striped Shrimp (*Pandalus montagui*) in SFA 4 are primarily taken as by-catch during the Northern Shrimp fishery in that area.*

The last Regional Peer Review Process that assessed Northern Shrimp in SFAs 4–6 was held in February, 2018 (DFO 2018a). A stock status update for shrimp in the Eastern and Western Assessment Zones and for Striped Shrimp in SFA 4 was held in January 2018 (DFO 2018b and 2018c).

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

This Science Advisory Report is from the February 12–13, 2019 Northern and Striped Shrimp Assessment. 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 in SFAs 5 and 6 was assessed based on DFO fall multi-species trawl survey data (1996–2018). Resource status for Northern Shrimp and Striped Shrimp in SFA 4 was assessed based on Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (2005–2018).
- Trawl survey data for SFAs 4–6 provided information on shrimp distribution, length frequencies and biomass. Trends in fisheries performance were inferred from total allowable catch (TAC), commercial catch to date, fisher catch per unit effort (CPUE) and fishing patterns.
- Research on larval dispersal 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. It also indicates low larval shrimp retention in SFAs 4 and 5, and higher larval retention in SFA 6.

Environment

- Early life history and adult stages of shrimp depend on phytoplankton (indirect) and zooplankton (direct) prey for feeding and nutrition. The key physical drivers indicate reduced primary and secondary inputs of the ecosystem (e.g., biomass) in recent years and changes in zooplankton community structure that may impact the transfer of energy to higher trophic levels across SFAs.
- Ocean physical conditions generally exhibited cold anomalies near the surface and warm anomalies near the bottom in SFAs 4–6. As a consequence, the area of the bottom thermal habitat (2–4°C), typically inhabited by Northern shrimp, was above the climatological averages.

SFA 6 *Pandalus borealis*

- TAC was reduced by 63%, to 10,400 t, from 2016/17 to 2017/18 and further, by 16%, to 8,730 t in 2018/19.
- The annual commercial CPUE declined considerably in recent years to the lowest levels in two decades and has remained low.
- Over 1996 to 2018 the fishable biomass index averaged 393,000 t and in 2018 the fishable biomass index was 89,600 t, a 3% increase from 2017 and the second lowest level in the time series.
- Over 1996 to 2018 the female spawning stock biomass (SSB) index averaged 246,000 t and in 2018 the SSB index was 66,800 t, a 27% increase from 2017 but still amongst the lowest levels in the time series.

- The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2018/19, and has averaged 15.7% in the last five years. If the TAC is fully taken in 2018/19 then the exploitation rate index will be 10%.
- The female SSB index is currently in the Critical Zone of the integrated Fisheries Management Plan (IFMP) Precautionary Approach (PA) Framework with greater than 99% probability.
- The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone. Should the 2018/19 TAC of 8,730 t be maintained and taken in 2019/20 the exploitation rate index will be 9.7%.

SFA 5 *Pandalus borealis*

- TAC was reduced by 14%, to 22,000 t, from 2016/17 to 2017/18 but was increased by 17% to 25,630 t in 2018/19.
- Standardized large-vessel CPUE over the last five years has varied without trend at relatively high levels.
- Over 1996 to 2018 the fishable biomass index averaged 133,000 t and in 2018 the fishable biomass index was 80,100 t, a 43% decrease from 2017 and the second lowest level in the time series.
- Over 1996 to 2018 the female SSB index averaged 64,800 t and in 2018 the SSB index was 38,400 t, a 31% decrease from 2017 and the second lowest level in the time series.
- The exploitation rate index varied without trend with a median value of 15% from 1997–2018/19. If the TAC is fully taken in 2018/19 then the exploitation rate index will be 18.2%.
- Female SSB index is in the Cautious Zone within the IFMP PA Framework with 51% probability. If the 25,630 t TAC is maintained and taken in 2019/20, then the exploitation rate index will be 32%.

SFA 4 *Pandalus borealis*

- PA reference points have been revised from the previous assessments in accordance with adjustments to a reduced survey area to exclude the Hatton Basin Marine Refuge, which is no longer surveyed. The PA framework itself has not changed.
- TAC was increased by 5%, to 15,725 t, from 2016/17 to 2017/18 and was unchanged in 2018/19. The TAC has been fully taken.
- Large-vessel standardized CPUE varied without trend near the long-term mean (1989–2017/18).
- Over 2005 to 2018 the fishable biomass index averaged 103,000 t and in 2018 the fishable biomass index was 42,100 t, a 46% decrease from 2017 and the lowest level in the time series.
- Over 2005 to 2018 the female SSB index averaged 63,700 t and in 2018 the SSB index was 32,200 t, a 39% decrease from 2017 and the lowest level in the time series.
- The average exploitation rate index was 17.4% for 2014–2017 and was 35.7% in 2018/19.
- Female SSB index in 2018 was in the Cautious Zone within the IFMP PA Framework with a 7% probability of having been in the Critical Zone.

SFA 4 *Pandalus montagui*

- The *Pandalus montagui* by-catch limit of 4,033 t has not been taken in the past six years.
- Over 2005 to 2018 the fishable biomass index averaged 27,800 t and in 2018 the fishable biomass index was 54,400 t, a 23% increase from 2017 and the highest level in the time series.
- Over 2005 to 2018 the female biomass index averaged 21,600 t and in 2018 the female biomass index was 46,500 t, a 33% increase from 2017 and the highest level in the time series.
- If the by-catch limit had been taken, the exploitation rate would have been 7.4% in 2018/19.
- There is no IFMP PA Framework for this resource.

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. Striped Shrimp (*Pandalus montagui*) are found in the Northwest Atlantic from Davis Strait south to the Bay of Fundy. Northern Shrimp prefer an ocean floor that is somewhat soft and muddy and where temperatures range from about 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 prefer a hard bottom and are typically found in colder waters from 1°C to 2°C at depths of 100–300 m. 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 primary shrimp resource in the North Atlantic.

While management boundaries are, to some extent, arbitrary and selected based on factors other than science, the northern boundary of SFA 4 leads to more questions/uncertainties than the boundaries between other SFAs; applying a similar harvest strategy across all areas mitigates the consequence of potential boundary issues. In addition to being found in SFA 4, both *P. borealis* and *P. montagui* are found in the Eastern and Western Assessment Zones, directly to the north of SFA 4 (DFO 2019). Hudson Strait is a highly dynamic system with strong currents and mixing. 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. Research on larval dispersal 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; Northern Shrimp larvae may travel several hundreds of kilometers before settlement. Further research has demonstrated that larvae originating in the Arctic also show high settlement in SFAs 4–6. This research also 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 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) (Le Corre et al. 2018).

Studies of genetics between Northern Shrimp populations in SFAs 4–6 have demonstrated that Northern Shrimp in these areas are largely homogenous genetically (Jorde et al. 2014). This is most likely due to larval and pelagic transport by the Labrador Current. Despite the relationships between SFAs 4–6, the Northern Shrimp resources in these areas are managed (and hence assessed) on an individual SFA basis rather than as a whole.

Species Biology

Both Northern and Striped 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. They 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.

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 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. As the fishery expanded to Hawke Channel, St. Anthony Basin and Funk Island Deep, and to the slope of the continental shelf in SFAs 4–6 during the early-1990s, TACs were increased periodically and were taken in most years.

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 exploitation was 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; however, the number of active licenses varies by year and has been less than 250 for the past five years.

In 2003, the management year was changed from a calendar (January 1–December 31) to a fiscal (April 1–March 1) year. In 2007, a seasonal bridging program was established that allows each license holder in the large-vessel fleet to carry over some unused quota from the previous year, or borrow from next year's quota; each license can bridge up to 750 t in each SFA. However, in SFA 6 bridging has not been permitted since 3,200 t was bridged in 2015/16.

Despite linkages between 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 TAC was 120,345 t in 2009/10 and 50,085 t in 2018/19.

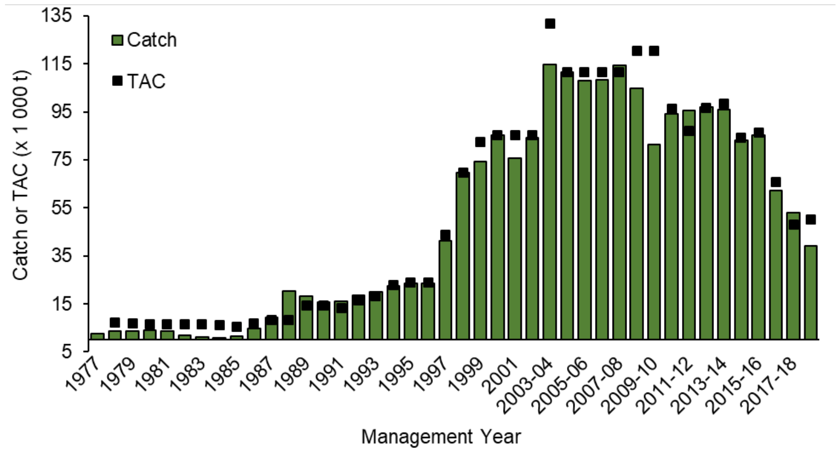

Figure 2. Historical Northern Shrimp catches and TACs (SFAs 4–6 combined) for the period 1977-2018/19. Catches for 2018/19 are preliminary and from the CAQR as of February 7, 2019. The management year changed from a calendar to a fiscal year in 2003 such that the values for 2003/04 are based upon a 15 month fishing season. Quota bridging and transfers are not reflected in TACs but are reflected in catches in this figure.

All Northern Shrimp fisheries in eastern Canada are subject to the Atlantic Fisheries Regulations, established under the *Fisheries Act*, regarding territorial waters, by-catch, discards, vessel logs, etc. These 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 minimum bar spacing is 22 mm and in SFAs 4–5 the minimum bar spacing is 28 mm. 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 ranged between 5–8% over the last ten years.

ASSESSMENT

The key considerations for assessment of a renewable resource are how fast the resource is renewing itself, how this might change, and how human activity can affect it. In management terms, the rate at which a resource renews itself informs decisions on harvest rates that are sustainable.

Resource status of Northern Shrimp in SFAs 5 and 6 was assessed based on DFO fall multi-species trawl survey data (1996–2018). Resource status for Northern Shrimp and Striped Shrimp in SFA 4 was assessed based on NSRF-DFO summer trawl survey data (2005–2018). Both surveys use the same gear and tow protocols with comparable sampling protocols.

Trawl survey data for SFAs 4–6 provided information on shrimp distribution, length frequencies and biomass. Prior to the 2019 assessment, this data also provided information on potential predators in SFAs 5–6. 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 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 et al. 2013). Trends in fisheries performance were inferred from TAC, commercial catch to date, fisher catch per unit effort (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) or the current year (for summer surveys).

Biomass indices are 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 2018d). This framework was developed in 2008–2010 following the 2008 framework workshop attended by a Marine Stewardship Certification (MSC) working group and included representation from DFO Science, DFO Fisheries Management and industry stakeholders.

Northern Shrimp reference points in the IFMP PA Framework were developed using proxies, 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 2005–2009 for SFA 4. The values of the PA reference points were revised slightly in 2016 and again in 2018, in accordance with refinements in the biomass estimation method. In 2019 the PA 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. There is no PA Framework for SFA 4 Striped Shrimp.

In order to demonstrate historic changes in SFAs 5 and 6 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 presented during the 2018 Regional Peer Review Process (DFO 2018a). 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. All three metrics were consistent with a general increase in shrimp biomass between 1990 and 1995, to a level between four to ten times the biomass of the pre-1990 level. These metrics also indicate that in recent years shrimp biomass has declined to a level consistent with their 1979–1990 levels in SFA 6. This should not, however, be taken to imply that the Newfoundland Shelf ecosystem has returned to its prior state in the past ten years, as groundfish biomass is still well below its pre-1990 levels and the environment and ecosystem are different.

Environment

Ocean physical conditions generally exhibited cold anomalies near the surface and warm anomalies near the bottom in SFAs 4–6 in 2018, with the normal period defined as the 1981–2010 average. For example, the sea surface temperature (SST) was colder than normal in the Labrador Sea, despite warmer than normal SSTs in coastal Newfoundland and south of 47°N. The cold intermediate layer core temperature (defined as the minimum temperature within the monthly average profile) was about normal, but continues its cooling trend since about 2012. This recent cooling was preceded by a warming period that started after the cold conditions between the mid-1980s and the mid-1990s. As a consequence, the area of the bottom thermal habitat (2-4°C), typically inhabited by Northern Shrimp, was above the climatological average in

2018. For example, in 2018 the surface of the ocean floor occupied by water between 2°C and 4°C was the second largest in Northwest Atlantic Fisheries Organization (NAFO) divisions 2J3KLNO since 1980 (exceeded only in 2005). This suggests that the thermal habitat is not a limiting factor for Northern Shrimp. At the coastal Station 27, integrated temperature over the water column (0–176 m) was normal, but the salinity exhibited its largest negative (fresh water) anomaly since the beginning of the time series in 1948.

Early life history and adult stages of shrimp depend on phytoplankton (indirect) and zooplankton (direct) prey for feeding and nutrition. The key physical drivers indicate reduced primary and secondary inputs of the ecosystem (e.g., biomass) in SFAs 5–6 during recent years and changes in zooplankton community structure that may impact the transfer of energy to higher trophic levels across SFAs.

In 2018, the biomass of chlorophyll-*a* in the first 100 m of the water column was back to above normal levels for the first time in 10 years. Positive chlorophyll-*a* anomalies were associated with an increase, in recent years, of nitrate concentration in the deeper layers (50–150 m) of the ocean in SFAs 5–6. However, low concentrations of deep nitrate observed across the shelf in 2018 may negatively affect chlorophyll-*a* biomass in the water column in 2019 in those two SFAs. Spring bloom indices derived from satellite data indicate that surface phytoplankton production was below the climatological average, with blooms occurring later than normal in SFAs 4–6. Zooplankton biomass was at historical low levels in 2018 for a fourth consecutive year, whereas abundance anomalies were among the highest in 20 years in SFAs 5–6. Changes in the size-structure of the zooplankton community are driven by an overall decrease in the abundance of large, energy-rich, copepods (*Calanus finmarchicus*) concurrent with an important increase in the abundance of small copepod taxa (*Pseudocalanus* spp. and *Oithona* spp.) in the fall.

SFA 6 *Pandalus borealis*

Ecosystem

Ecosystem conditions in the Newfoundland Shelf are indicative of an overall low productivity state, with both total shellfish and total finfish biomass showing declines since the early–mid 2010s (DFO 2018a). Shrimp per-capita net production had declined from the mid-1990s to 2017. While an update on ecosystem drivers and Northern Shrimp production was not available for the 2019 assessment, based on recent results and observed trends in identified drivers, shrimp per-capita production is expected to remain at low levels for the next 1–2 years. Long-term predictions based on correlations are not possible.

Fishery

TAC reductions have been applied periodically since 2009/10 due to stock declines. Subsequently, catches follow the same trend. TAC was reduced by 63%, to 10,400 t, from 2016/17 to 2017/18 and further, by 16%, to 8,730 t in 2018/19. As of the February 7, 2019 CAQR, 83% of the 2018/19 TAC had been taken (Figure 3).

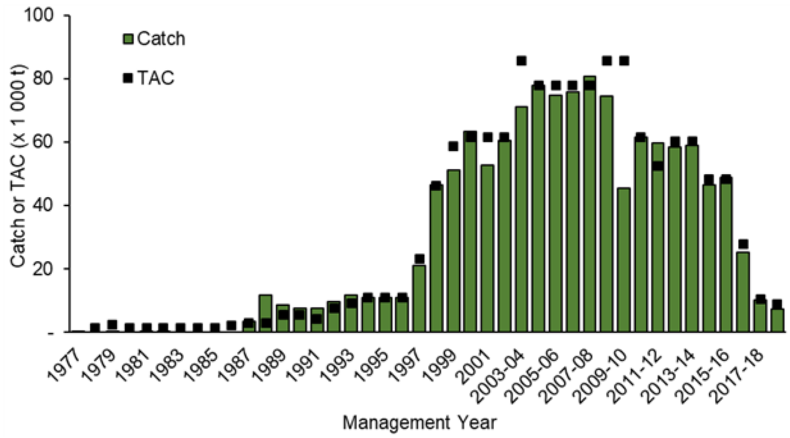

Figure 3. Historical Northern Shrimp catches and TAC in SFA 6 for the period 1977–2018/19. 2018/19 values are preliminary, based upon the CAQR as of February 7, 2019. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 month fishing season. Quota bridging and transfers are not reflected in TACs but are reflected in catches in this figure.

The annual commercial CPUE declined considerably in recent years to the lowest levels in two decades and has remained low (Figure 4).

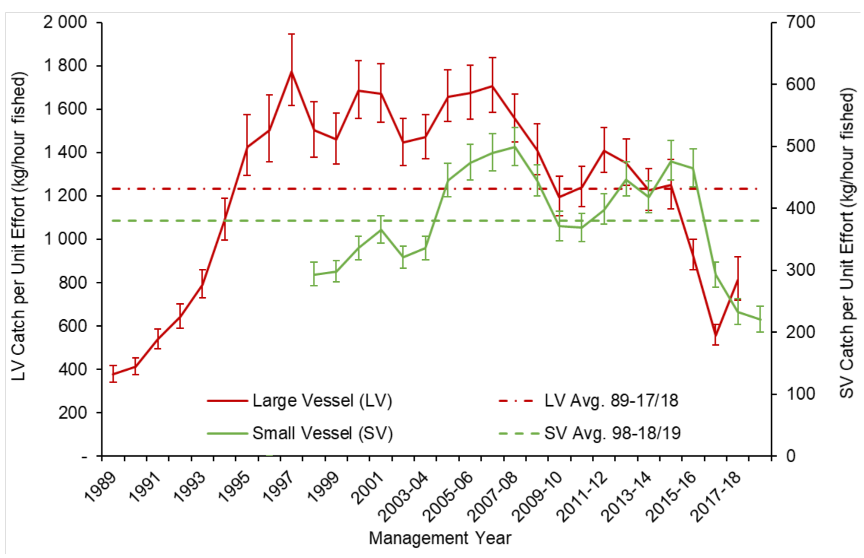

Figure 4. SFA 6 large-vessel (LV, red solid line beginning in 1989) and small-vessel (SV, green solid line beginning in 1998) annual standardized CPUE. Error bars indicate 95% confidence intervals and dashed horizontal lines indicate long term mean of CPUE series. The 2018/19 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2018 the fishable biomass index averaged 393,000 t and in 2018 the fishable biomass index was 89,600 t, a 3% increase from 2017 and the second lowest level in the time series. Over 1996 to 2018 the female SSB index averaged 246,000 t and in 2018 the SSB index was 66,800 t, a 27% increase from 2017 but still amongst the lowest levels in the time series (Figure 5).

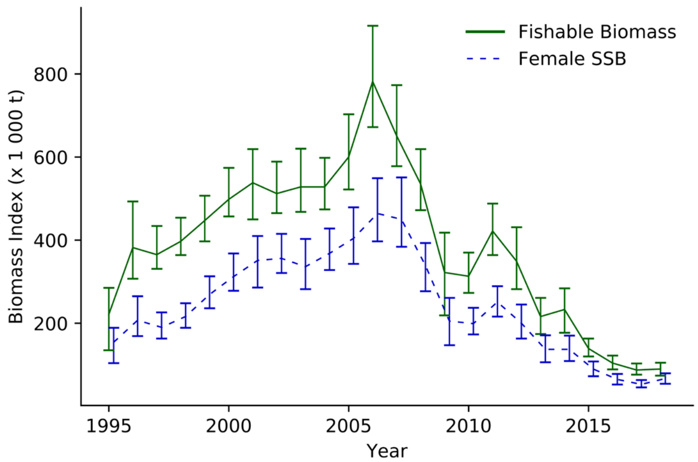

Figure 5. SFA 6 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Renewal

Renewal is the difference between the increase due to production, and removal largely due to predators and shrimp harvesting. Predation on shrimp, and the associated predation mortality rate, showed an increasing trend until 2011, and had decreased up to 2017 (DFO 2018a). This decrease was associated with an increase in consumption of capelin by predators in conjunction with the combined biomass of shrimp predators remaining relatively steady from 2011 to 2017. Shrimp is an important forage species, particularly when there is scarcity of high energy prey such as capelin. The ratio between predation and shrimp biomass is a relative index of predation mortality and, in 2017, was around double the level recorded in the mid-1990s and 2000s. Although there was no update on predation during the 2019 assessment, shrimp predation mortality in the near future is expected to remain relatively high unless abundance of alternative prey increases.

Exploitation

The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2018/19, and has averaged 15.7% in the last five years. If the TAC is fully taken in 2018/19 then the exploitation rate index will be 10% (Figure 6).

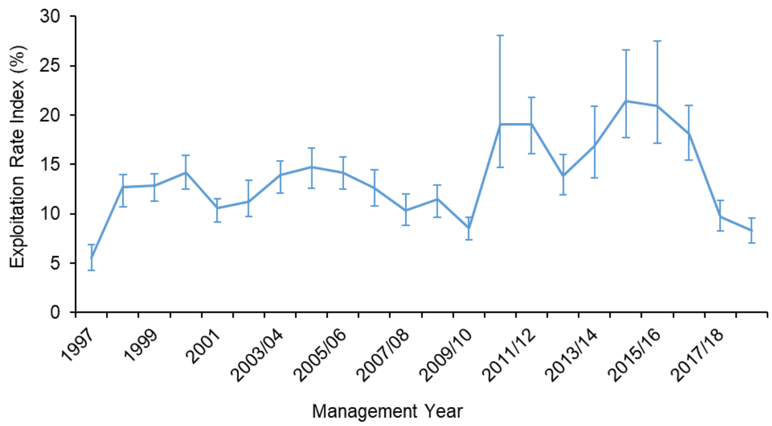

Figure 6. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The 2018/19 point is preliminary and based on total catch as of the February 7, 2019 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

The female SSB index is currently in the Critical Zone of the IFMP PA Framework with greater than 99% probability. The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone. Should the 2018/19 TAC of 8,730 t be maintained and taken in 2019/20 the exploitation rate index will be 9.7% (Figure 7).

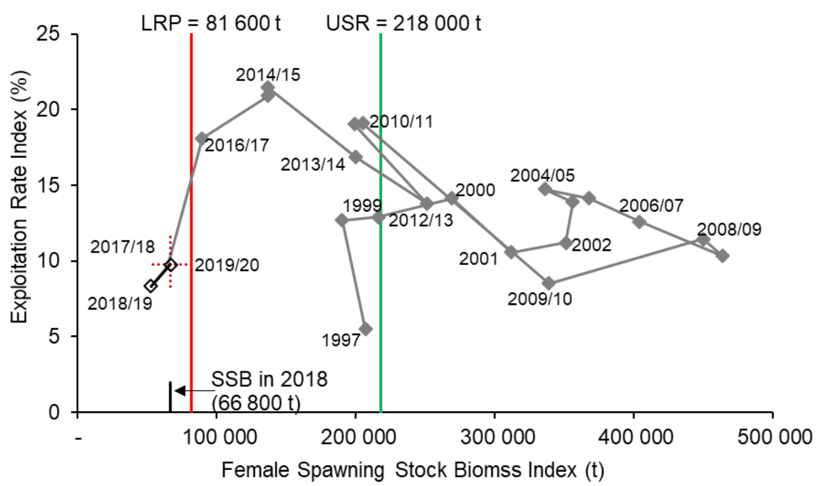

Figure 7. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2018/19 fishery was ongoing and based on reported catch as of February 7, 2019. The red cross on the 2019/20 point indicates 95% confidence intervals for the 2018 female SSB index (horizontal) and the 2019/20 exploitation rate index (vertical), assuming that the 8,730 t TAC is maintained and taken in the 2019/20 fishery.

SFA 5 *Pandalus borealis*

Fishery

TAC was reduced by 14%, to 22,000 t, from 2016/17 to 2017/18 but was increased by 17% to 25,630 t in 2018/19 (Figure 8).

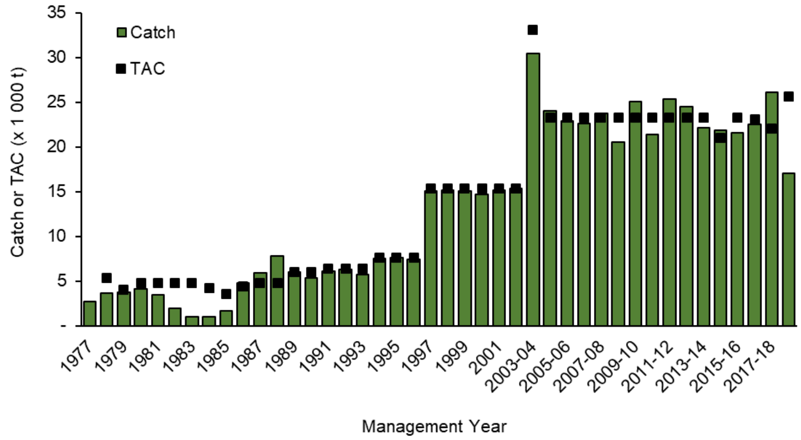

Figure 8. Historical Northern Shrimp catches and TACs in SFA 5 for the period 1977–2018/19. 2018/19 values are preliminary and based upon the CAQR as of February 7, 2019. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 month fishing season. Quota bridging and transfers are not reflected in TACs but are reflected in catches in this figure.

Standardized large-vessel CPUE over the last five years has varied without trend at relatively high levels (Figure 9). While the 2017/18 large-vessel CPUE showed a drastic decline from 2016/17, it was based on incomplete 2018 data so cannot be concluded that the decline pictured is an indication of reduced commercial fishery performance in SFA 5.

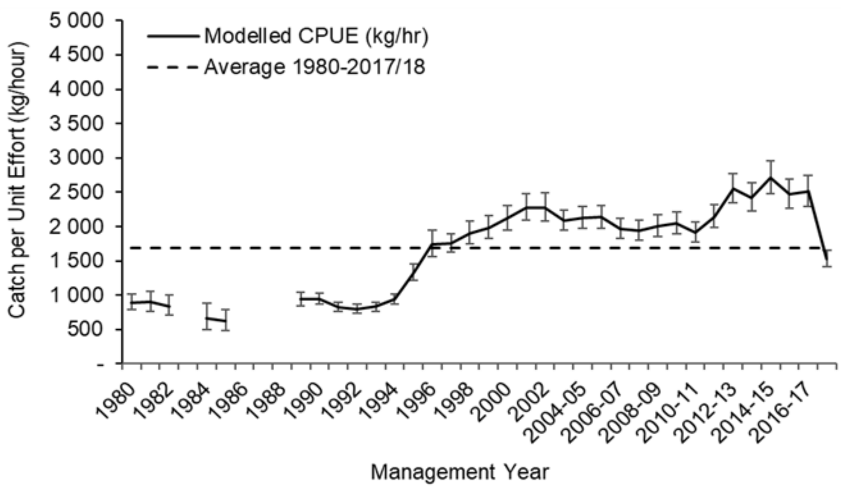

Figure 9. SFA 5 large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series. The 2018/19 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2018 the fishable biomass index averaged 133,000 t and in 2018 the fishable biomass index was 80,100 t, a 43% decrease from 2017 and the second lowest level in the time series. Over 1996 to 2018 the female SSB index averaged 64,800 t and in 2018 the SSB index was 38,400 t, a 31% decrease from 2017 and the second lowest level in the time series (Figure 10).

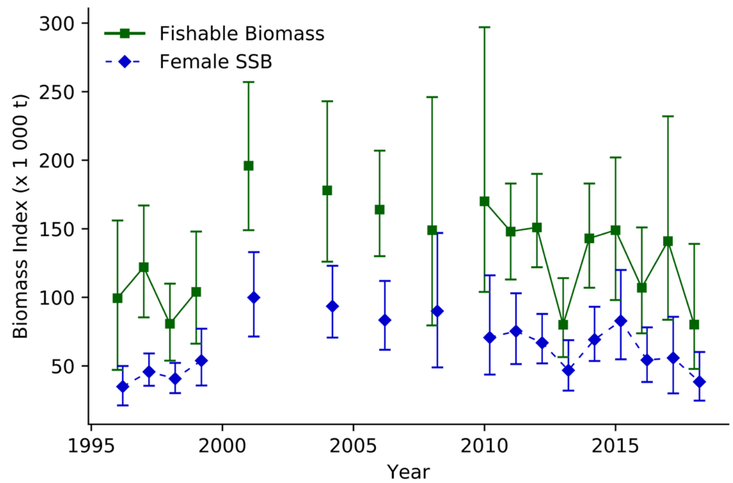

Figure 10. SFA 5 fishable biomass (green solid line and squares) and female SSB (blue dashed line and diamonds) indices. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index varied without trend with a median value of 15% from 1997–2018/19. If the TAC is fully taken in 2018/19 then the exploitation rate index will be 18.2% (Figure 11), however this could be higher if season bridging is permitted. For example, in 2017/18 the TAC was 22,000 (an anticipated 20.6% exploitation rate) t but the catch was 26,100 t (an actual 24.4% exploitation rate) due to season bridging.

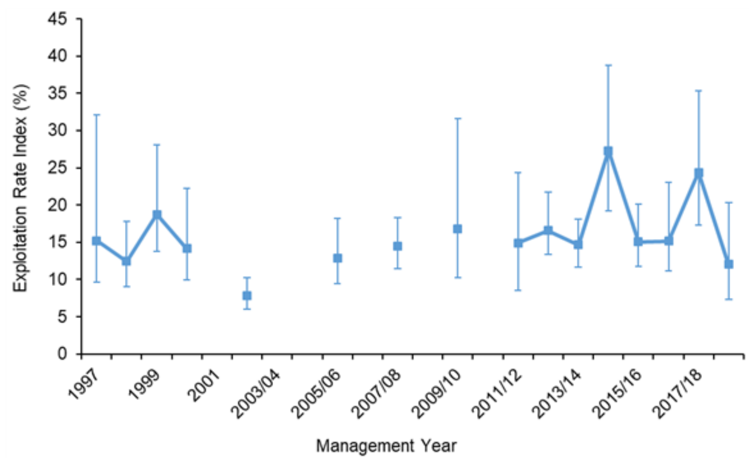

Figure 11. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. The 2018/19 point is preliminary and based on total catch as of the February 7, 2019 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index is in the Cautious Zone within the IFMP PA Framework with 51% probability. If the 25,630 t TAC is maintained and taken in 2019/20, then the exploitation rate index will be 32% (Figure 12).

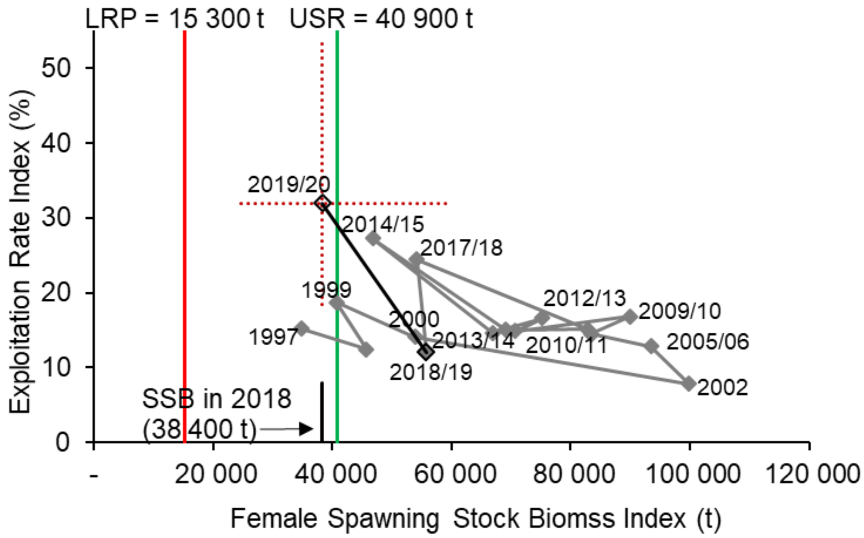

Figure 12. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2018/19 fishery was ongoing and based on reported catch as of February 7, 2019. The red cross on the 2019/20 point indicates 95% confidence intervals for the 2018 female SSB index (horizontal) and the exploitation rate index (vertical), assuming that the 25,630 t TAC is maintained and taken in the 2019/20 fishery.

SFA 4 *Pandalus borealis*

Fishery

TAC was unchanged from 2013/14 to 2016/17. It was increased by 5%, to 15,725 t, from 2016/17 to 2017/18 and was unchanged in 2018/19. The TAC has been fully taken (Figure 13).

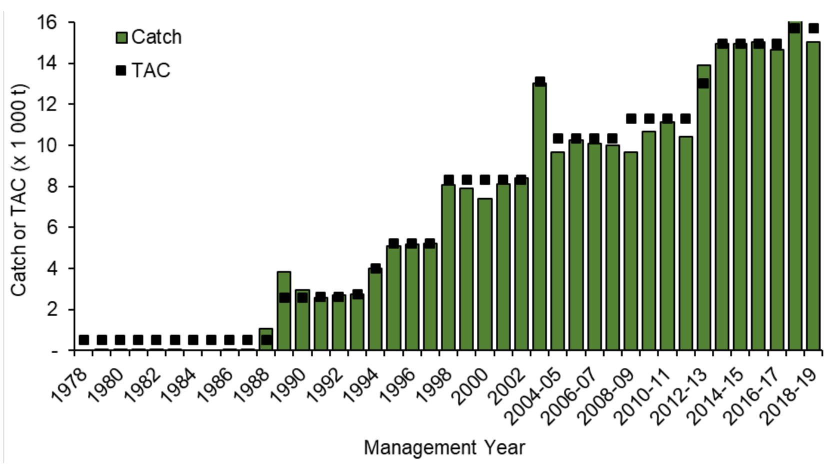

Figure 13. Historical Northern Shrimp catches and TACs in SFA 4 for the period 1978–2018/19. 2018/19 values are preliminary and based upon the CAQR as of February 7, 2019. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 month fishing season. Quota bridging and transfers are not reflected in TACs but are reflected in catches in this figure.

Large-vessel standardized CPUE varied without trend near the long-term mean (1989–2017/18, Figure 14). Several factors including changes in management measures and species composition of catches (i.e., catches of both Northern and Striped Shrimp in the same area) confound the interpretation of fishery performance in this area.

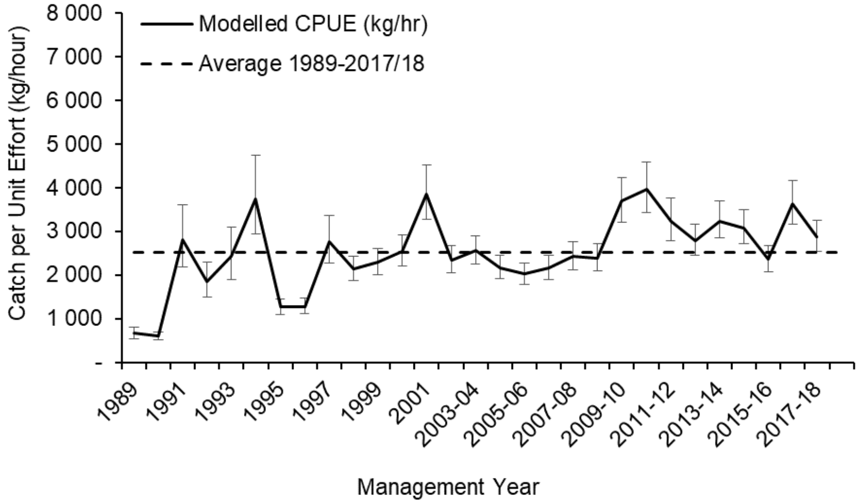

Figure 14. SFA 4 Northern Shrimp large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series. The 2018/19 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 2005 to 2018 the fishable biomass index averaged 103,000 t and in 2018 the fishable biomass index was 42,100 t, a 46% decrease from 2017 and the lowest level in the time series. Over 2005 to 2018 the female SSB index averaged 63,700 t and in 2018 the SSB index was 32,200 t, a 39% decrease from 2017 and the lowest level in the time series (Figure 15).

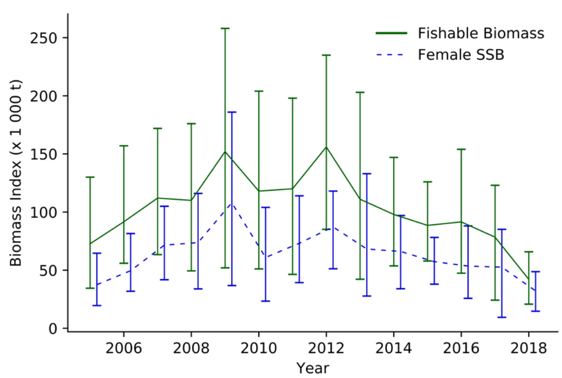

Figure 15. SFA 4 Northern Shrimp fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The average exploitation rate index was 17.4% for 2014–2017 and was 35.7% in 2018/19 (Figure 16). The TAC was set for SFA 4 Northern Shrimp under the assumption that biomass indices would not change from 2017 to 2018. 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 has been increasing since 2012/13, corresponding to a period of declining biomass indices. The exploitation rate index was very high in 2018 due to the significant decrease in fishable biomass index from 2017 to 2018.

The confidence intervals surrounding the 2017/18 and 2018/19 exploitation rate indices are very 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 two lowest values in the survey time series in 2017–18. For this reason the upper confidence interval of the 2017/18 and 2018/19 exploitation rate indices are very high.

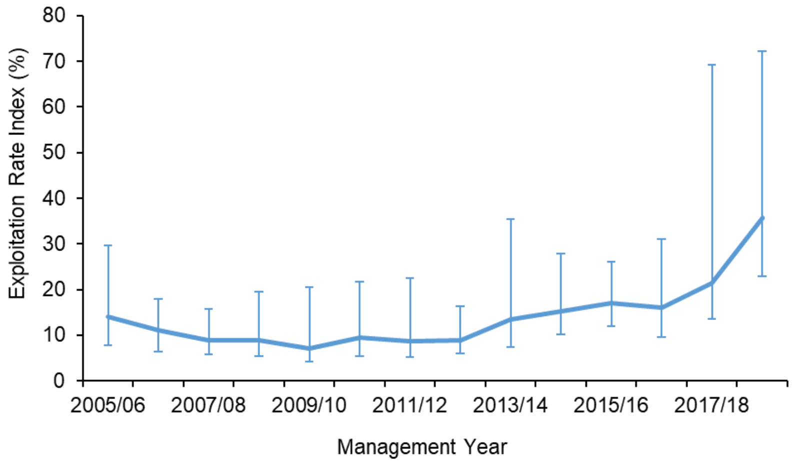

Figure 16. SFA 4 Northern Shrimp exploitation rate index, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

PA reference points have been revised from the previous assessments in accordance with adjustments to a reduced survey area to exclude the Hatton Basin Marine Refuge, which is no longer surveyed. The LRP changed from 20,400 t to 19,100 t and the USR from 54,500 t to 51,000 t. The PA framework itself has not changed.

Female SSB index in 2018 was in the Cautious Zone within the IFMP PA Framework with a 7% probability of having been in the Critical Zone (Figure 17).

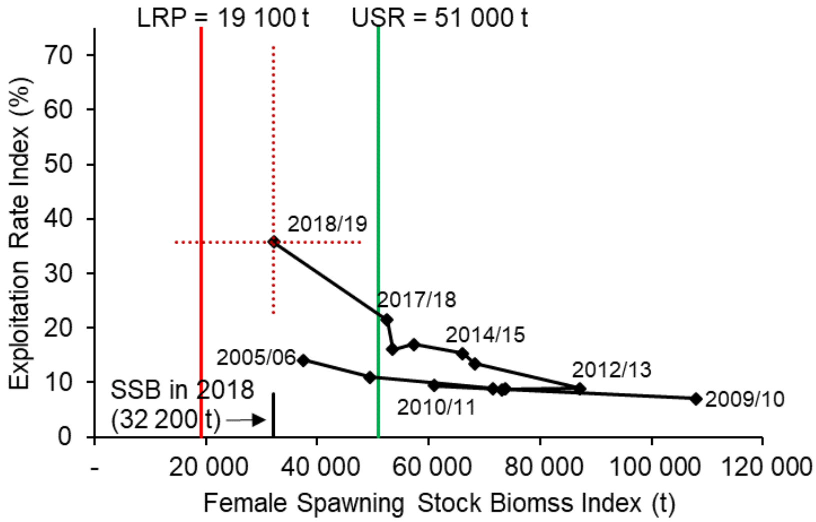

Figure 17. SFA 4 PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote year of the fishery. The red cross on the 2018/19 point indicates 95% confidence intervals for the 2018 female SSB index (horizontal) and the 2018/19 exploitation rate index (vertical).

SFA 4 *Pandalus montagui*

Fishery

The *Pandalus montagui* by-catch limit of 4,033 t has not been taken in the past six years (Figure 18).

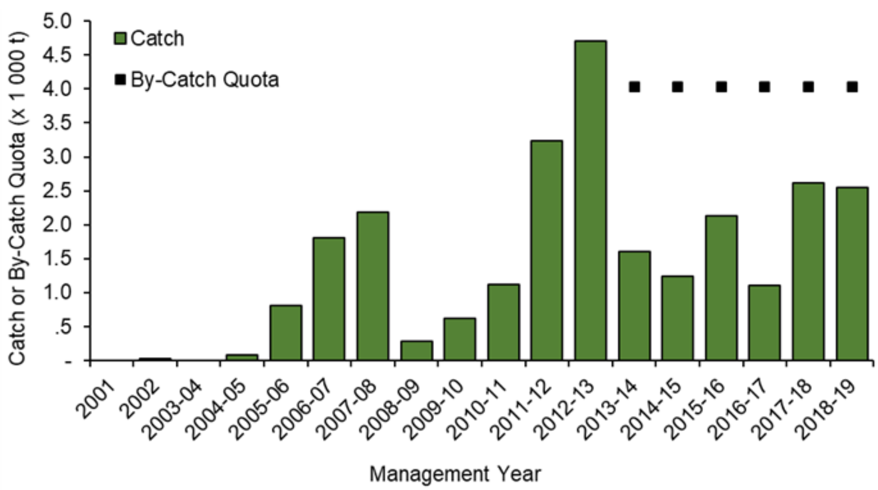

Figure 18. Striped Shrimp catches and by-catch quotas in SFA 4 for the period 2001–2018/19. 2018/19 values are preliminary and based upon the CAQR as of February 7, 2019.

Biomass

Over 2005 to 2018 the fishable biomass index averaged 27,800 t and in 2018 the fishable biomass index was 54,400 t, a 23% increase from 2017 and the highest level in the time series. Over 2005 to 2018 the female biomass index averaged 21,600 t and in 2018 the female biomass index was 46,500, a 33% increase from 2017 and the highest level in the time series (Figure 19).

The female SSB that is relevant to a 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 that area). The strong currents that likely affect all sizes of shrimp, especially larvae, in SFA 4 create especially severe problems with estimating female SSB for this particular SFA. The true female SSB is more than the females observed by the survey within SFA 4.

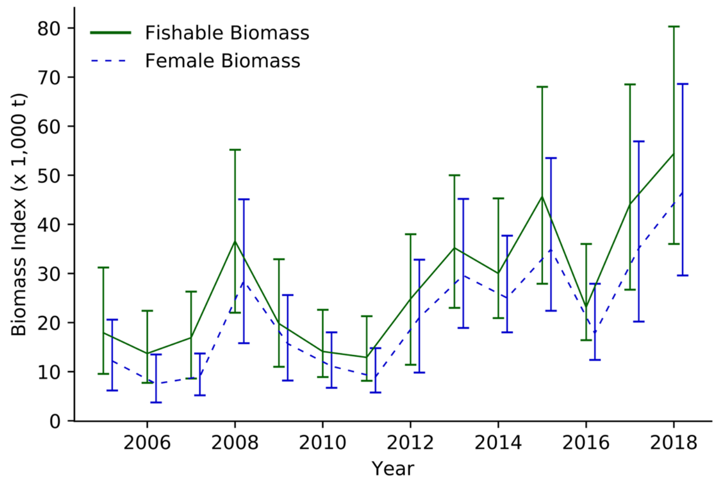

Figure 19. SFA 4 Striped Shrimp fishable biomass (green solid line) and female biomass (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The preliminary exploitation rate, based upon the February 7, 2019 CAQR catch of 2,500 t is 4.7% (Figure 20).

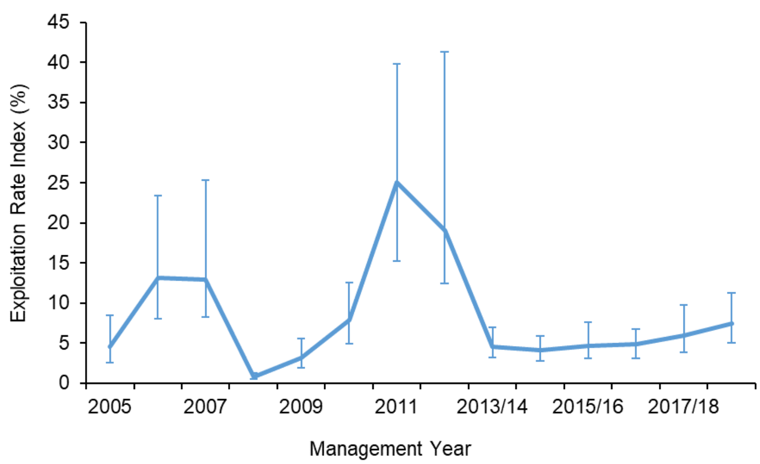

Figure 20. SFA 4 Striped Shrimp exploitation rate index, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

There is no IFMP PA Framework for this resource. If the by-catch limit had been taken, the exploitation rate would have been 7.4% in 2018/19.

SOURCES OF UNCERTAINTY

Spatio-temporal variation in survey efficiency among three DFO research vessels, particularly in NAFO Division 3K (SFA 6) is a source of uncertainty and the implications are unknown. Though the timing of the survey, and the proportion of sets performed by different research vessels, may change slightly from year to year, it is assumed that the effects are minimal.

The survey in SFA 4 was conducted by the Cape Ballard from 2005 to 2011. Beginning in 2012, the Aqviq was used. In 2014, the Kinguk was used; in 2015 the Katsheshuk II was used and in 2016–18, the vessel was again changed to the Aqviq. 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.

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 is more than the females observed by the survey alone. The existing management areas do not represent biological units. Causes 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, 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.

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}). However; there is no scientific basis on which to change the current reference points as there is no quantitative model of this resource; historical shrimp survey data will be incorporated into models wherever possible.

For the exploitation rate 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 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.

In trawl surveys, year effects are rare but can occur when estimating trawlable biomass. These effects are apparent when future surveys are added to the time series.

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 2–3 years for commercial catch rates to reflect declines in survey biomass indices.

CONCLUSIONS AND ADVICE

During the assessment in 2019, 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. Additionally, biomass indices of shrimp populations to the north (Eastern Assessment Zone and Western Assessment Zone) were presented. There was no research presented on how these factors may interact to drive Northern shrimp dynamics in SFAs 4–5, so the causes of the declining trend in these regions are unknown. 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 declined by 19% from 2016 to 2017 and returned to near-2016 levels in 2018. It is currently in the Critical Zone for the third consecutive year, based on the PA Framework. This follows three consecutive years of the female SSB index declining while in the Cautious Zone. The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone.

Fishery removal effects may become relatively high given the low level of net shrimp production after predator removals of shrimp in recent years. Thus, fishing mortality can be very important for determining whether gains (production) exceed losses (predation and fishing) and hence whether the stock increases or decreases. Recent environmental and ecosystem conditions along with harvest rates have not permitted the stock to increase.

SFA 5 *Pandalus borealis*

Biomass indices in SFA 5 have been declining since 2010, although with some annual variability. The fishable biomass index decreased by 43% and the female SSB index decreased by 31% between 2017 and 2018, both are at the second lowest levels of the survey time series. Female SSB index is in the Cautious Zone within the PA Framework with 51% probability. If the 25,630 t TAC is maintained and taken in 2019/20, then the exploitation rate index will be 32%.

SFA 4 *Pandalus borealis*

Biomass indices in SFA 4 have been declining since 2012. The fishable biomass index decreased by 46% and the female SSB decreased by 39% from 2017 to 2018 and are both at the lowest levels in the survey time series. Exploitation rate indices have been increasing since 2012/13. Female SSB index in 2018 was in the Cautious Zone with a 7% probability of having been in the Critical Zone.

SFA 4 *Pandalus montagui*

While both fishable and female biomass indices are at the highest levels in the time series, current status of this resource is unknown due to the large fluctuations in biomass from year to year, which are likely influenced by currents and tides in SFA 4. The potential exploitation rate of 7.4% is below the 20% maximum exploitation rate index that is proposed for a healthy SFA 4 resource. However, the status of the Striped Shrimp resource relative to a PA Framework could not be determined.

MANAGEMENT CONSIDERATIONS

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.

As predator biomass increases or remains stable and shrimp biomass decreases or remains low, as in recent years in SFA 6 and Southern SFA 5, fishery removals may become a large fraction of the net difference between shrimp production and total predation. Thus, fishing mortality can be very important for determining whether gains (production) exceed losses (predation) and hence whether the stock increases or decreases.

There is strong connectivity between the Arctic and SFAs 4–6; much of the recruitment to the pre-recruit biomass likely originates north of SFAs 5 and 6. Research on larval dispersal modeling shows highest potential settlement rates and highest rates of self-settlement (retention) were consistently observed in Northern Greenland and Newfoundland shelves (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. Main connectivity links were consistent over the years, but minor larval connections proportionally showed more variability. Sensitivity analysis of the larval dispersal models to pelagic larval duration did not affect the main larval settlement pattern in the region, but some areas displayed higher sensitivity to this variable (e.g., NAFO areas 1CD and 3KL).

A Science Response Process meeting 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. 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 6 would remain unchanged.

APPENDIX I – LIST OF PARTICIPANTS

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 12-13, 2019 Northern and Striped Shrimp Assessment. 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. 2019. Évaluation de la crevette nordique (Pandalus borealis) dans les zones de pêche à la crevette 4 à 6 et de la crevette ésope (Pandalus montagui) dans la zone de pêche la crevette 4 en 2018. Secr. can. de consult. sci. du MPO, Avis sci. 2019/027.