AN ASSESSMENT OF NORTHERN SHRIMP (*PANDALUS BOREALIS*) IN SHRIMP FISHING AREAS 4-6 IN 2019

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

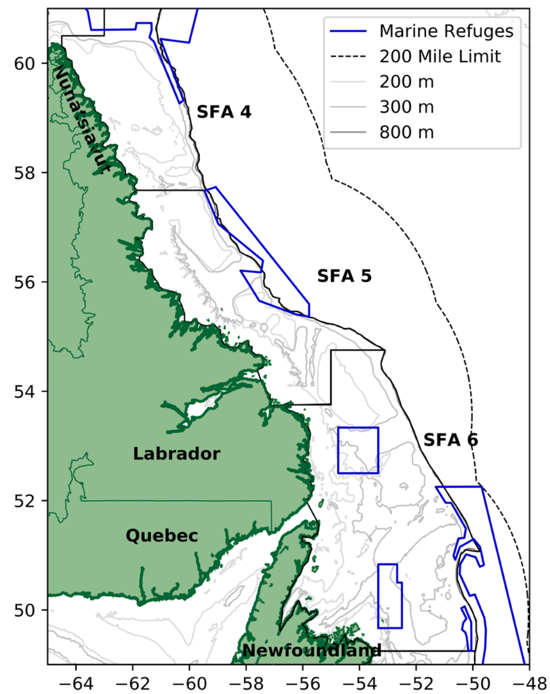

Figure 1. Map of Shrimp Fishing Areas (SFAs) 4-6. Blue polygons identify Marine Refuges (Hatton Basin, Hopedale Saddle, Hawke Box, Funk Island Deep Box and Northeast Newfoundland Slope from North to South) in which bottom-contact fishing (i.e., shrimp trawling) is not permitted.

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.*

The last Zonal Peer Review Process that assessed Northern Shrimp in SFAs 4-6 was held in February, 2019 (DFO 2019).

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 18-20, 2020 regional peer review meeting on the Assessment of Northern Shrimp in Shrimp Fishing Areas (SFAs) 4, 5 and 6. 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 (1996-2019). The coverage of this survey in 2019 was severely reduced due to weather such that biomass estimates, particularly in SFA 5, are likely an overestimate of true stock status. Resource status for Northern Shrimp in SFA 4 was assessed based on Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (2005-19).
- 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

- Bottom and surface temperatures are important drivers for the development of shrimp eggs and larvae, respectively. These variables have shown similar trends over the last 40 years, with a cold phase in the mid-1980s and 1990s, and a warm period in the late-1990s and early-2010s, but their trends have diverged since 2015. While warmer bottom temperatures led to above average bottom thermal habitat (2-4°C) in 2018 and 2019, colder surface waters since 2015 could have a negative impact on shrimp larval growth and survival.
- Chlorophyll concentration and zooplankton biomass were below normal in the mid-2010s, increasing to values above the long-term (1999-2015) average after 2017. Additionally there have been changes in zooplankton community structure (less large energy-rich, and more small copepods) as well as changes in seasonality (weaker spring and stronger fall zooplankton signals) which may change the quality and timing of food availability for shrimp.

Ecosystem

- Ecosystem conditions in the Newfoundland Shelf and Northern Grand Bank (Northwest Atlantic Fisheries Organization [NAFO] Divs. 2J3KL; SFA 7, 6, and southern part of SFA 5) are indicative of limited productivity of the fish community. Total biomass levels remain much lower than prior to the collapse in the early-1990s. After some recovery since the collapse, current levels of total biomass are reduced from those observed in the early-2010s.
- Northern Shrimp biomass in SFA 6 is currently similar to the 1980-90 period (substantially down from 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. The shrimp model and consumption analyses indicated that predation is a major driver of the stock. The shrimp predation mortality rate in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5) has increased over the last two years, to its highest levels on record.

- Predation and fishing remain negatively correlated with subsequent shrimp per-capita net production in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5). The build-up of shrimp until the mid-2000s occurred during a period of favorable environmental conditions and reduced predation. Shrimp per-capita net production has declined since the mid-2000s, and is expected to remain around current low values for the next 2-3 years.
- Under current ecosystem conditions (i.e. low shrimp biomass, high 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), but it could now be more influential on stock declines than it may have been in the past.
- The available information for the Labrador Shelf (NAFO Div. 2H, northern part of SFA 5) shows declines in total biomass from the levels observed in the early-2010s, as well as reductions in the dominance of shellfish in this community. 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).

SFA 6 *Pandalus borealis*

- TAC was reduced by 16%, to 8,730 t, from 2017/18 to 2018/19 and was increased slightly, by 3%, to 8,961 t in 2019/20.
- The annual commercial CPUE declined considerably between 2015/16 to 2017/18 to the lowest levels in two decades and has remained low since.
- Over 1996 to 2019 the fishable biomass index averaged 380,000 t and in 2019 the fishable biomass index was 82,900 t, an 8% decrease from 2018 and the lowest level in the time series.
- Over 1996 to 2019 the female spawning stock biomass (SSB) index averaged 238,000 t and in 2019 the SSB index was 49,900 t, a 25% decrease from 2018 and the lowest level in the time series.
- The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2019/20. The maximum exploitation rate index has been 10% for the last 3 years.
- 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 of being within the critical zone.
- The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone. If the 2019/20 TAC of 8,960 t is maintained and taken in 2020/21, the exploitation rate index would be 10.8%.

SFA 5 *Pandalus borealis*

- TAC was increased by 17%, to 25,630 t, from 2017/18 to 2018/19 but was decreased by 14% to 22,100 t in 2019/20.
- Standardized large-vessel CPUE had varied without trend at relatively high levels for more than a decade before falling below the long term mean beginning in 2017/18. Commercial catch rates may have been partly influenced by ice coverage.

- Over 1996 to 2019 the fishable biomass index averaged 129,000 t and in 2019 the fishable biomass index was 64,400 t, a 20% decrease from 2018 and the lowest level in the time series.
- Over 1996 to 2019 the female SSB index averaged 63,700 t and in 2019 the SSB index was 44,500 t, a 16% increase from 2018 and amongst the lowest levels in the time series.
- The exploitation rate index varied without trend with a median value of 15% from 1997-2019/20. If the TAC is fully taken in 2019/20 then the exploitation rate index will be 27.6%.
- Female SSB index is in the Healthy Zone within the IFMP PA Framework, just above the Upper Stock Reference (USR), with 33% probability of being in the cautious zone. If the 22,100 t TAC is maintained and taken in 2020/21, then the exploitation rate index will be 34%.

SFA 4 *Pandalus borealis*

- TAC was unchanged, at 15,725 t, from 2017/18 to 2018/19 and was reduced by 31% to 10,845 t in 2019/20.
- Large-vessel standardized CPUE varied without trend near the long-term mean (1989-2018/19).
- Over 2005 to 2019 the fishable biomass index averaged 99,700 t and in 2019 the fishable biomass index was 54,100 t, a 29% increase from 2018 and the second lowest level in the time series.
- Over 2005 to 2019 the female SSB index averaged 62,100 t and in 2019 the SSB index was 39,600 t, a 23% increase from 2018 and amongst the lowest levels in the time series.
- The exploitation rate index ranged between 7% and 37.3% from 2005/06 to 2018/19 and was 19.3% in 2019/20.
- Female SSB index in 2019 was in the Cautious Zone within the IFMP PA Framework with a 6% probability of having been in the Critical Zone and a 29% probability of having been in the Healthy 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 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. Although the temperature, depth, and bottom type preferences differ slightly between Striped Shrimp (*Pandalus montagui*) (DFO 2020a) and Northern Shrimp, their distributions overlap, particularly in SFA 4; 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, *P. borealis* and *P. montagui* are found in the Eastern and Western Assessment Zones, directly to the north of SFA 4 (DFO 2020b). 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. It 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. 2019, 2020).

Studies of genetics between Northern Shrimp populations in SFAs 4-6 have demonstrated that Northern Shrimp in these areas are largely genetically homogenous (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

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. 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, 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 six years.

In 2003, the management year was changed from a calendar year (January 1-December 31) to a fiscal year (April 1-March 31). 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. This policy applies without limitation when the stock is in the Healthy Zone but may be capped or suspended should there be a conservation concern. 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 generally allocated by SFA based on indices in 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 41,906 t in 2019/20.

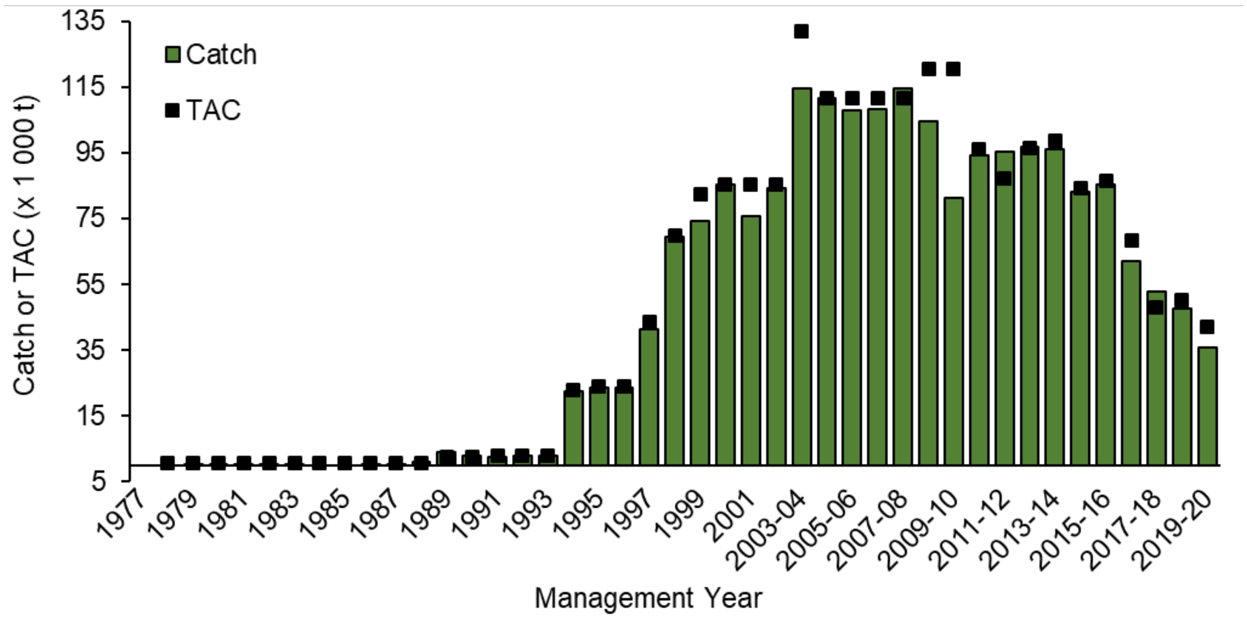

Figure 2. Historical Northern Shrimp catches and TACs (SFAs 4-6 combined) for the period 1977-2019/20. Catches for 2019/20 are preliminary and from the CAQR as of February 7, 2020. The management year changed from a calendar to a fiscal year in 2003 such that the values for 2003/04 are based upon a 15 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 10 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 (1996-2019). The coverage of this survey in 2019 was severely reduced due to weather such that biomass estimates, particularly in SFA 5, are likely an overestimate of true stock status. Resource status for Northern Shrimp in SFA 4 was assessed based on NSRF-DFO summer trawl survey data (2005-19). Both surveys use the same gear and tow protocols with comparable sampling protocols for Northern Shrimp.

Trawl survey data for SFAs 4-6 provided information on shrimp distribution, length frequencies 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 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 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 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 2018b). This framework was developed in 2008-10 following the 2008 framework workshop attended by a Marine Stewardship Certification (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, consistent with guidance in the DFO PA Framework (DFO 2009). The 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.

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 initially presented during the 2018 Regional Peer Review Process (DFO 2018a) and again at the CSAS Framework meeting in May 2019 and 2020 Regional Peer Review Process. 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 down from 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. The shrimp model and consumption analyses indicated that predation is a major driver of the stock. The shrimp predation mortality rate in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5) has increased over the last two years, to its highest levels on record.

A shrimp population model incorporating environmental and ecosystem drivers was developed and peer reviewed during a CSAS framework meeting in May, 2019. 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 accepted, the consensus from the external reviewers and meeting participants determined that model testing and refinements should take place prior to utilizing biomass estimates for management decisions. It is anticipated that this process will take several years. Additionally, the 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

Bottom and surface temperatures are important drivers for the development of shrimp eggs and larvae, respectively. These variables have shown similar trends over the last 40 years, with a cold phase in the mid-1980s and 1990s, and a warm period in the late-1990s and early-2010s, but their trends have diverged since 2015. While warmer bottom temperatures led to above average bottom thermal habitat (2-4°C) in 2018 and 2019, colder surface waters since 2015 could have a negative impact on shrimp larval growth and survival.

Early life history and adult stages of shrimp depend on phytoplankton (indirect) and zooplankton (direct) prey for feeding and nutrition. Chlorophyll concentration and zooplankton biomass were below normal in the mid-2010s, increasing to values above the long-term (1999-2015) average after 2017. Additionally there have been changes in zooplankton community structure (less large energy-rich, and more small copepods) as well as changes in seasonality (weaker spring and stronger fall zooplankton signals) which may change the quality and timing of food availability for shrimp.

SFA 6 *Pandalus borealis*

Ecosystem

Ecosystem conditions in the Newfoundland Shelf and Northern Grand Bank (NAFO Divs. 2J3KL; SFA 7, 6, and southern part of SFA 5) are indicative of limited productivity of the fish community. Total biomass levels remain much lower than prior to the collapse in the early-1990s. After some recovery since the collapse, current levels of total biomass are reduced from those observed in the early-2010s.

The available information for the Labrador Shelf (NAFO Div. 2H, northern part of SFA 5) shows declines in total biomass from the levels observed in the early-2010s, as well as reductions in the dominance of shellfish in this community. 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

Total Allowable Catch reductions have been applied periodically since 2009/10 due to stock declines. Subsequently, catches follow the same trend. TAC was reduced by 16%, to 8,730 t, from 2017/18 to 2018/19 and was increased slightly, by 3%, to 8,961 t in 2019/20. As of the February 7, 2020 CAQR, 77% of the 2019/20 TAC had been taken (Figure 3).

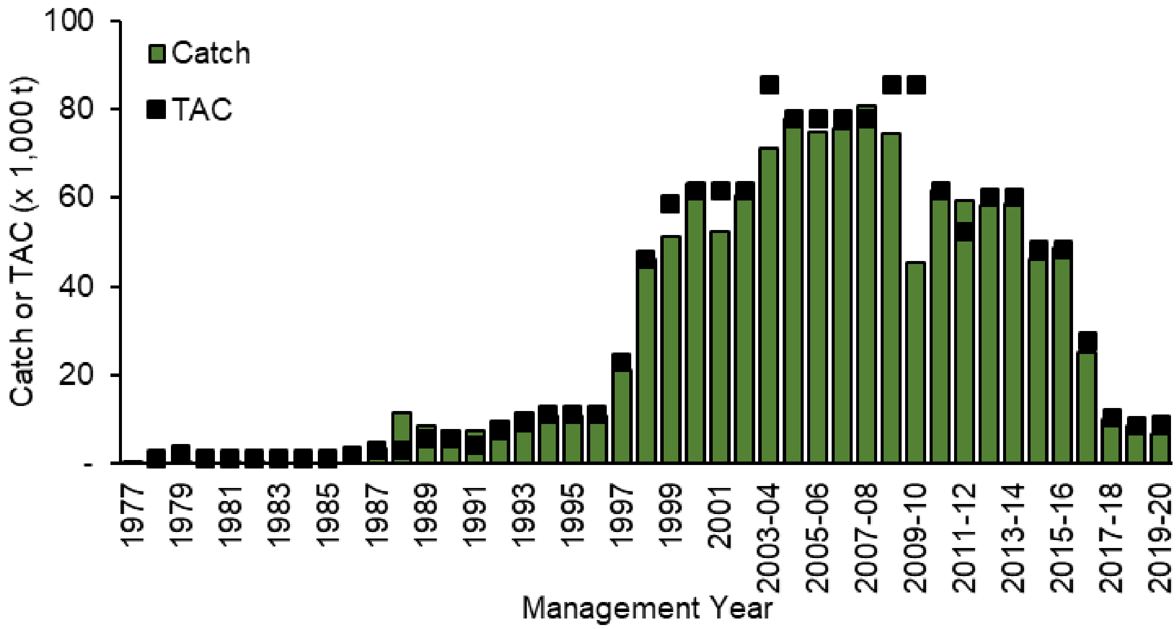

Figure 3. Historical Northern Shrimp catches and TAC in SFA 6 for the period 1977-2019/20. 2019/20 values are preliminary, based upon the CAQR as of February 7, 2020. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 month 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 between 2015/16 to 2017/18 to the lowest levels in two decades and has remained low since (Figure 4).

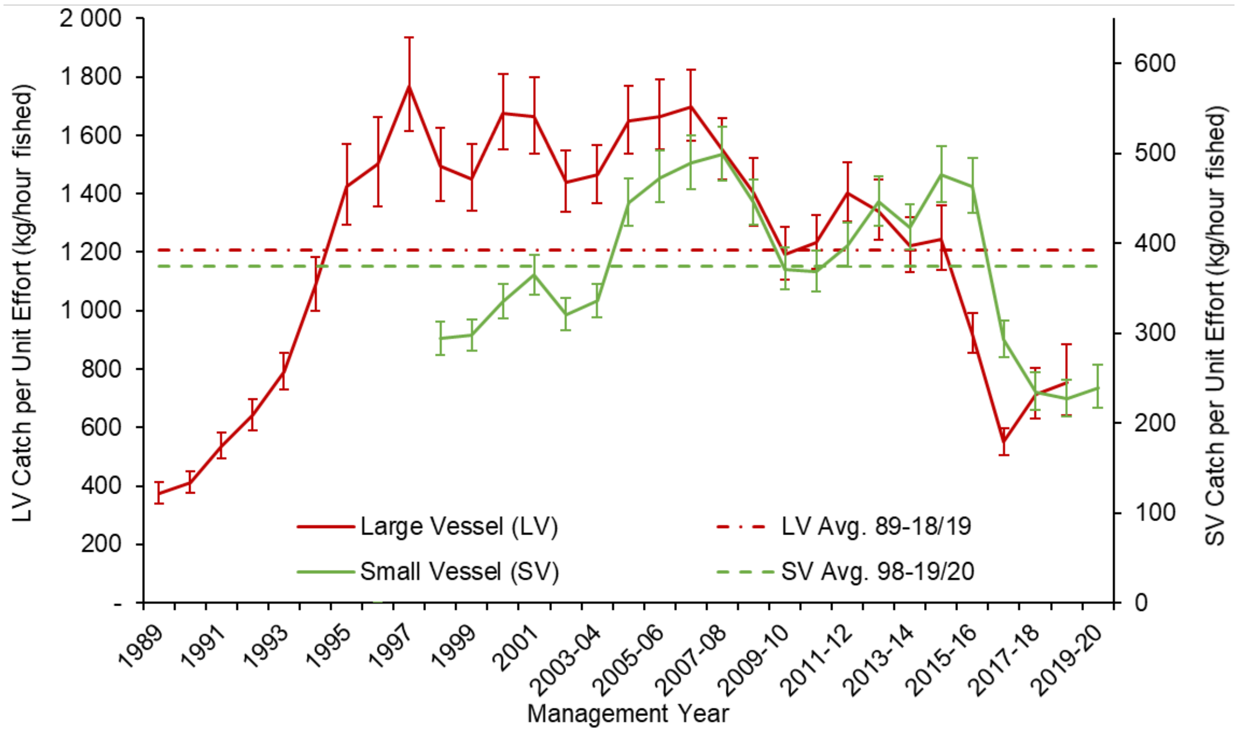

Figure 4. SFA 6 large-vessel (LV, red solid line beginning in 1989) and small-vessel (SV, green solid line beginning in 1998) annual standardized CPUE. Error bars indicate 95% confidence intervals and dashed horizontal lines indicate long term mean of CPUE series. The 2019/20 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2019 the fishable biomass index averaged 380,000 t and in 2019 the fishable biomass index was 82,900 t, an 8% decrease from 2018 and the lowest level in the time series. Over 1996 to 2019 the female SSB index averaged 238,000 t and in 2019 the SSB index was 49,900 t, a 25% decrease from 2018 and the lowest level in the time series. (Figure 5).

Coverage of the DFO Fall survey in 2019 was severely reduced due to poor weather such that biomass estimates in SFAs 5-6, particularly in SFA 5, are likely overestimates of true stock status. Analyses during the assessment tested previous survey years by removing sets to imitate the same reduced coverage. These analyses demonstrated that estimates are representative of the stock status.

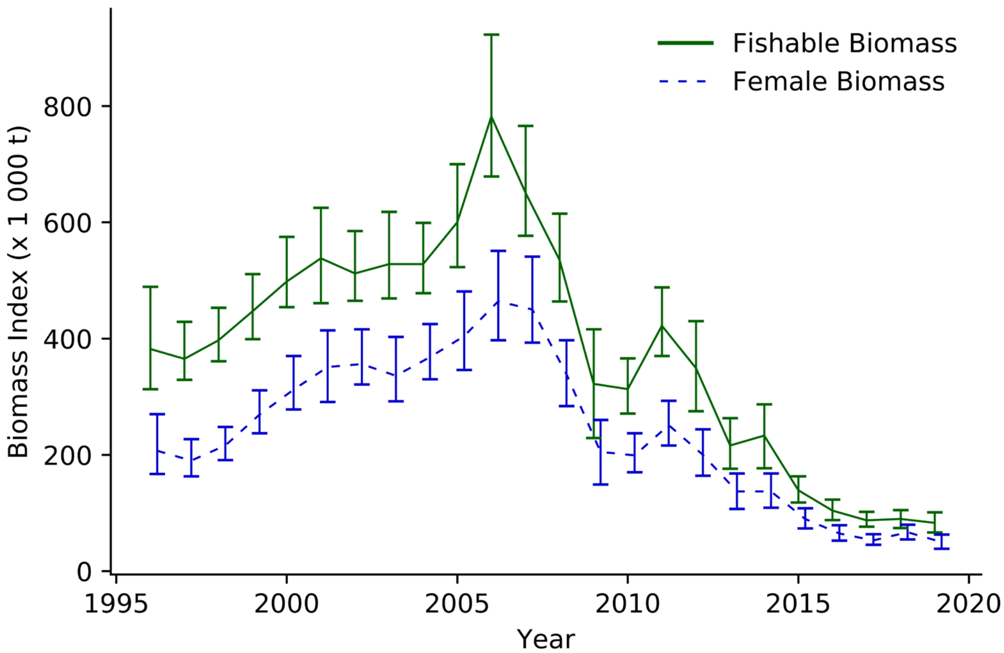

Figure 5. SFA 6 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Renewal

Renewal is the difference between the increase due to production, and removal largely due to predators and shrimp harvesting. Predation and fishing remain negatively correlated with subsequent shrimp per-capita net production in NAFO Divs. 2J3KL (SFA 7, 6, and southern part of SFA 5). The build-up of shrimp until the mid-2000s occurred during a period of favorable environmental conditions and reduced predation. Shrimp per-capita net production has declined since the mid-2000s, and is expected to remain around current low values for the next two to three years (Figure 6). Under current ecosystem conditions (i.e., low shrimp biomass and high 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), but it could now be more influential on stock declines than it may have been in the past.

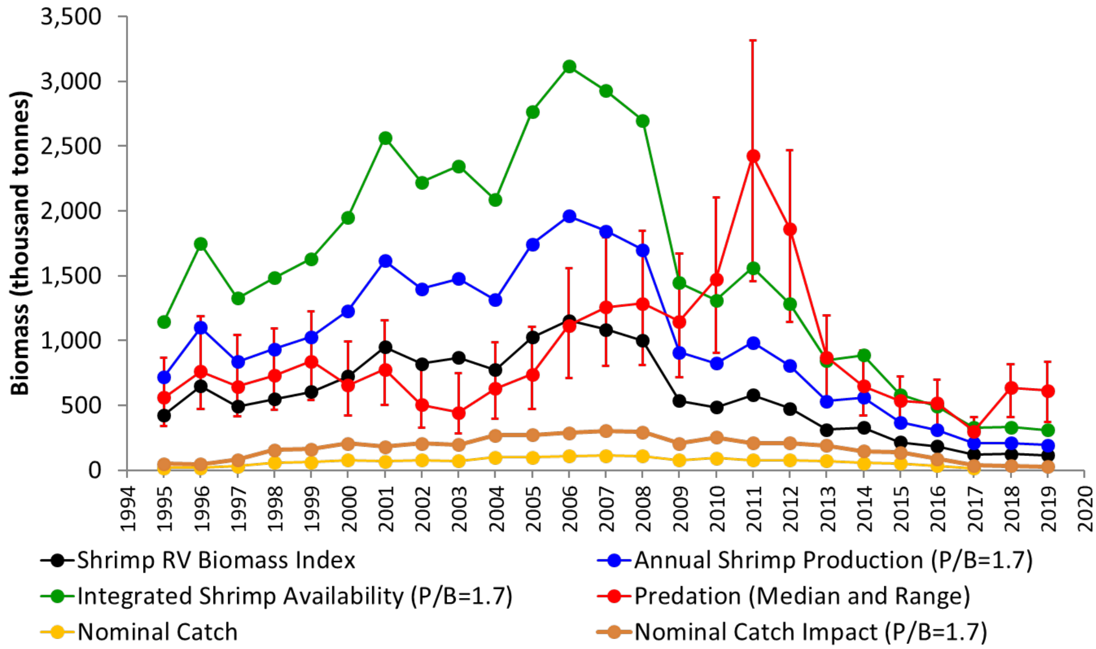

Figure 6. Comparison of predation and fisheries catches with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a production over biomass (P/B) ratio of 1.7.

Exploitation

The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2019/20. The 2018/19 index was 10% and the preliminary 2019/20 index was 7.7%. The maximum exploitation rate index has been 10% for the last three years. (Figure 7).

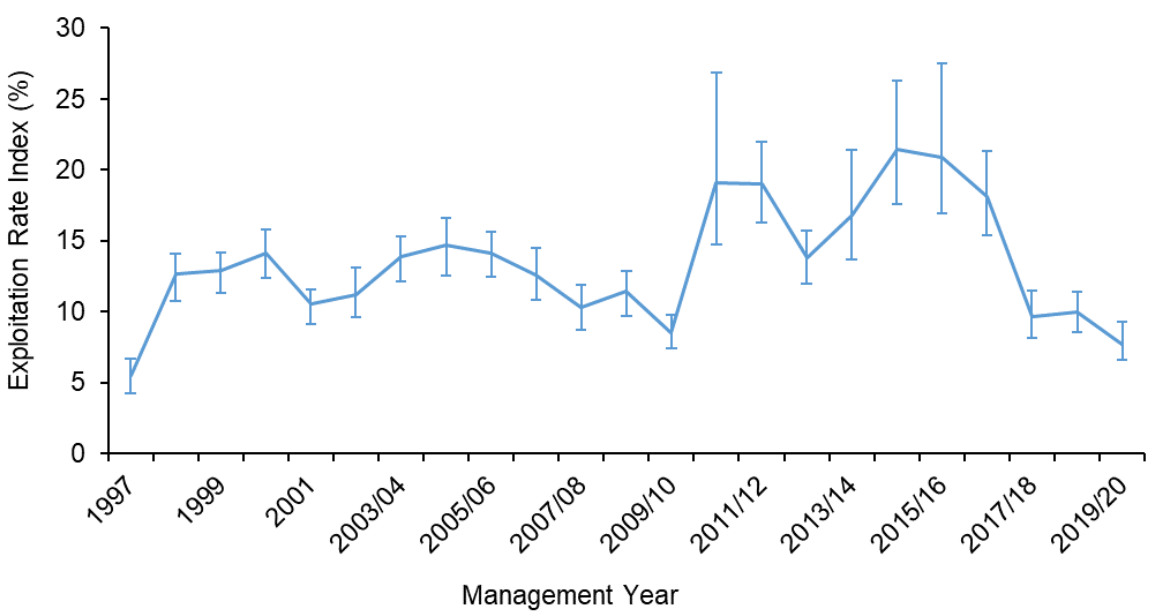

Figure 7. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The 2019/20 point is preliminary and based on total catch as of the February 7, 2020 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

The female SSB index is currently in the Critical Zone of the IFMP PA Framework with greater than 99% probability of being within the critical zone. The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone. If the 2019/20 TAC of 8,960 t is maintained and taken in 2020/21, the exploitation rate index would be 10.8% (Figure 8).

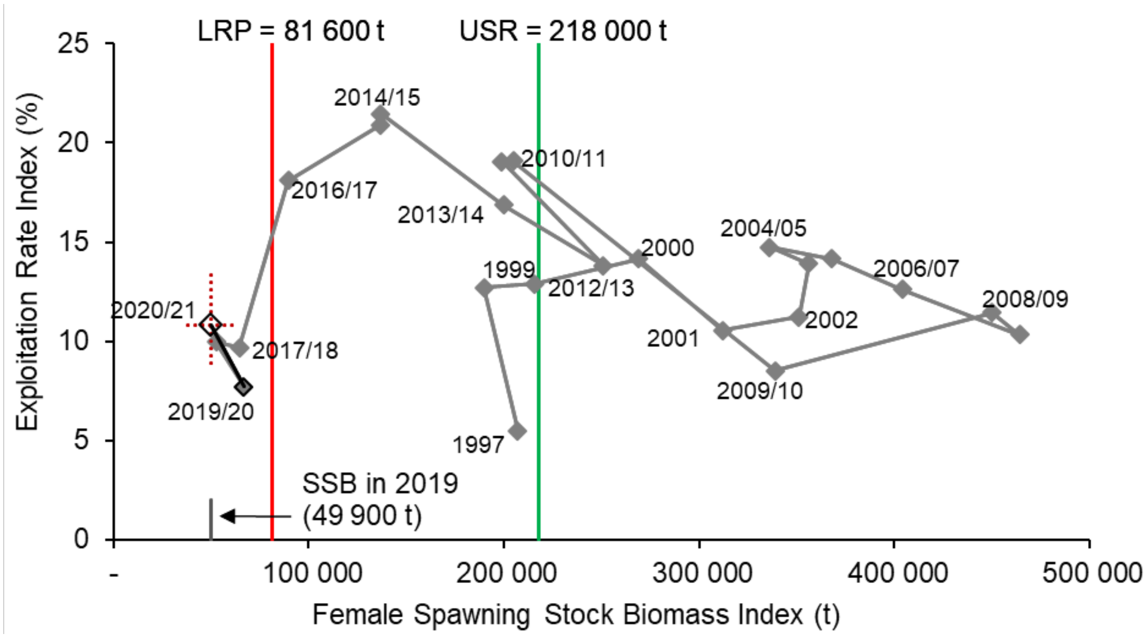

Figure 8. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2019/20 fishery was ongoing and based on reported catch as of February 7, 2020. The red cross on the 2020/21 point indicates 95% confidence intervals for the 2019 female SSB index (horizontal) and the 2020/21 exploitation rate index (vertical), assuming that the 8,960 t TAC is maintained and taken in the 2020/21 fishery.

SFA 5 *Pandalus borealis*

Fishery

TAC was increased by 17%, to 25,630 t, from 2017/18 to 2018/19 but was decreased by 14% to 22,100 t in 2019/20 (Figure 9).

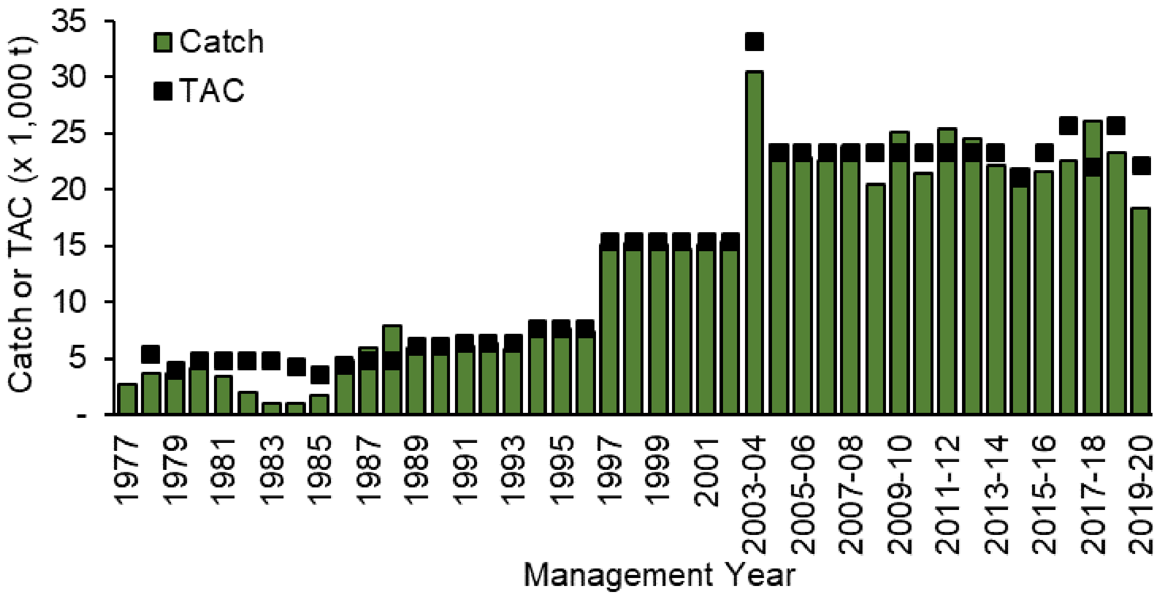

Figure 9. Historical Northern Shrimp catches and TACs in SFA 5 for the period 1977-2019/20. 2019/20 values are preliminary and based upon the CAQR as of February 7, 2020. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 month fishing season. Quota bridging and transfers are not reflected in TACs but are reflected in catches in this figure.

Standardized large-vessel CPUE had varied without trend at relatively high levels for more than a decade before falling below the long-term mean beginning in 2017/18. Commercial catch rates may have been partly influenced by ice coverage, however they may have been influenced by other factors, for example reduced commercial fishery performance (Figure 10).

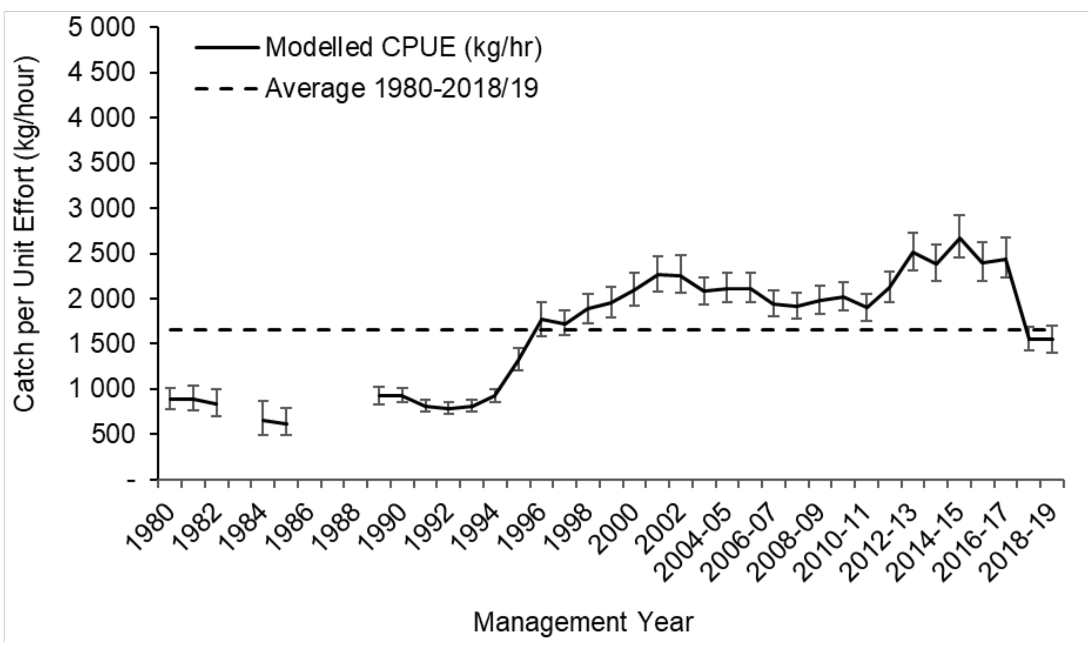

Figure 10. SFA 5 large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series. The 2019/20 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2019, the fishable biomass index averaged 129,000 t and in 2019 the fishable biomass index was 64,400 t, a 20% decrease from 2018 and the lowest level in the time series. Over 1996 to 2019 the female SSB index averaged 63,700 t and in 2019 the SSB index was 44,500 t, a 16% increase from 2018 and amongst the lowest levels in the time series (Figure 11).

Coverage of the DFO Fall survey in 2019 was severely reduced due to weather such that biomass estimates in SFAs 5-6, particularly in SFA 5, are likely overestimates of true stock status. Analyses during the assessment tested previous survey years by removing sets to imitate the same reduced coverage. These analyses demonstrated that estimates are representative of the stock status.

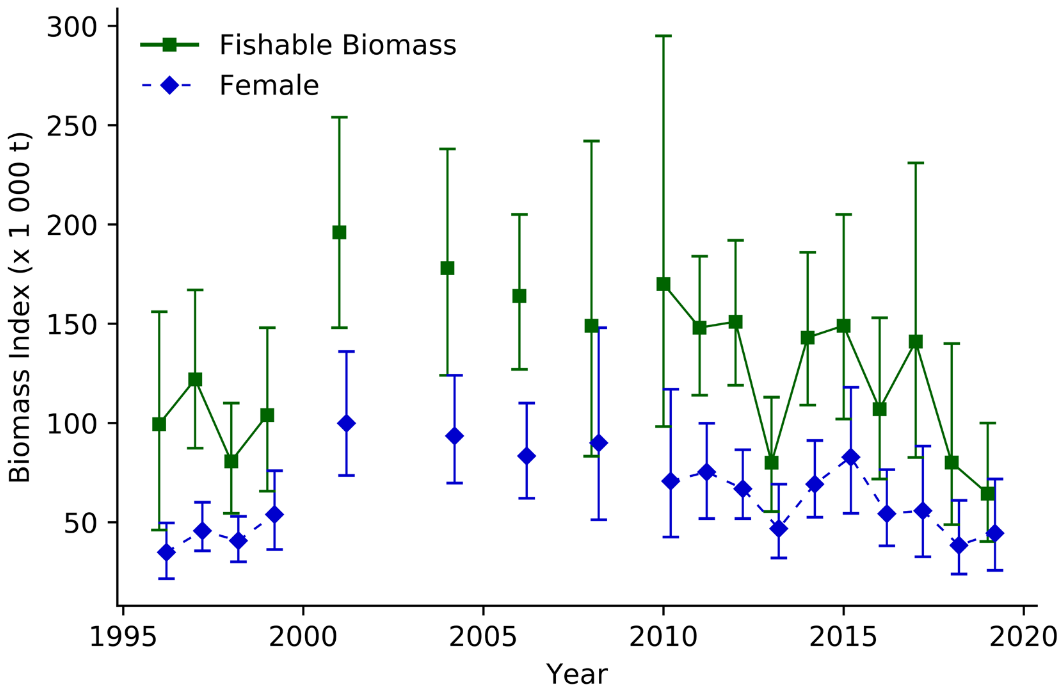

Figure 11. SFA 5 fishable biomass (green solid line and squares) and female SSB (blue dashed line and diamonds) indices. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index varied without trend with a median value of 15% from 1997 to 2019/20. If the TAC is fully taken in 2019/20 then the exploitation rate index will be 27.6% (Figure 12), 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. The 2018/19 index was 16.5% and the preliminary 2019/20 index was 23%.

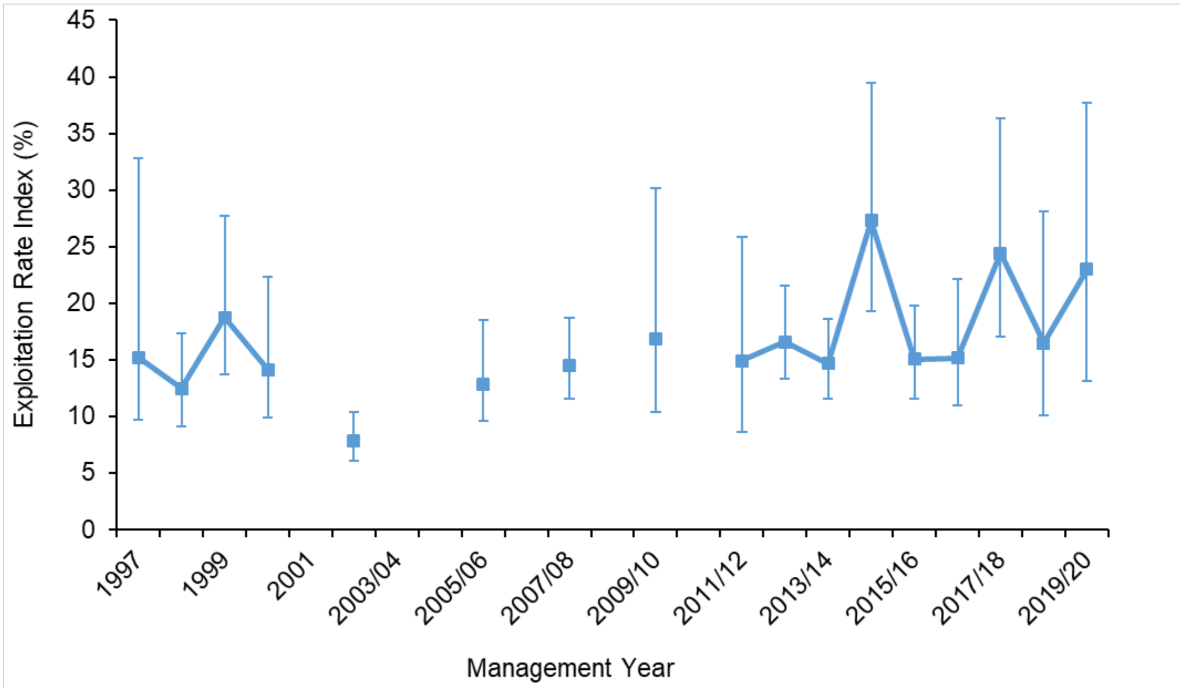

Figure 12. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. The 2019/20 point is preliminary and based on total catch as of the February 7, 2020 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index is in the Healthy Zone within the IFMP PA Framework, just above the USR, with 33% probability of being in the cautious zone. If the 22,100 t TAC is maintained and taken in 2020/21, then the exploitation rate index will be 34% (Figure 13).

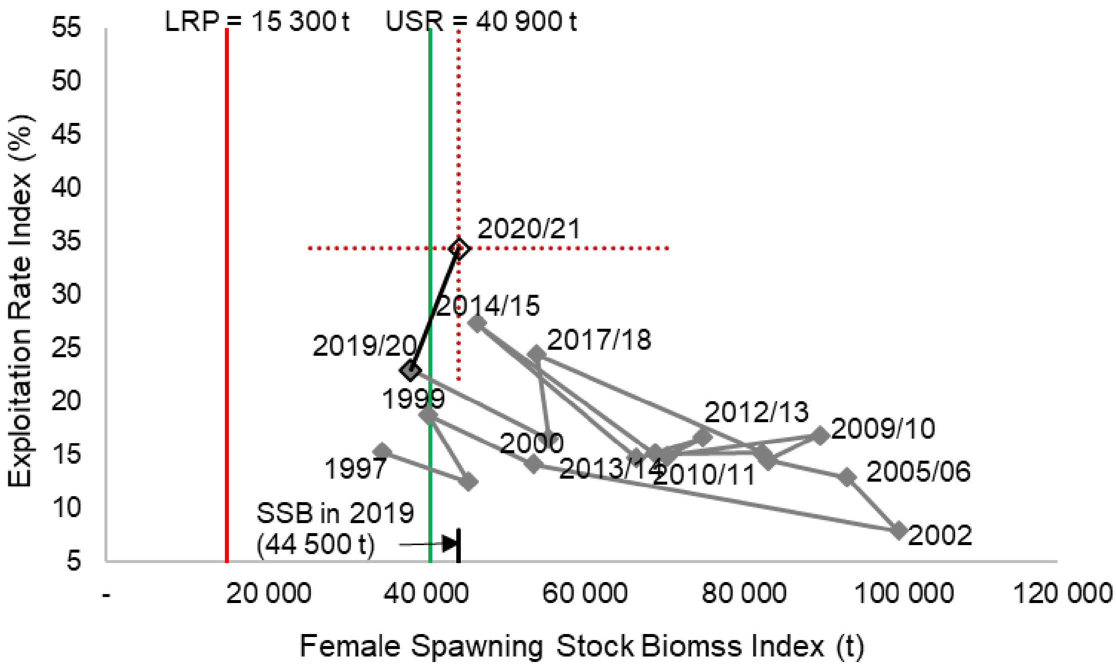

Figure 13. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2019/20 fishery was ongoing and based on reported catch as of February 7, 2020. The red cross on the 2020/21 point indicates 95% confidence intervals for the 2019 female SSB index (horizontal) and the exploitation rate index (vertical), assuming that the 22, 100 t TAC is maintained and taken in the 2020/21 fishery.

SFA 4 *Pandalus borealis*

Fishery

TAC was unchanged, at 15,725 t, from 2017/18 to 2018/19 and was reduced by 31% to 10,845 t in 2019/20. The TAC has been fully taken (Figure 14).

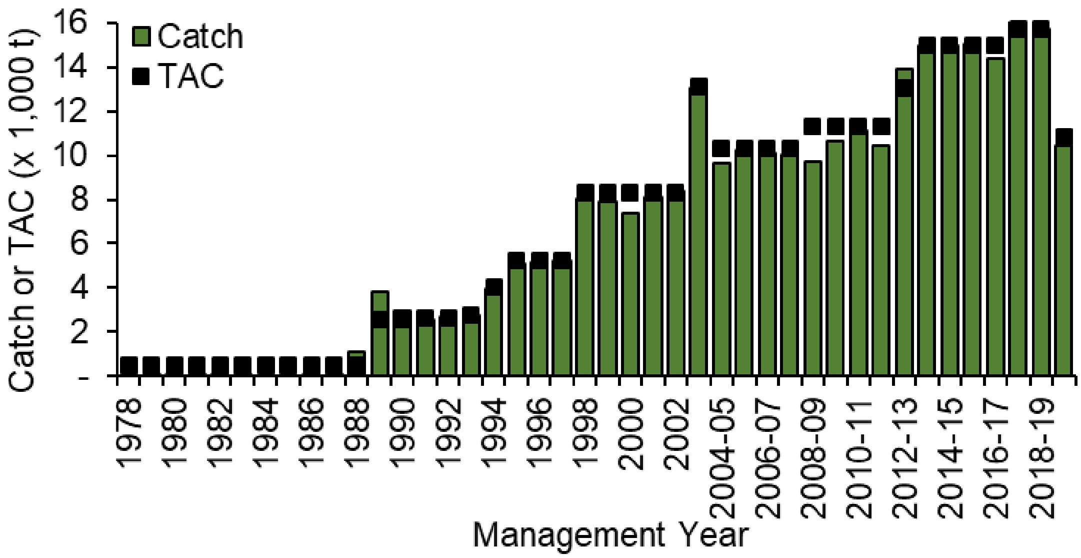

Figure 14. Historical Northern Shrimp catches and TACs in SFA 4 for the period 1978-2019/20. 2019/20 values are preliminary and based upon the CAQR as of February 7, 2020. In 2003, the management year changed from a calendar to a fiscal year and hence catches and TACs for that year are based on a 15 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 (1989-2018/19, Figure 15). 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.

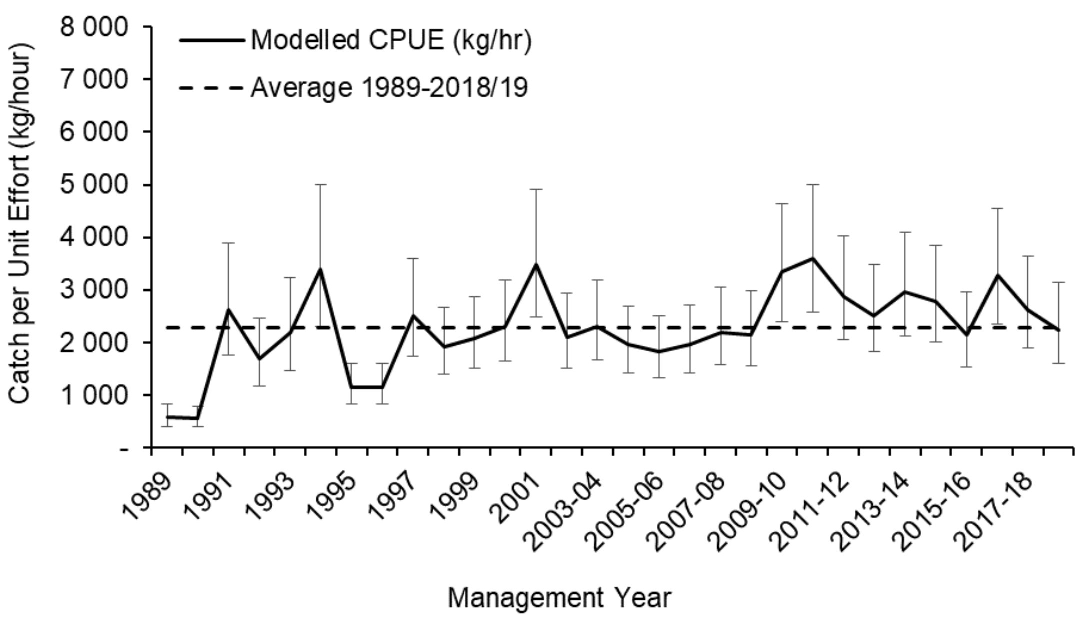

Figure 15. SFA 4 Northern Shrimp large-vessel annual standardized CPUE (solid line). Error bars indicate 95% confidence intervals and dashed horizontal line indicates long term mean of CPUE series. The 2019/20 LV annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 2005 to 2019, the fishable biomass index averaged 99,700 t and in 2019 the fishable biomass index was 54,100 t, a 29% increase from 2018 and the second lowest level in the time series. Over 2005 to 2019 the female SSB index averaged 62,100 t and in 2019 the SSB index was 39,600 t, a 23% increase from 2018 and amongst the lowest levels in the time series (Figure 16).

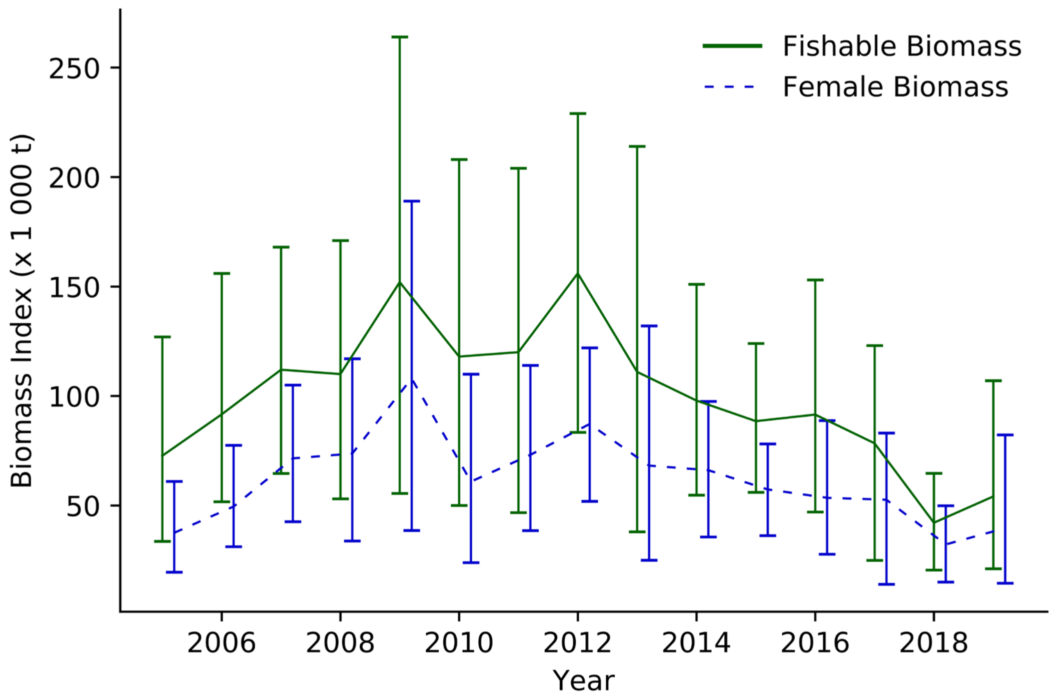

Figure 16. SFA 4 Northern Shrimp fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index ranged between 7% and 37.3% from 2005/06 to 2018/19 and was 19.3% in 2019/20 (Figure 17). The 2018/19 index was 37.3% and the preliminary 2019/20 index was 19.3%. 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 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 intervals of the 2017/18 and 2018/19 exploitation rate indices are very high.

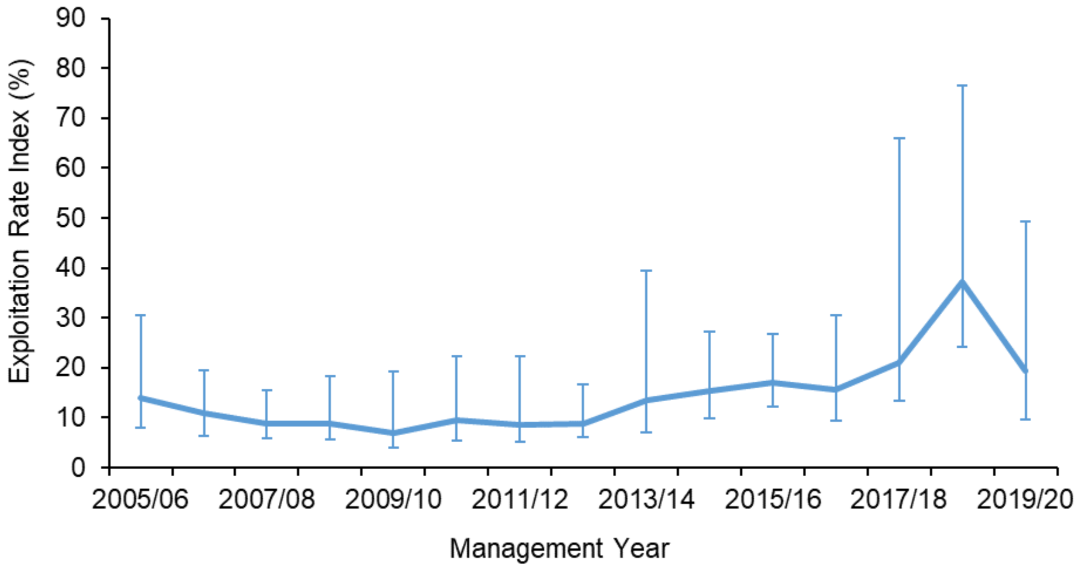

Figure 17. SFA 4 Northern Shrimp exploitation rate index, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index in 2019 was in the Cautious Zone within the IFMP PA Framework with a 6% probability of having been in the Critical Zone and a 29% probability of having been in the Healthy Zone (Figure 18).

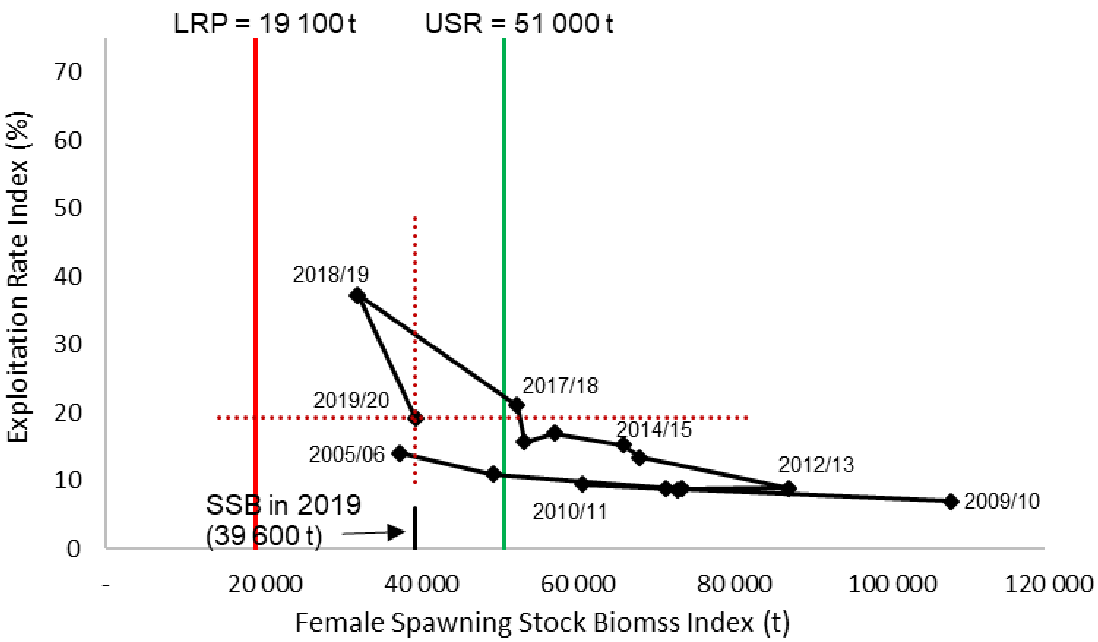

Figure 18. SFA 4 PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote year of the fishery. The red cross on the 2019/20 point indicates 95% confidence intervals for the 2019 female SSB index (horizontal) and the 2019/20 exploitation rate index (vertical).

Sources of Uncertainty

Spatio-temporal 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 is undertaken by two survey vessels, which begin the area at different times and survey at different rates depending on weather, mechanical issues, etc. 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. In some years survey coverage may be more impacted than others, for example in 2019. Analyses presented at the assessment tested previous survey years by removing sets to imitate the same reduced coverage. These analyses demonstrated that estimates are representative of the stock status (although likely a slight overestimate).

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 2016-19, 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 differs from 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 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.

Preliminary research at Memorial University of Newfoundland indicates 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 previous available research from the 1980s.

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 population model was 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 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. Additionally, changing fishing practices impact CPUE in unknown ways.

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 two to three years for commercial catch rates to reflect declines in survey biomass indices.

CONCLUSIONS AND ADVICE

During the assessment in 2020, 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). The May 2019 Shrimp Framework Meeting presented research demonstrating that changes in NAO and biomass of predators (Atlantic Cod, Redfish and Greenland Halibut) are significant predictors of subsequent shrimp production on a smaller scale (i.e., Voroni polygons). The specific causes of declining trends in SFAs 4-6 is 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 declined by 25% from 2018 to 2019 and it is currently in the Critical Zone for the fourth 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.

Impacts from fishery removals may become relatively high given the low level of net shrimp production after predator removals of shrimp in recent years. Under current ecosystem conditions (i.e., low shrimp biomass and high 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), but it could now be more influential on stock declines than it may have been in the past. Recent environmental and ecosystem conditions along with harvest rates have not permitted the stock to increase.

SFA 5 *Pandalus borealis*

There is concern for the current status of this resource. Biomass indices in SFA 5 have been declining since 2010, although with some annual variability. The fishable biomass index decreased by 20% and the female SSB index increased by 16% between 2018 and 2019, both are amongst lowest levels of the survey time series. Female SSB index is in the Healthy Zone within the PA Framework with 33% probability of being in the Cautious Zone. If the 22, 100 t TAC is maintained and taken in 2020/21, then the exploitation rate index will be 34%.

SFA 4 *Pandalus borealis*

There is concern for the current status of this resource. Biomass indices in SFA 4 have been declining since 2012, although with some annual variability. The fishable biomass index increased by 29% and the female SSB increased by 23% from 2018 to 2019, however both are amongst the lowest levels in the survey time series. Exploitation rate indices had been increasing from 2012/13 to 2018/19 until declining in 2019/20, corresponding to a reduced TAC. Female SSB index in 2019 was in the Cautious Zone, for the second consecutive year, with a 6% probability of having been in the Critical Zone.

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 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.

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 18-20, 2020 regional peer review meeting on the Assessment of Northern Shrimp in Shrimp Fishing Areas (SFAs) 4, 5 and 6. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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.

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