Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
Science Advisory Report 2018/018

AN ASSESSMENT OF NORTHERN SHRIMP (*PANDALUS BOREALIS*) IN SHRIMP FISHING AREAS 4-6 IN 2017

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

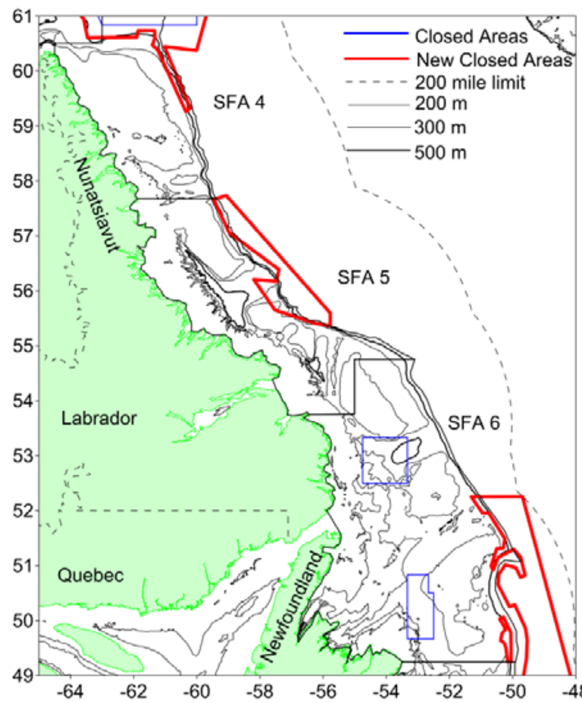

Figure 1. Map of Shrimp Fishing Areas (SFAs) 4-6. Blue polygons identify previously closed areas (Hawke Box and Funk Island Deep box from North to South) while red polygons identify new marine refuges implemented on January 1, 2018 (Hatton Basin, Hopedale Saddle and Northeast Newfoundland Slope from North to South.

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, Striped Shrimp in SFA 4 and both Northern and Striped Shrimp in the Eastern and Western Assessment Zones was held in February, 2017 (DFO 2017a and DFO 2017b).

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, predators and potential environmental drivers.

This Science Advisory Report is from the February 13–14, 2018 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 Fisheries and Oceans Canada (DFO) fall multi-species trawl survey data (1996–2017). Resource status for Northern Shrimp in SFA 4 was assessed based on Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (2005–17).
- 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 within SFAs 4–6 indicated strong downstream connectivity and that a majority of recruits in a particular SFA may come from SFAs farther north.
- Analysis was presented on the pre-1995 shrimp surveys, commercial and diet data in order to demonstrate historic changes in SFAs 5–6 indices. Results indicate that shrimp biomass has declined to a level consistent with their 1979-90 levels 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 that may impact the transfer of energy to higher trophic levels across SFAs in recent years.
- The area of the bottom thermal habitat (2–4°C) within many areas of SFAs 5 and 6, typically inhabited by shrimp, was near the long-term mean.

Ecosystem

- Ecosystem conditions in the Newfoundland Shelf (Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J3K) are indicative of an overall low productivity state, with both total shellfish and total finfish biomass showing declines since the early to mid-2010s. Current total biomass is at similar levels to those observed in the mid-1990s. However, shellfish make up a much lower proportion of the biomass.
- Predation, fishing and environmental forcing are correlated with subsequent shrimp production, although the precise linkage with environmental variables remains unclear. The build-up of shrimp until the mid-2000s occurred during a period of favourable environmental conditions and reduced predation.
- Shrimp per-capita net production has declined since the mid-1990s, and is expected to remain around current low values for the next 2–3 years.
- Shrimp is an important forage species, particularly when there is scarcity of high-energy prey such as capelin. Shrimp predation mortality in the near future is expected to remain relatively high unless abundance of alternative prey increases.
- Given current predation pressure on shrimp, fishing pressure could now be more influential on stock declines in SFA 6 than it was in the past.

SFA 6 *Pandalus borealis*

- TAC was reduced by 42%, to 27,825 t, from 2015/16 to 2016/17 and further, by 63%, to 10,400 t in 2017/18.
- The annual commercial CPUE declined considerably in recent years to the lowest levels in two decades.
- Over 1996 to 2017 the fishable biomass index averaged 407,000 t and in 2017 was 87,300 t; a 16% decrease from 2016 and the lowest level in the time series.
- Over 1996 to 2017 the female spawning stock biomass (SSB) index averaged 254,000 t and in 2017 was 52,700 t; a 19% decrease from 2016 and the lowest level in the time series.
- The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2017/18, and has averaged 17% in the last 5 years. If the TAC is fully taken in 2017/18 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% (corresponding to a 2018/19 TAC of 8,730 t) while the female SSB index is in the Critical Zone.

SFA 5 *Pandalus borealis*

- TAC was increased by 10%, to 25,630 t, from 2015/16 to 2016/17 but was reduced by 14% to 22,000 t in 2017/18.
- Standardized large-vessel CPUE over the last five years has varied without trend at relatively high levels.
- Over 1996 to 2017 the fishable biomass index averaged 136,000 t and in 2017 was 140,000 t; a 31% increase from 2016.
- Over 1996 to 2017 the female SSB index averaged 66,500 t and in 2017 was 55,700 t; a 3% increase from 2016.
- The exploitation rate index has varied without trend with a median value of 15% from 1997-2017/18. If the TAC is fully taken in 2017/18 then the exploitation rate index will be 20.6%.
- Female SSB index is in the Healthy Zone within the IFMP PA Framework, with a 12% chance of being in the Cautious Zone. If the 22,000 t TAC is maintained and taken in 2018/19, then the exploitation rate index will be 15.7%.

SFA 4 *Pandalus borealis*

- TAC was unchanged from 2013/14 to 2016/17 and was increased by 5% to 15,725 t in 2017/18. The TAC has been fully taken.
- Large-vessel standardized CPUE varied without trend near the long-term mean (1989-2016/17).
- Over 2005 to 2017 the fishable biomass index averaged 114,000 t and in 2017 was 82,700 t; a 13% decrease from 2016.

- Over 2005 to 2017 the female SSB index averaged 70,100 t and in 2017 was 55,600 t.
- The exploitation rate index was about 15% for 2014-16 and was 19.4% in 2017/18.
- Female SSB index in 2017 was in the Healthy Zone within the IFMP PA Framework with a 56% probability of having been in the Cautious Zone and a 3% probability of having been in the Critical 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. 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* is found in the Eastern and Western Assessment Zones, directly to the north of SFA 4 (DFO 2017b). 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 simulations of larval dispersal within SFAs 4–6 indicated that northern shrimp larvae may travel several hundreds of kilometres before settlement, implying strong downstream connectivity and that a majority of recruits in a particular SFA may come from SFAs farther north. However, larval dispersal simulations were not conducted north of SFA 4. High rates of self-settlement (retention) could occur in SFA 6, often in association with weaker currents in the area. 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. in press).

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

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 2) in the mid-1970s, primarily in the Hopedale and Cartwright Channels. Soon after, concentrations of Northern Shrimp were located within SFAs 4 and 6 leading to an expansion of the fishery into those areas. 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, in each SFA. Each license can bridge up to 750 t, but in SFA 6 3,200 t total was bridged in 2015/16 and no bridging has been permitted since.

Despite linkages between shrimp populations in SFAs 4–6, they are managed independently (i.e. TACs are allocated only with consideration for that particular SFA) from one another. TACs in SFAs 4–6 combined have been decreasing since the 2009/10 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 48,125 t in 2017/18.

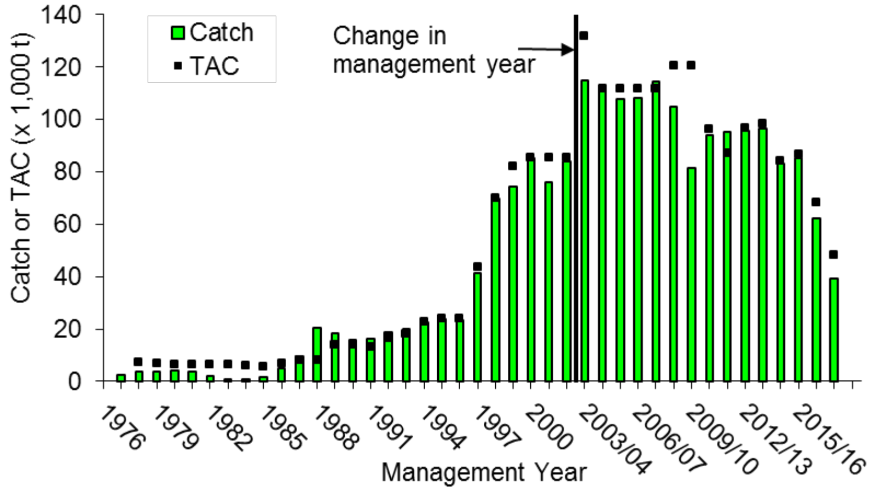

Figure 2. Historical Northern Shrimp catches and TACs (SFAs 4–6 combined) for the period 1977-2017/18. Catches for 2017/18 are preliminary and from the CAQR as of February 2, 2018. The black vertical line indicates the year in which the fishery switched from a calendar to a fiscal year. Quota transfers and season bridging are not represented 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 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 was assessed based on DFO fall multi-species trawl survey data (SFAs 5 and 6, 1996–2017) and NSRF summer trawl survey data (SFA 4, 2005-17); both surveys use the same gear and tow protocols with similar sampling protocols.

Trawl survey data for SFAs 4–6 provided information on shrimp distribution, length frequencies, biomass indices and potential predators (SFAs 5–6 only). 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 and Sullivan 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) 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 (DFO 2007b). This framework was developed in 2008–10 following the 2008 framework workshop attended by a Marine Stewardship Certification (MSC) working group and that included representation from DFO Science, DFO Fisheries Management and industry stakeholders.

Reference points for the DFO PA Framework (DFO 2006), also in use in the IFMP PA Framework, were developed using proxies. The upper stock reference (USR) was defined as 80%, and limit reference point (LRP) as 30%, of the geometric mean of female SSB index over a productive period. Because of differences in survey history, the reference periods were taken to be 1996–2003 for SFA 6, 1996–2001 for SFA 5 and 2005–09 for SFA 4. The value of the PA reference points were revised slightly in 2016 and again in 2018, in accordance with refinements in the biomass estimation method. The PA Framework itself has not changed.

In order to demonstrate historic changes in SFAs 5 and 6 shrimp biomass, analysis was presented on time series 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). 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 1979–90 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

A regional Composite Climate Index in SFAs 4–6 showed a warming trend since the mid-1990s that peaked in 2010, but thereafter decreased to mostly below normal conditions during the past 4-years. This implies generally colder and fresher ocean conditions than the 1981-2010 (normal) long-term average.

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 that may impact the transfer of energy to higher trophic levels across SFAs 4–6 in recent years.

The area of the bottom thermal habitat (2 to 4°C) within many areas of SFAs 5 and 6, typically inhabited by shrimp, was near the long-term mean, suggesting that thermal habitat is not a limiting factor for Northern Shrimp.

SFA 6 *Pandalus borealis*

Ecosystem

Ecosystem conditions in the Newfoundland Shelf (NAFO Divisions 2J3K) are indicative of an overall low productivity state, with both total shellfish and total finfish biomass showing declines since the early–mid 2010s. Current total biomass is at similar levels to those observed in the mid-1990s. However, shellfish comprises a much lower proportion of the current biomass.

Predation, fishing and environmental forcing are correlated with subsequent shrimp production at different time lags, although the precise linkage with environmental variables remains unclear. The build-up of shrimp until the mid-2000s occurred during a period of favourable environmental conditions and reduced predation. The Composite Environmental Index (CEI) is based on standard anamolies of meteorological data, ice cover, bottom temperature, cold intermediate layer and salinity (DFO 2017d). Large scale and persistent conditions, as captured by the Cumulative Composite Environmental Index (CENV), appear associated with shrimp per capita net production; however, inter-annual variations associated with the CEI and specific metrics of the spring phytoplankton bloom, while still significant, do not show a consistent pattern with previous analyses (DFO 2017a). The highest correlations found (three year lag unless otherwise specified) were (Figure 3):

- A negative correlation with the exploitation fraction (i.e. fishing) with a 2 year lag,
- A negative correlation with predation (i.e. with the DFO fall multi-species survey biomass index of the fish functional groups considered to be shrimp predators),
- A negative correlation with the estimated median shrimp consumption by these predators,
- A negative correlation with the cumulated composite environmental index,
- A negative correlation with the magnitude of the spring phytoplankton bloom,
- A negative correlation with the initiation time of the spring phytoplankton bloom with a 1 year lag, and
- A positive correlation with the duration of the spring phytoplankton bloom with a 1 year lag.

Shrimp per-capita net production has declined since the mid-1990s and, based on the current results and the observed trends in the identified drivers, is expected to remain around current low values for the next 2–3 years. Longer term predictions based on these correlations are not possible.

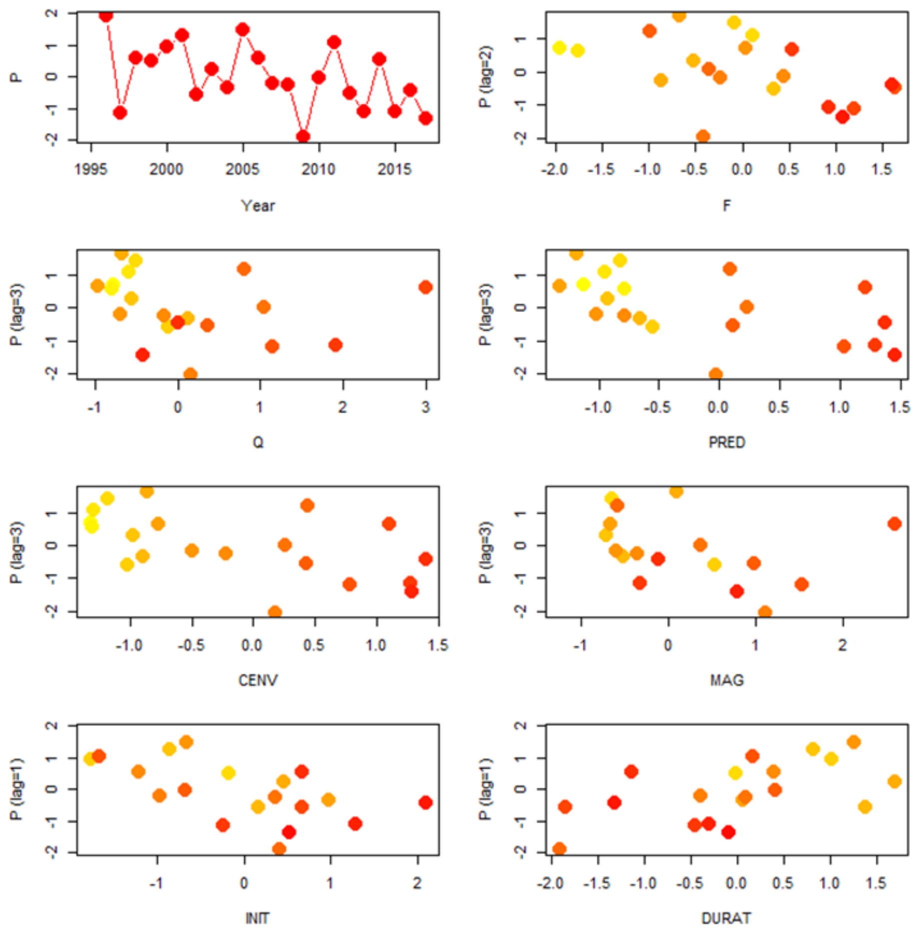

Figure 3. Relationships between shrimp per-capita net production (P in this figure) and fishing (F), predator consumption (Q), predation (PRED), cumulated composite environmental index (CENV), magnitude of spring bloom (MAG), initiation of spring bloom (INIT) and duration of spring bloom (DURAT) drivers in NAFO Divisions 2J3KL during the 1995–2017 period. The trend of shrimp per-capita net production over time (P in this figure) is presented in the upper left corner. All other plots display the relationship between P and key drivers at the lag that had the highest correlation. In these plots, the color of the markers provides an indication of the time dimension (yellow corresponds to the early years, gradually turning into red by the end of the time series). All drivers have been normalized; the x-axis is standard deviations from the mean.

Fishery

The TAC was set at 11,050 t in 1994 and increased to 23,100 t in 1997 (Figure 4) as a first step towards increasing the exploitation of an abundant resource. Most of the TAC increases from 1997 onwards were allocated to the small-vessel fleet. The TACs, and subsequently the catches, increased significantly to a maximum of 85,725 t in 2008/09–2009/10 after which TAC reductions were applied periodically. TAC was reduced by 42%, to 27,825 t, from 2015/16 to 2016/17 and further, by 63%, to 10,400 t in 2017/18; however it is uncertain if the TAC will be fully taken based on the portion of the catch taken as of the assessment and on verbal communication with harvesters. As of the February 2, 2018 CAQR, 78% of the TAC had been taken.

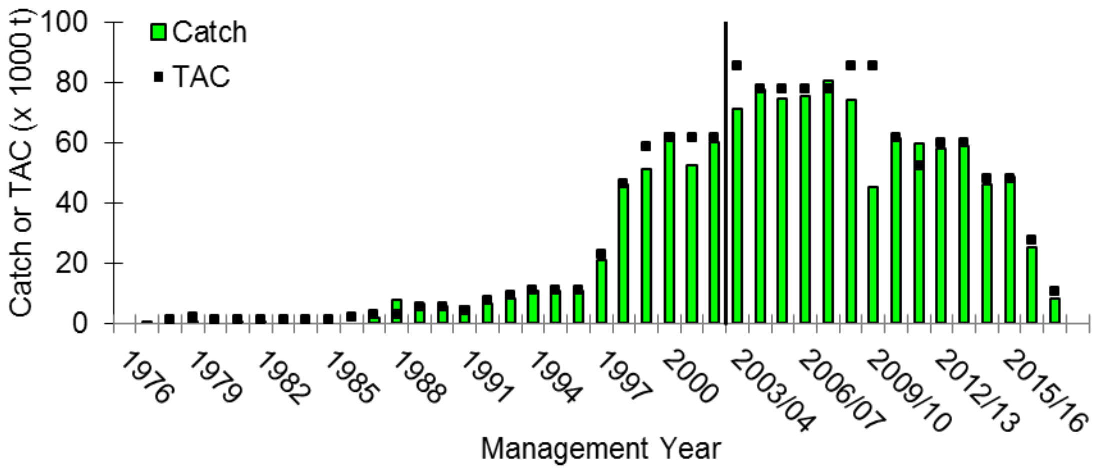

Figure 4. Historical Northern Shrimp catches and TAC in SFA 6 for the period 1977–2017/18. 2017/18 values are preliminary, based upon the CAQR as of February 2, 2018. In 2003, the management year changed from a calendar to a fiscal year, as indicated by the black vertical line.

The annual commercial CPUE declined considerably in recent years to the lowest levels in two decades (Figure 5).

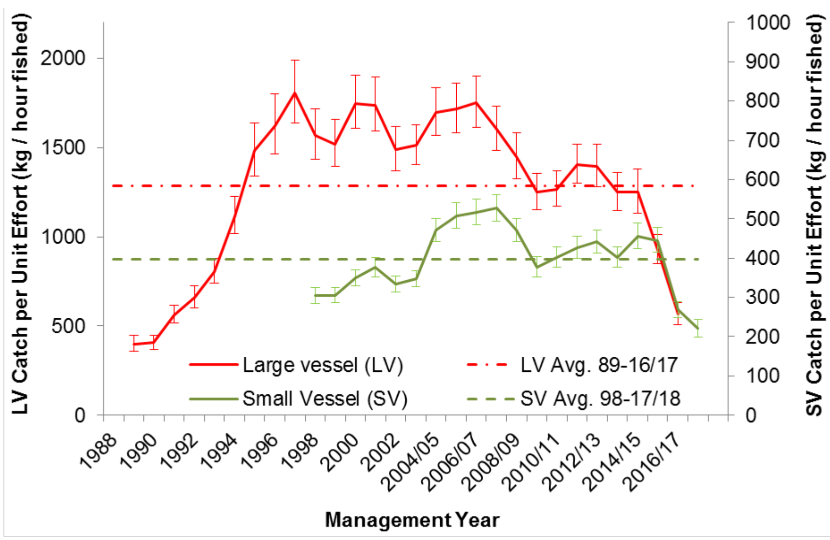

Figure 5. SFA 6 large-vessel annual standardized CPUE (red solid upper line) and small-vessel annual standardized CPUE (green solid lower line). Error bars indicate 95% confidence intervals. The 2017/18 large-vessel annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2017 the fishable biomass index averaged 407,000 t and in 2017 was 87,300 t; a 16% decrease from 2016 and the lowest level in the time series. Over 1996 to 2017 the female SSB index averaged 254,000 t and in 2017 was 52,700 t; a 19% decrease from 2016 and the lowest level in the time series (Figure 6).

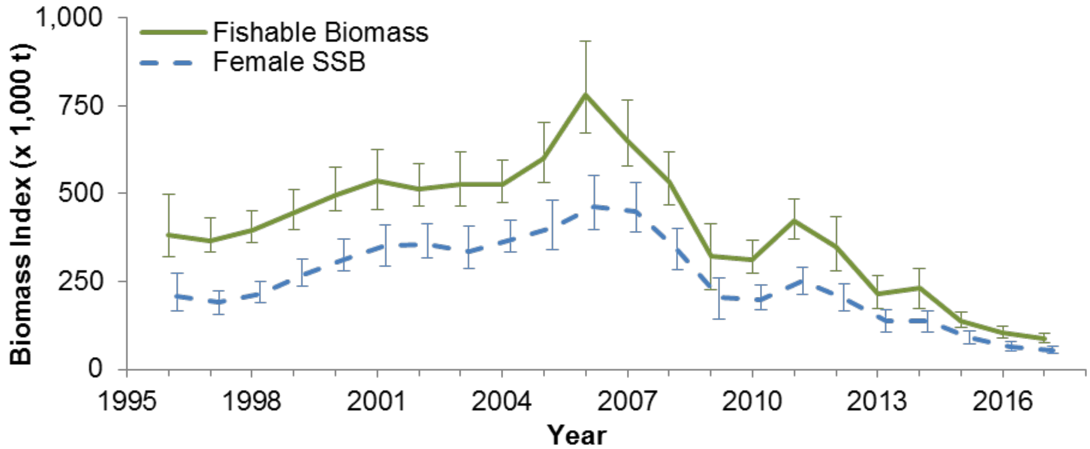

Figure 6. SFA 6 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Renewal

Resource renewal was examined considering both the causes of net change in total biomass as a result of production (growth and reproduction), as well as predation and fishing, and inferences that could be drawn from the 1995–2017 time series of survey and shrimp commercial catch data.

Renewal is the difference between the increase due to production, and removal largely due to predators and shrimp harvesting. The amount of total biomass produced by a unit of biomass of a given species during a year before predation and fishing are taken into account is commonly known as the production over biomass ratio (P/B); although actual P/B ratios are expected to vary, an expectation of annual production can be estimated under certain assumptions (e.g., average conditions). In other shrimp populations, the P/B ratio for shrimp has been estimated to be around 1.7 which was the P/B ratio used for SFA 6 Northern Shrimp. A P/B ratio of 1.7 implies that the biomass of shrimp available for predator consumption should be somewhere between 1 and 2.7 times the beginning of year biomass. Integrated shrimp availability provides an approximation of how many shrimp would be available to any form of mortality (predation, fishing, etc.) over the entire year. For NAFO Divisions 2J3KL (largely corresponding to SFA 6), estimates of predation by fish were obtained based on the mass of shrimp found in predator stomachs during the fall multi-species survey (see DFO 2015 for references).

Predation on shrimp, and the associated predation mortality rate, showed an increasing trend until 2011, and has decreased since (Figure 7). This decrease is associated with an increase in consumption of capelin by predators in conjunction with the combined biomass of shrimp predators remaining relatively steady since 2011. 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 (i.e. the red and black lines in Figure 7) is a relative index of predation mortality and is currently around double the level in the mid-1990s and 2000s. Shrimp predation mortality in the near future is expected to remain relatively high unless abundance of alternative prey increases.

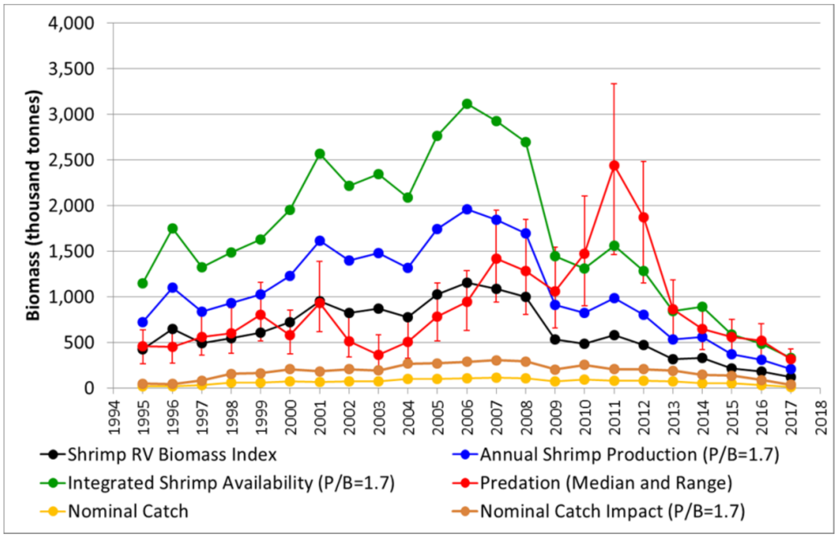

Figure 7. Comparison of predation and fisheries catches with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a P/B ratio of 1.7.

Uncertainty about various conversion factors (e.g., P/B ratio, species catchability, conversion from stomach contents to predation rates) makes it difficult to derive precise conclusions, especially when subtracting two series that depend on different factors; but production appears to have sufficiently exceeded predation until about 2008. This suggests that a large fraction of shrimp biomass being produced (through growth or recruitment of new shrimp) is being consumed by predators. High levels of predation combined with low shrimp biomass indices in recent years suggests low recruitment to the fishable biomass.

Given current predation pressure on shrimp, fishing pressure could now be more influential on stock declines in SFA 6 than it has been in the past. Fishery removals appear to be small relative to removals by predators, but could be important in determining whether gains (production) exceed losses (predation and fishing) in recent years and hence whether the stock increases or decreases.

Exploitation

The exploitation rate index ranged between 5.5% and 21.5% from 1997 to 2017/18, and has averaged 17% in the last five years (Figure 8). If the TAC is fully taken in 2017/18 then the exploitation rate index will be 10%.

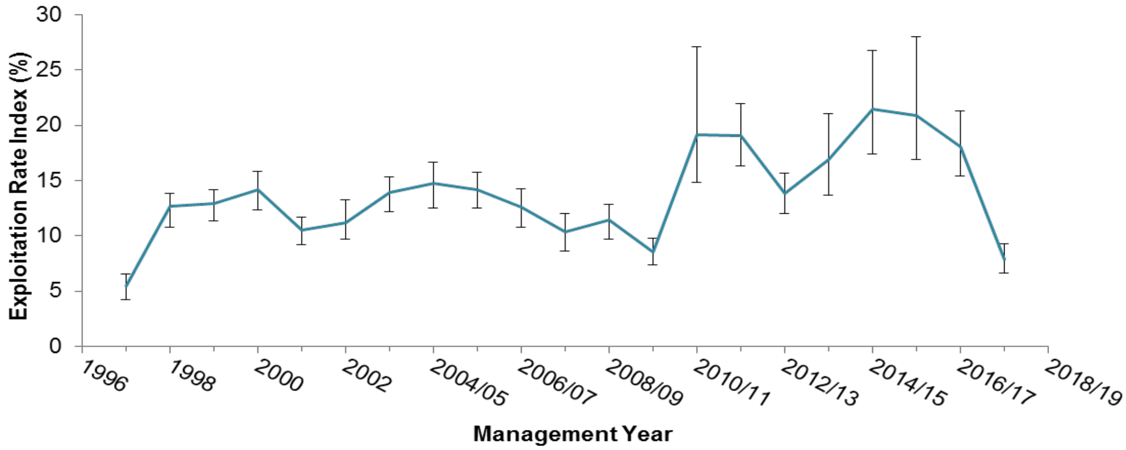

Figure 8. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The 2017/18 point is preliminary and based on total catch as of the February 2, 2018 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

The female SSB index is currently in the Critical Zone of the IFMP PA Framework with greater than 99% probability (Figure 9). The IFMP states that the exploitation rate should not exceed 10% (corresponding to a 2018/19 TAC of 8,730 t) while the female SSB index is in the Critical Zone.

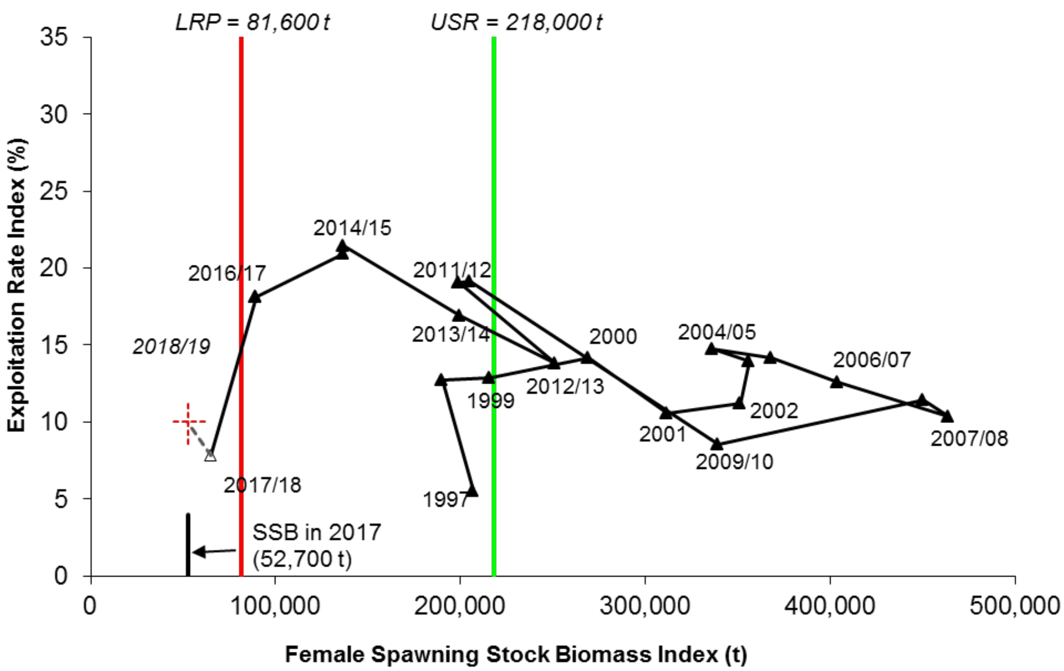

Figure 9. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2017/18 fishery was ongoing and based on reported catch as of February 2, 2018. The red cross on the 2018/19 point indicates 95% confidence intervals for the 2017 female SSB index (horizontal) and the 2018/19 exploitation rate index (vertical), assuming that a 10% exploitation rate is achieved during the 2018/19 fishery.

SFA 5 *Pandalus borealis*

Fishery

TAC was increased by 10%, to 25,630 t, from 2015/16 to 2016/17. It is expected that the 2016/17 TAC will be taken (Figure 10).

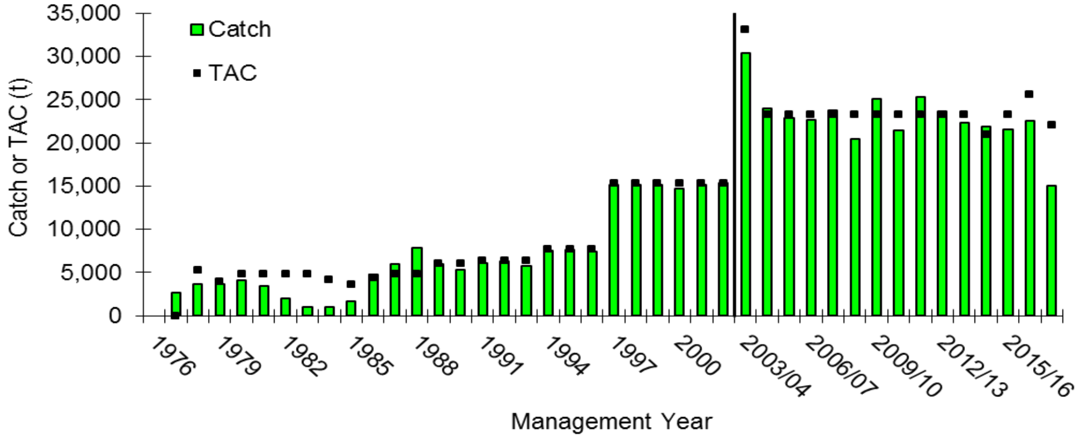

Figure 10. Historical Northern Shrimp catches and TAC in SFA 5 for the period 1977–2017/18. 2017/18 values are preliminary and based upon the CAQR as of February 2, 2018. In 2003, the management year changed from a calendar to a fiscal year, indicated by the black vertical line.

Standardized large-vessel CPUE over the last five years has varied without trend at relatively high levels (Figure 11).

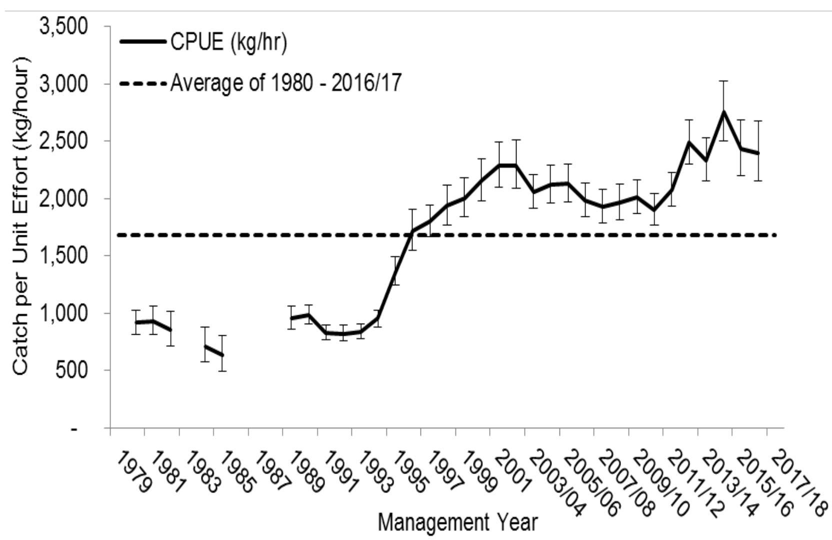

Figure 11. SFA 5 large-vessel annual standardized CPUE. Error bars indicate 95% confidence intervals. The 2017/18 large-vessel annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 1996 to 2017 the fishable biomass index averaged 136,000 t and in 2017 was 140,000 t; a 31% increase from 2016. Over 1996 to 2017 the female SSB index averaged 66,500 t and in 2017 was 55,700 t; a 3% increase from 2016 (Figure 12). The low biomass index in 2013 was likely due to year-to-year variation in survey sampling (i.e. a year effect), rather than low shrimp biomass.

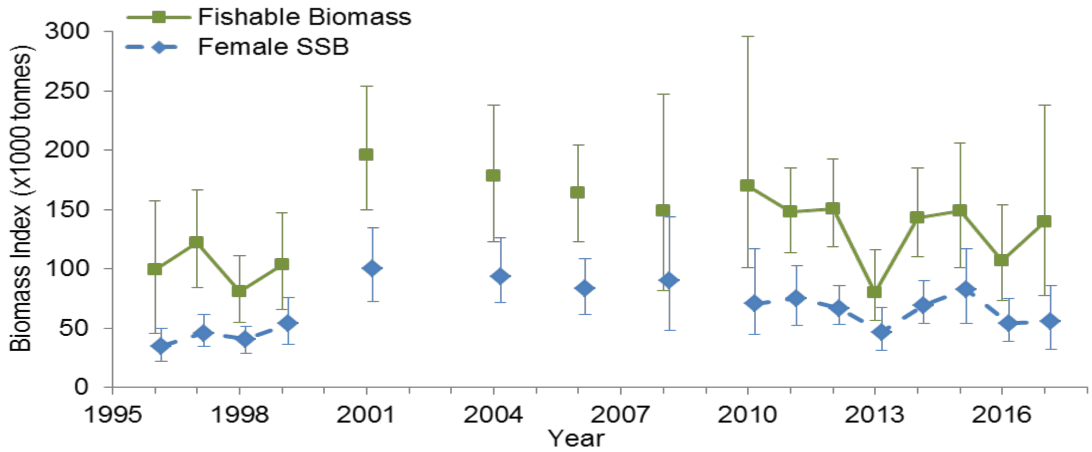

Figure 12. SFA 5 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index has varied without trend with a median value of 15% from 1997–2017/18 (Figure 13). If the TAC is fully taken in 2017/18 then the exploitation rate index will be 20.6%.

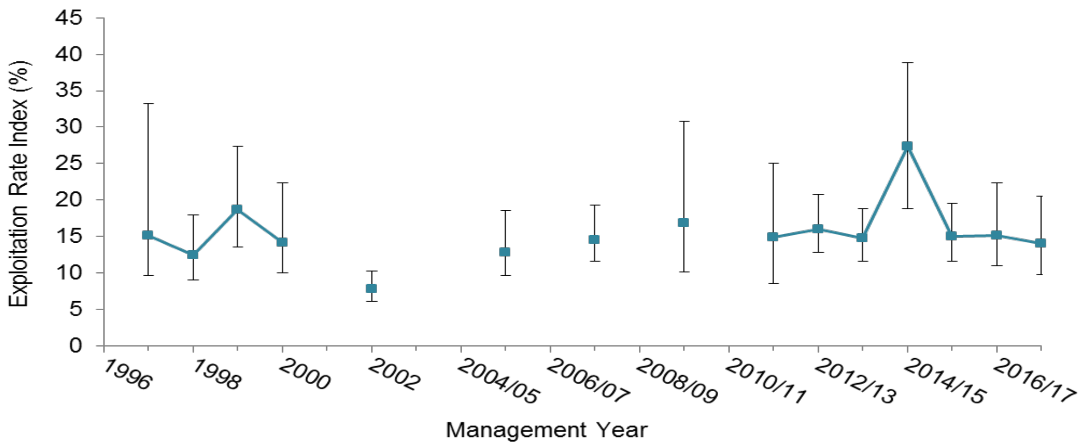

Figure 13. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. Disconnected series points represent years during which the DFO fall multi-species survey did not sample NAFO Division 2H. The 2017/18 point is preliminary and based on total catch as of the February 2, 2018 CAQR. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index is in the Healthy Zone within the IFMP PA Framework, with a 12% chance of being in the Cautious Zone. If the 22,000 t TAC is maintained and taken in 2018/19, then the exploitation rate index will be 15.7% (Figure 14).

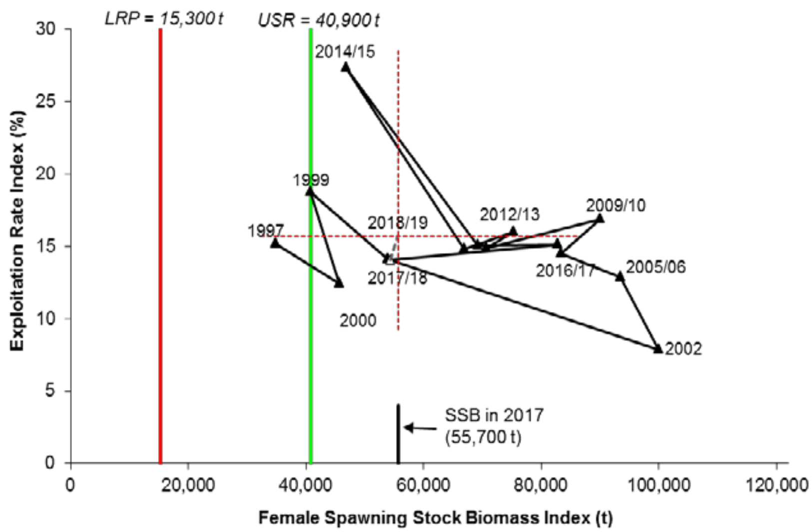

Figure 14. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2017/18 fishery was ongoing and based on reported catch as of February 2, 2018. The red cross on the 2018/19 point indicates 95% confidence intervals for the 2017 female SSB index (horizontal) and the exploitation rate index (vertical), assuming that the 22,000 t TAC is maintained and taken in the 2018/19 fishery.

SFA 4 *Pandalus borealis*

Fishery

The TAC increased from 5,200 t in 1995 to 8,320 t in 1998. From 1998 until 2008/09 a portion of the TAC was allocated to the area south of 60°N to promote spatial expansion of the fishery, during which time the TAC was increased about every four years. TAC was unchanged from 2013/14 to 2016/17 and was increased by 5% to 15,725 t in 2017/18. The 2017/18 TAC has been fully taken (Figure 15).

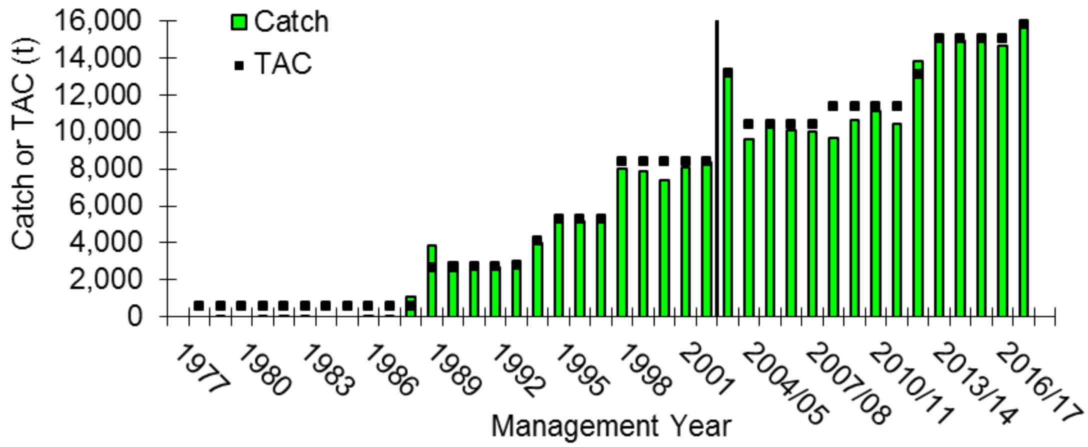

Figure 15. Historical Northern Shrimp catches and TAC in SFA 4 for the period 1977–2017/18. 2017/18 values are preliminary and based upon the CAQR as of February 2, 2018, however the full TAC had been taken at the time of the assessment. In 2003, the management year changed from a calendar to a fiscal year, indicated by the black vertical line.

Large-vessel standardized CPUE varied without trend near the long-term mean (1989-2016/17, Figure 16). 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.

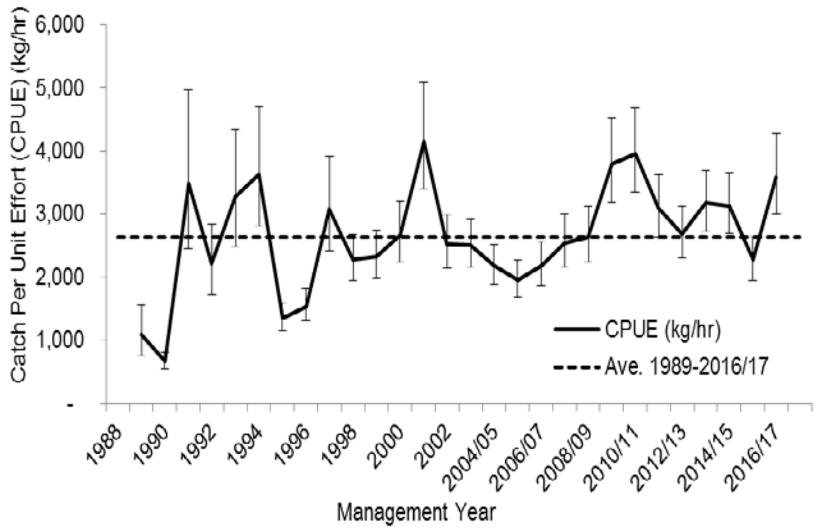

Figure 16. SFA 4 large-vessel standardized CPUE (kg/hr) for Northern Shrimp. Error bars indicate 95% confidence intervals and the dashed line indicates the long term average. The 2017/18 large-vessel annual standardized CPUE index is not displayed due to incomplete data.

Biomass

Over 2005 to 2017 the fishable biomass index averaged 114,000 t and in 2017 was 82,700 t; a 13% decrease from 2016. Over 2005 to 2017 the female SSB index averaged 70,100 t and in 2017 was 55,600 t (Figure 17).

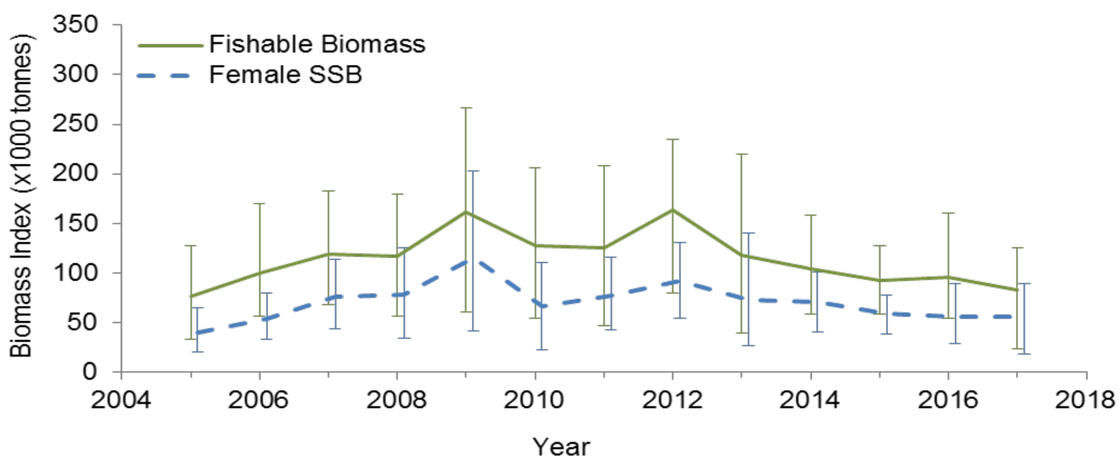

Figure 17. SFA 4 fishable biomass (green solid line) and female SSB (blue dashed line) indices for Northern Shrimp. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index was about 15% for 2014-2016 and was 19.4% in 2017/18 (Figure 18). The confidence intervals surrounding the 2017/18 exploitation rate index 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 is the lowest in the time series in 2017. For this reason the upper confidence interval of the 2017/18 exploitation rate index is very high.

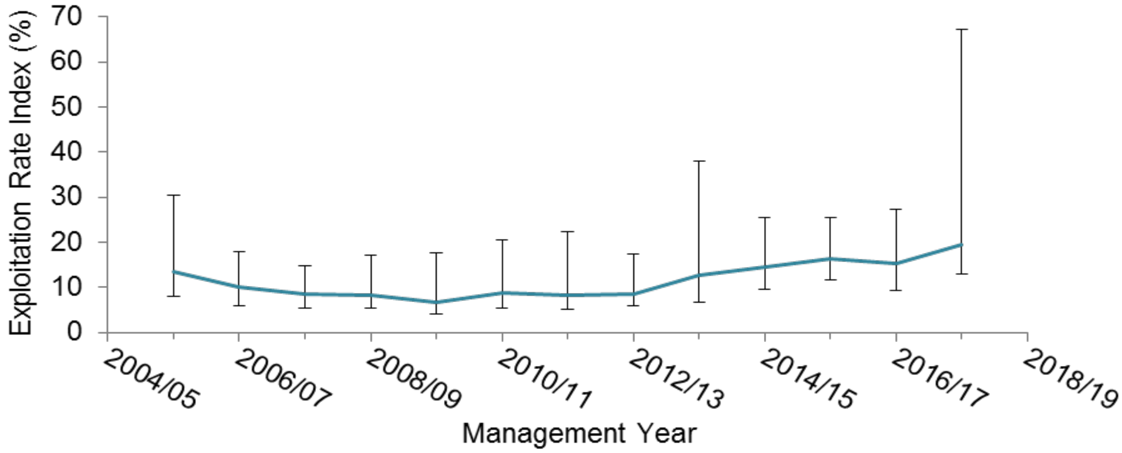

Figure 18. SFA 4 exploitation rate index for Norther Shrimp, based on total catch divided by fishable biomass index, both from the same year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index in 2017 was in the Healthy Zone within the IFMP PA Framework with a 56% probability of having been in the Cautious Zone and a 3% probability of having been in the Critical Zone (Figure 19). Given the relatively wide and asymmetric confidence intervals, there is a >50% chance the current SSB index is not in the healthy zone. The point estimate, however, falls just above the boundary between the cautious and healthy zones (i.e. the USR).

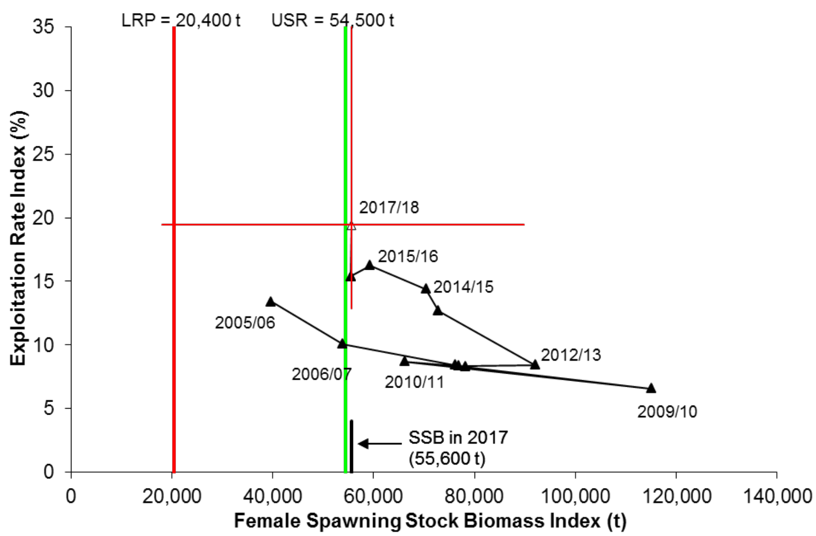

Figure 19. SFA 4 PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote year of the fishery. The red cross on the 2017/18 point indicates 95% confidence intervals for the 2017 female SSB index (horizontal) and the 2017/18 exploitation rate index (vertical, upper limit ends at 67%).

Sources of Uncertainty

Estimates of predation on the shrimp population, in comparison with its productive potential, depend on a number of assumptions that may need to be investigated and refined:

1. It is assumed that there is always sufficient prey available to predators.
2. It is assumed that the diet composition (and species overlap) observed in stomachs collected in fall surveys applies throughout the year for each year in which that data was available. No inferences can be made from species without stomach sampling.
3. Inferences for future consumption require further assumptions about how the diet composition changes as the relative amount of different prey types changes; these assumptions may or may not hold true.
4. It may well be that many of the shrimp found in stomachs of predators are of a size too small to be caught well by the research survey gear.
5. The P/B ratio gives an upper bound on the amount of shrimp production. The higher predation pressure is, the more shrimp will be eaten early in the year, before their (potential) production can happen.

Furthermore, the ecosystem in which shrimp live is changing. Predator populations had been increasing and are now stable at relatively high levels for the DFO multi-species survey time series, and the physical determinants of production are expected to change in unknown ways.

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 had been 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 2016–17, 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 not be important. 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 (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 (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 multi-species survey in SFA 6 have not been resolved. Fleet representatives at the meeting confirmed that catch rates in SFA 6 have been poor this year.

CONCLUSIONS AND ADVICE

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 is currently in the Critical Zone for the second 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*

The fishable biomass index increased by 31% and the female SSB index increased by 3% between 2016 and 2017, both are near their long-term mean. Female SSB index is in the Healthy Zone within the PA Framework with a 12% probability of being in the Cautious Zone. If the 22,000 t TAC is maintained and taken in 2018/19, then the exploitation rate index will be 15.7%.

SFA 4 *Pandalus borealis*

The fishable biomass index decreased by 13% and the female SSB index changed little from 2016 to 2017. Female SSB index in 2016 was in the Healthy Zone, slightly above the USR within the PA Framework, with a 56% probability of having been in the Cautious Zone and a 3% 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 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, as in recent years, 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 SFAs 4, 5 and 6; much of the recruitment to the pre-recruit biomass likely originates north of SFAs 5 and 6. Larvae released from shallow areas achieved much higher settlement success than larvae released from offshore areas, irrespective of the year of study.

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 2017c). 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.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 13-14, 2018 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. 2006. A Harvest Strategy Compliant with the Precautionary Approach. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2006/023.

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

DFO. 2007b. Integrated Fisheries Management Plan: Northern Shrimp - Shrimp Fishing Areas (SFAs) 0-7 and the Flemish Cap.

DFO. 2009. Proceedings of the Precautionary Approach workshop on shrimp and prawn stocks and fisheries; November 26-27, 2008. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2008/031.

DFO. 2015. Assessment of Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Areas 4-6 (NAFO Divisions 2G-3K) and of Striped Shrimp (*Pandalus montagui*) in Shrimp Fishing Area 4 (NAFO Division 2G). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/018.

DFO. 2017a. 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 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/012.

DFO. 2017b. *Assessment of Northern Shrimp, Pandalus borealis, and Striped Shrimp, Pandalus montagui*, in the Eastern and Western Assessment Zones, February 2017. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/010. (Erratum: April 2017).

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

DFO. 2017d. Oceanographic conditions in the Atlantic zone in 2016. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/031.

Evans, G.T., Parsons, D.G., Veitch, P.J., and Orr, D.C. 2000. A local-influence method of estimating biomass from trawl surveys, with Monte Carlo confidence intervals. J. Northw. Atl. Fish. Sci. 27: 133–138.

Fisheries Act (R.S.C., 1985, c. F-14)

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

Le Corre, N., Pepin, P., Han, G., Ma., Z., Snelgrove, PVR. Submitted. Assessing connectivity patterns among management units of the Newfoundland and Labrador shrimp population. Fisheries Oceanography FOG-18-1441.

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

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ISSN 1919-5087

Correct Citation for this Publication:

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

Aussi disponible en français :

MPO. 2018. Évaluation de la crevette nordique (Pandalus borealis) dans les zones de pêche de la crevette 4 à 6 en 2017. Secr. can. de consult. sci. du MPO, Avis sci. 2018/018.