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Canadian Science Advisory Secretariat
Newfoundland and Labrador Region **Science Advisory Report 2017/012**

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

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

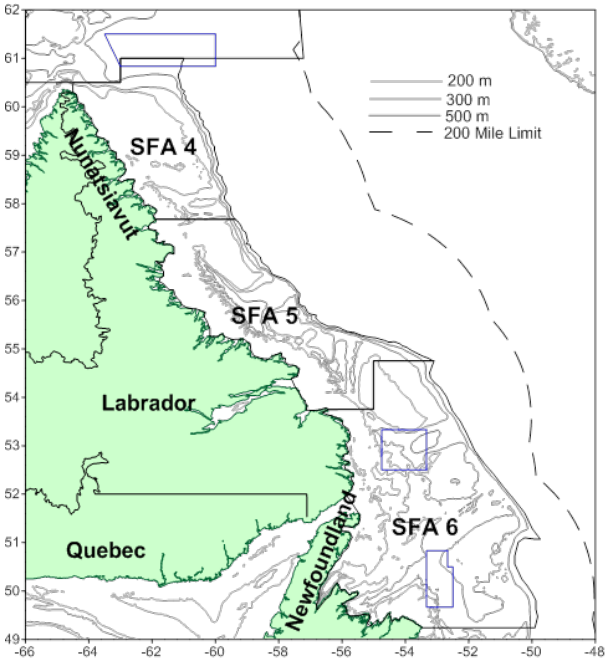

Figure 1. Map of Shrimp Fishing Areas (SFAs) 4-6. Blue boxes indicate closed areas (Coral box, Hawke Box and Funk Island Deep box from North to South).

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. Striped Shrimp (*Pandalus montagui*) in SFA 4 are primarily taken as by-catch during the Northern Shrimp Fishery in that area.*

The last Zonal Peer Review Process that assessed both Northern Shrimp in SFAs 4-6 and Striped Shrimp in SFA 4, and Northern and Striped Shrimp in the Eastern and Western Assessment Zones was held in February, 2015 (DFO 2015a and 2015b). A stock status update for shrimp in the Eastern and Western Assessment Zones was held in January 2016 (DFO 2016b). The February 2016 update of Northern and Striped Shrimp in SFAs 4-6 (DFO 2016a) triggered a full assessment which was held in April, 2016 (DFO 2016c).

A Zonal Peer Review Process was held February 16–17, 2017 in St. John's, Newfoundland and Labrador (NL) to assess Northern and Striped Shrimp. Participants included DFO scientists, fisheries

managers, and representatives from the NL Provincial Government, Nunatsiavut Government, academia, Aboriginal communities and organizations, and industry.

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 Zone Monitoring Program (AZMP). Together these provided information on catch rates, distribution, exploitation rate, biomass, predators and potential environmental drivers.

SUMMARY

- Resource status of Northern Shrimp in Shrimp Fishing Areas (SFAs) 5 and 6 was assessed based on Fisheries and Oceans Canada (DFO) fall multi-species trawl survey data (1996–2016). Resource status for Northern Shrimp and Striped Shrimp in SFA 4 was updated based on Northern Shrimp Research Foundation (NSRF)-DFO summer trawl survey data (2005–16).
- 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, fishery catch per unit effort (CPUE) and fishing patterns.

Environment and Ecosystem (SFA 6 and Southern SFA 5)

- The regional Composite Climate Index recovered in 2016 to above 1981–2010 average (normal) conditions after declining for several years in a row to among the lowest in the time series.
- Fall bottom temperatures were above normal in 2016, resulting in above normal areas of potential thermal (2 °C to 4 °C) habitat.
- Consistent with below normal sea ice extent, the phytoplankton bloom in 2016 was earlier than in the past three years. This could lead to a further reduction in shrimp productivity in the short term.
- Environmental forcing, predation and fishing are correlated with subsequent shrimp production. The build-up of shrimp until the mid-2000s occurred during a period of favourable environmental conditions and reduced predation.
- Shrimp per-capita production has declined since the mid-2000s. Environmental conditions and increasing predation pressure appear as important drivers for the decline. Recent environmental conditions may lead to improved shrimp per-capita production but are unlikely to trigger rebuilding of the resource in SFA 6 (at a rate similar to the build-up period) over the medium term when considered in combination with high predation pressure.
- 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 high unless abundance of alternative prey increases.
- Given declining production of shrimp, fishing pressure could now be influencing stock declines in SFA 6 more than it did in the past.

SFA 6 *Pandalus borealis*

- TAC was reduced by 42%, to 27,825 t, from 2015/16 to 2016/17; however, it is uncertain if the TAC will be fully taken.

- The annual commercial CPUE has demonstrated a declining trend for about the last ten years.
- Commercial and survey data demonstrate a contraction of the resource within recent years.
- Fishable biomass index declined from 785,000 t in 2006 to 104,000 t in 2016, which is the lowest in the time series. There was a 25% decline between 2015 and 2016.
- Female spawning stock biomass (SSB) index declined from 466,000 t in 2006 to 65,000 t in 2016 which is the lowest in the time series. There was a 27% decline between 2015 and 2016.
- The exploitation rate index ranged between 5.5% and 21.4% from 1997 to 2016/17, and has averaged 17.8% in the last five years. The 2016/17 exploitation rate index will be 20.2% if the TAC is taken.
- 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. If the 27,825 t TAC is maintained and taken in the 2017/18 season, the exploitation rate index will be 26.8%.
- The IFMP states that the exploitation rate should not exceed 10% 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.
- Standardized large-vessel CPUE over the last five years has been stable at relatively high levels.
- Fishable biomass index has decreased, by 27%, from 149,000 t in 2015 to 110,000 t in 2016.
- Female SSB index has decreased, by 35%, from 83,200 t in 2015 to 54,300 t in 2016.
- The exploitation rate index has varied without trend around 15% from 1997–2016/17.
- Female SSB index is in the Healthy Zone within the IFMP PA Framework, with a 6% chance of being in the Cautious Zone. If the 25,630 t TAC is maintained and taken in 2017/18, then the exploitation rate index will be 23.3%.

SFA 4 *Pandalus borealis*

- TAC has remained the same, at 14,971 t, since 2013/14.
- Large-vessel standardized CPUE fluctuated without trend near the long-term mean.
- Between 2005 and 2012 the fishable biomass index ranged between 76,600 t and 164,000 t and in 2016 was 95,300 t.
- Between 2005 and 2012 the female SSB index ranged between 39,700 t and 115,000 t and in 2016 was 55,500 t.
- The exploitation rate index has been about 15% for the past three years.
- Female SSB index in 2016 was in the Healthy Zone within the IFMP PA Framework with a 45% probability of having been in the Cautious Zone.

SFA 4 *Pandalus montagui*

- Commercial catch of *P. montagui*, taken as by-catch in the *P. borealis* fishery, increased from 280 t in 2008 to 4,700 t in 2012 and declined to 1,092 t in 2016. The by-catch limit of 4,033 t has not been taken in the past four years.
- Fishable biomass index for 2016 was 23,900 t, a decrease of 49% from 2015.
- Female SSB is unknown.
- If the by-catch limit had been taken, the exploitation rate would have been 8.7% in 2016/17.
- There is no IFMP PA Framework for this resource.

BACKGROUND

Species Distribution and Stock Boundaries

Northern or Pink Shrimp (*Pandalus borealis*) are found in the Northwest Atlantic from Baffin Bay south to the Gulf of Maine. Striped Shrimp (*Pandalus montagui*) are found in the Northwest Atlantic from Davis Strait south to the Bay of Fundy. Northern Shrimp prefer an ocean floor that is somewhat soft and muddy and where temperatures range from about 1 °C to 6 °C. However; the majority of Northern Shrimp are caught in waters from 2 °C to 4 °C. These conditions typically occur at depths of 150–600 m and exist throughout the Newfoundland and Labrador offshore area. In contrast, Striped Shrimp prefer a hard bottom and are typically found in colder waters from 1 °C to 2 °C at depths of 100–300 m. Although the temperature, depth and bottom type preferences differ slightly between species, their populations overlap; the extent of the overlap has not been examined. Northern Shrimp represents the primary shrimp resource in the North Atlantic.

While management boundaries are, to some extent, arbitrary and selected based on factors other than science, the northern boundary of SFA 4 leads to more questions/uncertainties than the boundaries between other SFAs; applying a similar harvest strategy across all areas mitigates the consequence of potential boundary issues. In addition to being found in SFA 4, both *P. borealis* and *P. montagui* are found in the Eastern and Western Assessment Zones, directly to the north of SFA 4 (DFO 2016b). 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. This current transports shrimp, particularly larvae, from north to south; however, the extent and full effects are unknown. Studies of genetics between Northern Shrimp populations in SFAs 4–6 have demonstrated that the Northern Shrimp in these areas are largely homogenous genetically (Jordel et al. 2014). This is most likely due to larval and pelagic transport by the Labrador Current. Despite the relationships between SFAs 4–6, the Northern Shrimp resources in these areas are managed (and hence assessed) on an individual SFA basis rather than as a whole.

Species Biology

Both Northern and Striped Shrimp are protandrous hermaphrodites. They are born and first mature as males, mate as males for one or more years and then change sex to spend the rest of their lives as mature females. They are thought to live for more than eight years. Some northern populations exhibit slower rates of growth and maturation, but greater longevity results

in larger maximum size. Females produce eggs in the late summer-fall and carry the eggs on their pleopods until they hatch in the spring.

Shrimp are thought to begin to recruit to the fishery around age three. Most of the fishable biomass is female; however, the proportion of females in the fishable catch varies by SFA and year.

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

Fishery

The fishery for Northern Shrimp off the coast of Labrador began in SFA 5 (Figure 1) in the mid-1970s, primarily in the Hopedale and Cartwright Channels. Soon after, concentrations of Northern Shrimp were located within SFAs 4 and 6 leading to an expansion of the fishery into those areas. As the fishery expanded to Hawke Channel, St. Anthony Basin and Funk Island Deep (three small areas within SFA 6), 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.

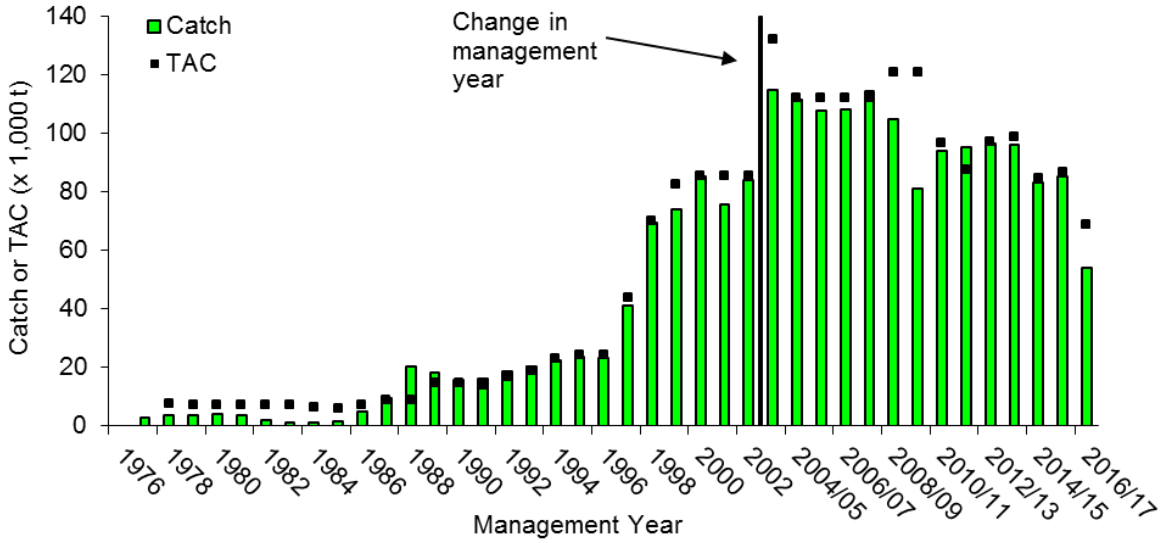

Figure 2. Historical Northern Shrimp catches and TACs (SFAs 4–6 combined) for the period 1977-2016/17. 2016/17 catches are preliminary and from the CAQR as of February 8, 2017. The black vertical line indicates the year in which the fishery switched from a calendar to a fiscal year.

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 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. To facilitate this change, an additional interim 20,229 t quota was allocated to the large-vessel fleet during the 15-month long management year (January 1, 2003

to March 31, 2004). The amount of additional quota differed by SFA and was based on average commercial catch, by the large-vessel fleet, from January to March during 1998–2002. 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 could be bridged in 2015/16 and no bridging was permitted in 2016/17.

Despite linkages between shrimp populations in SFAs 4–6, they are managed independently (i.e. TACs are allocated only with consideration for the population in that particular SFA) from one another. TACs in SFAs 4–6 combined have been decreasing since the 2009/10 management year, mainly due to TAC reductions in SFA 6; the combined TAC was 120,345 t in 2009/10. The overall TAC in 2015/16 was 86,467 t. The 2015 survey showed declines in SFA 6 leading to a 42% reduction in the TAC while the SFA 5 TAC was increased by 10% and the SFA 4 TAC remained the same; the overall TAC in 2016/17 was 68,426 t.

Northern Shrimp has generally been the target shrimp species in SFA 4. Management measures implemented in 2013/14 designated SFA 4 Striped Shrimp as a by-catch only fishery with a harvest limit of 4,033 t. Northern Shrimp are usually more valuable and marketable than Striped Shrimp. Depending on market conditions, and in order to reduce by-catch, vessels often move away from areas where the catch has a significant proportion of Striped Shrimp.

Although the fishery is open year-round in SFAs 4–6, ice conditions in SFA 4 typically only allow access from early summer to late fall or early winter. Moreover, the catch of Striped Shrimp is mainly at the northern fringe of SFA 4 (north of 60 °N), rather than being distributed over the entire SFA.

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 rarely achieved.

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 of which a resource renews itself informs decisions on harvest rates that are sustainable. For ecosystem-based management, which is not yet defined or incorporated into the IFMP, 'harvest' would be replaced by some combination of harvest and ecosystem function.

Resource status of Northern Shrimp in SFAs 5 and 6 was updated based on DFO fall multi-species trawl survey data (1996–2016). Resource status for Northern Shrimp and Striped Shrimp in SFA 4 was updated based on the NSRF-DFO summer shrimp trawl survey data (2005–16).

Trawl survey data for SFAs 4–6 provided information on shrimp distribution, length frequencies, biomass indices and potential predators (SFAs 5–6). Fishable biomass is defined as the weight of all males and females with a carapace length > 17 mm and female SSB is defined as the weight of all female shrimp. 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. Trends in fisheries performance were inferred from TAC, commercial catch to date, fishery CPUE and fishing patterns.

Exploitation rate index was determined by dividing the commercial catch 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 reflected in the IFMP (DFO 2007b). This framework was developed in 2008-10, following the 2008 framework workshop, by a Marine Stewardship Certification (MSC) working group 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. PA reference points have been revised from the assessments prior to 2016, in accordance with refinements in the biomass estimation method. The PA Framework itself has not changed.

A Science Response Process meeting was held in January 2017 to review the reference points used in the PA Framework for Northern Shrimp in SFA 6 (DFO 2017). Since the PA reference points were developed, there have been changes in environment, ecosystem and predation; factors that can have negative impacts on Northern Shrimp. Despite the decline in shrimp per-capita net production as a result of these changing factors, there was insufficient evidence of a change in shrimp productivity regime, how it might change in the short term or how changing the reference points would affect the resource. Because of the high level of uncertainties, lowering the current biomass reference points would involve a high amount of risk to the ecosystem and to the resource. It was concluded that the current biomass reference points used in the Northern Shrimp PA would remain unchanged.

SFA 6 *Pandalus borealis*

Environment and Ecosystem

The regional Composite Climate Index recovered in 2016 to above 1981–2010 average (normal) conditions after declining for several years in a row to among the lowest in the time series.

Consistent with below normal sea ice extent, the phytoplankton bloom in 2016 was earlier than in the past three years (DFO 2016d). This could lead to a further reduction in shrimp productivity in the short term.

Fall bottom temperatures were above normal in 2016, resulting in above normal areas of potential thermal (2 °C to 4 °C) habitat for Northern Shrimp.

Environmental forcing, predation and fishing are correlated with subsequent per-capita shrimp net production 1–4 years later. The highest correlations (three-year lag unless otherwise stated) found were:

- A negative correlation with the Composite Climate Index,
- A positive correlation with the peak timing of the spring phytoplankton bloom,

- 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, and
- A negative correlation with the exploitation fraction (i.e. fishing) with a four-year lag.

The dominant 3–4 year lags observed between per-capita shrimp net production and the suite of drivers considered suggest that the environment/ecosystem and indirect effects of fishing are possibly impacting shrimp recruitment processes (Figure 3). The build-up of shrimp until the mid-2000s occurred during a period of favourable environmental conditions and reduced predation.

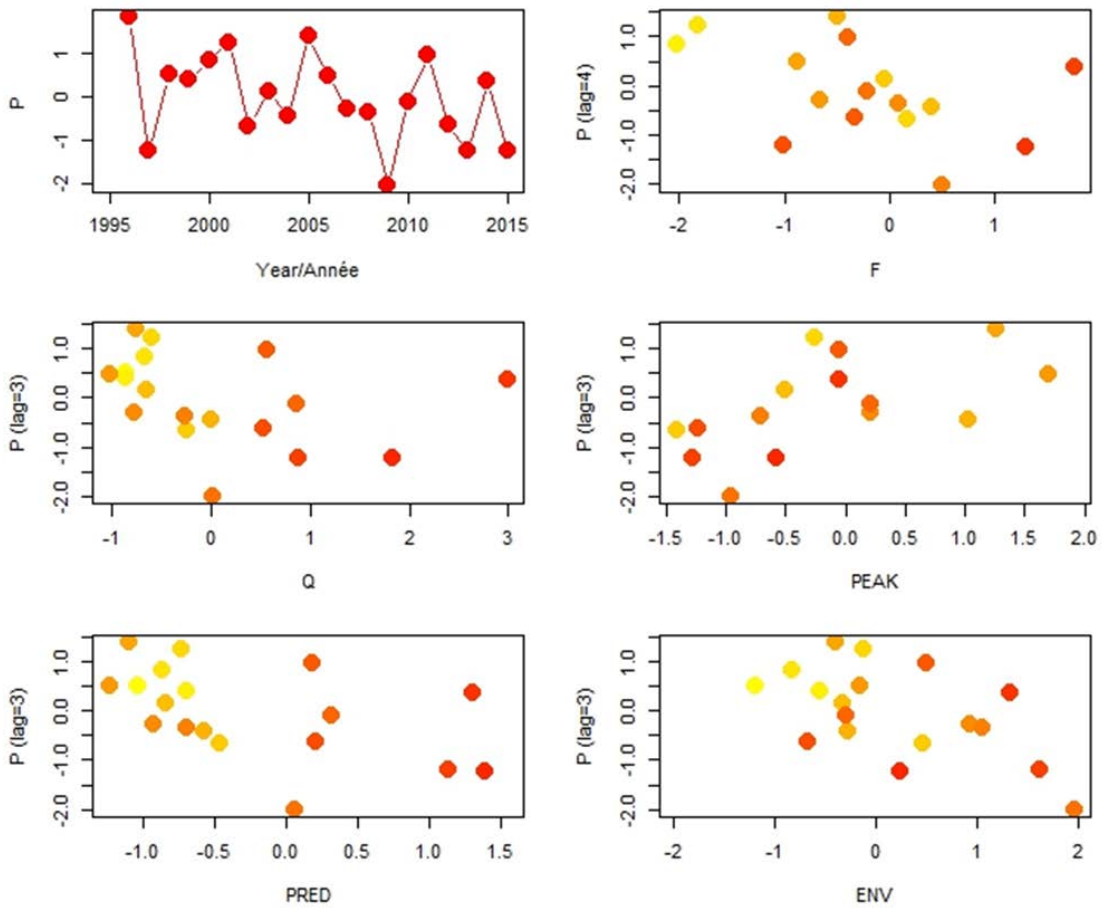

Figure 3. Relationships between shrimp per-capita net production (P in this figure), and environmental (ENV), predation (PRED), predator consumption (Q), phytoplankton bloom (PEAK) and fishing (F) drivers in Northwest Atlantic Fisheries Organization (NAFO) Divs. 2J3KL during the 1995–2015 period. The trend of shrimp per-capita net production (P in this figure) over time 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 correspond to the early years, gradually turning into red by the end of the time series). F: exploitation fraction, Q: estimated median annual shrimp consumption by fish functional groups considered predators of shrimp, PRED: DFO multi species fall survey biomass index for the fish functional groups considered predators of shrimp (medium and large benthivores, piscivores, and plank-piscivores), PEAK: estimated peak timing of the spring phytoplankton bloom, and ENV: Composite Climate Index. All drivers have been normalized; the x-axis is standard deviations from the mean.

Shrimp per-capita net production has declined since the mid-2000s. Environmental conditions and increasing predation pressure appear as important drivers for the decline. Recent environmental conditions, which would take several years to translate into an impact to the resource, may lead to improved shrimp per-capita net production but are unlikely to trigger rebuilding of the resource in SFA 6 (at a rate similar to the build-up period) over the medium term when considered in combination with high predation pressure.

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; 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 8, 2017 CAQR, 79% of the TAC had been taken.

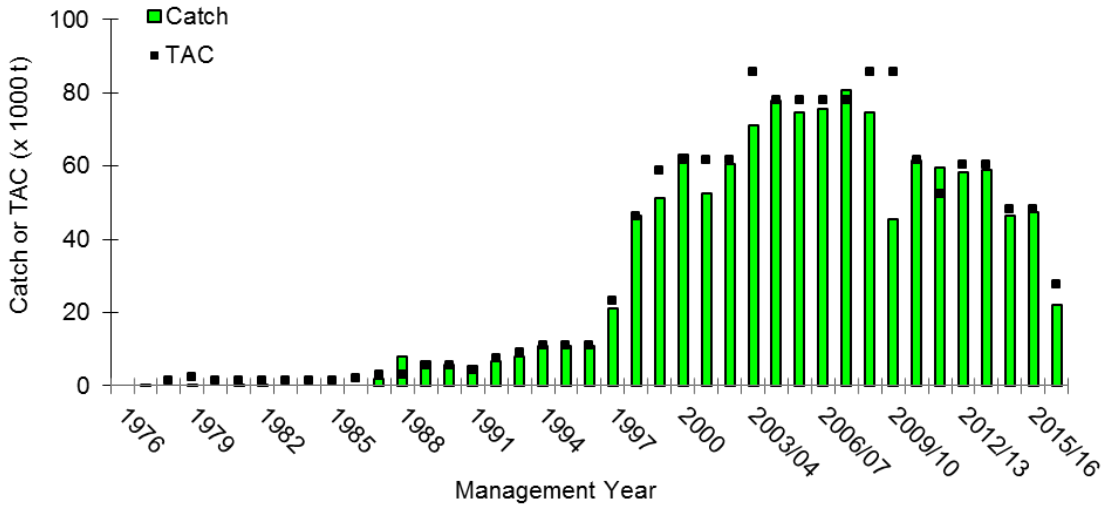

Figure 4. Historical Northern Shrimp catches and TAC in SFA 6 for the period 1977–2016/17. 2016/17 values are preliminary, based upon the CAQR as of February 8, 2017. In 2003, the management year changed from a calendar to a fiscal year.

The annual commercial CPUE has demonstrated a declining trend for about the last ten years (Figure 5).

An analysis of weekly CPUE, cumulative catch throughout the fishing season, and CPUE by survey strata, for both commercial fleets (large- and small-vessel) together with an analysis of biomass indices by survey strata were reviewed during the meeting. The conclusion based on these analyses was that commercial and survey data demonstrate a contraction of the resource within recent years.

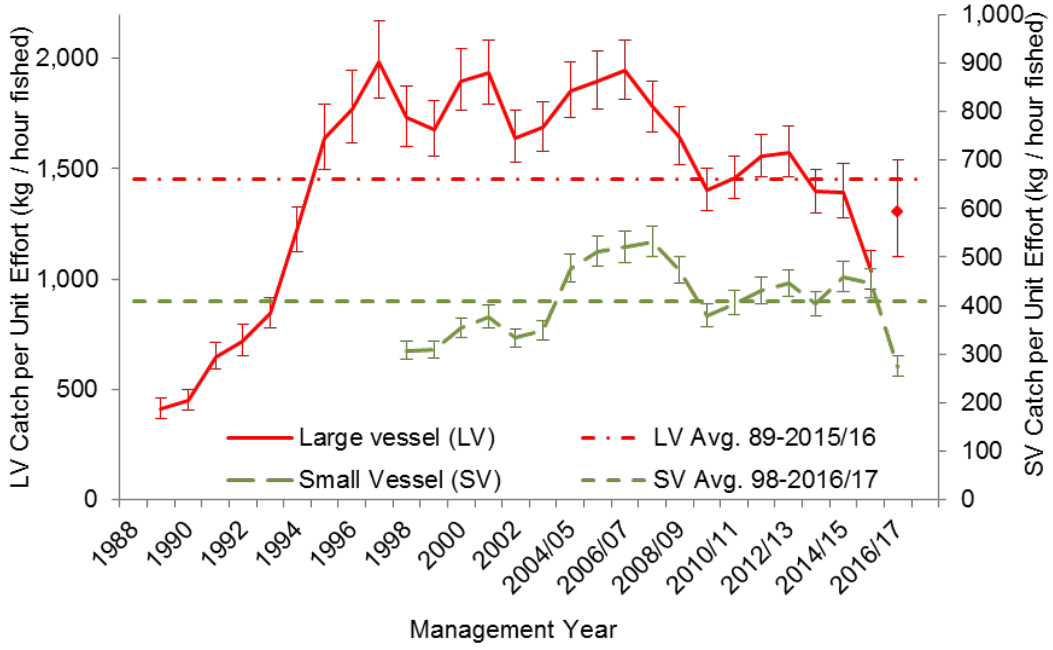

Figure 5. SFA 6 large-vessel annual standardized CPUE (red solid line) and small-vessel annual standardized CPUE (green dashed line). Error bars indicate 95% confidence intervals. The 2016/17 large-vessel annual standardized CPUE index is preliminary and based on logbook data up to December 31, 2016.

Biomass

Fishable biomass index declined from 785,000 t in 2006 to 104,000 t in 2016, which is the lowest in the time series. There was a 25% decline between 2015 and 2016. Female SSB index declined from 466,000 t in 2006 to 65,000 t in 2016 which is the lowest in the time series. There was a 27% decline between 2015 and 2016 (Figure 6).

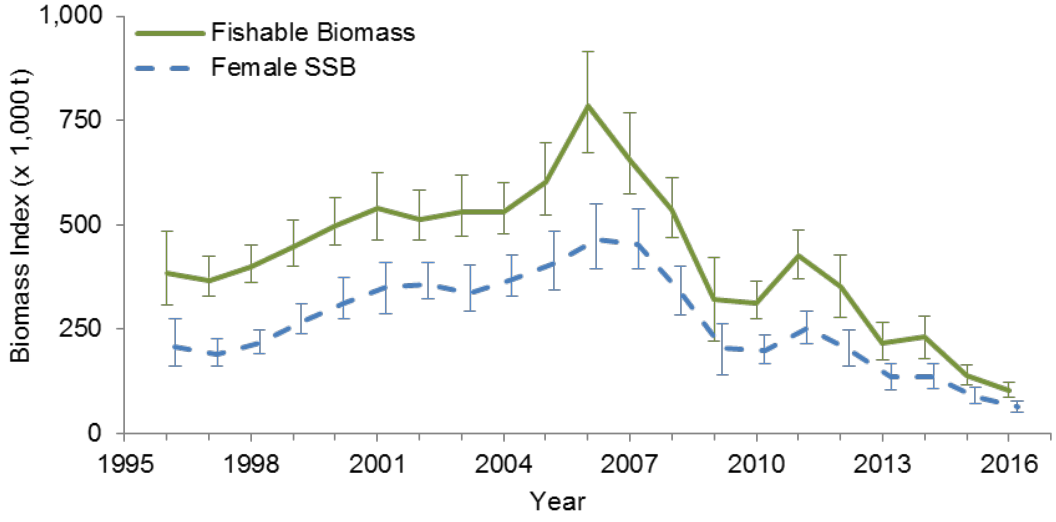

Figure 6. SFA 6 fishable (green solid line) and female SSB (blue dashed line) biomass indices. Error bars indicate 95% confidence intervals.

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 1995–2016 time series of survey and catch shrimp 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. For NAFO Divs. 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 autumn 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 high unless abundance of alternative prey increases.

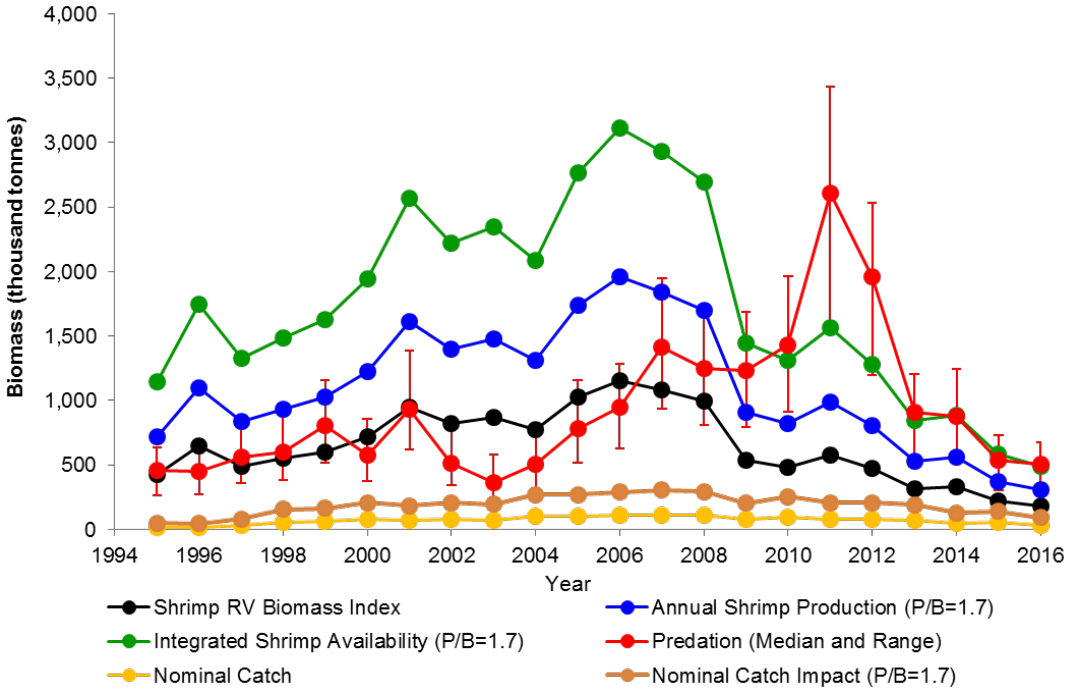

Figure 7. Comparison of predation and fisheries catches with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a P/B ratio of 1.7.

Uncertainty about various conversion factors (e.g., P/B ratio, species catchability, conversion from gut 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. The population of predators suggests low recruitment to the fishable biomass in recent years. Environmental conditions (e.g., time of phytoplankton bloom) have departed from the recent decadal trend and were later than normal in 2013-15, which may lead to an increase in per-capita shrimp net production in the medium term. However, the phytoplankton bloom was earlier in 2016 than in the past three years which may result in lower productivity. Early blooms associated with warming appear to be related to a high larval mortality (Koeller et al. 2009). Additionally, current low spawning stock means that absolute rebuilding to the Healthy Zone would be slow.

Given declining per-capita net production of shrimp, fishing pressure will now be influencing stock declines in SFA 6 more than it did in the past. Fishery removals appear to be small relative to removals by predators, but could be pivotal 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 21.4% from 1997 to 2016/17, and has averaged 17.8% in the last five years. The 2016/17 exploitation rate index will be 20.2% if the TAC is taken (Figure 8).

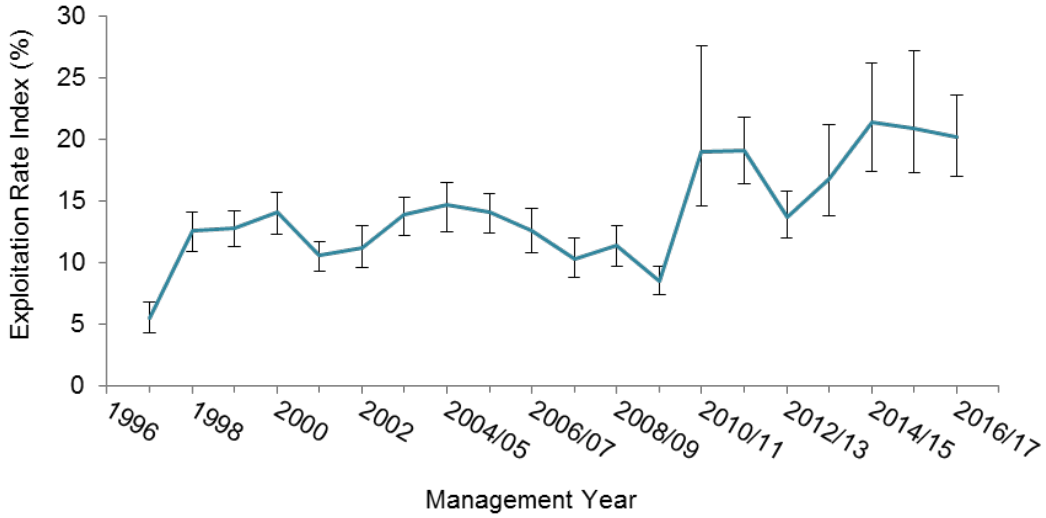

Figure 8. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The 2016/17 point assumes that the 27,825 t TAC will be taken. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

The female SSB index is currently in the Critical Zone of the IFMP PA Framework, with greater than 99% probability. Should the 27,825 t TAC be maintained and taken in the 2017/18 season, the exploitation rate index will be 26.8% (Figure 9). The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone.

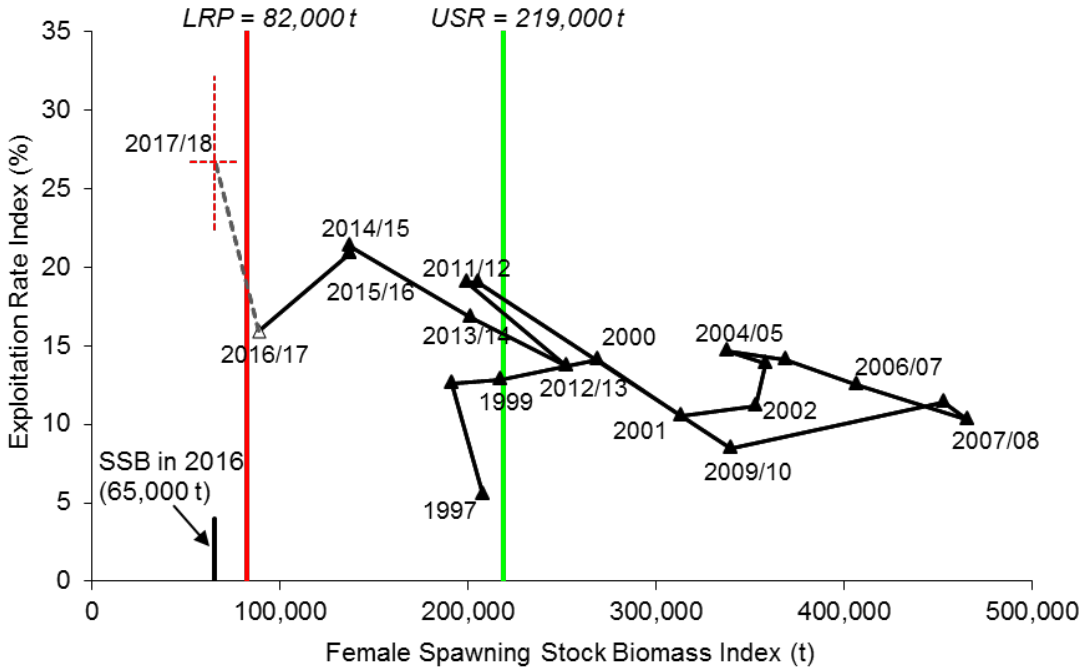

Figure 9. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2016/17 fishery was ongoing and based on reported catch as of February 8, 2017. The red cross on the 2017/18 point indicates 95% confidence intervals for the 2016 female SSB index (horizontal) and the 2017/18 exploitation rate index (vertical), assuming that the 27,825 t TAC is maintained and taken in the 2017/18 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).

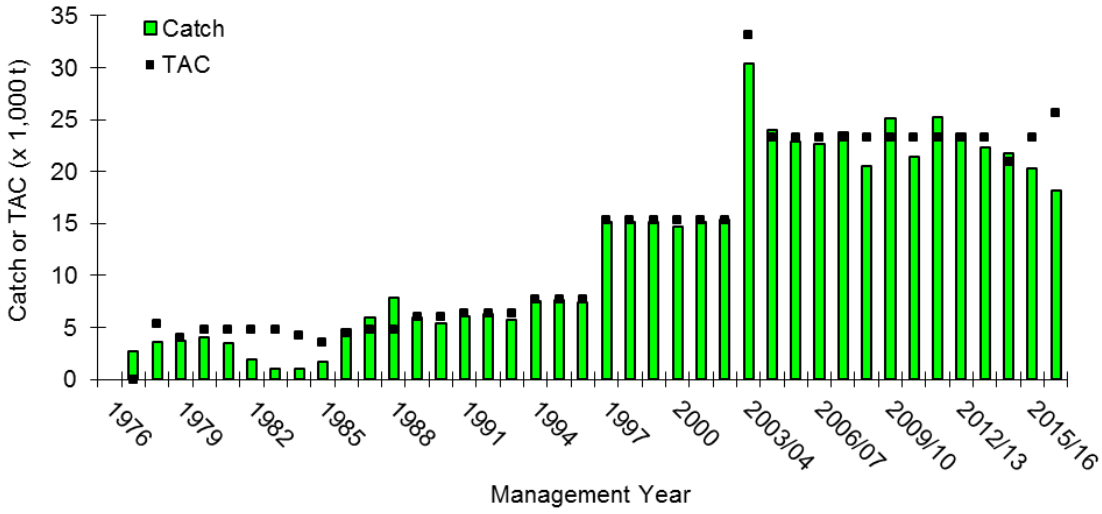

Figure 10. Historical Northern Shrimp catches and TAC in SFA 5 for the period 1977–2016/17. 2016/17 values are preliminary and based upon the CAQR as of February 8, 2017. In 2003, the management year changed from a calendar to a fiscal year.

Standardized large-vessel CPUE over the last five years has been stable at relatively high levels (Figure 11).

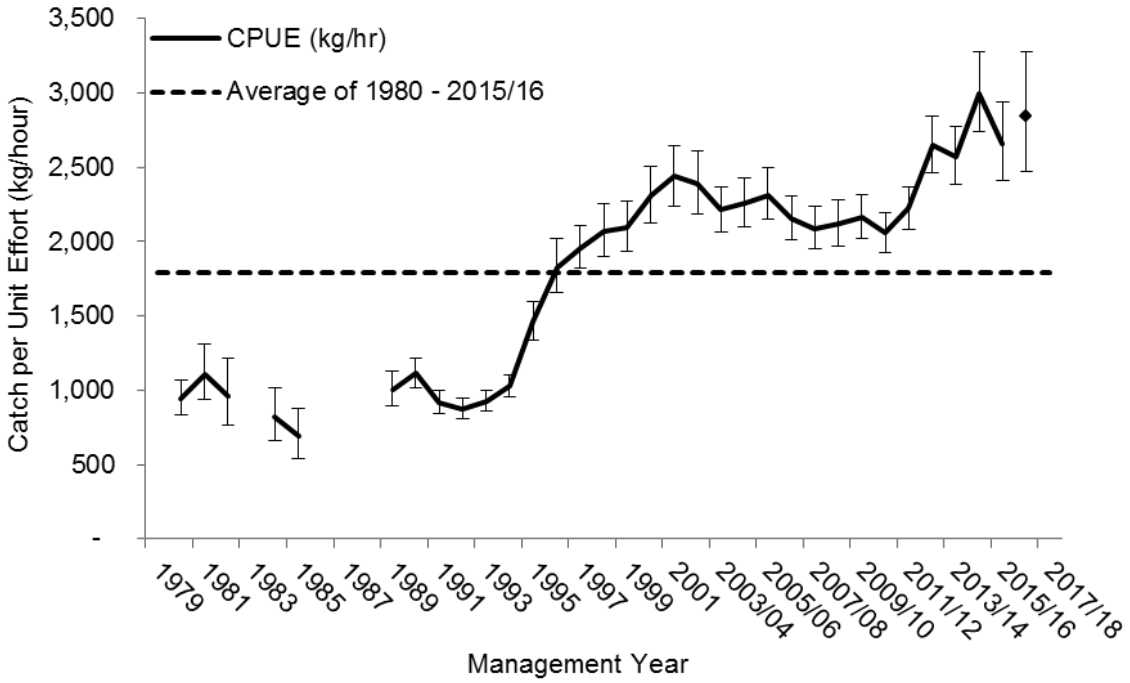

Figure 11. SFA 5 large-vessel standardized CPUE. Error bars indicate 95% confidence intervals and the dashed line indicates the long term average. The 2016/17 large-vessel annual standardized CPUE index is preliminary and based on logbook data up to December 31, 2016.

Biomass

Fishable biomass index has decreased, by 27%, from 149,000 t in 2015 to 110,000 t in 2016. Female SSB index has decreased, by 35%, from 83,200 t in 2015 to 54,300 t in 2016 (Figure 12). The low 2013 biomass indices were likely due to an unexplained occurrence affecting shrimp survey catches.

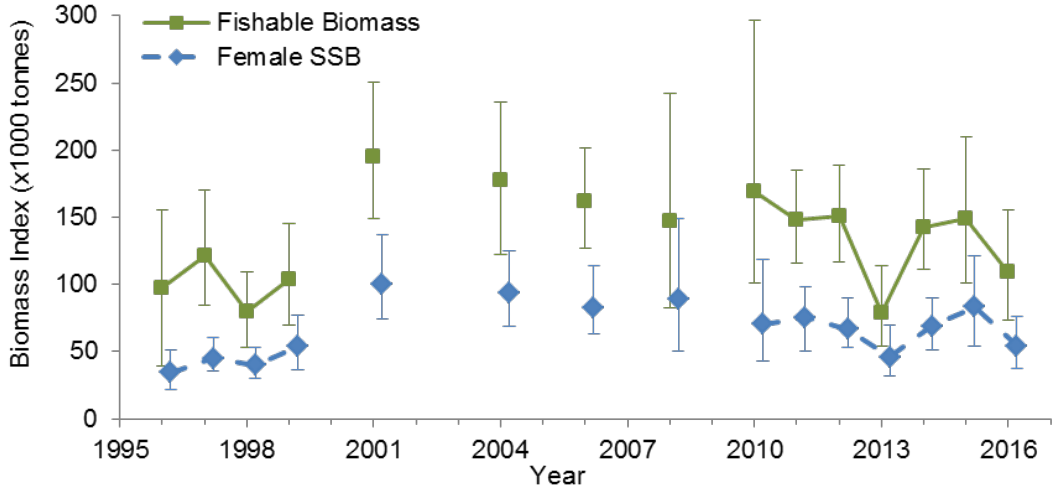

Figure 12. SFA 5 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index has varied without trend around 15% from 1997–2016/17 (Figure 13).

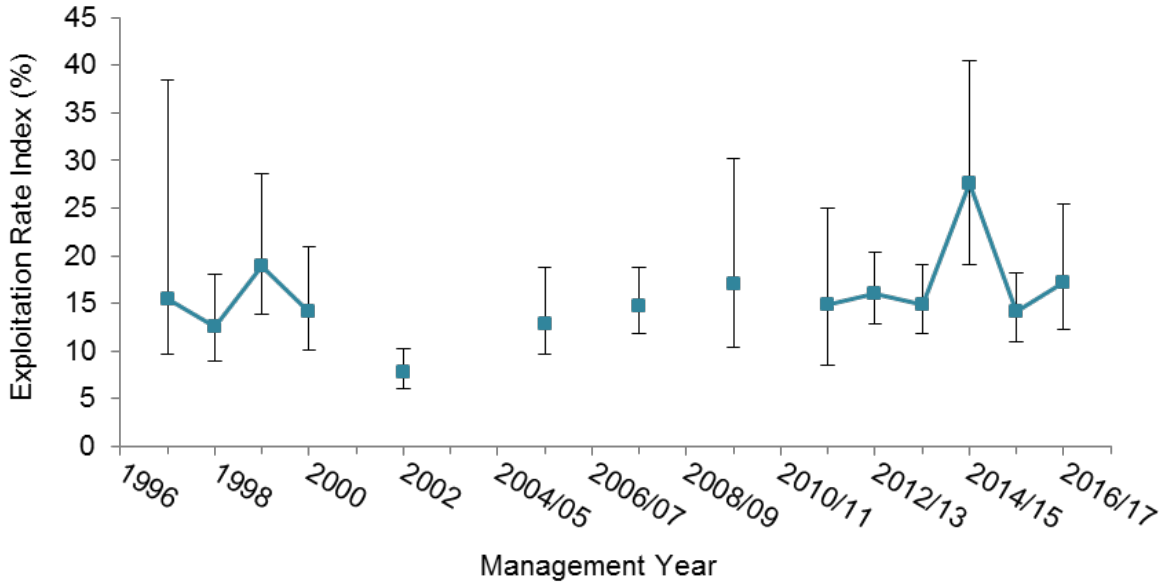

Figure 13. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The exploitation rate index in 2016/17 assumes that the 25,630 t TAC will be taken. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index is in the Healthy Zone within the IFMP PA Framework, with a 6% chance of being in the Cautious Zone. If the 25,630 t TAC is maintained and taken in 2017/18, then the exploitation rate index will be 23.3% (Figure 14). The LRP was adjusted to 15,200 t from 15,300 t since the 2016 assessment because the biomass indices were generated to three significant figures rather than rounded to the nearest thousands.

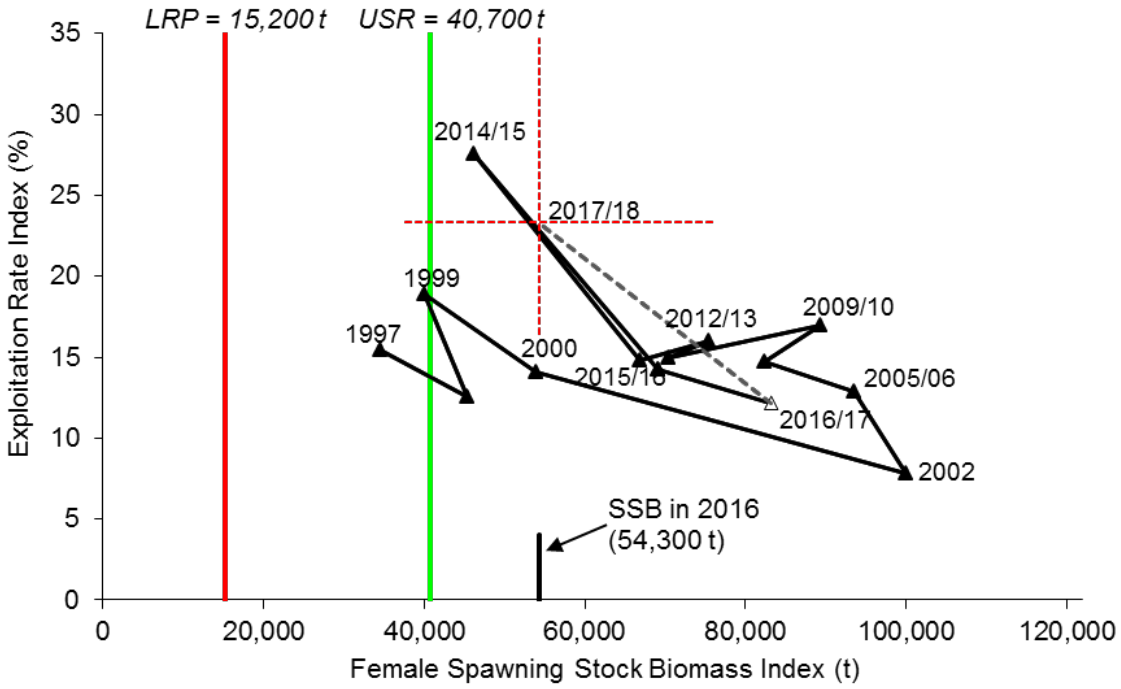

Figure 14. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2016/17 fishery was ongoing and based on reported catch as of February 8, 2017. The red cross on the 2017/18 point indicates 95% confidence intervals for the 2016 female SSB index (horizontal) and the exploitation rate index (vertical), assuming that the 25,630 t TAC is maintained and taken in the 2017/18 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. The TAC has remained the same, at 14,971 t, since 2013/14. Commercial catch increased from approximately 10,000 t from 2005/06–2011/12 to about 15,000 t in the past four years (Figure 15).

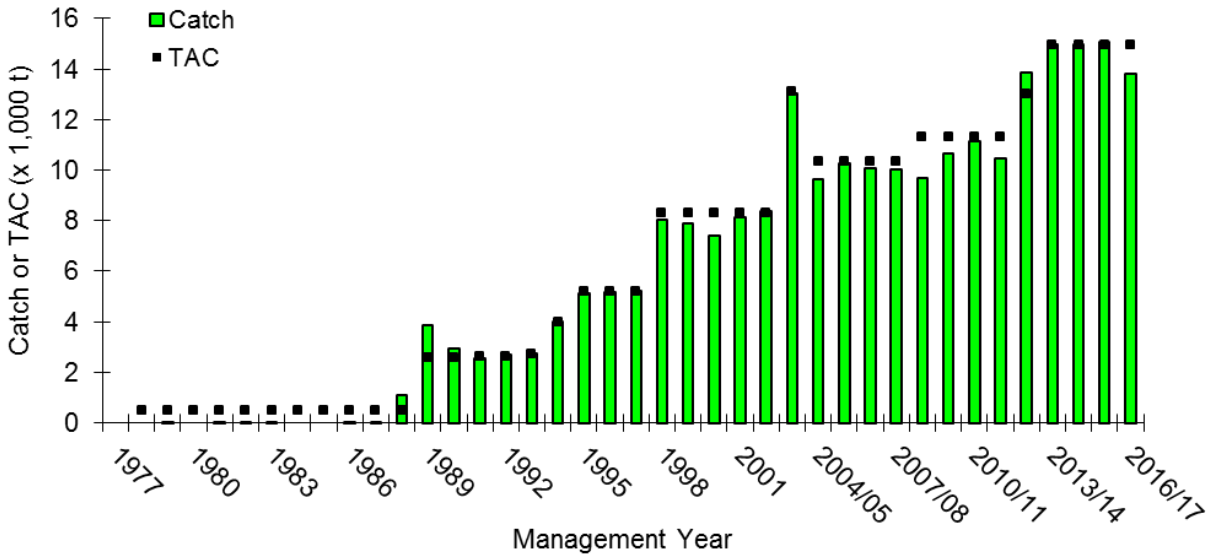

Figure 15. Historical Northern Shrimp catches and TAC in SFA 4 for the period 1977–2016/17. 2016/17 values are preliminary and based upon the CAQR as of February 8, 2017. In 2003, the management year changed from a calendar to a fiscal year.

Large-vessel standardized CPUE fluctuated without trend near the long term mean (Figure 16). Several factors including changes in management measures and species composition of catches confound the interpretation of fishery performance in this area.

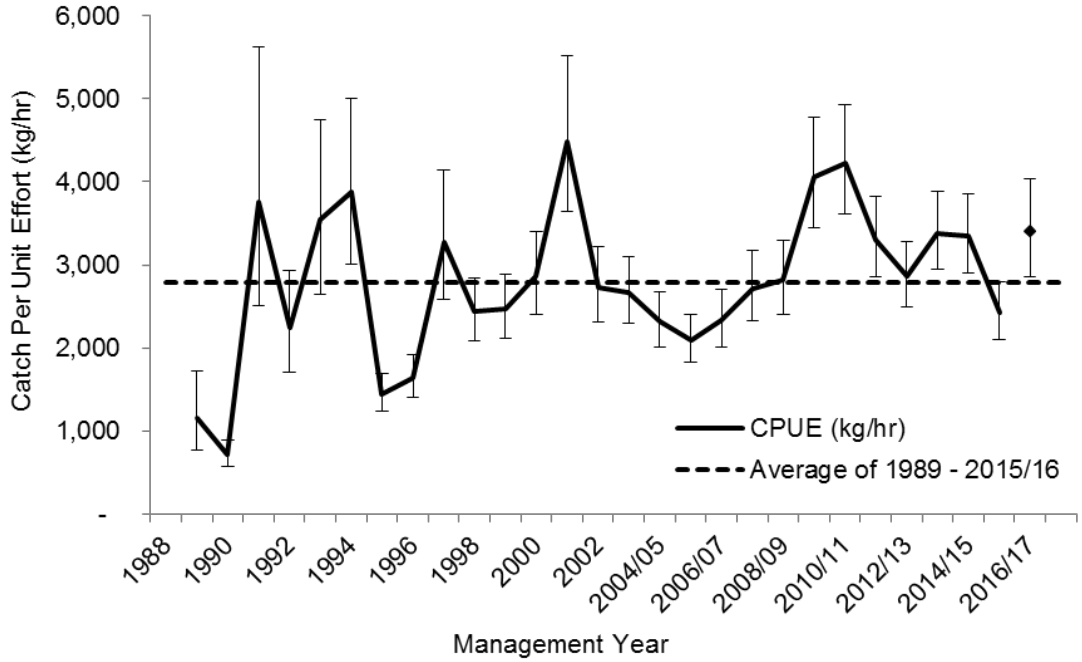

Figure 16. SFA 4 large-vessel standardized CPUE (kg/hr) for Northern Shrimp. Error bars indicate 95% confidence intervals and the dashed line indicates the long term average. The 2016/17 large-vessel annual standardized CPUE index is preliminary and based on logbook data up to December 31, 2016.

Biomass

Between 2005 and 2012, the fishable biomass index ranged between 76,600 t and 164,000 t and in 2016 was 95,300 t. Between 2005 and 2012, the female SSB index ranged between 39,700 t and 115,000 t and in 2016 was 55,500 t (Figure 17).

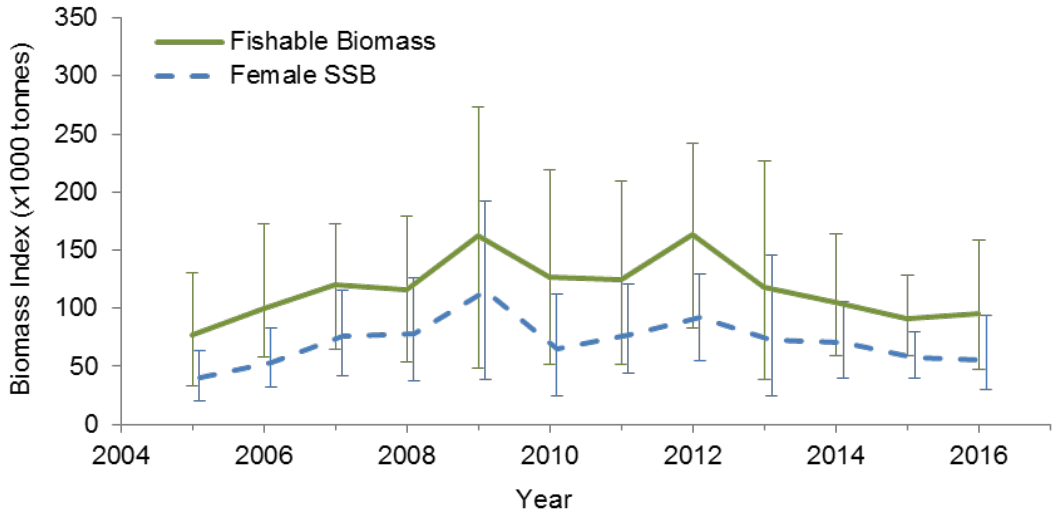

Figure 17. SFA 4 fishable biomass (green solid line) and female SSB (blue dashed line) indices for Northern Shrimp. Error bars indicate 95% confidence intervals.

Exploitation

The exploitation rate index has been about 15% for the past three years (Figure 18).

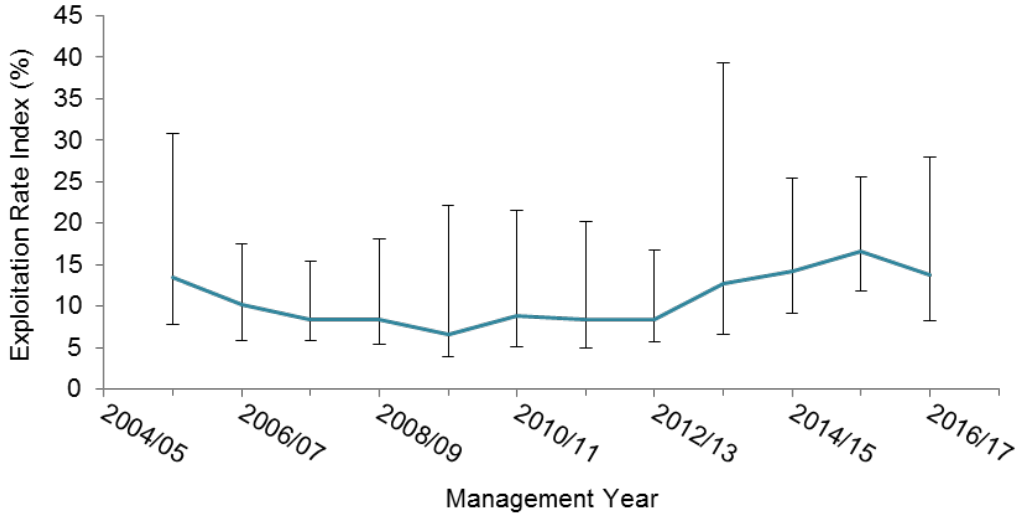

Figure 18. SFA 4 exploitation rate index for Northern Shrimp, based on total catch divided by fishable biomass index, both from the current year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

Female SSB index in 2016 was in the Healthy Zone within the IFMP PA Framework, with a 45% probability of having been in the Cautious Zone (Figure 19). The USR was adjusted to 54,400 t

from 54,300 t since the 2016 assessment because the biomass indices were generated to three significant figures rather than rounded to the nearest thousands.

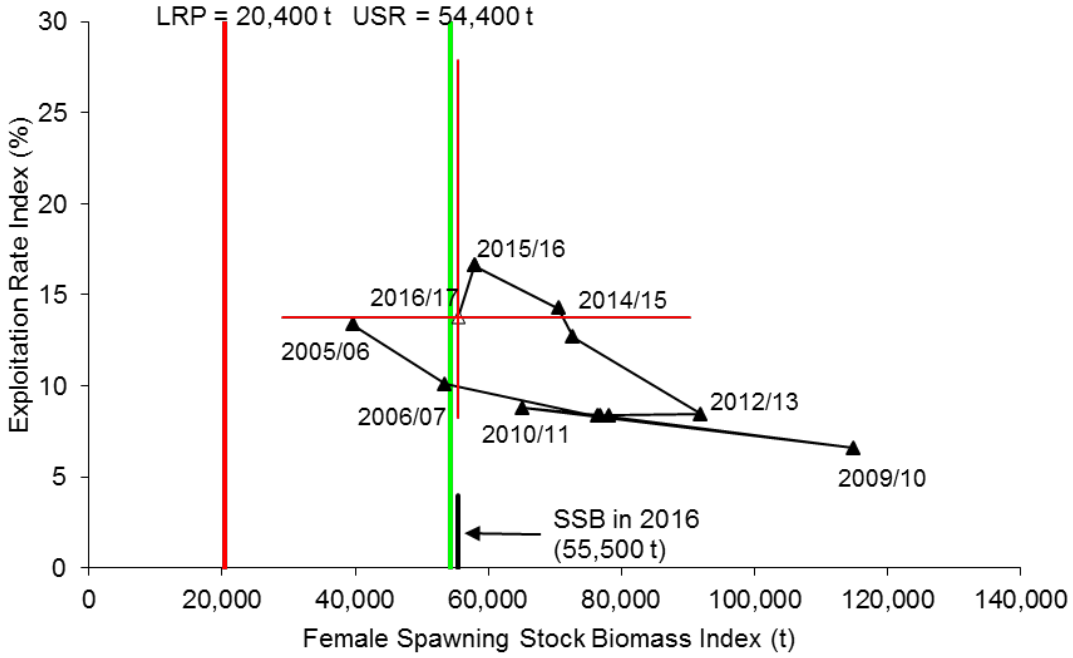

Figure 19. SFA 4 PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote year of the fishery. The red cross on the 2016/17 point indicates 95% confidence intervals for the 2016 female SSB index (horizontal) and the 2016/17 exploitation rate index (vertical).

SFA 4 Pandalus montagui

Fishery

Commercial catch of *P. montagui*, taken as by-catch in the *P. borealis* fishery, increased from 280 t in 2008 to 4,700 t in 2012 and declined to 1,092 t in 2016. The by-catch limit of 4,033 t has not been taken in the past four years (Figure 20). Until 2012, the sole source of catch information for Striped Shrimp was logbooks; however by-catch was recorded in the CAQR beginning in 2013.

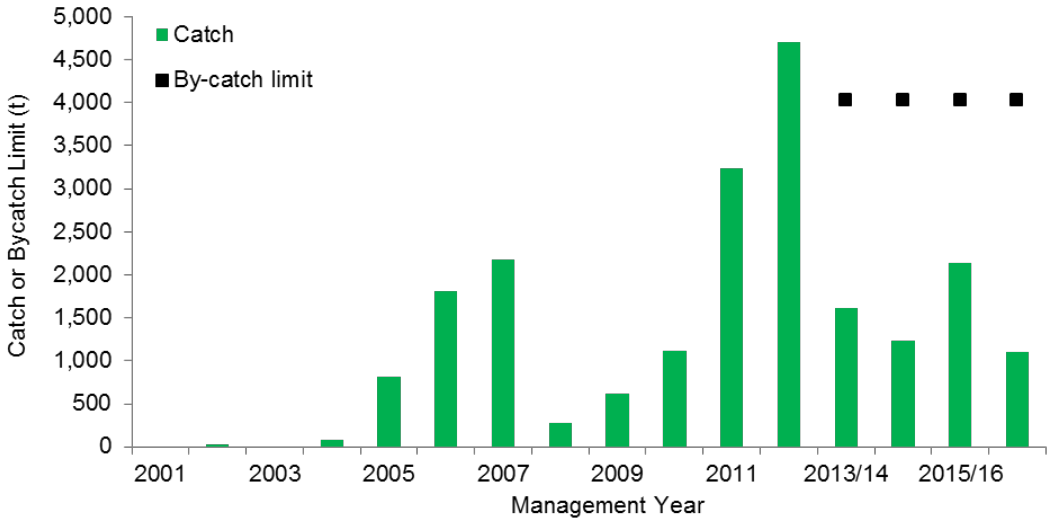

Figure 20. SFA 4 Striped Shrimp catch for the period 2002–2016/17, along with the by-catch limit established beginning in 2013/14. The catches from 2002–12 were based on log books within calendar year whereas the catch from 2013/14 onward was based on the CAQR, as of February 8, 2017, within management year.

Biomass

Some of the fluctuations in biomass indices in SFA 4 likely result from transfer across management boundaries, particularly from the Western Assessment Zone to the northwest of SFA 4 (DFO 2016b), rather than local dynamics within a population. Fishable biomass index for 2016 was 23,900 t, a decrease of 49% from 2015; however the biomass index fluctuates without trend throughout the survey time series (Figure 21).

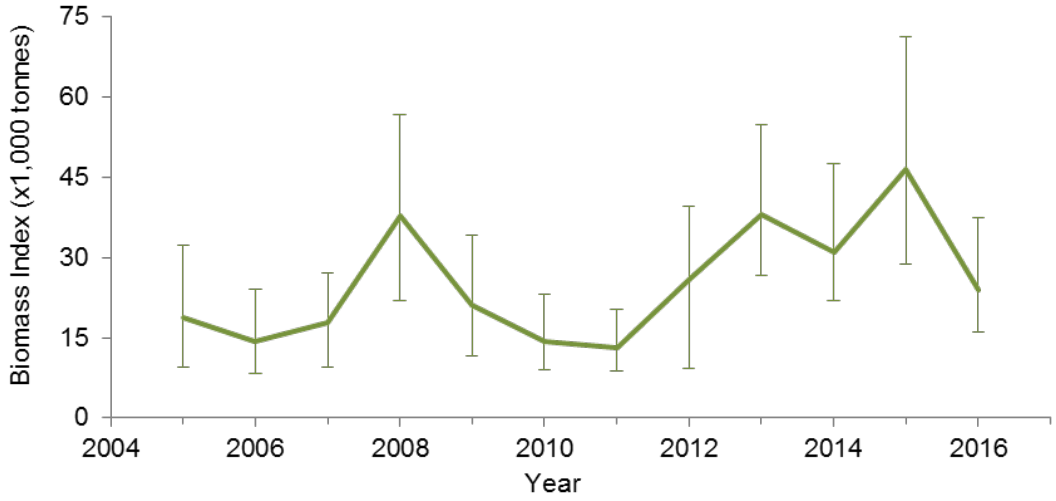

Figure 21. SFA 4 fishable biomass index for Striped Shrimp. Error bars represent 95% confidence intervals.

The female SSB that is relevant to a PA for an area consists of the animals whose spawning products will ultimately be caught in that area (as opposed to the animals that spawn in the area). The strong currents that likely affect all sizes of shrimp, especially larvae, into SFA 4 create especially severe problems with estimating female SSB for this particular SFA. The true

female SSB is more than the females observed by the survey within SFA 4. Therefore, female SSB for Striped Shrimp is unknown in SFA 4.

Exploitation

The reported exploitation rate index in 2016/17 was 4.6% (Figure 22). If the by-catch limit had been taken, the exploitation rate would have been 8.7% in 2016/17.

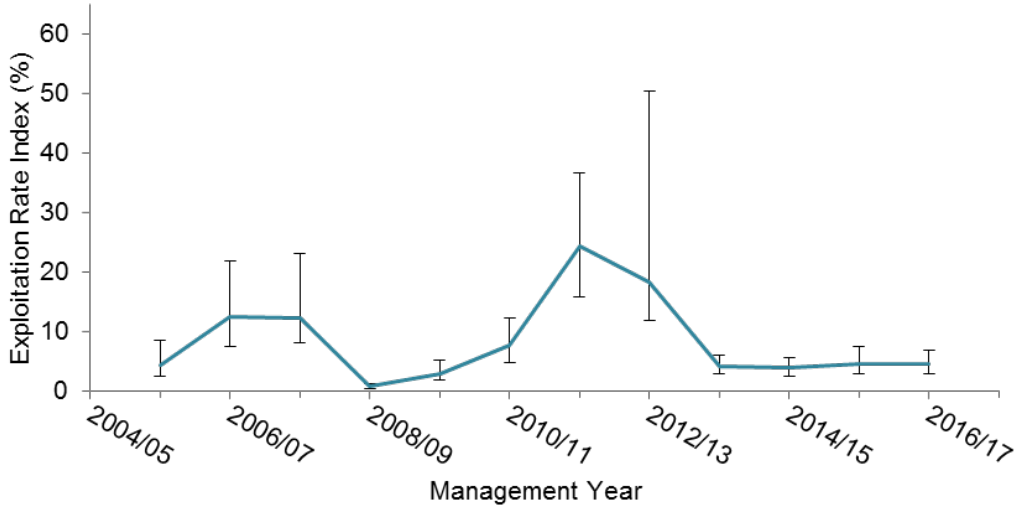

Figure 22. SFA 4 exploitation rate index for Striped Shrimp, based on total catch divided by fishable biomass index, both from the current year, expressed as a percentage. Error bars indicate 95% confidence intervals.

Current Outlook and Prospects

There is no IFMP PA Framework for this resource. The potential exploitation rate index of 8.7% is below the 20% maximum exploitation rate index that is proposed for a healthy SFA 4 resource. However, without a reliable female SSB index, the status of the resource relative to a PA Framework could not be determined.

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 autumn surveys applies throughout the year for each year in which that data was available.
3. Inferences for future consumption require further assumptions about how the diet composition changes as the relative amount of different prey types changes.
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, and the physical determinants of production are expected to change in unknown ways. These changes raise questions about a PA Framework which was designed around the assumption of stable ecosystem conditions.

Spatio-temporal variation in survey efficiency among three DFO research vessels, particularly in NAFO Div. 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 unimportant.

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, 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 inter-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 may produce effects in other management areas.

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 on this resource.

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.

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 spatially uniform in all fisheries and is a source of uncertainty if one attempts to use commercial catch rates as an index of stock status. For example, in SFA 4 for *P. montagui* a large fraction of the fishable biomass estimated from the survey is in a region that is never fished; therefore the local exploitation rate in the small area fished in the north is far greater than the nominal exploitation rate.

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 is currently in the Critical Zone, based on the PA Framework. This follows three consecutive years of the female SSB index declining while in the Cautious Zone. If the TAC is taken then the exploitation rate index will be 20.2%. It is noteworthy that, based on catch as of the assessment date and verbal communication with harvesters, the TAC is not expected to be fully taken. The IFMP states that the exploitation rate should not exceed 10% while the female SSB index is in the Critical Zone. If the 27,825 t TAC is maintained and taken in the 2017/18 season, the exploitation rate index will be 26.8%.

Fishery removals may become relatively high given the 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 and harvest rates have not permitted the stock to increase. This suggests that lowering the exploitation rates would be required to allow growth in the stock under current conditions.

SFA 5 *Pandalus borealis*

The fishable biomass index declined by 27% and the female SSB index declined by 35% between 2015 and 2016. Female SSB index is in the Healthy Zone within the PA Framework with a 6% probability of being in the Cautious Zone. If the 25,630 t TAC is maintained and taken in 2017/18, then the exploitation rate index will be 23.3%.

SFA 4 *Pandalus borealis*

There was little change in the fishable biomass or female SSB indices from 2015 to 2016. Female SSB index in 2016 was in the Healthy Zone, close to the USR within the PA Framework, with a 45% probability of having been in the Cautious Zone.

SFA 4 *Pandalus montagui*

Current status of this resource is unknown due to the large fluctuations in biomass from year to year, which are likely influenced by currents and tides in that area. The potential exploitation rate of 8.7% is below the 20% maximum exploitation rate index that is proposed for a healthy SFA 4 resource. However, without a reliable female SSB index, the status of the Striped Shrimp resource relative to a PA Framework could not be determined.

MANAGEMENT CONSIDERATIONS

Although shrimp is managed on a single-species basis, management of key forage species such as shrimp, under an ecosystem approach, requires adoption of a conservative approach with lower fishing mortality reference points and higher biomass reference points than those that would be adopted under a 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 fishery removals may become a large fraction of the net difference between shrimp production and total predation in recent years. Thus, fishing mortality can be very important for determining whether

gains (production) exceed losses (predation) and hence whether the stock increases or decreases.

SOURCES OF INFORMATION

This Science Advisory Report is from the February 16–17, 2017 Northern and Striped Shrimp Assessment. Additional publications from this meeting will be posted on the DFO Science Advisory Schedule as they become available.

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Aussi disponible en français :

MPO. 2017. Évaluation de la crevette nordique (Pandalus borealis) dans les zones de pêche de la crevette 4 à 6 et de la crevette ésope (Pandalus montagui) dans la zone de pêche de la crevette 4 en 2016. Secr. can. de consult. sci. du MPO, Avis sci. 2017/012.