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**Canadian Science Advisory Secretariat**
**Newfoundland and Labrador Region** **Science Advisory Report 2016/028**

# 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 2015

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

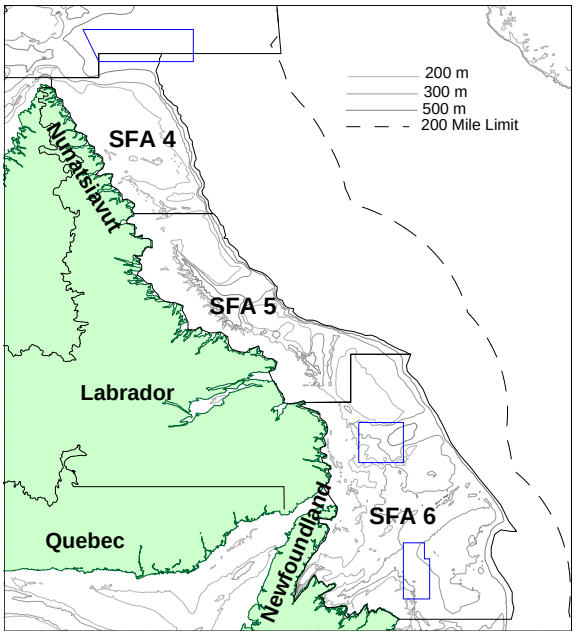


*Figure 1. Map of Shrimp Fishing Areas (SFAs) 4-6. Blue boxes indicate closed areas (Coral box, Hawke Box and Funk Island Deep box from North to South).*

## 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.*

*These resource areas were last assessed in February, 2015 (DFO 2015). The February 2016 Stock Status Update of Northern and Striped Shrimp in SFAs 4, 5 and 6 (DFO 2016a) reported significant declines in resource status, particularly in SFA 6. Subsequently, Fisheries and Oceans Canada (DFO) Ecosystems and Fisheries Management requested a full regional science assessment on the status of Northern Shrimp in SFAs 4, 5 and 6 and on the status of Striped Shrimp in SFA 4.*

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

*A Regional Peer Review Process was held April 6-8 and April 11-12, 2016 in St. John's, NL to assess Northern and Striped Shrimp. Participants included DFO scientists, fisheries managers, and representatives from the NL Provincial Government, academia, Aboriginal communities and organizations, and industry.*

# SUMMARY


- Resource status of Northern Shrimp in Shrimp Fishing Areas (SFAs) 5 and 6 was updated based on DFO fall multi-species trawl survey data (1996-2015). 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 (2005-15).
- 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.
- Precautionary Approach (PA) reference points have been revised from the previous assessments, in accordance with refinements in the biomass estimation method. The PA framework itself has not changed.

## Environment and Ecosystem

- The regional Composite Climate Index declined for the fifth year in a row to seventh lowest in 66 years, indicating a continued regional cooling trend since 2010 which is a departure from broader warmer-than-average conditions across the north Atlantic.
- As in 2014, the seasonal cycle of surface sea temperature was characterized by a colder than average spring which, combined with a delayed retreat of sea ice, resulted in later than average onset of the spring phytoplankton bloom. This may lead to stronger shrimp productivity in the medium term.
- Fall bottom temperatures in SFA 6 were above normal, resulting in near normal and above normal areas of the potential thermal habitat for shrimp in Northwest Atlantic Fisheries Organization (NAFO) Divisions 2J and 3K, respectively.
- Environmental forcing, predation and fishing are correlated with subsequent shrimp production. The build-up of shrimp until the mid-2000s occurred during a period with a combination of favorable 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 recent decline. However, recent departures in environmental conditions from the decadal trend may lead to increased shrimp per-capita production over the medium term but are unlikely to trigger a rapid rebuilding of the resource.

## SFA 6 *Pandalus borealis*

- Commercial catch has been about 50,000 t over the past two years. It is expected that the 2015/16 TAC of 48,196 t will be taken.
- Large and small-vessel standardized CPUE have varied without trend since 2010 around the long-term mean.
- Fishable biomass index declined from 785,000 t in 2006 to 138,000 t in 2015 which is the lowest in the time series. There was a 41% decline between 2014 and 2015.

- Female spawning stock biomass (SSB) index declined from 466,000 t in 2006 to 89,000 t in 2015 which is the lowest in the time series. There was a 35% decline between 2014 and 2015.
- The exploitation rate index ranged between 5.5% and 21.4% from 1997 to 2015/16, and has averaged 18.3% in the last five years. The 2015/16 exploitation rate index will be 20.7% if the TAC is taken.
- The female SSB index is currently close to the limit reference point (LRP), in the Cautious Zone of the Integrated Fisheries Management Plan (IFMP) PA Framework, with a 20% probability that it is in the Critical Zone. If the 48,196 t TAC is maintained and taken in the 2016/17 season, the exploitation rate index will be 34.9%.

### SFA 5 *Pandalus borealis*

- Commercial catch has been about 23,000 t over the past five years. It is expected that the 2015/16 TAC of 23,300 t will be taken.
- Standardized large-vessel CPUE over the last four years has been stable at high levels.
- Fishable biomass index has been relatively stable since 2010, and was 148,000 t in 2015.
- Female SSB index has changed little since 2010, and was 83,000 t in 2015.
- The exploitation rate index has varied without trend around 15% from 1997-2015/16.
- Female SSB index is in the Healthy Zone within the IFMP PA Framework. If the 23,300 t TAC is maintained and taken in 2016/17, then the exploitation rate index will be 16%.

### SFA 4 *Pandalus borealis*

- Commercial catch increased from approximately 10,000 t from 2005/06-2011/12 to about 15,000 t in the past three years.
- Large-vessel standardized CPUE fluctuated without trend near the long term mean.
- The fishable biomass index varied without trend from 2005 to 2015 with the 2015 point estimate at 91,000 t, which represents a decrease of 13% from 2014.
- The female SSB index for 2015 was 58,000 t, representing a decrease of 18% from 2014.
- The exploitation rate index reached 16.5% by 2015/16.
- Female SSB index in 2015 was in the Healthy Zone within the IFMP PA Framework with a 40% 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 2,135 t in 2015. The by-catch limit of 4,033 t has not been taken in the past three years.
- Fishable biomass index for 2015 was 47,000 t, an increase of 52% from 2014.
- Female SSB is unknown.
- If the by-catch limit had been taken, the exploitation rate would have been 8.6% in 2015/16.
- 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-6°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-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.

Both species are found over a wide area in SFA 4. 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 effects are unknown.

## 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.

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*.), Snow Crab (*Chionoecetes opilio*) 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 the St. Anthony Basin, Funk Island Deep and 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). Instances (overall or by SFA) where the TAC was not taken are often due to operational or market constraints and not the inability to catch shrimp.

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 reserved for the development of a small-vessel (< 100' feet) fleet, which has since grown to include about 250 license holders.

In 2003 the management year was changed from a calendar (January 1-December 31) to a fiscal (April 1-March 31) 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). 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. In 2016 each license can bridge 750 t, but the maximum that can be bridged in SFA 6 is 3,200 t.

Due to significant declines in resource status for SFAs 5-6 in 2013, TACs for 2014/15 were reduced by 10% in SFA 5 and 20% in SFA 6 but stayed the same in SFA 4. The overall TAC was 84,137 t. After the 2014 survey, the SFA 5 survey of 2013 appeared to be anomalous. The TAC was restored to the 2013/14 level while SFAs 4 and 6 remained the same as 2014/15; the overall TAC was 86,467 t.

Northern Shrimp has generally been the target shrimp species in SFA 4. Management measures implemented in 2013/14 designate 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 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.

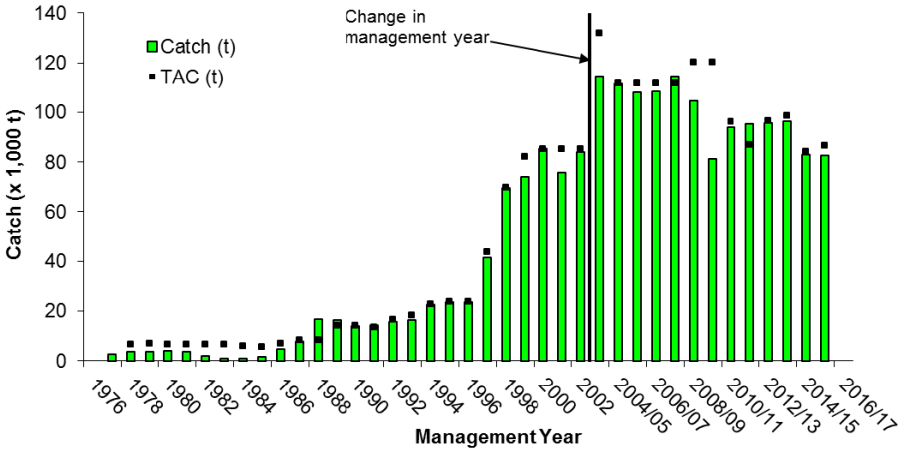


*Figure 2. Historical Northern Shrimp catches (SFAs 4-6) and TACs for the period 1977-2015/16. 2015/16 catches are preliminary and from the CAQR as of March 23, 2016. The black vertical line indicates the year in which the fishery switched from a calendar to a fiscal year.*

## 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 first consideration would translate as the harvest that is sustainable. For ecosystem-based management, 'harvest' would be replaced by some combination of harvest and ecosystem function.

This assessment follows the framework developed in 2007 for Northern Shrimp off Labrador and the northeastern coast of Newfoundland (DFO 2007a). Resource status of Northern Shrimp in SFAs 5 and 6 was updated based on DFO fall multi-species trawl survey data (1996-2015). Resource status for Northern Shrimp and Striped Shrimp in SFA 4 was updated based on the NSRF-DFO summer trawl survey data (2005-2015).

Trawl survey data for SFAs 4-6 provided information on shrimp distribution, length frequencies, biomass indices and potential predators. 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 pre-recruit numbers 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 from the previous year (for fall surveys) or the current year (for summer surveys).

Biomass indices are derived from ogive mapping methods (Ogmap).

There is an IFMP for shrimp in SFAs 4-6 (DFO 2007b). Reference points for the DFO PA Framework (DFO 2006) were developed using proxies (DFO 2009). The upper stock reference (USR) was defined as 80%, and 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 previous assessments, in accordance with refinements in the biomass estimation method. The PA Framework itself has not changed.

## SFA 6 *Pandalus borealis*

### Environment and Ecosystem

The regional Composite Climate Index declined for the fifth year in a row to seventh lowest in 66 years, indicating a continued regional cooling trend since 2010 but which is a departure from broader warmer than average conditions across the north Atlantic.

As in 2014, the seasonal cycle of surface sea temperature was characterized by a colder than average spring, which combined with a delayed retreat of sea ice resulted in later than average onset of the spring phytoplankton bloom. This may lead to stronger shrimp productivity in the medium term.

Fall bottom temperatures in SFA 6 were above normal, resulting in near normal and above normal areas of the potential thermal habitat for shrimp in 2J and 3K, respectively.

The build-up of shrimp until the mid-2000s occurred during a period with a combination of favorable environmental conditions and reduced predation. Environmental forcing, predation and indirect effects of fishing were significantly correlated with subsequent shrimp per-capita production (P) 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 P and the suite of drivers considered suggest that the environment/ecosystem and indirect effects of fishing are likely impacting shrimp recruitment processes (Figure 3).

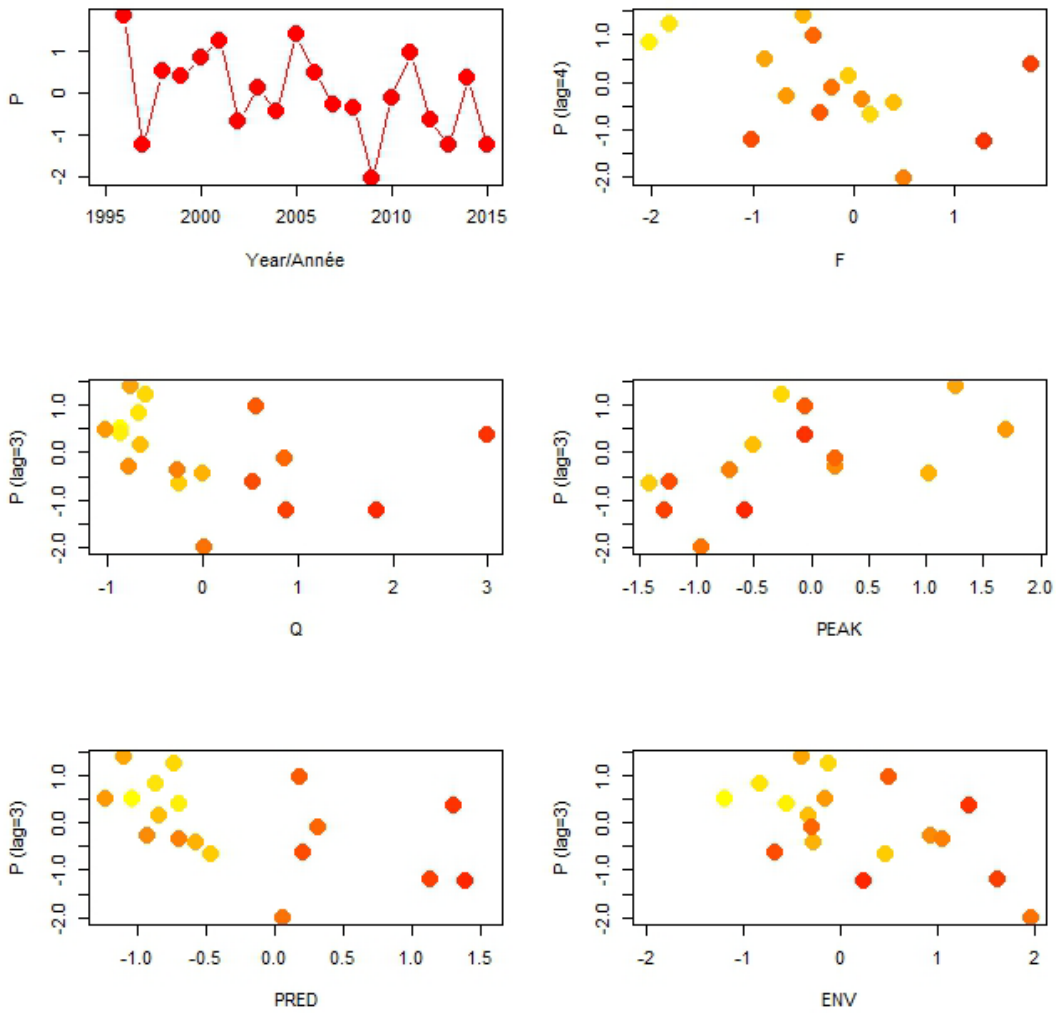


*Figure 3. Relationships between shrimp per-capita production (P), and environmental, predation and fishing drivers in NAFO Divs. 2J3KL during the 1995-2015 period. The trend of P over time is presented in the upper left corner. All other plots display the relationship between P and key drivers at the 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.*

Shrimp per-capita production has declined since the mid-2000s. Environmental conditions and increasing predation pressure appear as important drivers for the recent decline. Environmental conditions (e.g., time of phytoplankton bloom) have departed from the recent decadal trend and may lead to increased per-capita shrimp production in the medium term. However, current low spawning stock means that absolute rebuilding would be slow.

### Fishery

The TAC was set at 11,050 t in 1994 and increased to 23,125 t in 1997 (Figure 4) as a first step towards increasing the exploitation of an abundant resource. Most of the increase was reserved for development of the small-vessel fleet. The TACs, and subsequently the catches, increased

significantly every several years to a maximum of 85,725 t in 2008/09-2009/10. Poor resource status led to TAC decreases in the following years. Commercial catch has been about 50,000 t over the past two years. It is expected that the 2015/16 TAC of 48,196 t will be taken.

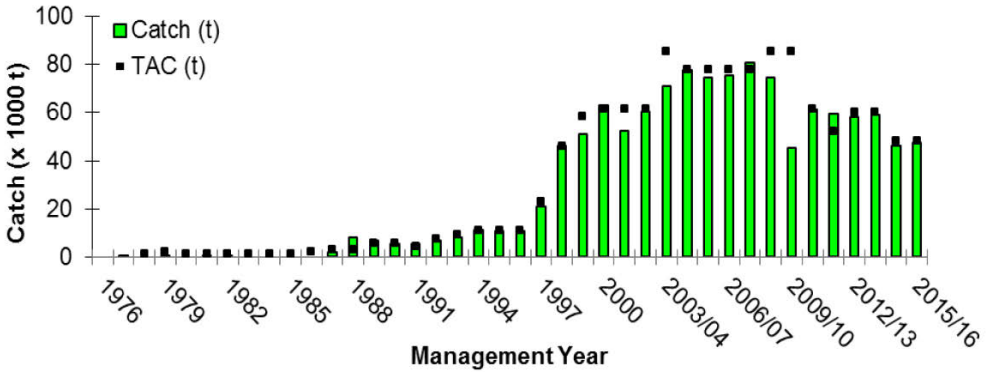


*Figure 4. Historical Northern Shrimp catch and TAC in SFA 6 for the period 1977-2015/16. 2015/16 values are preliminary, based upon the CAQR as of March 23, 2016. In 2003, the management year changed from a calendar to a fiscal year.*

Large and small-vessel annual standardized CPUE have varied without trend since 2010 around the long-term mean (Figure 5).

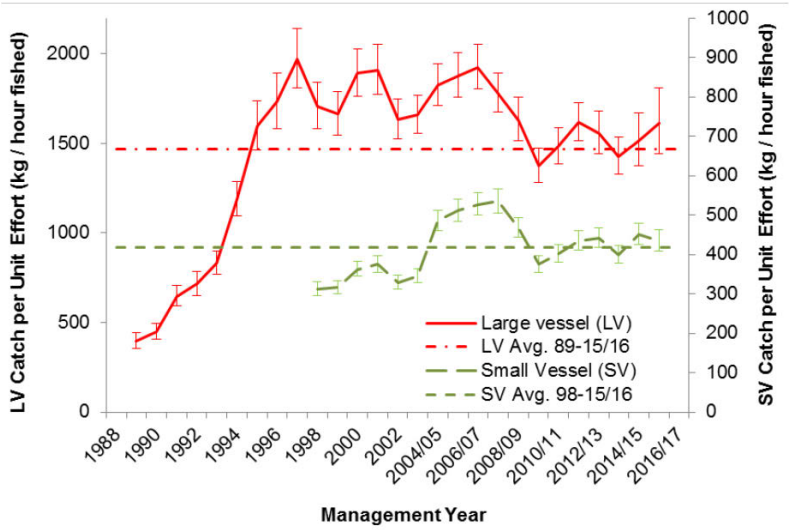


*Figure 5. SFA 6 large-vessel annual standardized CPUE (red solid line) and small-vessel annual standardized CPUE (green dashed line). Error bars indicate 95% confidence intervals. The large-vessel annual standardized CPUE index is preliminary and based on data up to December 31, 2015.*

The distribution of fishing effort has changed in recent years. Weekly catch rates varied significantly throughout the fishing season; the small-vessel and large-vessel fisheries in SFA 6 typically take place at different times in the management year (Figure 6). Catch rates in July 2015 were the highest in the small-vessel logbook series and declined thereafter to some of the lowest weekly catch rates. In the large-vessel fishery in 2015, catch rates were high in the spring, low in the fall and then increased in the winter; however the winter levels were some of the lowest in the catch rate series.

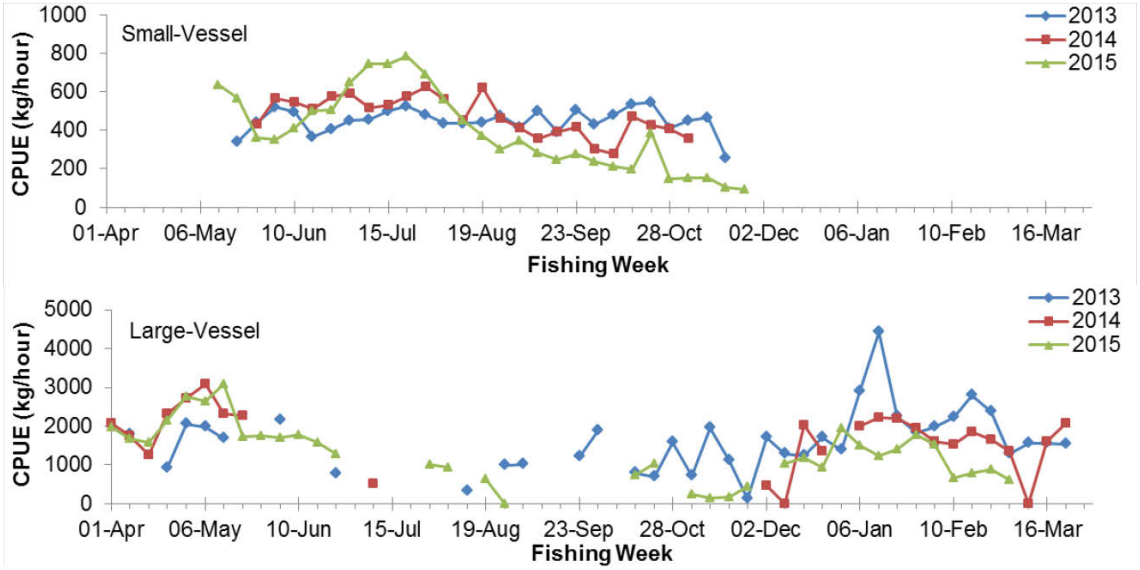


*Figure 6. SFA 6 small-vessel (top panel) and large-vessel (bottom panel) weekly CPUE for management years 2013/14 (blue diamonds), 2014/15 (red squares) and 2015/16 (green triangles), as calculated from logbook data.*

### Biomass

Fishable biomass index declined from 785,000 t in 2006 to 138,000 t in 2015 which is the lowest in the time series. There was a 41% decline between 2014 and 2015. Female SSB index declined from 466,000 t in 2006 to 89,000 t in 2015 which is the lowest in the time series. There was a 35% decline between 2014 and 2015 (Figure 7).

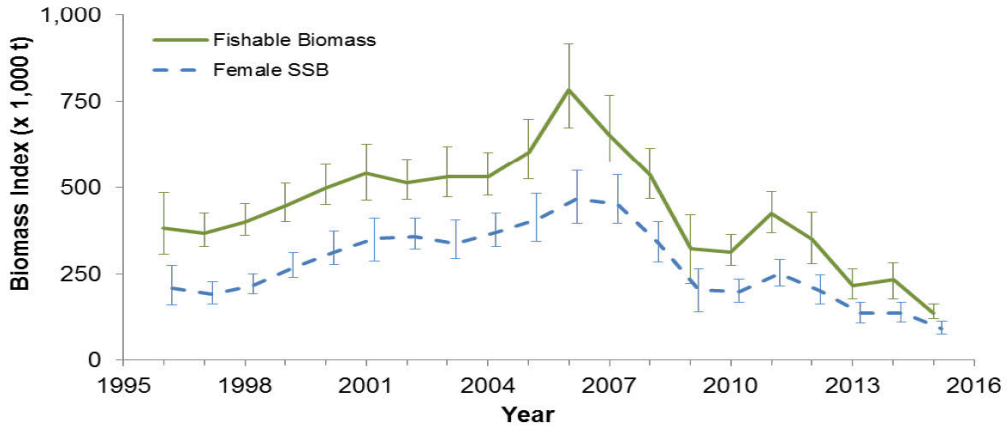


*Figure 7. SFA 6 fishable (green solid line) and female spawning stock (blue dashed line) biomass indices. Error bars indicate 95% confidence intervals.*

### Renewal

Resource renewal was examined considering both the causes of net change in population as a result of production (growth and reproduction) and predation (including fishing), and inferences that could be drawn from time series of shrimp data.

Renewal is the difference between the increase due to production, and removal largely due to predators. The amount of biomass produced by a unit of biomass of a given species during a

year is commonly known as the production over biomass ratio (P/B); although actual P/B ratios are expected to vary, and expectation of annual production can be estimated under certain assumptions (e.g., average conditions). The P/B ratio for shrimp has been estimated to be around 1.7, which implies that the biomass of shrimp available for consumption should be somewhere between 1 and 2.7 times the initial biomass. 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 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 8). This decrease is associated with an increase in capelin consumption. The ratio between predation and shrimp biomass (i.e. the red and black lines in Figure 8) is a relative index of predation mortality and is currently around double the level in the mid-1990s and 2000s.

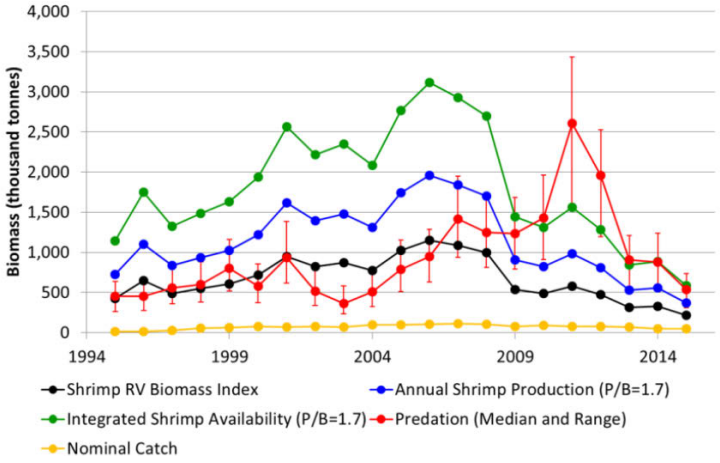


*Figure 8. Comparison of predation and fisheries catches with the Integrated Shrimp Availability derived from the DFO Fall survey biomass index for shrimp, and a P/B ratio of 1.7.*

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 natural 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 may lead to increased per-capita shrimp production in the medium term. However, current low spawning stock means that absolute rebuilding would be slow. Early blooms associated with warming appear to be related to high larval mortality.

Fishery removals appear to be a small fraction of total removals by all predators. Even so, they may be a large fraction of the net difference between shrimp production and total predation in recent years. Thus, fishing mortality may be very important for determining whether gains (production) exceed losses (predation) and hence whether the stock is increasing or decreasing.

### Exploitation

The exploitation rate index ranged between 5.5% and 21.4% from 1997 to 2015/16, and has averaged 18.3% in the last five years. The 2015/16 exploitation rate index will be 20.7% if the TAC is taken (Figure 9).

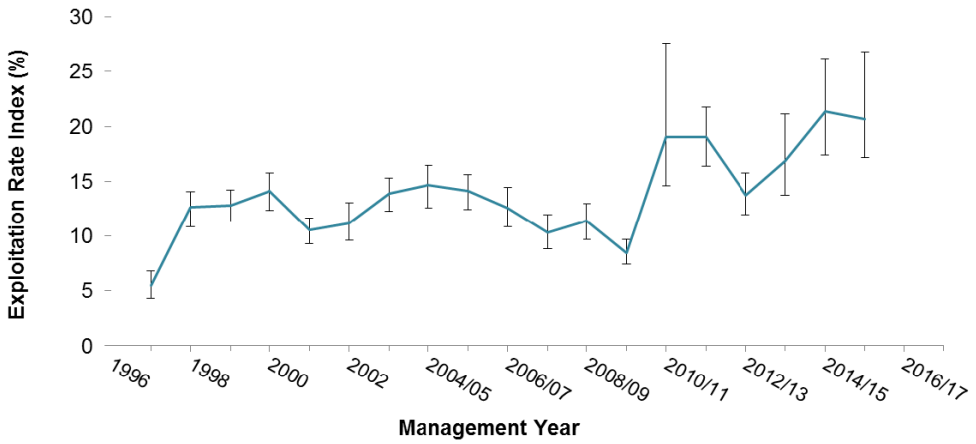


*Figure 9. SFA 6 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The 2015/16 point assumes that the 48,196 t TAC will be taken. Error bars indicate 95% confidence intervals.*

### Current Outlook and Prospects

The female SSB index is currently close to the LRP, in the Cautious Zone of the IFMP PA Framework, with a 20% probability that it is in the Critical Zone. If the 48,196 t TAC is maintained and taken in the 2016/17 season, the exploitation rate index will be 34.9% (Figure 10). The PA reference points were adjusted to reflect refinements to assessment methodology, which were implemented during the 2015 assessment.

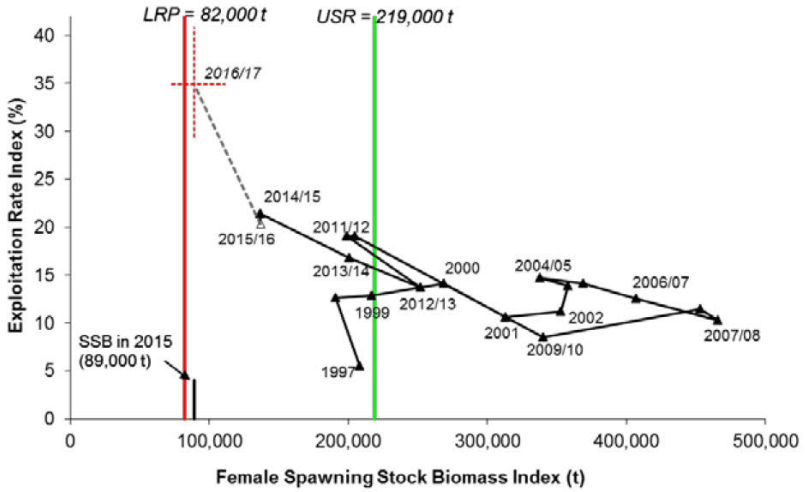


*Figure 10. SFA 6 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2015/16 fishery was ongoing, however it is expected that the TAC will be taken, and hence the 2015/16 point is based upon the TAC rather than catch to date. The red cross on the 2016/17 point indicates 95% confidence intervals for the 2015 female SSB index (horizontal) and the 2016/17 exploitation rate index (vertical), assuming that the 48,196 t TAC is maintained and taken in the 2016/17 fishery.*

## SFA 5 *Pandalus borealis*

### Fishery

The TAC doubled from 7,650 t in 1994-96 to 15,300 t over the 1997-2002 period. In 2003, the TAC increased to 23,300 t and has basically stayed at that level since. Commercial catch has

been about 23,000 t over the past five years. It is expected that the 2015/16 TAC of 23,300 t will be taken (Figure 11).

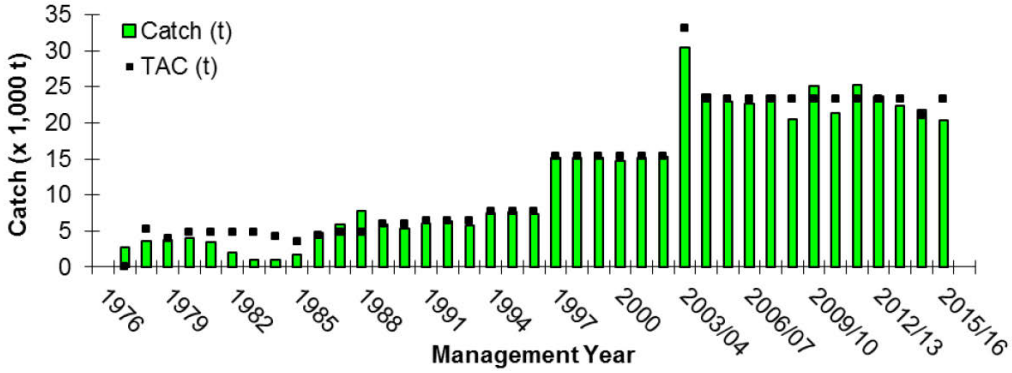


*Figure 11. Historical Northern Shrimp catches and TAC in SFA 5 for the period 1977-2015/16. 2015/16 values are preliminary and based upon the CAQR as of March 23, 2016. In 2003, the management year changed from a calendar to a fiscal year.*

Standardized large-vessel CPUE over the last four years has been stable at high levels (Figure 12).

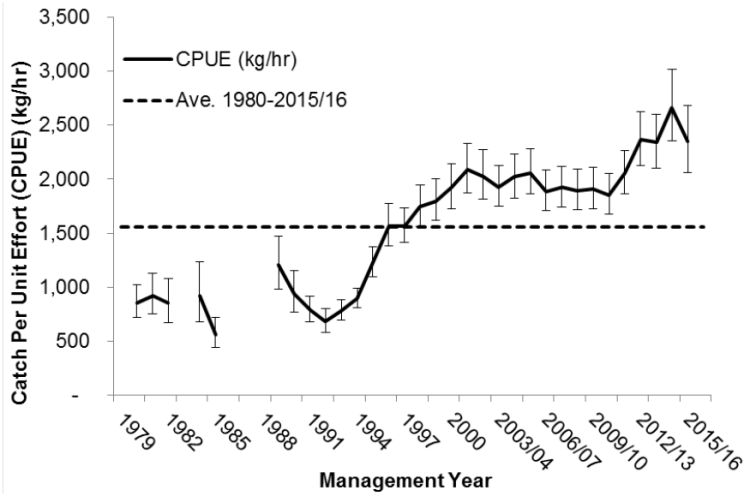


*Figure 12. SFA 5 large-vessel standardized CPUE. Error bars indicate 95% confidence intervals and the dashed line indicates the long term average.*

### Biomass

Fishable biomass index has been relatively stable since 2010, and was 148,000 t in 2015. Female SSB index has changed little since 2010, and was 83,000 t in 2015 (Figure 13). The low 2013 biomass indices were likely due to a survey year effect.

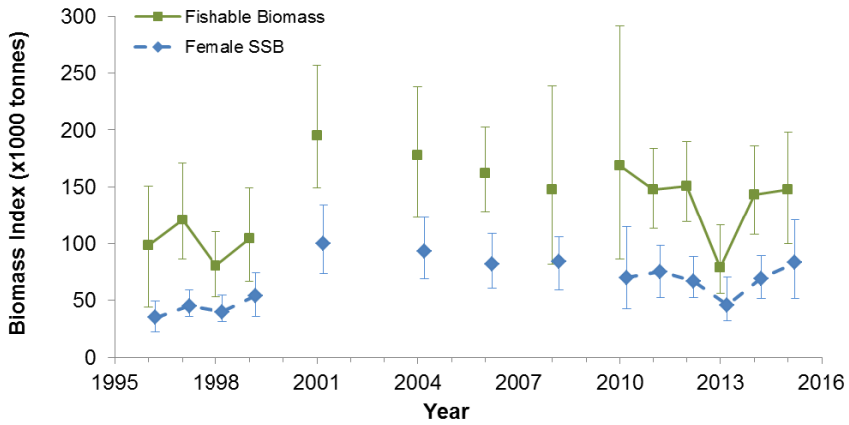


*Figure 13. SFA 5 fishable biomass (green solid line) and female SSB (blue dashed line) indices. Error bars indicate 95% confidence intervals.*

### Exploitation

The exploitation rate index has varied without trend around 15% from 1997–2015/16 (Figure 14).

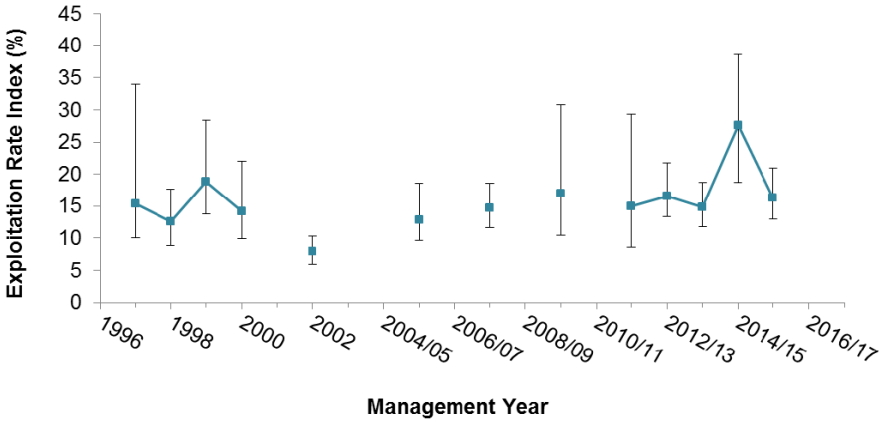


*Figure 14. SFA 5 exploitation rate index, based on total catch in current year divided by the fishable biomass index from previous year, expressed as a percentage. The exploitation rate index in 2015/16 assumes that the 23,300 t TAC will be taken. Error bars indicate 95% confidence intervals.*

### Current Outlook and Prospects

Female SSB index is in the Healthy Zone within the IFMP PA Framework. If the 23,300 t TAC is maintained and taken in 2016/17, then the exploitation rate index will be 16% (Figure 15). The PA reference points were adjusted to reflect refinements to assessment methodology, which were implemented during the 2015 assessment.

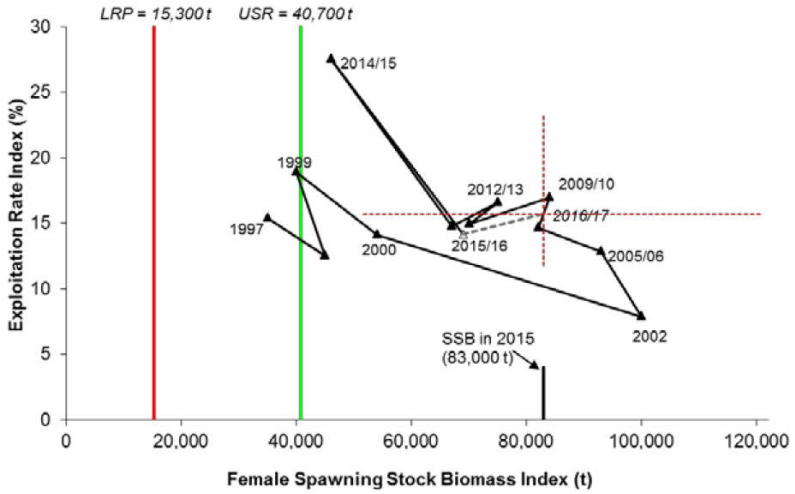


*Figure 15. SFA 5 PA Framework with trajectory of exploitation rate index versus female SSB index. Point labels denote year of the fishery. The 2015/16 fishery was ongoing and based on reported catch as of March 23, 2016.The red cross on the 2016/17 point indicates 95% confidence intervals for the 2015 female SSB index (horizontal) and the exploitation rate index (vertical), assuming that the 23,300 t TAC is maintained and taken in the 2016/17 fishery.*

## SFA 4 *Pandalus borealis*

### Fishery

The TAC increased from 5,200 t in 1995 to 9,320 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 been 14,971 t for the past three years. Commercial catch increased from approximately 10,000 t from 2005/06-2011/12 to about 15,000 t in the past three years (Figure 16).

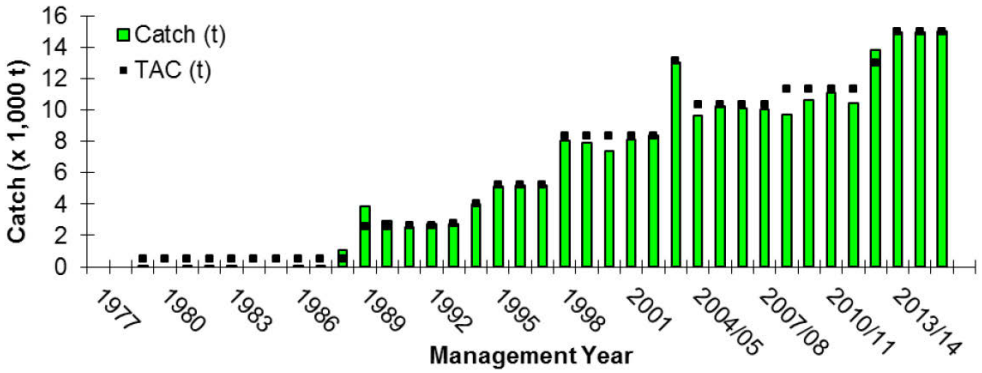


*Figure 16. Historical Northern Shrimp catches and TAC in SFA 4 for the period 1977-2015/16. In 2003, the management year changed from a calendar to a fiscal year.*

Large-vessel standardized CPUE fluctuated without trend near the long term mean (Figure 17). Several factors including changes in management measures and species composition of catches confound the interpretation of fishery performance in this area.

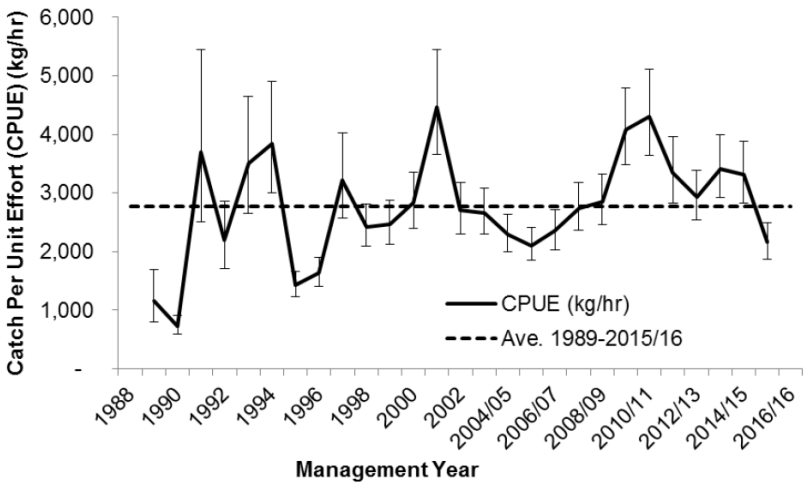


*Figure 17. SFA 4 large-vessel standardized CPUE (kg/hr) for Northern Shrimp. Error bars indicate 95% confidence intervals and the dashed line indicates the long term average.*

### Biomass

The fishable biomass index varied without trend from 2005 to 2015 with the 2015 point estimate at 91,000 t, which represents a decrease of 13% from 2014. The female SSB index for 2015 was 58,000 t, representing a decrease of 18% from 2014 (Figure 18).

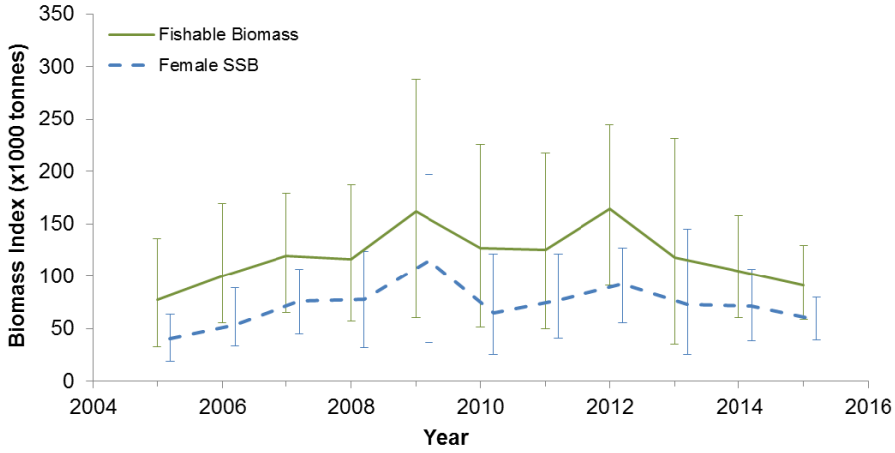


*Figure 18. SFA 4 fishable biomass (green solid line) and female SSB (blue dashed line) indices for Northern Shrimp. Error bars indicate 95% confidence intervals.*

### Exploitation

The exploitation rate index reached 16.5% by 2015/16 (Figure 19).

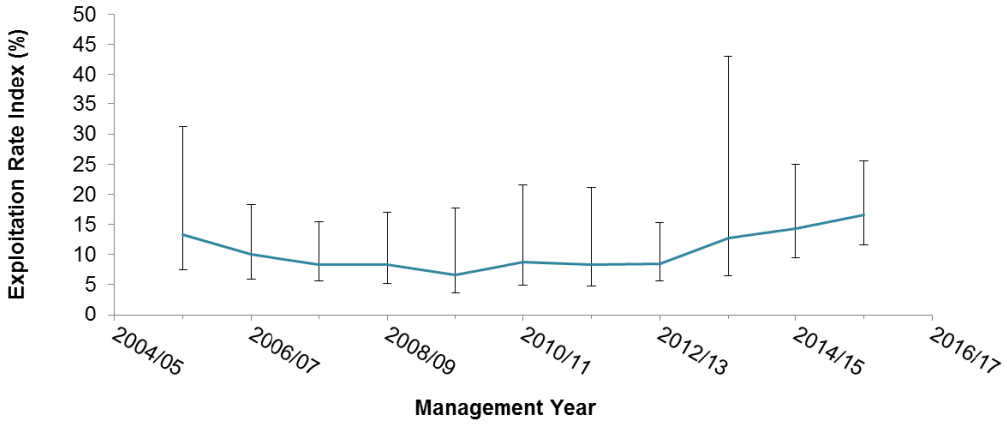


*Figure 19. SFA 4 exploitation rate index for Northern Shrimp, based on total catch divided by fishable biomass index, both from the current year, expressed as a percentage. Error bars indicate 95% confidence intervals.*

### Current Outlook and Prospects

Female SSB index in 2015 was in the Healthy Zone within the PA Framework with a 40% probability of having been in the Cautious Zone (Figure 20). The PA reference points were adjusted to reflect refinements to assessment methodology, which were implemented during the 2015 assessment.

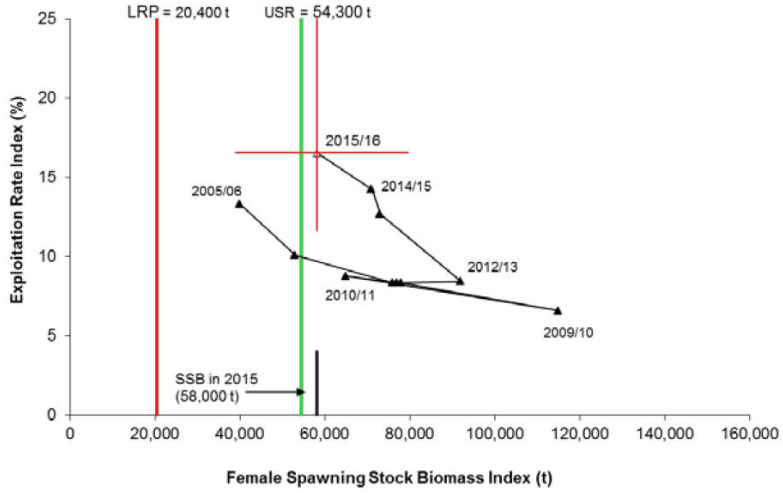


*Figure 20. SFA 4 PA Framework with trajectory of exploitation rate index versus female SSB index for Northern Shrimp. Point labels denote year of the fishery. The red cross on the 2015/16 point indicates 95% confidence intervals for the 2015 female SSB index (horizontal) and the 2015/16 exploitation 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 2,135 t in 2015/16. The by-catch limit of 4,033 t has not been taken in the past three years (Figure 21). Until 2012, the sole source of catch information for Striped Shrimp was logbooks; however by-catch was recorded in the CAQR beginning in 2013.

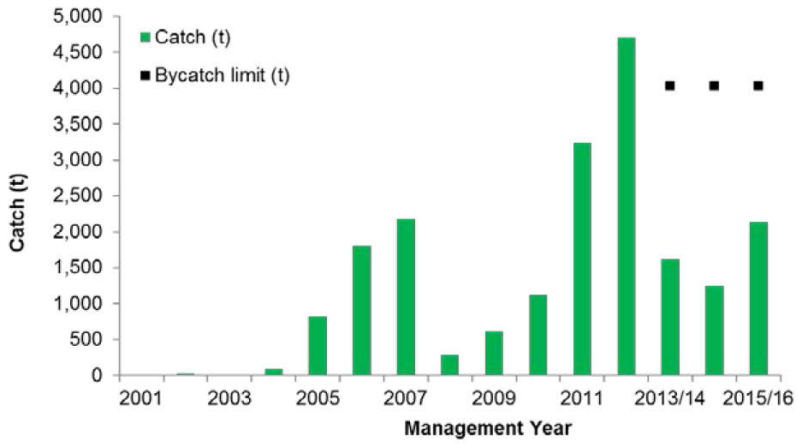


*Figure 21. SFA 4 Striped Shrimp catch for the period 2002-2015/16, along with the by-catch limit established beginning in 2013/14. The catches from 2002-12 were based on log books within calendar year whereas the catch from 2013/14 onward was based on the CAQR, as of March 23, 2016, within management 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 2015 was 47,000 t, an increase of 52% from 2014 (Figure 22).

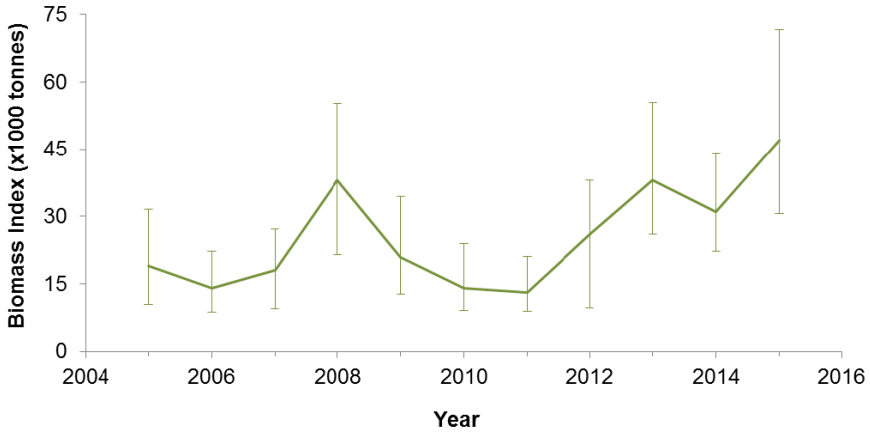


*Figure 22. SFA 4 fishable biomass index for Striped Shrimp. Error bars represent 95% confidence intervals.*

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 advect 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 2015/16 was 4.5% (Figure 23). If the by-catch limit had been taken, the exploitation rate would have been 8.6% in 2015/16.

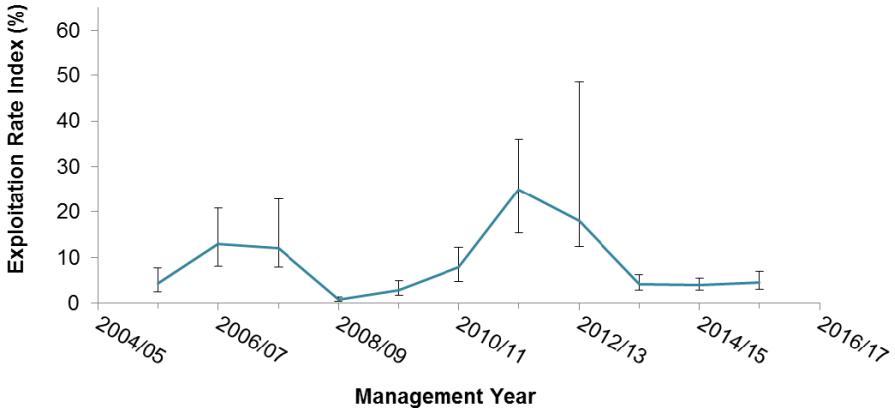


*Figure 23. SFA 4 exploitation rate index for Striped Shrimp, based on total catch divided by fishable biomass index, both from the current year, expressed as a percentage. Error bars indicate 95% confidence intervals.*

### Current Outlook and Prospects

There is no IFMP PA framework for this resource. The potential exploitation rate index of 8.6% 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; however, this is not always true.
2. It is assumed that the diet composition (and species overlap) observed in stomachs collected in autumn surveys applies throughout the year.
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 are increasing, 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 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 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 vessel was again changed to the *Katsheshuk II*. The first three vessels 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 advect 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 survey biomass relates to the biomass of maximum sustainable yield ($B_{MSY}$).

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.

# CONCLUSIONS AND ADVICE

## SFA 6 *Pandalus borealis*

There is concern for the current status of this resource. The female SSB index is currently close to the LRP and below the mid-point of the Cautious Zone, based on the PA Framework, for the third consecutive year. There is a 20% probability that the female SSB index is in the Critical Zone. If the TAC is taken, as it is expected to be, the 2015/16 exploitation rate index will be 20.7%. The IFMP states that the exploitation rate should not exceed 15% when the female SSB is below the midpoint of the Cautious Zone. If the 48,196 t TAC were maintained and taken in the 2016/17 season, the exploitation rate index would increase to 34.9%. Fishery removals may be becoming 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 is increasing or decreasing.

### SFA 5 *Pandalus borealis*

Current status of this resource is positive, at levels close to 2014. Female SSB index is in the Healthy Zone within the PA Framework. If the 23,300 t TAC is maintained and taken in 2016/17, then the exploitation rate index will be 16%.

### SFA 4 *Pandalus borealis*

Current status of this resource is positive. Female SSB index in 2015 was in the Healthy Zone, close to the USR within the PA Framework, with a 40% probability of having been in the Cautious Zone.

### SFA 4 *Pandalus montagui*

Current status of this resource appears positive given the increase in biomass. The potential exploitation rate of 8.6% 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

In general, 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. Keeping the exploitation rate at or below 15% for the Healthy Zone of the PA Framework is thought to be conservative and leaves forage for predators. A better understanding of ecosystem demands on shrimp as a forage species is required.

As predator biomass increases and shrimp biomass decreases, fishery removals may be becoming 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 is increasing or decreasing.

## SOURCES OF INFORMATION

This Science Advisory Report is from the April 6-8 and April 11-12, 2016 Assessment of Northern and Striped Shrimp. 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. 2016. 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 2015. Secr. can. de consult. sci. du MPO, Avis sci. 2016/028.*