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

Newfoundland and Labrador Region
Canadian Science Advisory Secretariat
Science Response 2017/009

REVIEW OF REFERENCE POINTS USED IN THE PRECAUTIONARY APPROACH FOR NORTHERN SHRIMP *(PANDALUS BOREALIS)* IN SHRIMP FISHING AREA 6

Context

Shrimp biomass indices in Shrimp Fishing Area (SFA) 6 have declined to the lowest levels in the twenty-year survey time series. Science advice (DFO 2014 and DFO 2016) has indicated that a decline in shrimp production has been associated with a recent warming trend, early timing of the phytoplankton bloom, increasing biomass of predatory fishes and commercial fishing. The fishable biomass index is expected to remain low, or decline further, in the short-term assuming that unfavourable conditions continue.

The current Precautionary Approach (PA) framework for Northern Shrimp in SFA 6 was developed by a working group which included participation from industry, Fisheries and Oceans Canada (DFO) Fisheries and Ecosystems Management, DFO Science, Government of Newfoundland and Labrador (NL), and Aboriginal groups. It was developed following the PA Workshop on Canadian Shrimp and Prawn Stocks and Fisheries in 2008 (DFO 2009) which included DFO Fisheries and Ecosystems Management, DFO Science, Government of NL, Aboriginal groups, and industry participation. The provisional reference points and harvest control rules developed by this working group have been used in assessments since 2010.

Given the changes in environmental conditions and the predatory fish communities on the NL Shelves, Fisheries and Ecosystems Management requested that Science assess risks associated with potential alternative interim reference points on the basis that a maximum harvest rate of 10% will remain in place if the female spawning stock biomass (SSB) index declines below the current Limit Reference Point (LRP) of 82,000 t (i.e. the harvest control rule currently in place). Consequently, a DFO Science Response Process (SRP) was undertaken on January 25, 2017. No new data since the 2016 Regional Peer Review of the Assessment of Northern and Striped Shrimp (DFO 2016) were available for review.

An assessment model and subsequent revised PA framework will be explored, and peer-reviewed at a framework meeting in 2-3 years.

The objectives of the SRP were:

Provide a summary review of existing information on:

1. Environmental changes, fish community changes, estimations of consumption, and impact of these on net shrimp production.
2. Changes in productivity conditions for shrimp, and whether these changes are expected to continue in the short, medium and long terms. This includes the review of available information from surveys and the fishery before 1995.
3. The role of shrimp as a forage species considering an ecosystem based management approach.

Engage in discussion regarding:

4. The applicability of the reference points in place for Northern Shrimp, given recent changes in the ecosystem and environment, and whether there are alternative interim reference points that could be applied.
5. Qualitative descriptions of risks (including uncertainties and limitations) associated with current and potential interim proxy reference points, recognizing that there is no model for this stock.

This Science Response Report results from the SRP of January 25, 2017 on the Review of Reference Points used in the Precautionary Approach for Northern Shrimp (*Pandalus borealis*) in Shrimp Fishing Area 6.

Analysis and Response

Objective 1: Environmental changes, fish community changes, estimations of consumption, and impact of these on net shrimp production

The physical environment experienced a warming period from 1995-2010, cooled to below normal in 2014-15, and warmed again in 2016 (Fig. 1). The remainder of the Northwest Atlantic has not experienced the recent cooling, as NL receives an outflow of cold air from the Arctic. The extent of suitable thermal habitat for shrimp (a range of 2°C to 4°C) has declined since the mid-2000s; however it remains above the 1981-2010 long-term average (Fig. 2) and roughly the same as during the ‘productive’ period from 1996-2000.

There has been a decline in overall subsurface nutrient inventories (which provide the standing stock for phytoplankton to grow) and the deep nutrient inventories have been below the 1999-2010 mean since 2006-08 (Fig. 3). Ocean colour observations used to characterize the timing, duration, amplitude and overall magnitude of the spring phytoplankton bloom indicate that the magnitude of the spring phytoplankton bloom has declined since 2011 (Fig. 4), but the onset of the bloom has been variable, with a trend towards early blooms in 2009-13 and later blooms in 2014-16 (Fig. 5). Early blooms are unfavourable for the survival of young shrimp. Since 2010, the integrated phytoplankton biomass from oceanographic surveys has generally been below the long-term mean (1999-2010; Fig. 6), which may be related to long-term declines in deep nutrient inventories. Zooplankton biomass is a combined biomass of large and small-size fractions, and since 2010, has been at or below the long-term mean. Zooplankton biomass reached the lowest level in the time series in 2015 (Fig. 7). As well, there has been a shift toward smaller zooplankton and ephemeral species though the relevance to shrimp is unclear.

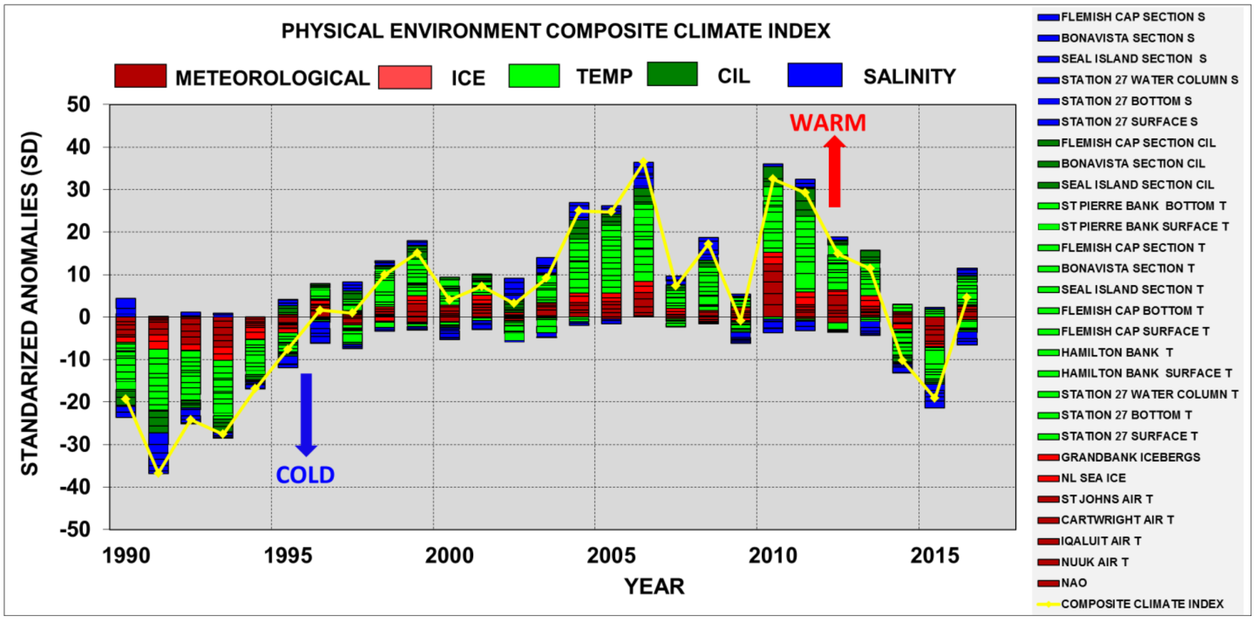

Figure 1. Composite climate index derived by summing the standardized anomalies of North Atlantic Oscillation (NAO), air temperature, ice, water temperature and salinity and cold-intermediate-layer (CIL) areas from several locations in the Northwest Atlantic. The standardized anomalies for each series are computed based on the 1981-2010 reference period.

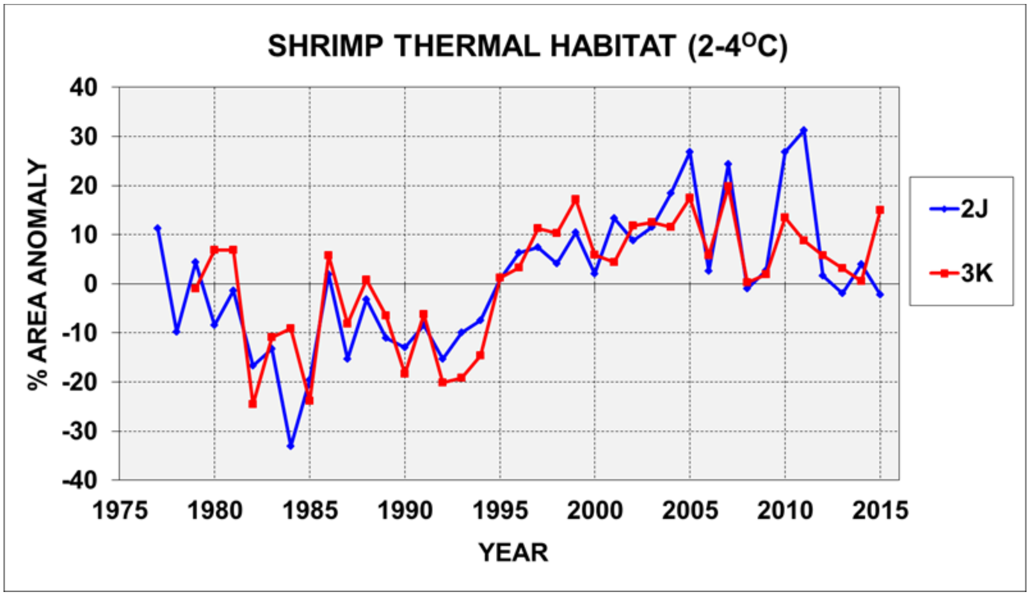

Figure 2. Percentage area anomalies in shrimp thermal habitat for NAFO Divs. 2J and 3K from fall surveys. The long-term mean is computed from 1981-2010.

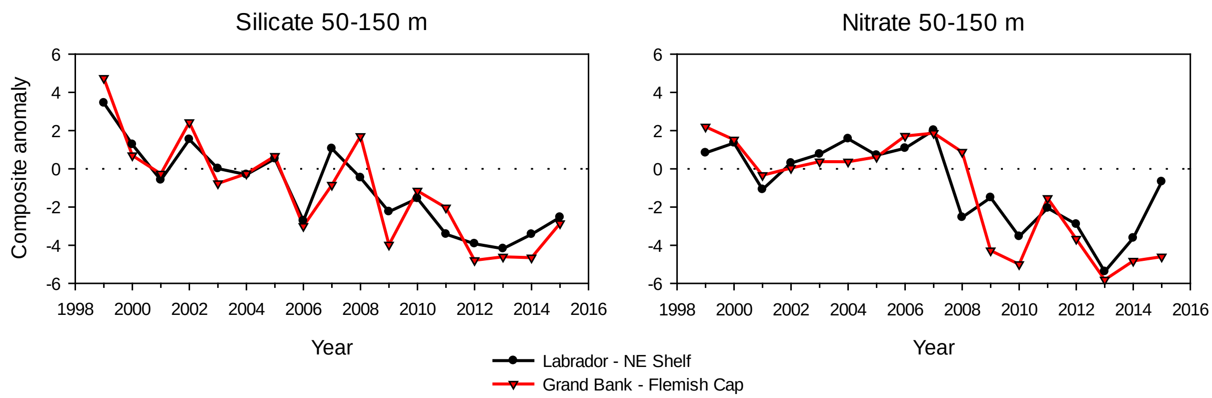

Figure 3. Composite annual anomalies in nutrient inventories across the Labrador and northeast Newfoundland shelf and Grand Bank-Flemish Pass/Cap Sections and fixed station (Station 27). The summed standardized anomalies are the differences between the annual average for a given year and the long-term mean (1999-2010) divided by the standard deviation. Negative anomalies imply below average levels while positive values indicate the reverse.

	Magnitude																	
Petrie Box	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Hudson Strait (0B, 2G)	0.2	-0.7	-0.3	-0.8	-0.5	3.0	-0.4	0.1	0.8	-0.5	-0.4	-0.6	0.1	-0.8	-0.6	-0.5	-1.2	-0.9
N Labrador Shelf (2H)	0.0	0.0	-0.7	0.6	-1.0	0.7	-0.7	-0.1	-0.1	-0.5	2.8	0.0	-1.1	-0.8	-0.7	-1.6	-1.0	0.4
Hamilton Bank (2J)	-0.4	0.7	-1.1	1.5	-1.0	-0.5	-1.0	-0.2	0.9	-1.5	0.5	1.0	1.1	-0.9	-0.1	-1.6	-1.3	-0.3
St. Anthony Basin (3K)	-0.3	0.3	-0.9	0.0	0.7	-0.3	-0.5	-0.8	-0.3	-0.6	3.0	0.3	-0.5	0.7	-0.5	-0.7	-1.0	-0.1
NE Newfoundland Shelf (3KL)	0.1	0.2	0.6	-1.4	0.1	-0.5	-0.7	-0.8	1.6	-0.2	-0.7	2.3	-0.4	3.1	-0.9	-1.3	-1.0	-1.0
Avalon Channel (3L)	-1.5	-0.7	-0.7	-0.2	0.4	-0.3	-0.4	-0.8	0.2	0.4	-0.2	1.3	2.4	0.8	-0.9	-0.6	-0.9	-1.6
Hibernia (3L)	-0.6	1.7	1.7	-0.9	-0.2	-1.3	0.6	-1.1	-0.3	-0.3	1.0	0.3	-0.5	-0.1	-1.0	-0.6	-0.5	-1.2
Flemish Pass (3L, 3M)	-1.5	-0.4	0.0	-1.2	1.8	-0.3	0.3	0.6	-0.3	-0.2	-1.1	1.5	0.9	-1.5	-0.8	-0.1	-1.8	-2.9
Flemish Cap (3M)						0.6	0.1	0.8	1.2	-1.6	-0.7	-1.0	0.6	-1.0	-0.2	-0.1	-0.7	-1.7
St. Pierre Bank (3Ps)	-0.8	-0.4	-1.1	1.7	-0.2	-0.7	0.0	-0.5	0.1	-0.2	-1.0	1.8	1.3	0.5	1.4	-1.2	-0.5	-1.8
SE Shoal (3NO)	-0.4	0.5	-1.6	0.0	1.3	-0.5	-0.8	-1.0	0.2	-0.8	1.9	1.0	0.2	0.5	-0.9	0.8	2.0	-1.5

Figure 4. Annual standardized scorecard anomaly indices for overall magnitude of the spring phytoplankton bloom across the NL statistical sub-regions during 1998-2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation.

	Peak Timing																	
Petrie Box	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Hudson Strait (0B, 2G)	0.4	-0.3	0.6	-0.7	-0.1	2.4	-0.7	-1.2	-0.7	0.9	-1.2	0.1	0.5	-0.1	-0.5	-0.2	-1.8	0.1
N Labrador Shelf (2H)	-0.4	-0.1	0.1	-0.4	0.8	-0.7	-0.3	-0.4	-0.4	2.8	-1.4	0.3	0.1	-0.4	-0.2	-0.1	-0.1	-0.5
Hamilton Bank (2J)	-0.5	-0.2	1.1	0.8	1.6	0.2	-0.1	-0.5	-1.8	0.8	-1.2	0.7	-1.0	-0.3	-0.9	-0.1	0.4	-0.3
St. Anthony Basin (3K)	-0.2	-0.7	-1.0	0.1	0.2	1.8	0.8	0.1	-0.1	0.4	-1.1	-1.7	1.4	1.1	1.5	2.0	1.7	1.6
NE Newfoundland Shelf (3KL)	-0.3	-1.2	0.2	1.4	1.3	1.2	0.7	-0.9	-1.0	0.0	0.6	-0.3	-1.6	0.0	-0.7	0.2	0.8	1.2
Avalon Channel (3L)	0.0	-1.2	-0.5	1.1	0.4	2.1	-0.2	-0.9	0.3	0.0	1.0	-0.9	-1.3	0.1	-0.7	0.3	1.0	2.2
Hibernia (3L)	0.7	-0.9	-0.9	0.9	1.7	0.4	-0.3	0.2	0.1	0.1	0.9	-0.8	-2.1	0.3	-0.5	-0.6	0.6	1.9
Flemish Pass (3L, 3M)	-0.3	-1.7	0.2	1.1	1.1	1.8	0.2	-0.8	-1.4	-0.2	-0.2	-0.3	0.6	-0.1	-0.6	-0.9	-0.5	0.2
Flemish Cap (3M)						2.0	0.8	-0.9	-0.8	-0.5	-0.3	-0.8	0.5	1.2	-0.8	-1.1	-1.0	0.4
St. Pierre Bank (3Ps)	-0.1	0.9	-0.3	0.4	0.2	1.3	0.3	-0.7	0.2	-0.2	0.6	0.2	-2.8	-0.5	-1.2	0.0	0.6	-0.1
SE Shoal (3NO)	0.2	-0.4	-0.8	0.5	0.7	1.6	0.7	0.0	-0.1	0.7	0.6	-2.1	-1.5	-0.7	-0.3	0.0	0.2	1.7

Figure 5. Annual standardized scorecard anomaly indices for peak timing of the spring phytoplankton bloom across the NL statistical sub-regions during 1998-2016. The standardized anomalies are the differences between the annual average for a given year and the long-term mean (1998-2010) divided by the standard deviation. Negative anomalies indicate earlier blooms while positive anomalies indicate the reverse.

Section	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Seal Island (2J)	2.7	0.1	0.8	0.1	-0.8	-0.4	-0.1	0.1	-0.9	-0.9	-0.1	-0.7	-1.0	-0.9	-0.9	-0.2	-0.9
Bonavista (3K)	-1.4	1.2	0.1	-1.2	-1.5	0.6	0.6	0.6	0.4	-0.9	1.4	0.1	-1.3	-1.7	-0.7	-0.6	-1.2
Station 27 (3L)	3.1	-0.1	0.0	-0.1	-0.4	-0.2	-0.6	-0.2	-0.3	-0.7	-0.2	-0.3	-0.7	-0.4	-1.0	-0.7	-0.7
Flemish Cap (3L, 3M)	2.1	-0.2	-0.1	-0.9	-1.8	0.0	0.2	-0.7	0.9	-0.5	1.0	0.0	-2.0	-1.5	-0.1	0.2	-2.6
SE Grand Bank (3LNO)	1.8	-1.5	0.2	-0.3	-1.1	-0.4	0.4	-0.7	1.1	-0.8	1.3	0.1	-1.7	-0.7	1.0	-2.2	-2.1
St. Pierre Bank (3Ps)										-1.5	1.7	1.0	-0.6	0.1	0.2	-0.2	-0.8

Figure 6. Annual scorecard anomaly indices for integrated phytoplankton biomass across the different ocean sections and fixed station (Station 27). The reference period used to compute annual anomalies was 1999 to 2010.

Section - NAFO Div.	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Seal Island (Div. 2J)	0.3	-2.5	-0.6	1.1	0.7	-0.1	0.8	0.6	1.0	-0.6	-0.7	-0.1	-0.5	-1.0	0.0	-1.2	-2.2
Bonavista (Div. 3K)	-0.7	-1.7	-1.4	0.2	0.8	1.5	0.3	0.2	0.4	-0.6	-0.1	1.4	-0.1	-0.7	0.1	-0.3	-3.3
Stn27 Fixed (Div. 3L)	-0.5	0.6	1.2	1.5	-0.6	1.1	-0.1	-0.7	0.1	-2.1	-0.4	-0.3	-1.1	-2.6	-2.0	-1.8	-3.1
Flemish Cap (Div. 3LM)	-1.5	-1.5	-0.2	2.3	0.2	-0.3	-0.5	0.4	-0.1	-0.2	0.6	0.8	0.3	-0.4	0.0	0.2	-3.1
SE Grand Bank (Div. 3LNO)	-1.5	-1.5	-1.4	0.7	0.5	0.4	0.7	0.6	0.8	-0.2	1.4	-0.4	0.4	0.1	-0.9	-1.8	-3.0

Figure 7. Annual scorecard anomaly indices for combined zooplankton biomass across the different ocean sections and fixed station (Station 27). The reference period used to compute annual anomalies was 1999 to 2010.

The ecosystem changes observed in the 1990s involved the collapse of both groundfish and capelin stocks (a key forage species for groundfish), in conjunction with an increase in shellfish abundance. This collapse period also involved a decline in average finfish size. Signals consistent with a rebuilding of the groundfish community appeared in the mid to late 2000s. These signals are associated with an increase in fish size and coincided with a moderate increase in capelin availability. Nevertheless, current groundfish and capelin levels are well below pre-collapse levels (Fig. 8, Fig. 9). The changes in the fish community have shown a coherent internal structure of small fish and shellfish versus forage and large fish. The combined biomass of all fish species in the 2010s has shown a moderate decreasing signal linked to a reduction in shellfish in conjunction with an increase in the dominance of groundfish. The combined biomass of the groundfish community has not changed in the 2010s. Recent increases in cod imply a higher dominance within groundfish, but do not indicate a broader rebuilding of fish biomass.

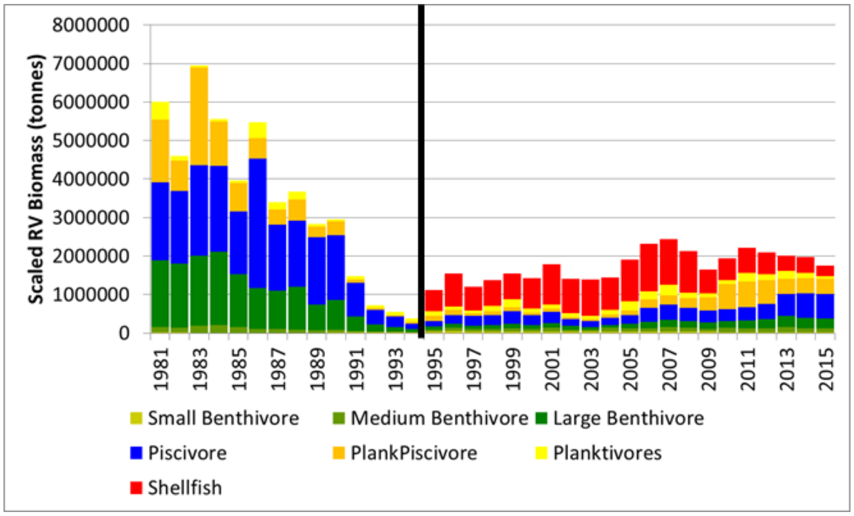

Figure 8. Trends in the Research Vessel (RV) Biomass Index by fish functional groups in core strata of NAFO Divs. 2J3KL from the DFO fall RV Survey. The vertical black line indicates a change in survey gear from Engels to Campelen. The shellfish functional group includes Pandalus shrimp and Snow Crab, but its signal is heavily dominated by shrimp; reliable RV survey data for these species are only available since the introduction of the Campelen gear in the survey. Conversion factors between gears are only available for a handful of groundfish species; the scaling factors used here were applied at the fish functional group level and provide a general approximation for comparing across gears. These scaling factors were derived from all available data from comparative fishing tows and included a large suite of fish species; however sample sizes and taxonomic coverage were insufficient to derive reliable species-specific conversion factors for all species in the survey.

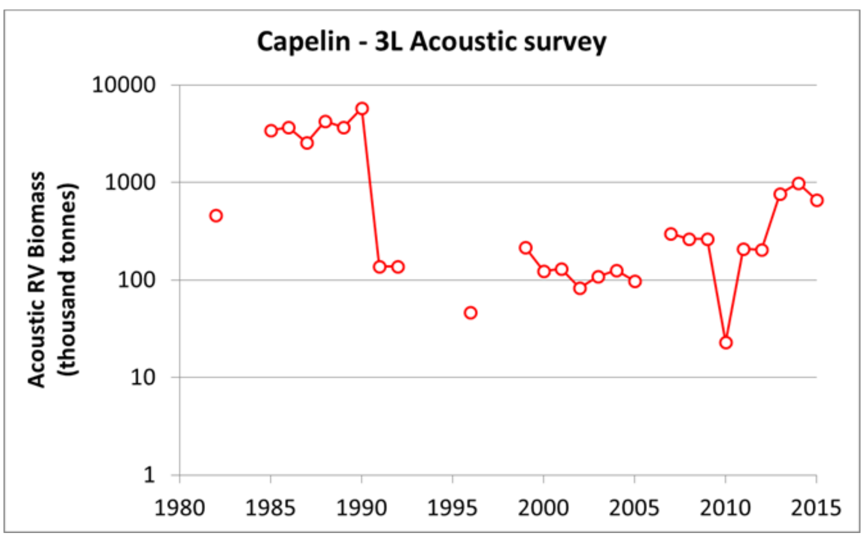

Figure 9: Trend in the capelin acoustic biomass index from Div. 3L DFO spring capelin survey. The index is presented in log scale to allow a better visualization of the trajectory at low stock levels.

Food consumption is based on estimating food requirements for different taxa and assuming those requirements are met. Food consumption estimates were based on diet composition from the fall period and estimated for the full year. Four fish functional groups (medium benthivores, large benthivores, piscivores and plank-piscivores) are considered as predators for key forage species such as shrimp and capelin. Total food consumption by predators has been relatively stable since 2011. Since 1995, consumption of shrimp and capelin has been between 30-50% of the total food consumption by predators (Fig. 10). Predation on shrimp showed an increasing trend until 2011 and has decreased since. This decrease is associated with an increase in capelin consumption. Predation mortality on shrimp increased rapidly in 2008-11 and decreased afterwards. Nevertheless, the current predation level on shrimp is around double the level in the mid-1990s and early 2000s (Fig. 11).

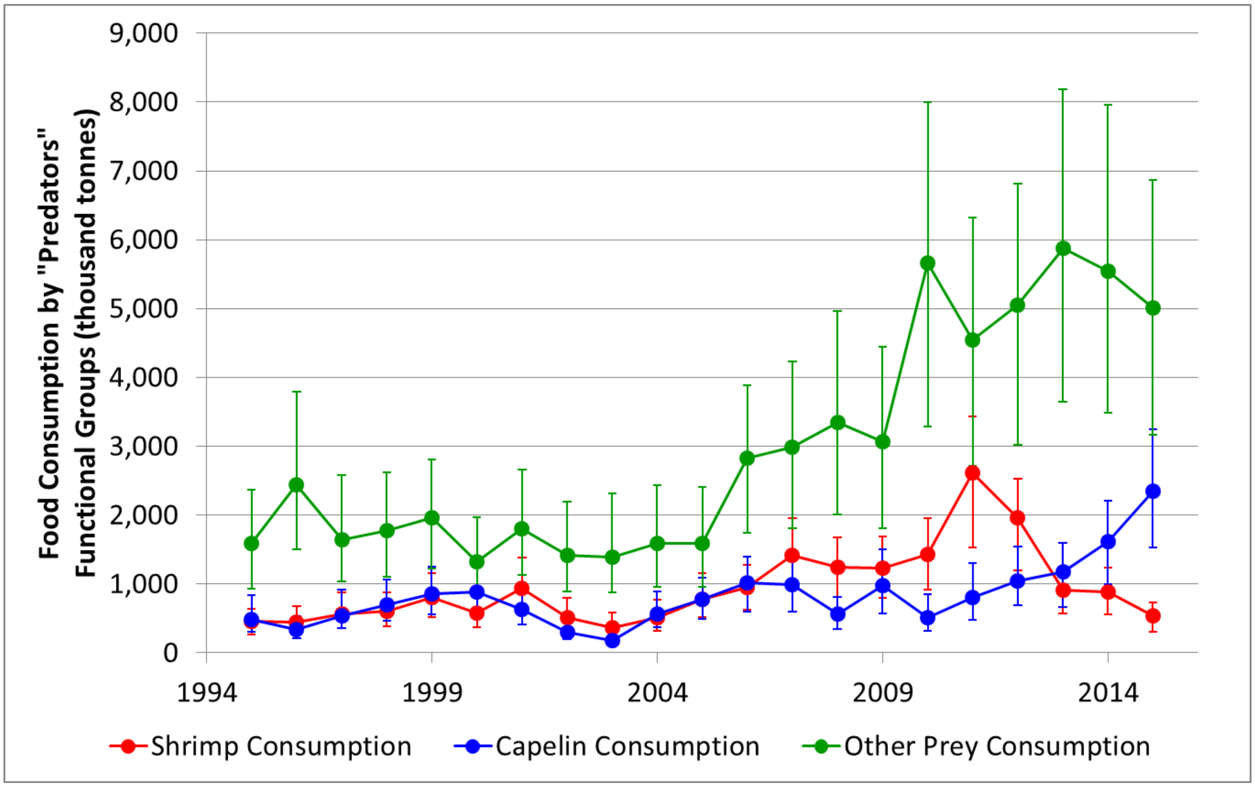

Figure 10. Median of estimates of consumption of shrimp (red), capelin (blue) and other prey types (green) by those functional groups considered predators of shrimp and capelin (medium benthivores, large benthivores, piscivores, and plank-piscivores) in Divs. 2J3KL. The error bars correspond to the range of estimated consumption from different models, and represent the envelope within which actual consumption is likely to be. The fractions of shrimp and capelin were derived from stomach content analysis of key groundfish species.

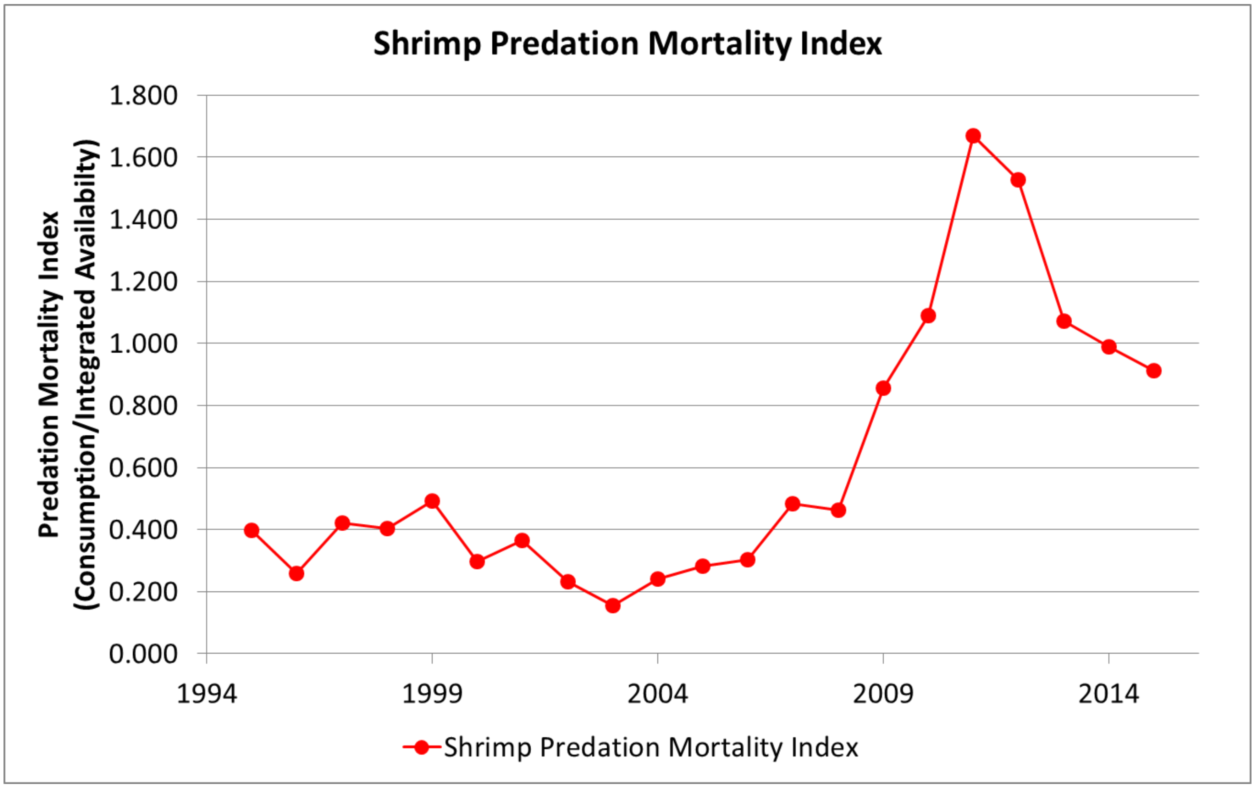

*Figure 11. Shrimp predation mortality index in Divs. 2J3KL. This index is estimated as the ratio between the estimated median consumption of shrimp (Fig. 10) and the estimated integrated shrimp availability. (ISA) is derived from the RV Biomass index for shrimp (SB) and an assumed Production/Biomass ratio (P/B) of 1.7 as ISA=SB+P/B*SB. In these calculations SB correspond to total RV biomass.*

The impact of various drivers (shrimp stock size, fishing, environment, peak timing of the spring phytoplankton bloom, magnitude of the phytoplankton bloom, predator biomass, and estimated shrimp consumption by predator functional groups) on net (after supplying predators) shrimp production has been examined using correlations between per capita shrimp production rate and the aforementioned drivers considering different time lags. Shrimp per capita production has declined since the mid-1990s. Shrimp stock biomass in SFA 6 does not emerge as a significant driver of shrimp production, possibly because of a dependence on spawning from upstream stock, while fishing, predator biomass, environmental forcing, peak timing of the spring phytoplankton bloom, and shrimp consumption by predator functional groups (in no order of importance) appear to be significant drivers of shrimp production. Predator biomass has impacts with lags of 1-3 years and fishing has detectable indirect impacts on shrimp production with lags of 2-4 years. Environmental forcing as a significant driver appears to be strongly linked to the timing of the spring phytoplankton bloom. For most drivers, a lag of 3 years is the most significant (Fig. 12). Based on this observation, some drivers (timing of the bloom and decreasing predation) suggest that shrimp per capita production could improve over the next 3 years, while others (fishing pressure and predator biomass) suggest a continuation of current conditions.

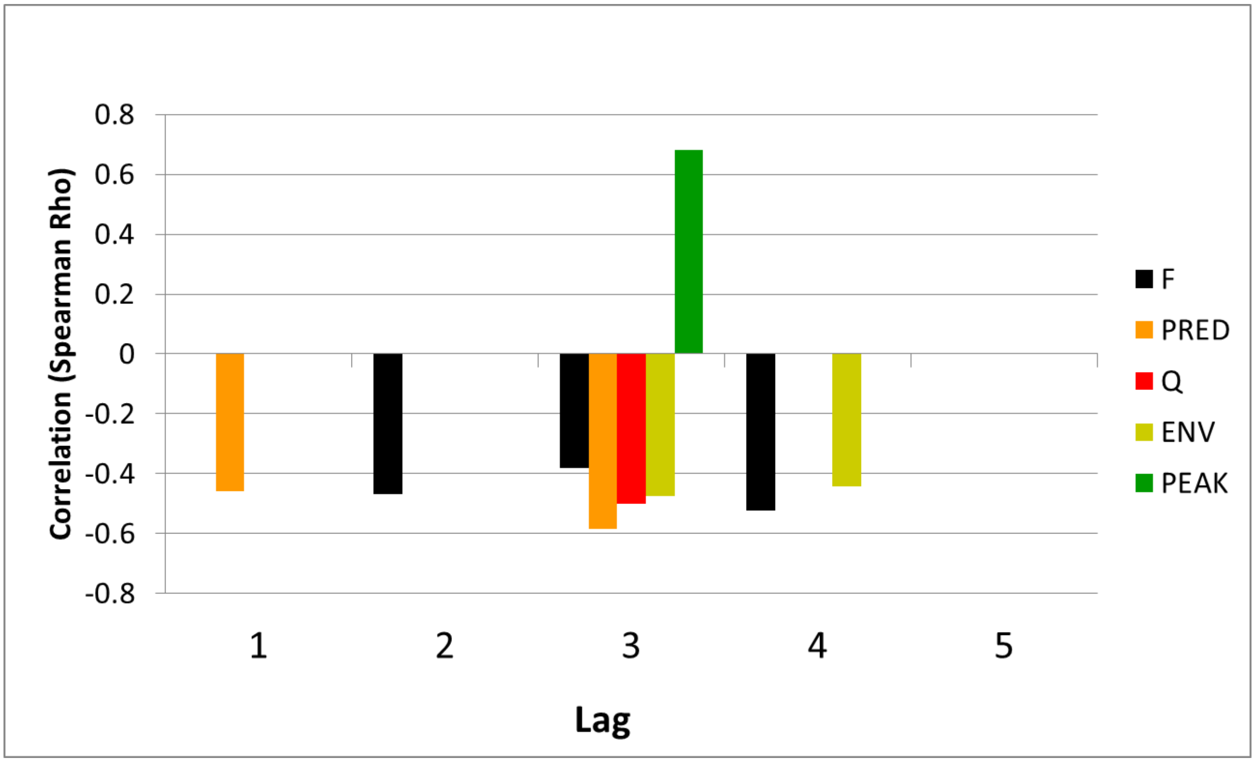

Figure 12. Significant lagged correlations of shrimp per capita production versus drivers. F = exploitation fraction, PRED = predators biomass, Q = estimated shrimp consumption by predator functional groups, ENV = composite environmental index, and PEAK = peak timing of the spring phytoplankton bloom.

Objective 2: Changes in productivity conditions for shrimp, and whether these changes are expected to continue in the short, medium and long terms

There is not enough information to determine whether shrimp are experiencing a new productivity regime and it is not clear whether there were low or high productivity regimes in the past. There is not a sufficiently long and stable time series available to draw any conclusions on this issue.

Shrimp data prior to 1995 were collected from shrimp surveys conducted in areas of assumed Northern Shrimp concentrations in SFA 6 from 1978-86 and 1988-92 using a Sputnik 1600 shrimp trawl. Biomass indices were produced by integrating over regions much smaller than the whole of SFA 6. There were inconsistencies between the areas sampled, the timing of the surveys, and the vessels used. Since 1995, surveys informing on the status of shrimp have been conducted as part of the DFO multispecies trawl surveys following a random stratified experimental design using a Campelen 1800 shrimp trawl. The data and analyses of the survey series prior to 1995 cannot be quantitatively compared to the data and analyses of the multispecies trawl surveys as comparative fishing was not performed, and therefore the data are not available to determine shrimp productivity or associated indices prior to 1995 (Fig. 13). Consequently, lower biomass indices indicated by historical survey data cannot be confirmed. At this point, it is impossible to conclude if a “normal” biomass index level, at which a certain commercial exploitation rate could be maintained, is evident from the survey series under the current environmental and ecosystem drivers.

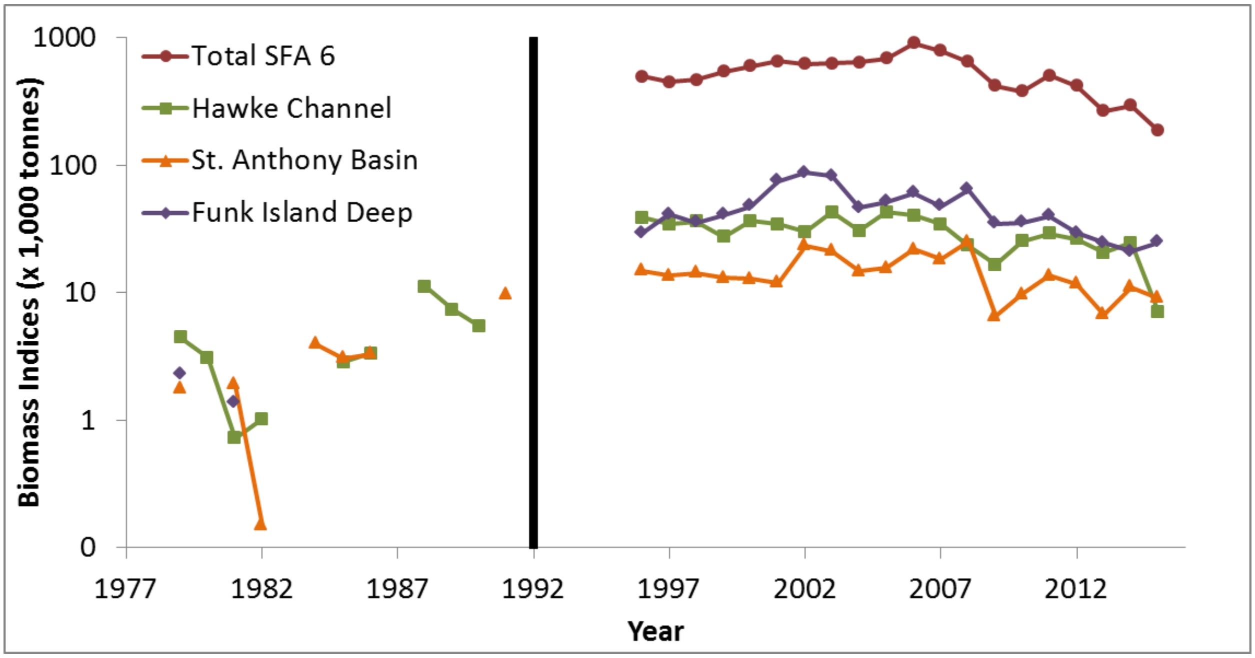

Figure 13. Comparison of total biomass indices from 3 study areas before and after the introduction of the multispecies trawl survey in 1995 and total biomass index from SFA 6 from 1996-2015. In 2007, the biomass and abundance indices from the 1995 multispecies trawl survey were deemed unsuitable for analysis (DFO 2007).

The Northern Shrimp biomass indices have been declining since 2006 in SFA 6 and were at the lowest levels in the multispecies trawl survey time series in 2015 (analysis of data for 2016 is not available at this time).

The exploitation rate increased sharply when the PA framework was introduced in 2010, and has been 20% for the past 3 years (Fig. 14). While the Total Allowable Catch (TAC), and associated commercial catch, have been decreasing since 2009, they have not translated into any decrease in exploitation rates. The biomass index level at which a certain commercial exploitation rate can be maintained remains unclear.

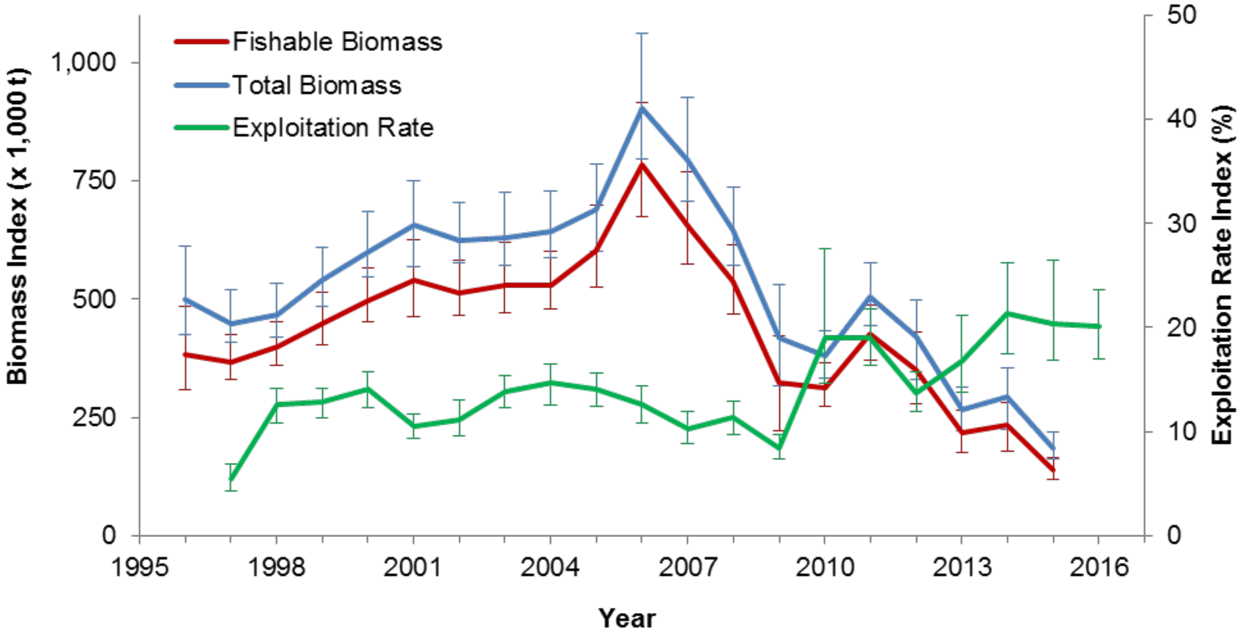

Figure 14. Fishable (red) and total (blue) biomass indices and exploitation rate index (green) for Northern Shrimp in SFA 6. The exploitation rate is based on total catch in current year/fishable biomass index from previous year, expressed as a percentage. The 2016 exploitation rate index assumes that the TAC will be fully taken, the fishery is ongoing. Error bars indicate 95% confidence intervals.

In the short-term (maximum 3 years), the current declining trend in shrimp biomass could continue or reverse depending on which drivers have a greater influence on the system. A later peak of the spring phytoplankton bloom and decreased predation could lead to improved shrimp per capita production over the next 3 years, while increased fishing pressure and increased predator biomass could result in a continuation of current per capita production conditions. At present, DFO Science cannot quantitatively predict medium and long-term trends for changes in productivity conditions for shrimp. Currently, only climate projections and Atlantic Multidecadal Oscillations (AMO) data could be considered when looking past the short-term, and no improvements in environmental conditions are expected in the near future. Overall, expectations are that environmental conditions will get warmer in the medium-term, which will most likely translate to less shrimp productivity. Cold conditions with few groundfish, as was seen during the shrimp boom of the late 1990s, are unlikely. Nevertheless, if the groundfish community does not rebuild to previous levels, or if alternative prey are available, then impacts on net shrimp production would not be as large. Even if there were a current assessment model for Northern Shrimp in SFA 6, it would likely predict no more than 3 years into the future.

Objective 3: Overview of the role of shrimp as a forage species considering an ecosystem based management approach

In SFA 6, total biomass of fish that are potential shrimp predators has increased. As a consequence, fish consumption of all types of food is estimated to have increased since the late-1990s (Fig. 10). Because capelin remains below pre-collapse levels (Fig. 9), shrimp remains an important forage species. The trend in shrimp predation mortality in the near future appears highly associated with the availability of capelin as alternative prey. Capelin appears as a fundamental driver of groundfish rebuilding, while shrimp appears as a key food source for the subsistence of groundfish during low capelin periods. If capelin stocks were to recover and become the preferred prey species for larger fish, this may result in decreased pressure on shrimp. The decline in shrimp production is a decline in net production, which may not translate into low gross production. In order to have a build-up of standing stock, production needs to exceed consumption. It is important to note that productivity may be consumed by predators rather than caught by the fishery. In that case, a low stock does not mean low productivity; it indicates that predators are eating what is being produced. Due to heavy predation on shrimp, fishing pressure could now be influencing stock declines more than it did in previous years.

In considering an ecosystem based management approach, fishing must be managed in a way that does not compromise the biological diversity, productivity and overall environmental quality of marine ecosystems (DFO 2017). Due to heavy predation on shrimp, fishing pressure could now be influencing stock declines much more than it did in previous years. To apply the principles of the PA of fisheries on forage species, the biomass of forage species used for LRPs should ensure both that future recruitment of the target species is not impaired, and account for food supply for predators. In situations where risk presented by a particular level of harvest and consequences of over-harvesting are especially uncertain, exceptionally risk-adverse decisions are necessary. This is particularly relevant when a stock is approaching the LRP and hence the critical zone. According to the PA framework, in the cautious zone there is a balance of ecological and socio-economic considerations. However, once a stock is in the critical zone, biological considerations prevail as conservation concerns are paramount.

Objective 4: The applicability of the reference points in place for Northern Shrimp, given recent changes in the ecosystem and environment, and whether there are alternative interim reference points that could be applied

In 2004, the *Atlantic Fisheries Policy Review* (AFPR) led by DFO called for a comprehensive risk management framework for decision making (including the PA) which incorporated reference points linked to stock and ecosystem indicators, objectives for desirable resource and fishery outcomes, and resource use strategies to scale resource use that avoids undesirable outcomes. With respect to the creation of a shrimp PA, a PA Workshop on Canadian Shrimp and Prawn Stocks and Fisheries took place in November 2008 with participation by DFO Science and Fisheries and Ecosystems Management, Government of NL, Aboriginal groups, and industry stakeholders. The workshop explored approaches for defining reference points and presented potential reference points. However, the potential reference points were not adopted in later assessments and no harvest control rules were proposed (DFO 2009). The shrimp reference points were set at a series of meetings of the Marine Stewardship Council (MSC) Working Group and first applied in the March 2010 Zonal Advisory Process on Northern and Striped Shrimp (DFO 2010). Consistent with the PA framework, a relatively productive period (1996-2003) was chosen in absence of a modelled $B_{MSY.}$ The Northern Shrimp LRP was defined as 30%, and the USR as 80%, of the mean of the SSB index of the productive period. These reference points differ from the DFO PA framework which provides guidance suggesting that 40% and 80% should be used to set the LRP and USR where there is insufficient stock specific information available. The shrimp reference points of 79,600 t (LRP) and 212,200 t (USR) were used until 2015 when they were adjusted to reflect refinements to assessment methodology that were implemented during the April 2016 Regional Peer Review Assessment of Northern and Striped Shrimp (DFO 2016). The current LRP is 82,000 t and the USR is 219,000 t (Fig. 15). Another difference between the shrimp PA and the DFO PA framework is that the former allows an exploitation rate of 10% in the critical zone, while the latter calls for reducing exploitation to the minimum possible level.

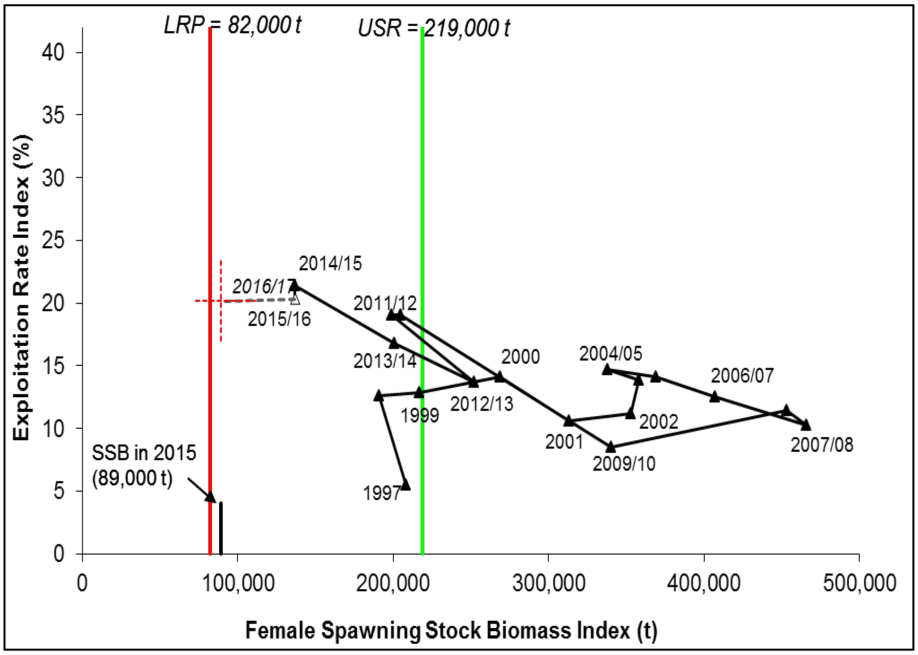

Figure 15. SFA 6 PA framework with trajectory of exploitation rate versus female SSB index. Point labels denote year of the fishery. The 2015/16 point assumes that the 48,196 t TAC was taken in that fishing year. The 2016/17 point assumes that the 27,825 t TAC will be taken, however that fishery is ongoing.

The biomass reference points were estimated during a relatively productive period. The average net increase in biomass during 1996-2008 was around 20% per year. The current exploitation rate is roughly 20% per year and the stock continues to decline. This suggests that the current fishing mortality is much greater than the average net growth rate.

It has not been possible to document an agreed exploitation fraction reference point. The perceived reference fishing mortality may have been set too high when the shrimp PA framework was developed as it was based upon Northern Shrimp stocks where a 30% exploitation rate is sustainable. When the per capita productivity in an area is higher than at B_{MSY} levels and there is still a decline, this suggests that reference fishing mortality has been set too high. In SFA 6, the exploitation rate of 20% has not allowed the stock to sustain itself or increase which suggests that adjustment of the reference fishing mortality is required. It has been suggested that the current biomass LRP may not be appropriate for the current state of the shrimp resource as it was derived based on a period of more favourable ecosystem conditions. However, due to the absence of a Northern Shrimp assessment model, the importance of shrimp to other species as a forage species, and changing environmental and ecosystem conditions, DFO Science does not have sufficient evidence to recommend alternative interim reference points. Consequently, the existing biomass LRP will remain unchanged. In order to change the current reference points, patterns in overall productivity of the stock and how they might have changed would need to be determined from the existing data. Biomass needed to support other resources in the current state of the ecosystem would also need to be assessed. This is not easily accomplished as one must understand how the stock is reproducing and account for other ecosystem demands on the stock. In the case of SFA 6, recent environmental and ecosystem conditions, and harvest rates have not permitted the stock to increase.

Objective 5: Qualitative descriptions of risks (including uncertainties and limitations) associated with current and potential interim proxy reference points, recognizing that there is no model for this stock

The major uncertainties associated with current and potential interim proxy reference points for Northern Shrimp in SFA 6 are the influence of oceanographic conditions, predation, and fishing mortality. These impacts cannot be ranked and are very difficult to partition and quantify. With respect to fishing mortality, the exploitation rate in SFA 6 is currently 20%; however the stock continues to decline which suggests that recent exploitation rates have been too high to support net shrimp production (Fig. 14). According to the PA framework, when a stock is in the cautious zone the exploitation rate should progressively decrease as the stock level approaches the critical zone. However, the exploitation rate for shrimp in SFA 6 increased while the stock declined which merits further evaluation in relation to the full application of the PA for shrimp. Because of the high level of uncertainties, changing the current biomass reference points would involve a high amount of risk to the ecosystem and the resource, while reducing exploitation rate would likely be required to see any growth in the stock. Consideration must be taken of the overall demands of the ecosystem, the potential productivity of the stock (net productivity between the current biomass and what is taken by the fishery) and the potential harm to the resource in order to evaluate the effects of a variety of different exploitation rates. In the absence of a model, B_{MSY} is currently estimated as the average biomass (or index of biomass) over a productive period and F_{MSY} is unknown for Northern Shrimp in SFAs 2-7. An assessment model and subsequent revised PA framework may be available in 2-3 years.

Conclusions

Objective 1: Environmental changes, fish community changes, estimations of consumption, and impact of these on net shrimp production

- The environmental composite index and suitable thermal habitat for shrimp have been above the long-term mean (1981-2010), nutrient inventories, the magnitude of the spring phytoplankton bloom and phytoplankton and zooplankton biomasses have been below the long-term mean (1999-2010), and the timing of the peak spring phytoplankton bloom has been variable.
- In the 1990s, the groundfish and capelin community collapsed and shellfish increased. Groundfish began to show signs of rebuilding in the mid-to-late 2000s. In the 2010s, the dominance of groundfish has increased and shellfish decreased, however, current groundfish and capelin levels are well below pre-collapse levels, and the combined community of groundfish are not currently increasing.
- Predation on shrimp showed an increasing trend until 2011, and has decreased since. This decrease is associated with an increase in capelin consumption.

Objective 2: Changes in productivity conditions for shrimp, and whether these changes are expected to continue in the short, medium and long terms

- Data cannot confirm whether there is a new shrimp productivity regime or whether there were low or high productivity regimes in the past.
- Shrimp productivity could improve in the short-term with a later peak of the spring phytoplankton bloom and decreased predation, or remain at current levels with increased fishing pressure and increased predator biomass.

- Predictions in shrimp productivity cannot be made for the medium-or long-term.

Objective 3: Overview of the role of shrimp as a forage species considering an ecosystem based management approach

- The trend in shrimp predation mortality in the near future appears highly associated with the availability of capelin as alternative prey for groundfish.
- In considering an ecosystem based management approach, fishing must be managed in a way that does not compromise the biological diversity, productivity and overall environmental quality of marine ecosystems. Due to heavy predation on shrimp, fishing pressure could now be influencing stock declines much more than it did in previous years.

Objective 4: The applicability of the reference points in place for Northern Shrimp, given recent changes in the ecosystem and environment, and whether there are alternative interim reference points that could be applied

- As a result of the absence of a Northern Shrimp assessment model, the importance of shrimp to other species as a forage species, and changing environmental and ecosystem conditions, alternative interim biomass reference points cannot be recommended with any certainty.
- The exploitation rate of 20% has been too high to allow the stock to sustain itself which suggests that adjustment of the exploitation rate is required to allow growth in the stock under current productivity conditions.

Objective 5: Qualitative descriptions of risks (including uncertainties and limitations) associated with current and potential interim proxy reference points, recognizing that there is no model for this stock

- Due to the high level of uncertainties, changing the current biomass reference points would involve a high amount of risk to the ecosystem and resource. The current biomass reference points used in the Northern Shrimp PA framework will remain unchanged at this time.

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