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Central and Arctic Region

Information in support of establishing new Limit Reference Points for Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*) stocks in the Western Assessment Zone and updating the existing Limit Reference Points for the Eastern Assessment Zones

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The Precautionary Approach (PA) is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty. An implementation of this approach, in the form of the PA Framework, serves as a foundation for the establishment of Limit Reference Points (LRPs), below which productivity is sufficiently impaired to cause serious harm to a fishery. Fisheries and Oceans Canada (DFO) has committed to implementing a PA Framework (DFO 2006) in the management of the Northern (*Pandalus borealis*) and Striped (*P. montagui*) shrimp fisheries located in Hudson Strait and Ungava Bay (Western Assessment Zone; WAZ). To support these efforts, this document provides directions for establishing of LRPs and suggests the Upper Stock Reference Points (USRs) for these stocks. This document also discusses updated LRPs and suggests USRs for the Northern and Striped Shrimp fisheries in Davis Strait (Eastern Assessment Zone; EAZ). Two approaches to establishing the LRPs are considered herein: 30% and 40% of the geometric mean of female spawning stock biomass (SSB).

In the WAZ, based on a 6-year time series, new LRPs based on a 30% scenario were calculated as 3,100 and 9,200 t for Northern Shrimp and Striped Shrimp, respectively. The 40% scenario in the WAZ would result in new LRPs of 4,100 and 12,300 t for Northern Shrimp and Striped Shrimp, respectively. New proposed USRs in the WAZ, based on a 6-year time series and calculated at 80% of the geometric mean of SSB, would be 8,200 and 24,600 t for Northern Shrimp and Striped Shrimp, respectively.

Similarly in the EAZ, two scenarios for calculating updated LRPs were also considered (i.e., 30% and 40% of the geometric mean of SSB). Based on a longer, 11-year time series, updated LRPs based on a 30% scenario were calculated as 11,800 t (increase from 6,800 t) and 2,300 t (no change) for Northern Shrimp and Striped Shrimp, respectively. The 40% scenario in the EAZ would result in updated LRPs of 15,800 t (increase from 6,800 t) and 3,100 t (increase from 2,300 t) for Northern Shrimp and Striped Shrimp, respectively. The updated USRs, based on 80% of geometric mean of SSB, in the EAZ are proposed at 31,600 t (increase from 18,200 t) for Northern Shrimp and 6,100 t (no change) for Striped Shrimp. The updated reference points for the EAZ reflect a longer time series (11 years versus 3 years as previously explored) and expanded spatial coverage to reflect current assessment extent.

The intent of this document is to serve as a source of supporting information to provide advice to DFO Resource Management, consistent with the Department's PA Framework in support of the sustainable management of these fisheries.

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The intent of this document is to serve as a source of supporting information to provide advice to DFO Resource Management, consistent with the Department's PA Framework in support of the sustainable management of these fisheries.

INTRODUCTION

The Precautionary Approach (PA) to Fisheries Management is a general philosophy to managing threats of serious or irreversible harm where there is scientific uncertainty (DFO 2006). The reference points within the PA framework (Limit Reference Point [LRP] and Upper Stock Reference [USR]) provide a benchmark against which stock biomass can be compared to determine current stock condition. Under the PA framework, the stock can be in one of three zones: Healthy, Cautious, or Critical, divided by the LRP and USR (Figure 1). The USR divides the Healthy and Cautious Zones. This is the point below which removals must be reduced and the management should be focused on avoiding reaching the LRP. The USR can be a management target and is developed by DFO Resource Management with input from stakeholders, co-managers, and Science. The LRP is the stock level below which productivity is sufficiently impaired to cause serious harm (Critical Zone) and below the LRP the risk of stock collapse becomes a concern (DFO 2006). While in the Critical Zone, the stock's removal rates are kept to the lowest possible level to promote stock growth.

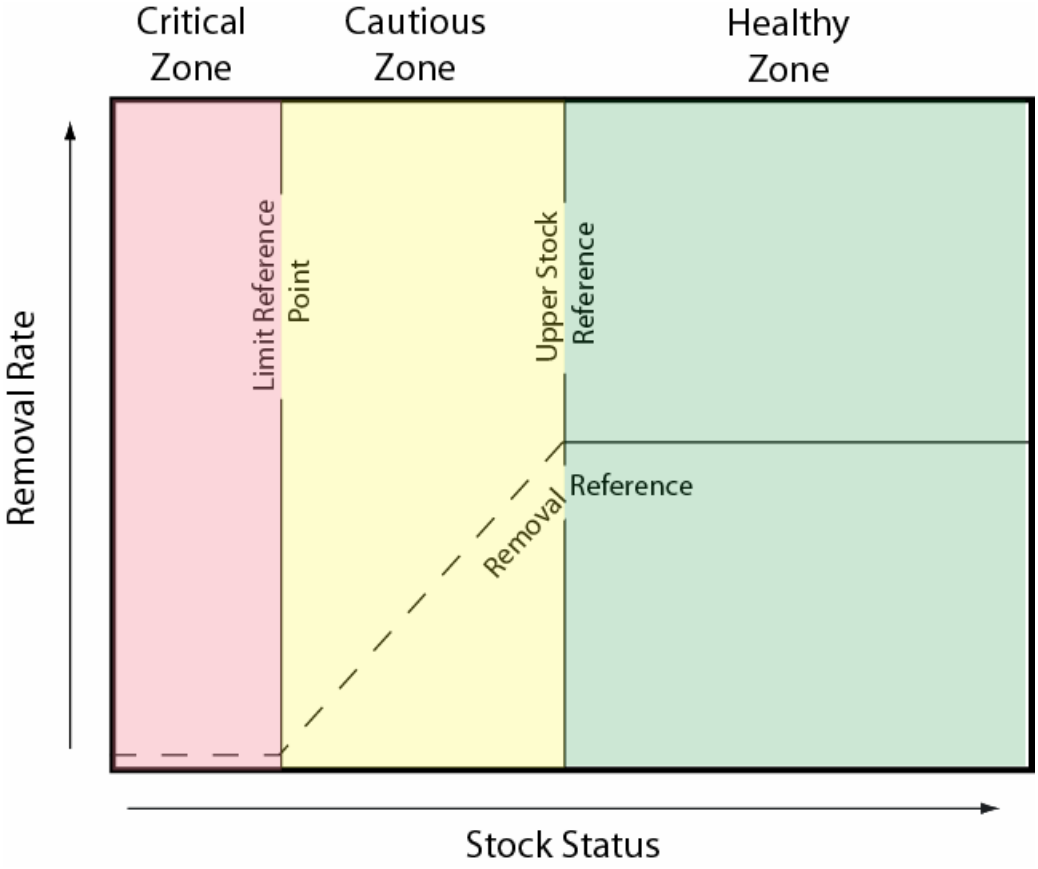

Figure 1. Schematic of a Fisheries Management framework that is consistent with a Precautionary Approach (DFO 2006).

DFO has committed to implementing a PA Framework in the management of Northern Shrimp (*Pandalus borealis*) and Striped Shrimp (*Pandalus montagui*) fisheries in the Western Assessment Zone (WAZ; Figure 2). In parallel, DFO made a decision to revisit existing LRPs and USRs in the Northern and Striped Shrimp fisheries in the Eastern Assessment Zone (EAZ;

Figure 2). This was driven by a longer time series currently available (11 years) that would be more reliable than the data used in the past (3 years).

Further, this paper provides characteristics of the two shrimp species, discusses historical biomass trends, and provides information on fishery removals. Previous attempts to establish a PA Framework in both the WAZ and EAZ and the uncertainty surrounding these processes are also discussed. Finally, this document provides information on potential LRP scenarios for each species within each assessment zone, and suggests potential USR points for consideration in future consultation processes led by DFO Resource Management.

This document and its findings are based on relatively limited data collection. While the data on shrimp biomass indices and their temporal changes are relatively well recognized, the document is lacking information on ecosystem variables that help determine shrimp productivity. Therefore, the content of this document should be viewed with this limitation in mind and the potential scientific advice based on this paper should be considered temporary until sufficient environmental data is collected to provide adequate background information (i.e., creation of the production model) on shrimp ecology and biology.

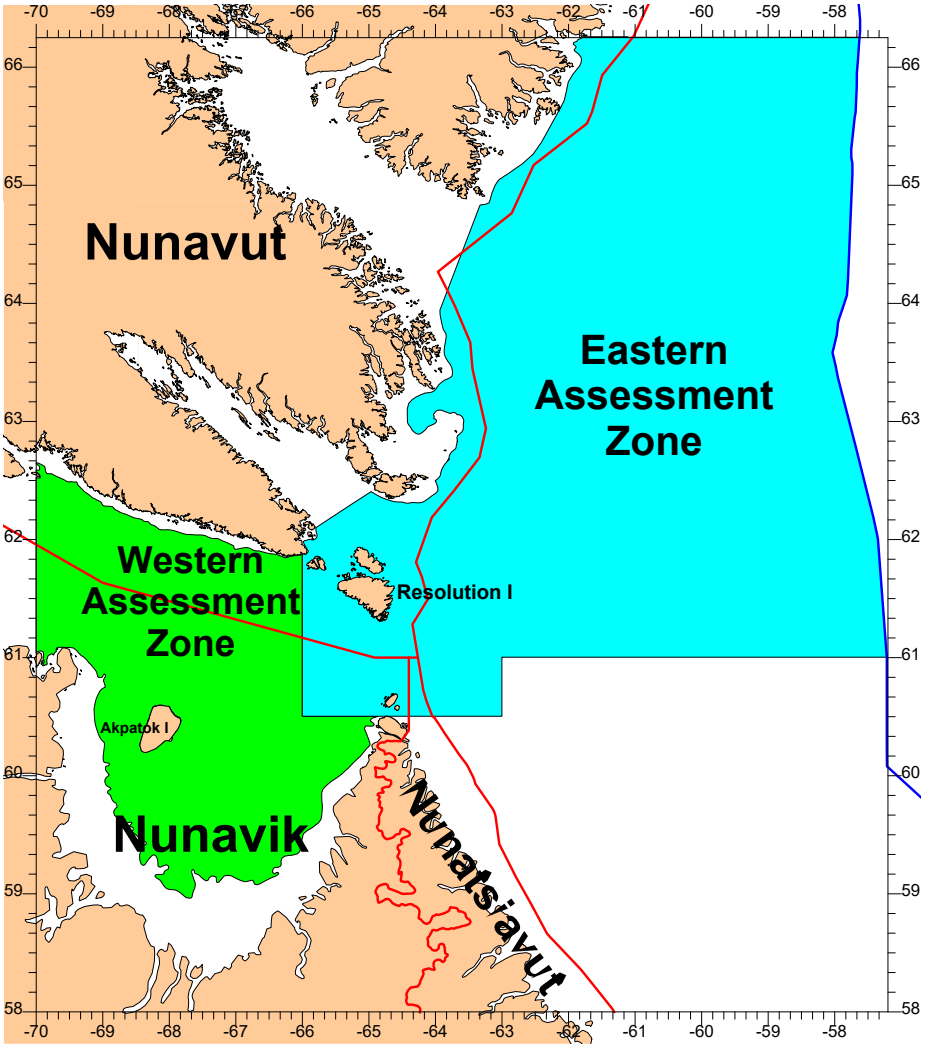

Figure 2. Western (green) and Eastern (blue) Assessment zones (WAZ, EAZ) for Northern and Striped Shrimp fisheries. Red lines indicate land claims boundaries. The dark blue line indicates the Canadian Exclusive Economic Zone (EEZ).

SPECIES CHARACTERISTICS

Northern Shrimp and Striped Shrimp are protandrous hermaphrodites. They are born as males, mature, and mate as males for one to three years. After that they change sex, spending the rest of their lives as mature females. Amongst multiple factors potentially affecting this sexual transition, temperature and population density are considered important (Koeller et al. 2000, Wieland 2004). Most shrimp reach sexual maturity during the second or third year of life and generally transition to female-form in winter. Mating takes place in late summer and fall. Fertilized eggs are attached to the female's abdominal appendages for seven to eight months until they hatch in the spring. Larvae are pelagic, spending three to four months in the water column. At the end of this period, they move to the ocean floor where they mature (DFO 2017a,b). There is a difference in life-span between northern and southern areas of the shrimp population range. In more northern areas (e.g., Baffin Bay), shrimp are thought to live longer than eight years, while in the south (e.g., off Newfoundland) shrimp likely live for six or seven years.

Recent research by Le Corre (2019, 2020) on the connectivity of management units via shrimp larval drift found that virtually the entire population of Northern Shrimp along the Canadian Atlantic coast (from Baffin Bay to the Scotian Shelf) is connected through larval drift processes with variable retention success in a given management zone. Also, larval drift was found to promote genetic homogeneity in areas with strong currents (Jorde et al. 2015). These findings improved our understanding of recruitment mechanisms and may help to inform the management of Canadian shrimp stocks.

Shrimp can grow to about 15 to 16 cm in total length, although the average size is 7 to 8 cm. They are considered fishable once their carapace length (CL) exceeds 17 mm, which occurs at approximately three years of age. Most of the fishable biomass, based on commercial data, consists of females (DFO 2017a,b), however, the male/female ratio in catches varies by area and year (Siferd 2015).

Northern Shrimp are found in the Northwest Atlantic from Baffin Bay in the north to the Gulf of Maine in the south. They show preference for muddy substrate, near bottom water temperatures of 2–4 °C, and depths of 150–600 m (DFO 2017a,b).

Striped Shrimp are found from Davis Strait in the north to the Bay of Fundy in the south. Striped Shrimp prefer a hard bottom and are typically found in waters with temperatures between -1 and 2 °C, at depths of 100–500 m (DFO 2017a,b).

Both species of shrimp are believed to feed on zooplankton and dead organic matter that is deposited on the bottom (carrion), thus they play an important role in the transfer of energy through marine food webs (Hopkins et al. 1993).

As forage species, these shrimp are important prey items for several species including Atlantic Cod (*Gadus morhua*), Greenland Halibut (*Reinhardius hippoglossides*), redfishes (*Sebastes* spp.), skates (*Raja* spp.), wolffishes (*Anarhichas* spp.), and Harp Seals (*Phoca groenlandica*). Shrimp are not as fat-rich as some of the pelagic forage species (including forage fishes), however, their abundance is particularly important when the availability of desired high-energy prey is low.

SURVEY DESCRIPTION, DATA ORIGIN AND PROCESSING

Data used for shrimp biomass assessments in the WAZ and EAZ are provided through the joint DFO-Northern Shrimp Research Foundation (NSRF) shrimp survey. The NSRF manages survey logistics, while DFO provides scientific guidance, including station allocations and

sampling protocols. The historical background of survey efforts, including survey design in the WAZ and EAZ, can be found in Siferd (2015).

Station allocation for each survey was done using a buffered random sampling method (Kingsley et al. 2004), which uses depth strata in both the WAZ and EAZ as a basis for set distribution. A Standard Campelen 1800 shrimp trawl was used in the EAZ until 2009, after which the Modified Campelen 1800 shrimp trawl was used. The difference between the two types of shrimp trawls is the size of the rock hopper gear (see details in Siferd and Legge 2014). The Modified Campelen 1800 trawl has been used in the WAZ since the beginning of the current survey time series in 2014. Data sets from 2009 onward in the EAZ and from 2014 onward in the WAZ are compatible in regards to methods used, which provides opportunity for future studies to compare the biomass dynamics between these assessment zones.

After completion of the survey, the collected data are processed by DFO in accordance with methods described in Siferd (2015). In short, the data are quality checked for potential errors and inconsistencies by DFO Science, Winnipeg, MB. The swept area of each tow is determined through the multiplication of speed, bottom time, and wing spread which are recorded for each particular tow. Three biomass indices for both shrimp species are calculated from the observed survey catch: total, fishable and female spawning stock. Total biomass index includes all individuals collected in a catch regardless of the size. Fishable biomass index is considered to be all individuals, regardless of the sex, greater than 17 mm CL. Female spawning stock biomass index (SSB) is all females present in the catch. The fishable biomass index is used to calculate the exploitation rate. The SSB, deemed to be consistent with the biomass corresponding to Maximum Sustainable Yield (B_{MSY}) (DFO 2009), is used as a stock status indicator in the PA Framework.

Trends in biomass indices could not be assessed effectively at present due to the short data series and variable nature of the biomass estimates. While there is no prescribed number of observations required to perform regression analysis, review of the common approaches in ecology suggest that running tests for trend determination on a very short data set would yield weak analytical power, and as such trends in biomass indices have not been calculated for these fisheries.

Potential exploitation rate, which assumes the entire Total Allowable Catch (TAC) is taken, is calculated each year by dividing the TAC by the fishable biomass. Potential exploitation rate is used as another variable in the PA Framework.

BIOMASS TRENDS

Biomass, regardless of which index in considered, was calculated using the bootstrapping method. In each year, data points from each depth strata were averaged and the resulting value was multiplied by the total area of the depth strata (i.e., aerially expanded). Biomass values from all strata were then pooled to calculate an overall biomass for the assessment zone. Upper and lower confidence intervals (CI) were estimated by resampling statistics (Bruce et al. 2000) and represent 95% confidence.

The three Northern Shrimp biomass indices (total, fishable, SSB) in the WAZ (Figure 3) followed the same pattern, however, due to the variable nature of the biomass estimates and relatively short time series, no trend can be inferred at this time.

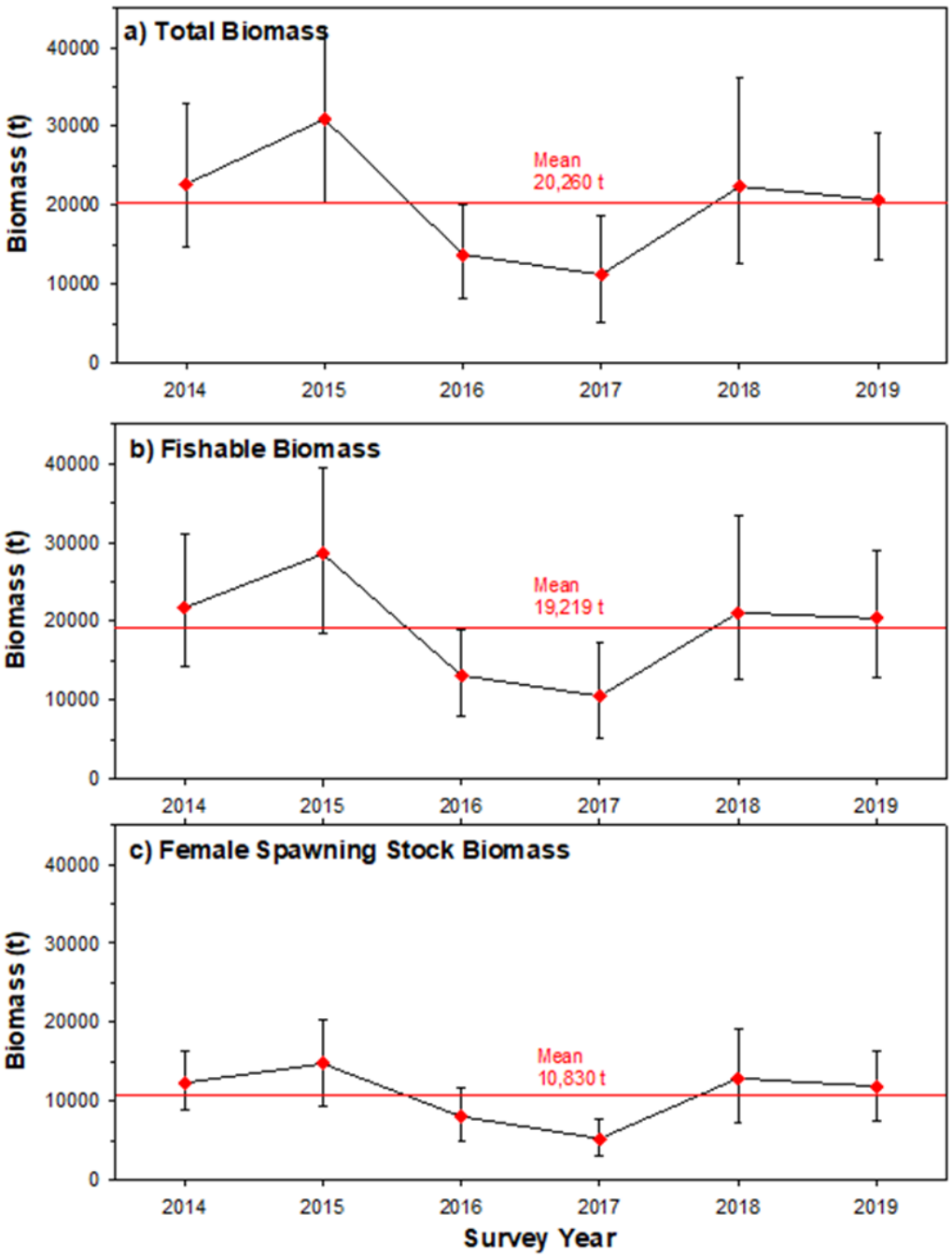

Figure 3. Total biomass (a), fishable biomass (b) and female spawning stock biomass (c) of Northern Shrimp in the Western Assessment Zone, based on data from 2014 to 2019 surveys. Error bars represent 95% confidence intervals. Horizontal lines indicate arithmetic means of the biomass data.

The three indices of Striped Shrimp biomass in the WAZ (Figure 4) showed similar patterns, however, due to the variable nature of the biomass estimates and relatively short time series, no trend can be inferred at this time.

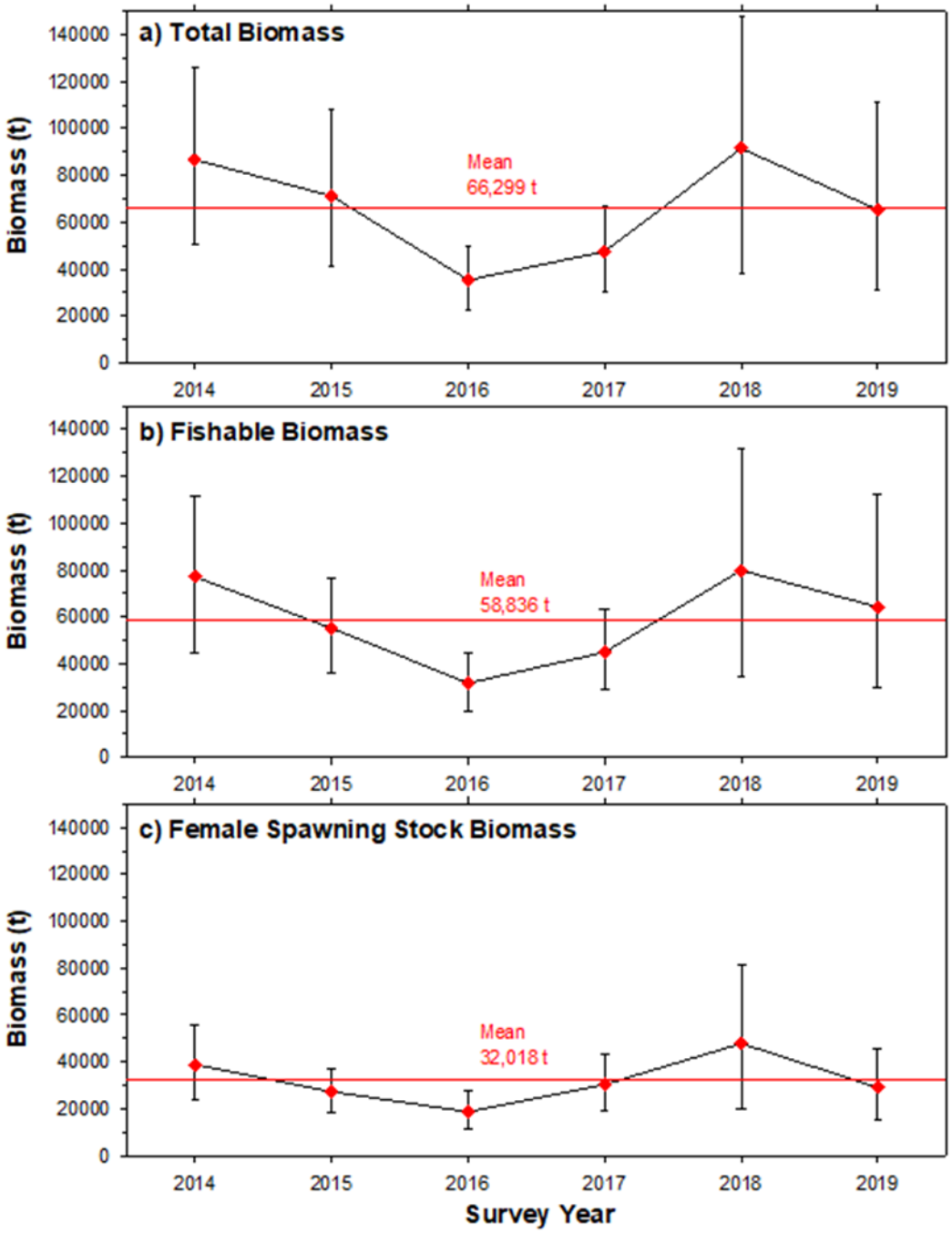

Figure 4. Total biomass (a), fishable biomass (b) and female spawning stock biomass (c) of Striped Shrimp in the Western Assessment Zone, based on data from 2014 to 2019 surveys. Error bars represent 95% confidence intervals. Horizontal lines indicate arithmetic means of the biomass data.

The three biomass indices of Northern Shrimp in the EAZ fluctuated around the long-term mean with no apparent trend observed (Figure 5). In 2019, total and fishable biomass indices recorded their highest values in the time series, while the spawning stock biomass had its second highest value.

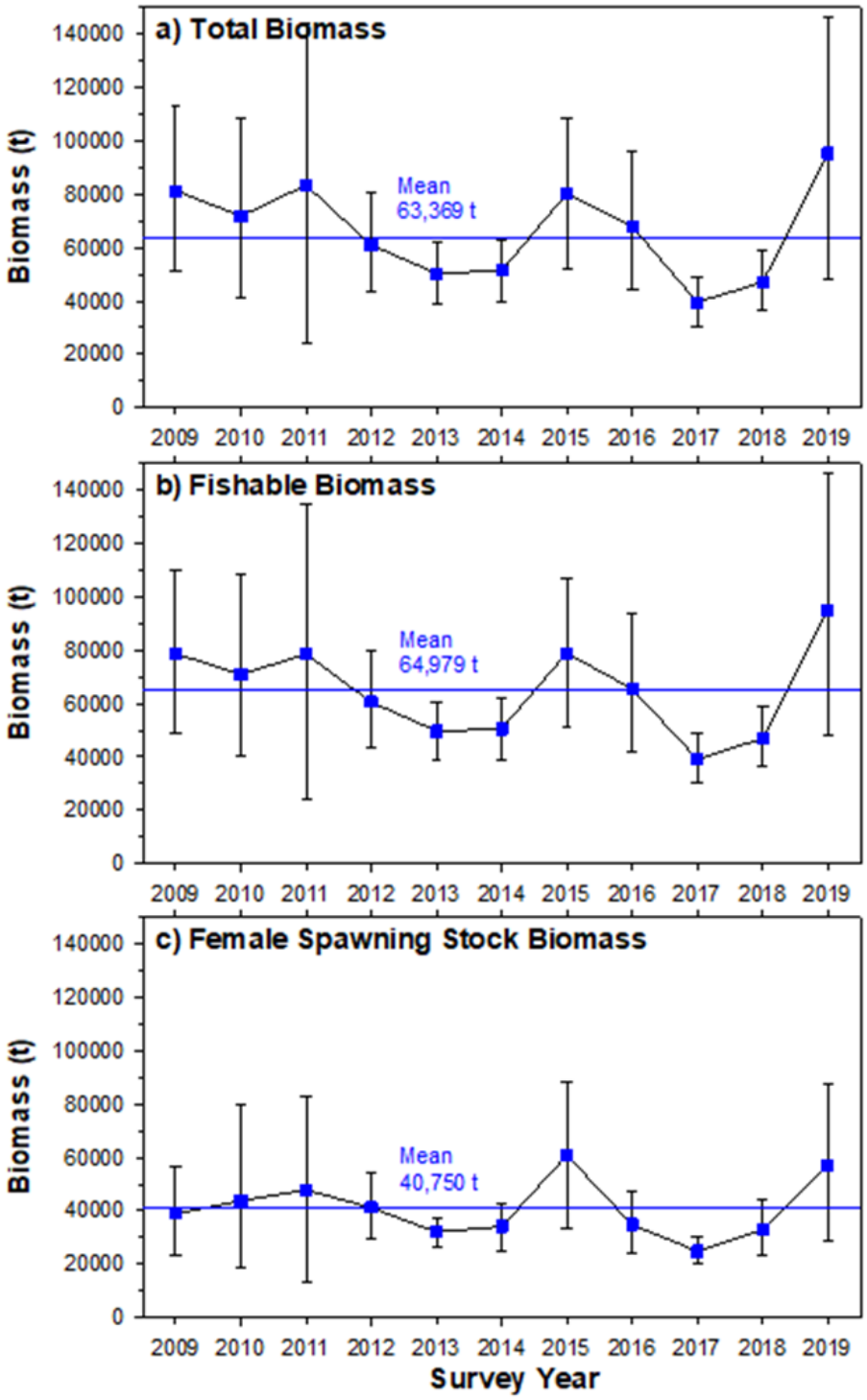

Figure 5. Total biomass (a), fishable biomass (b) and female spawning stock biomass of Northern Shrimp in the Eastern Assessment Zone, based on data from 2009 to 2019 surveys. Error bars represent 95% confidence intervals. Horizontal lines indicate arithmetic means of the biomass data.

The three biomass indices for Striped Shrimp in the EAZ showed no apparent trend in the time series and were below the long-term mean in 2019, following an increase between 2015 and 2017 (Figure 6).

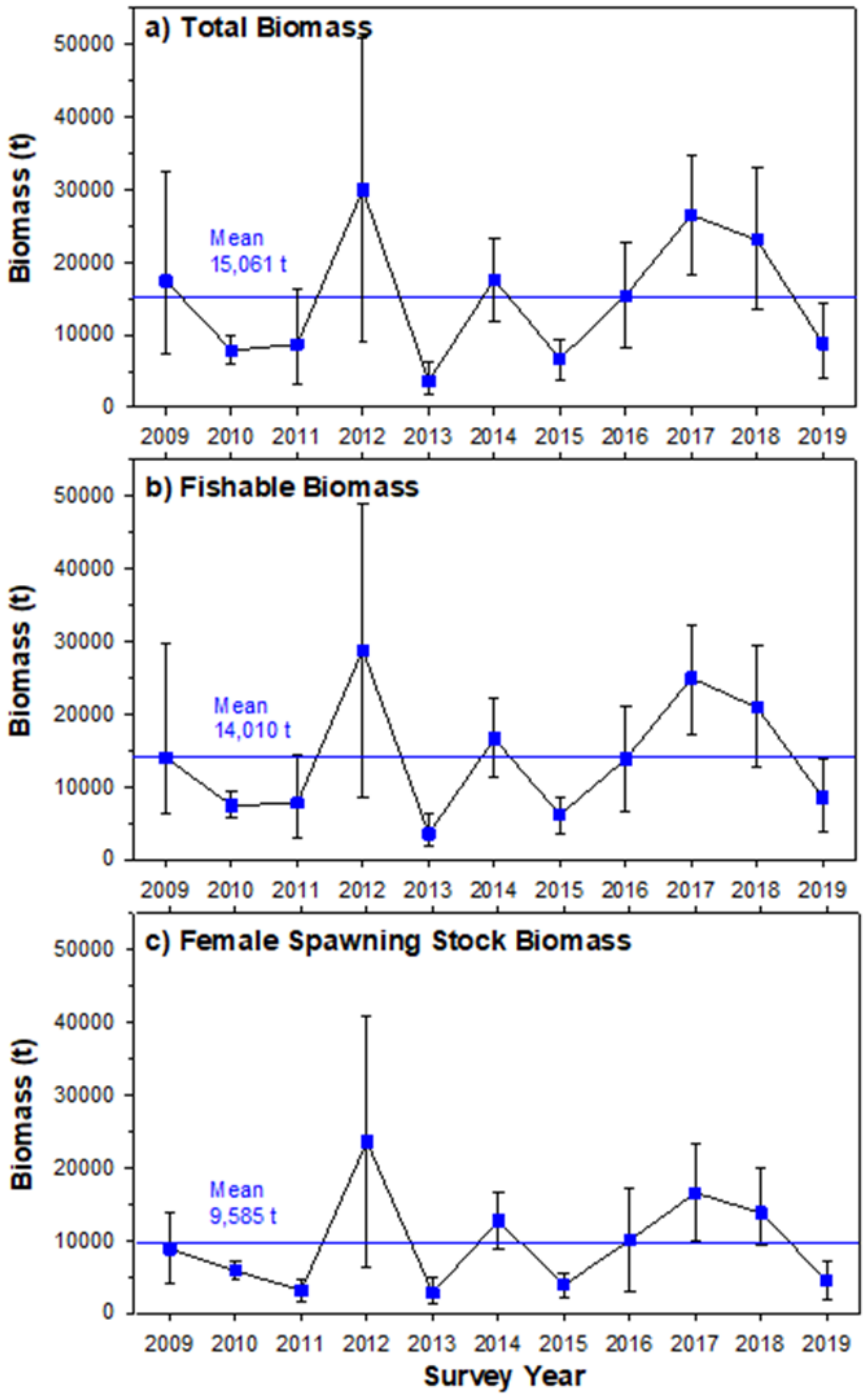

Figure 6. Total biomass (a), fishable biomass (b) and female spawning stock biomass of Striped Shrimp in the Eastern Assessment Zone, based on data from 2009 to 2019 surveys. Error bars represent 95% confidence intervals. Horizontal lines indicate arithmetic means of the biomass data.

FISHERY DESCRIPTION

Northern Shrimp and Striped Shrimp are commercially fished in the WAZ and EAZ during the ice-free season (usually July to November). The TAC is set annually and includes perspectives

obtained during a consultative process between DFO, Wildlife Management Boards (Nunavik and Nunavut), and the Northern Shrimp Advisory Committee (NSAC), among other considerations. Pursuant to their respective land claims, the Wildlife Management Boards (Nunavut and Nunavik) submit TAC and harvest level decisions and recommendations, as appropriate, for the WAZ and EAZ that are subject to the Minister's authority to accept, reject, or vary. In the EAZ, the establishment of TACs is guided by the harvest decision rules outlined in the existing PA Framework for those stocks. Once the TAC is established, it is distributed among the fishers according to the existing management units (Figure 7) and applicable sharing arrangements between licence holders.

Of note, the boundaries of the EAZ, formerly known as Shrimp Fishing Area (SFA) 2 and part of SFA 3, changed in 2013 such that boundaries are the same for both science assessment and management purposes. As a result, the area around Resolution Island (rectangular shape, Figure 7) is now considered part of the EAZ (Figure 2).

The record of commercial catches during the season is held in DFO's Canadian Atlantic Quota Report (CAQR). The CAQR tracks what percentage of the TAC has been harvested within each management unit, for each fishing season. This allows for determination of the fraction of the TAC taken.

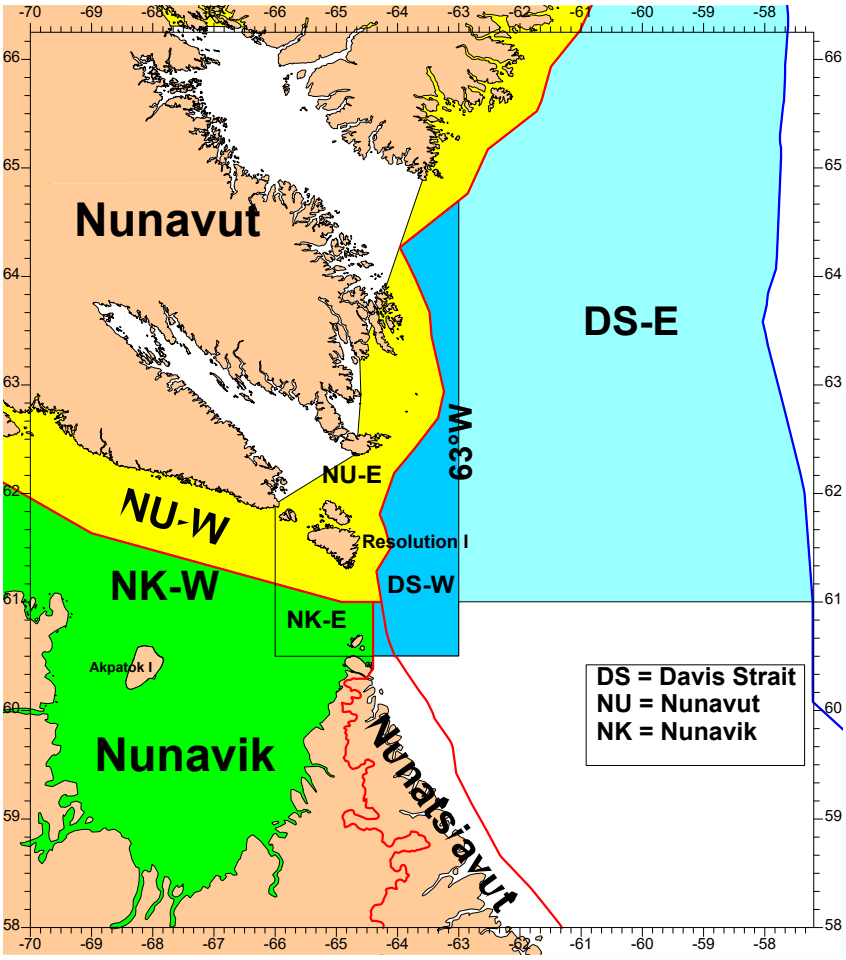

Figure 7. Fishery management units located within the Western and Eastern Assessment Zones. Management Units Nunavut-West (NU-W) and Nunavik-West (NK-W) are within the WAZ. The remaining units, Nunavut-East (NU-E), Nunavik-East (NK-E), Davis Strait-West (DS-W) and Davis Strait-East (DS-E) are within the EAZ.

The Northern Shrimp TAC in the WAZ was increased in the 2019/20 season, after several years of consistent TACs (Figure 8). Typically the entire TAC is not caught in this fishery as this is not a directed fishery, but rather it is taken as bycatch in the Striped Shrimp fishery.

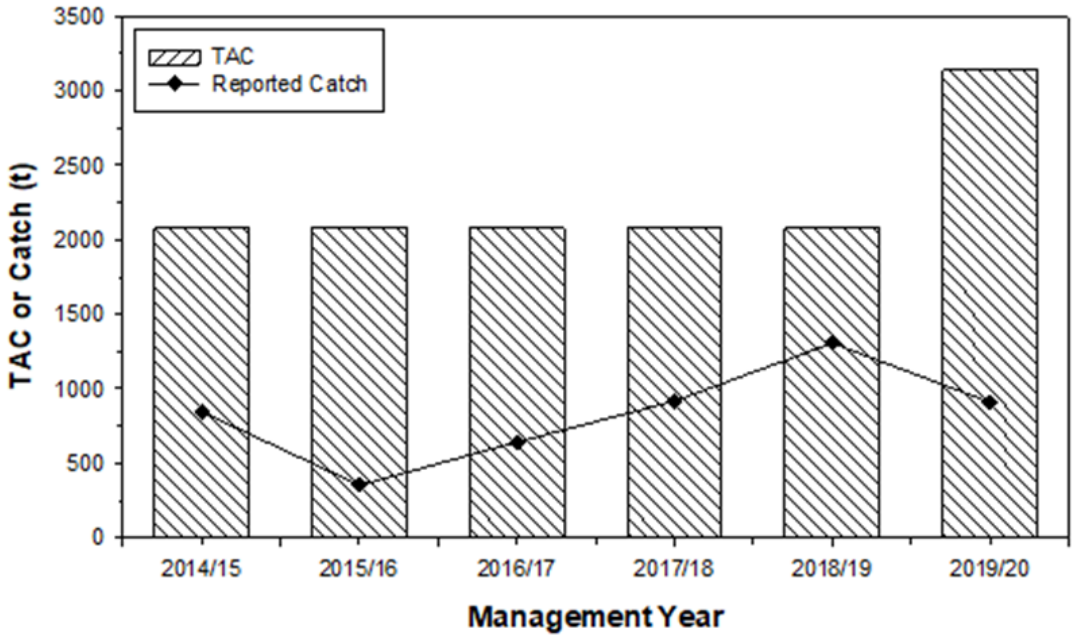

Figure 8. Western Assessment Zone Northern Shrimp TAC and catch recorded in the CAQR. Catch based on CAQR as of March 31, 2020.

The potential exploitation rate in 2019/20 (15.5%), which assumes the entire TAC has been taken, would be slightly above the long-term mean for this stock (Figure 9).

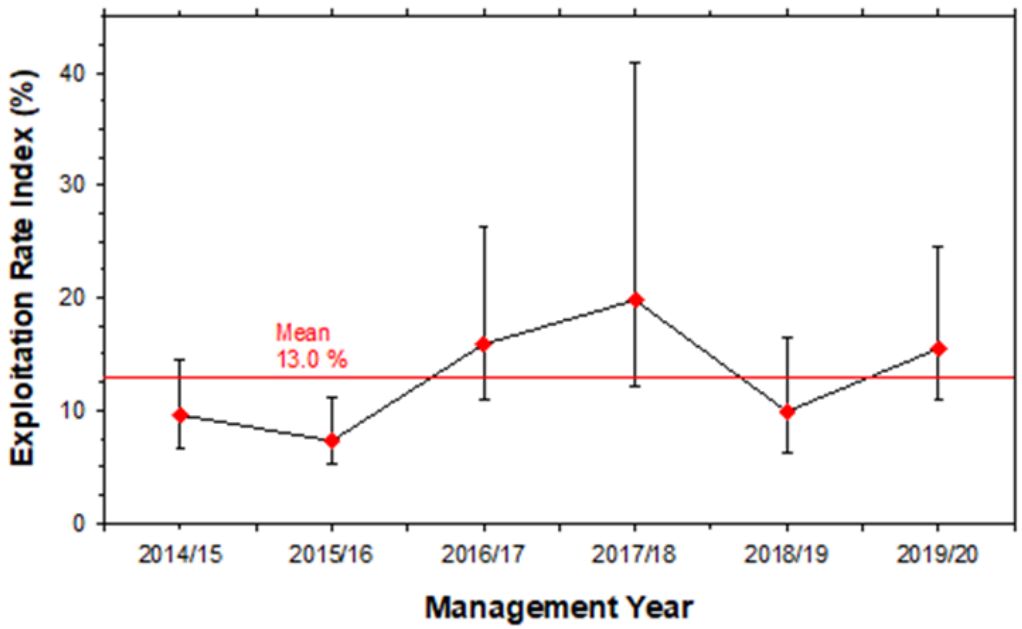

Figure 9. Potential exploitation rate for Northern Shrimp in the Western Assessment Zone. Horizontal line indicates the arithmetic mean of the exploitation rate.

The TAC for Striped Shrimp in the WAZ was increased in the 2019/20 season (Figure 10). There was also an increase in exploitation rate. The potential exploitation rate oscillated around the long-term mean with 2019/20 (18.6%) being above the long-term mean (Figure 11).

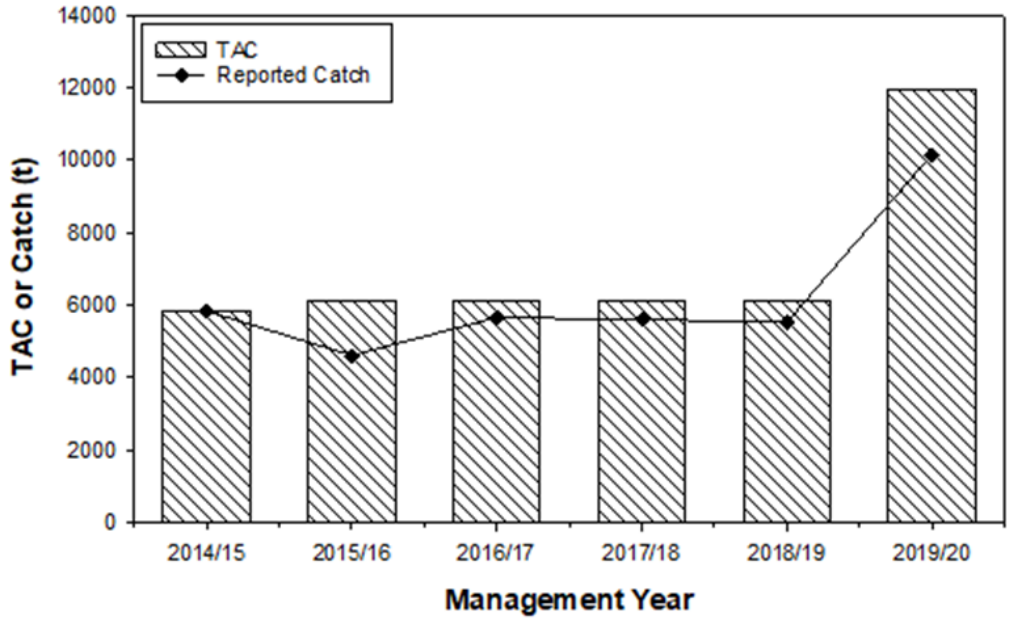

Figure 10. Western Assessment Zone Striped Shrimp TAC and catch recorded in the CAQR. Catch based on CAQR as of March 31, 2020.

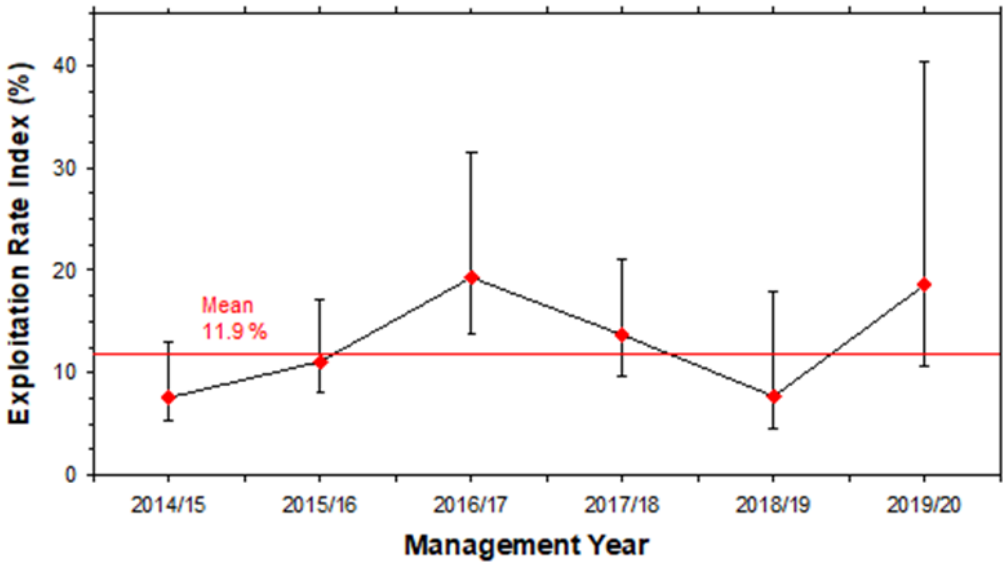

Figure 11. Potential exploitation rates for Striped Shrimp in the Western Assessment Zone. Horizontal line indicates arithmetic mean of the exploitation rate.

The TAC for Northern Shrimp in the EAZ varied throughout the time series in response to changes in the fishable biomass index during that period (Figure 12). The TAC has never been fully taken in the period considered here. Along with the variable TAC, potential exploitation rate varied as well and the 2019/20 value (8.8%) was below the long-term mean (Figure 13).

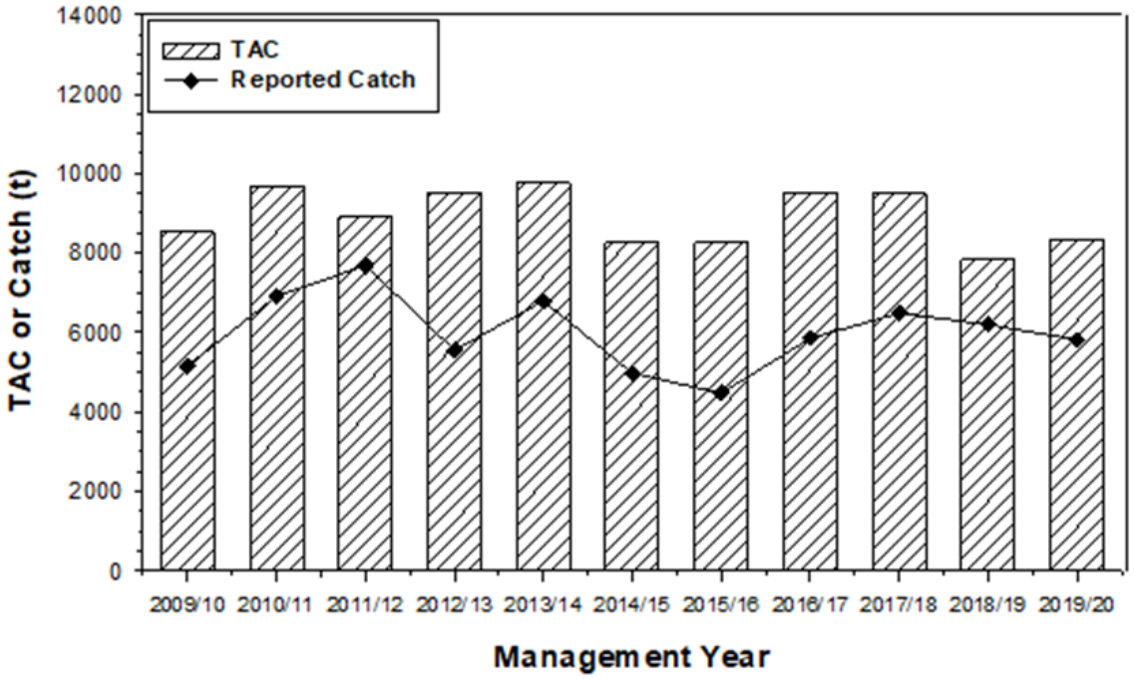

Figure 12. Eastern Assessment Zone Northern Shrimp TAC and catch recorded in the CAQR. Catch based on CAQR as of March 31, 2020.

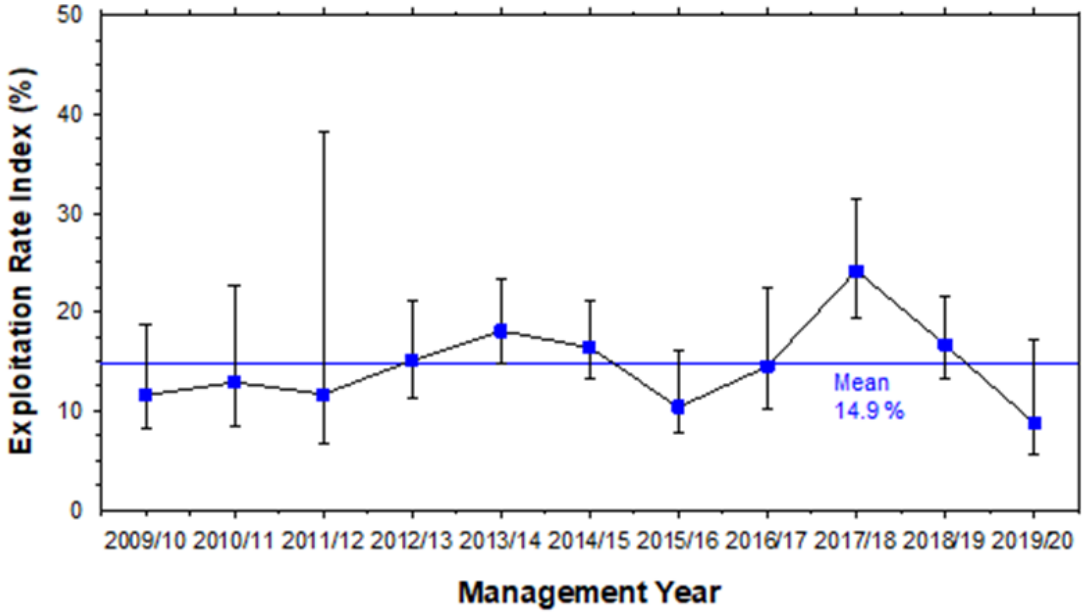

Figure 13. Potential exploitation rate for Northern Shrimp in the Eastern Assessment Zone. Horizontal line indicates arithmetic mean of the exploitation rate.

The TAC for Striped Shrimp in the EAZ has been stable over the past six seasons (Figure 14). The boundaries defining the management zone changed in 2012/13. Consequently, a major part of the resource is now managed within the WAZ. The potential exploitation rate was well below the long-term mean in the last number of years (Figure 15).

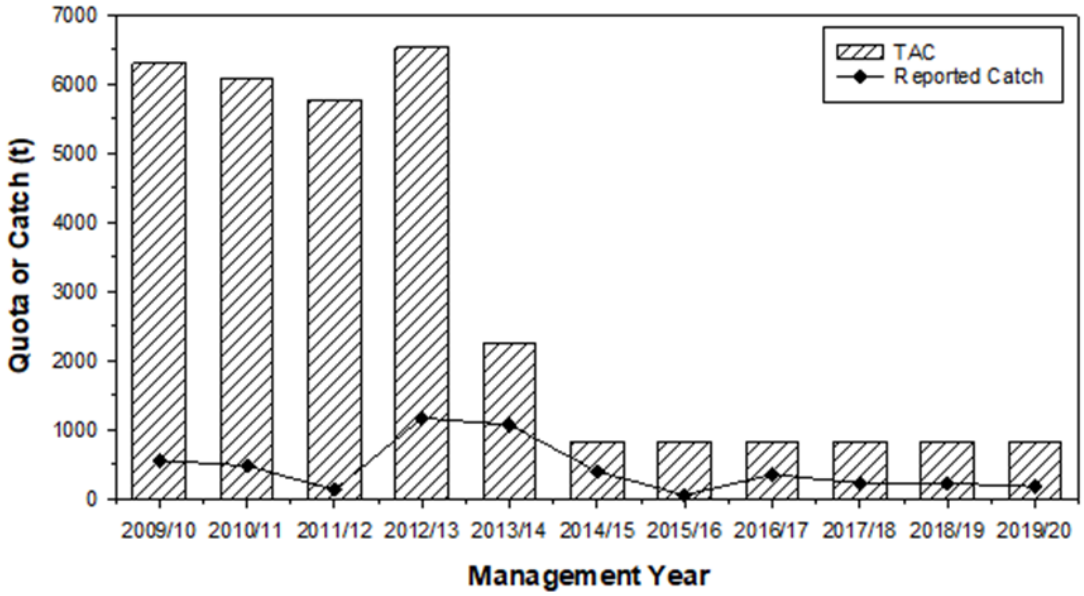

Figure 14. Eastern Assessment Zone Striped Shrimp TAC and catch recorded in the CAQR. Catch based on CAQR as of March 31, 2020.

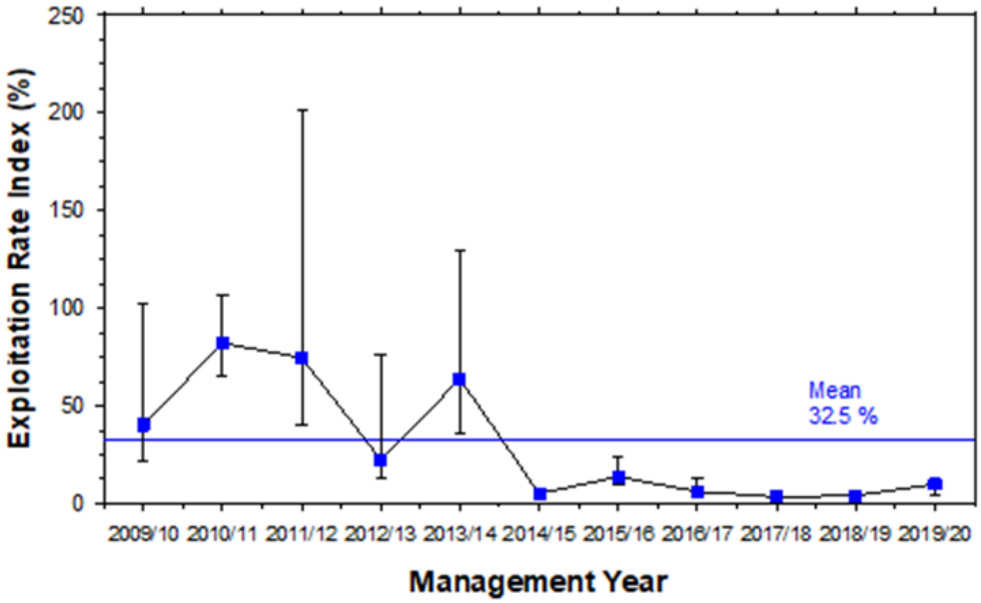

Figure 15. Potential exploitation rates for Striped Shrimp in the Eastern Assessment Zone. Horizontal line indicates arithmetic mean of the exploitation rate.

HISTORY OF PRECAUTIONARY APPROACH FRAMEWORK PROCESSES IN THE WESTERN AND EASTERN ASSESSMENT ZONES

Reference points for the purpose of the PA Framework for the WAZ had been created based on results from biennial DFO surveys in 2007–2011 (Siferd 2014). Since 2014, the WAZ has been surveyed annually in conjunction with the NSRF-DFO survey of the EAZ. This change in the survey approach translated into significant changes in survey timing, vessel, and gear used.

While the survey became consistent between the EAZ and WAZ, the changes reset the data time series in the WAZ and subsequently invalidated the established PA Framework. Following the 2019 survey, the new time series reached its sixth data point, which is considered to be sufficient to establish a new PA Framework (Siferd 2015).

In the EAZ, shrimp are assessed within a PA Framework with reference points that were developed during two workshops that included participation from DFO Science, DFO Resource Management, and stakeholder representatives (DFO 2009; Figures 16 and 17). The LRP and the USR were agreed to be 30% and 80%, respectively, of the geometric mean of female SSB. The SSB was used as the estimate of B_{MSY}. Establishing the LRP at the level of 30% of the geometric mean of SSB was consistent with the approach taken by NAFO for an adjacent shrimp fishing area (DFO 2009). These reference points first developed for Shrimp Fishing Area 2 (SFA 2) included three surveys conducted in 2006–2008. The SFA 2, in this case, does not exactly match the boundaries of the assessment zone (EAZ). Still, in 2011 during the Zonal Advisory Process, the SFA 2 reference points were adopted unchanged for the EAZ (Siferd 2015).

Since that time, precaution has been advised when applying the EAZ PA Framework to decision-making for a number of reasons. The first major issue was that the reference points were based on a relatively short data series of only three years (2006–2008) of survey results. Second, these reference points were developed for SFA 2 and not specifically for the geographic area of the EAZ, which is larger than the original management area. Since the establishment of the PA Framework, the EAZ has been continually surveyed by the NSRF-DFO survey which provides consistency in the methods used and thus reliability of the results. This consistency of methods and increased reliability of the data offer the opportunity to re-evaluate the current PA Framework.

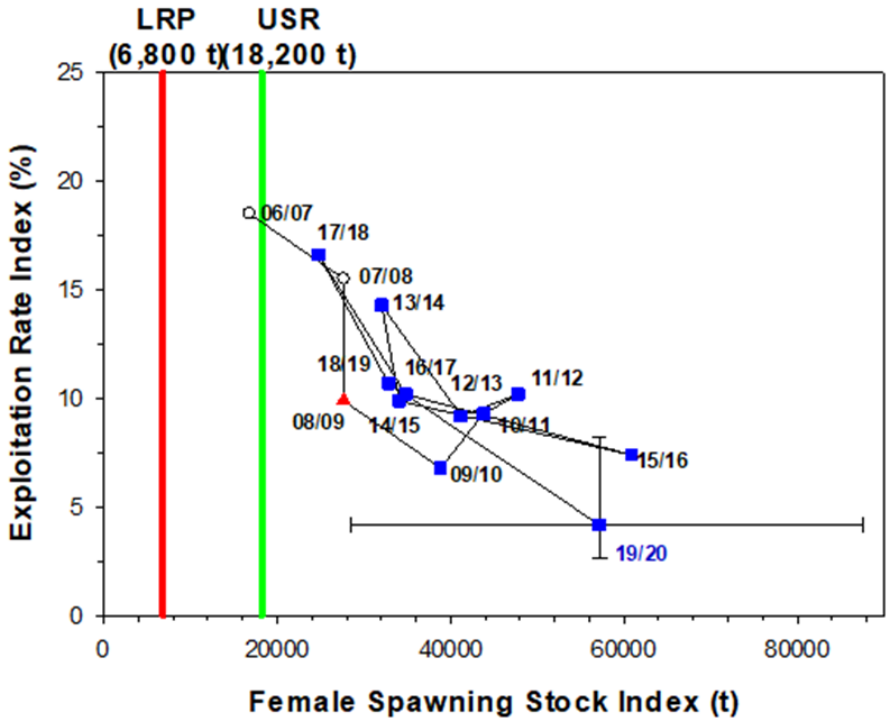

Figure 16. Currently used EAZ PA Framework for Northern Shrimp established on the basis of three years (two open circles and a triangle) of data in SFA 2. Blue symbols are annual stock status values. Numbers indicate the fishing season. Red line denotes the LRP, green line indicates the USR.

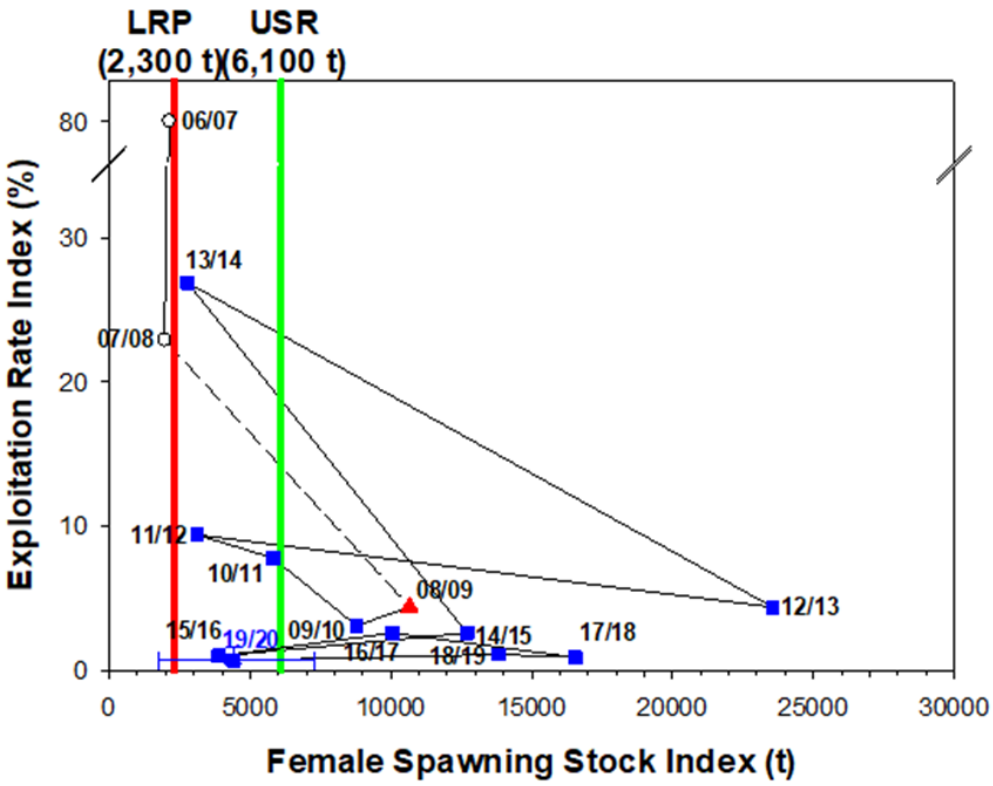

Figure 17. *Currently used EAZ PA Framework for Striped Shrimp established on the basis of three years (two open circles and a triangle) of data in SFA 2. Blue symbols are annual stock status values. Numbers indicate the fishing season. Red line denotes the LRP, green line indicates the USR.*

METHODS AND RESULTS

Two approaches to establishing the LRPs are considered herein. One approach, consistent with that used to calculate the LRP for the SFA 1, EAZ and Newfoundland and Labrador Region shrimp stocks (SFAs 4, 5 and 6), consists of the LRP calculated as 30% of the geometric mean of the SSB index (DFO 2019, 2020a). Another approach, consistent with guidance in DFO's PA Policy and using a more conservative scenario (e.g., in stocks with limited environmental data to support decision making), recommends setting the LRP calculated as 40% of the geometric mean of the SSB index.

The USR is informed by science advice and will be later developed through a consultative process between DFO's Resource Management, co-management partners, and relevant stakeholders. DFO Science was requested to provide a suggestion for a possible USR point. A proposed USR has been calculated here as 80% of the geometric mean of the SSB index, which is consistent with both DFO's PA Policy (DFO 2009) and the approach for shrimp stocks in the EAZ and Newfoundland and Labrador Region (DFO 2019, 2020a).

PROPOSED NEW LIMIT REFERENCE POINTS FOR THE WESTERN ASSESSMENT ZONE

Approach 1: LRP=30% SSB Index

The LRP for Northern Shrimp in the WAZ calculated at 30% of the geometric mean of SSB index is 3,100 t (Figure 18). The USR, if established at 80% of the geometric mean for SSB index, would be 8,200 t. Plotting SSB as a function of exploitation rate indicates that the stock has been in the Healthy Zone in 4 out of 6 years of the survey time series.

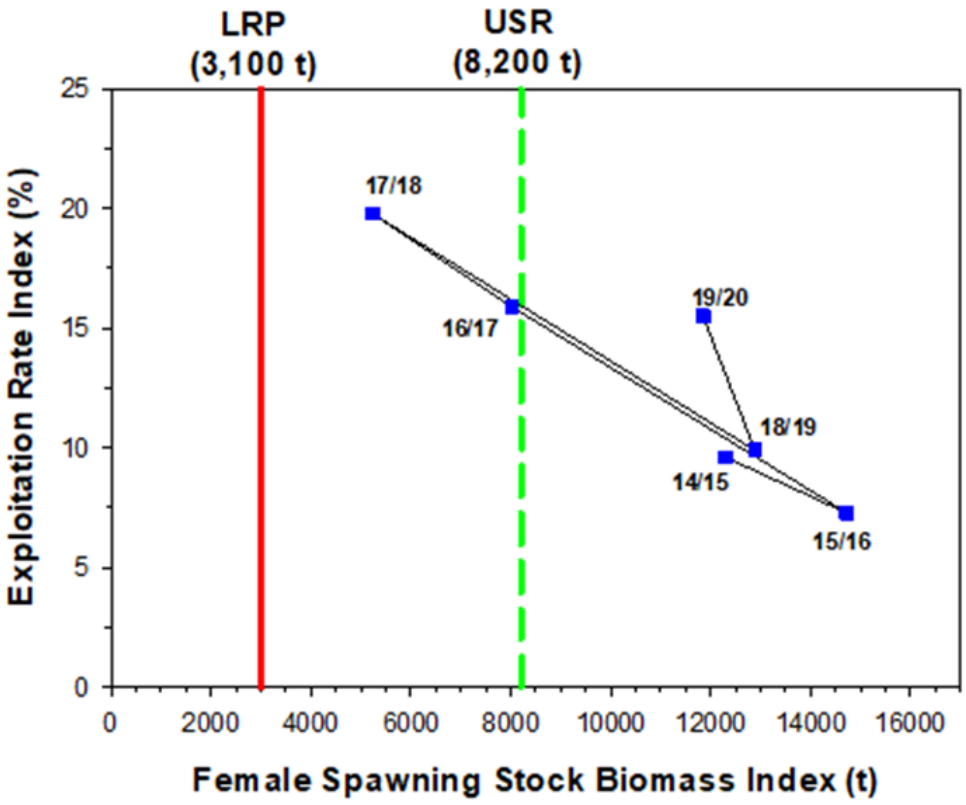

Figure 18. PA Framework for Northern Shrimp in the WAZ based on the LRP (red line) calculated as 30% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

The LRP for Striped Shrimp in the WAZ calculated at 30% of the geometric mean of the SSB index is 9,200 t (Figure 19). The USR, if established at 80% of the geometric mean for SSB index, would be 24,600 t. Plotting SSB as a function of exploitation rate indicates that the stock was in the Healthy Zone in 5 out of 6 years of the survey time series.

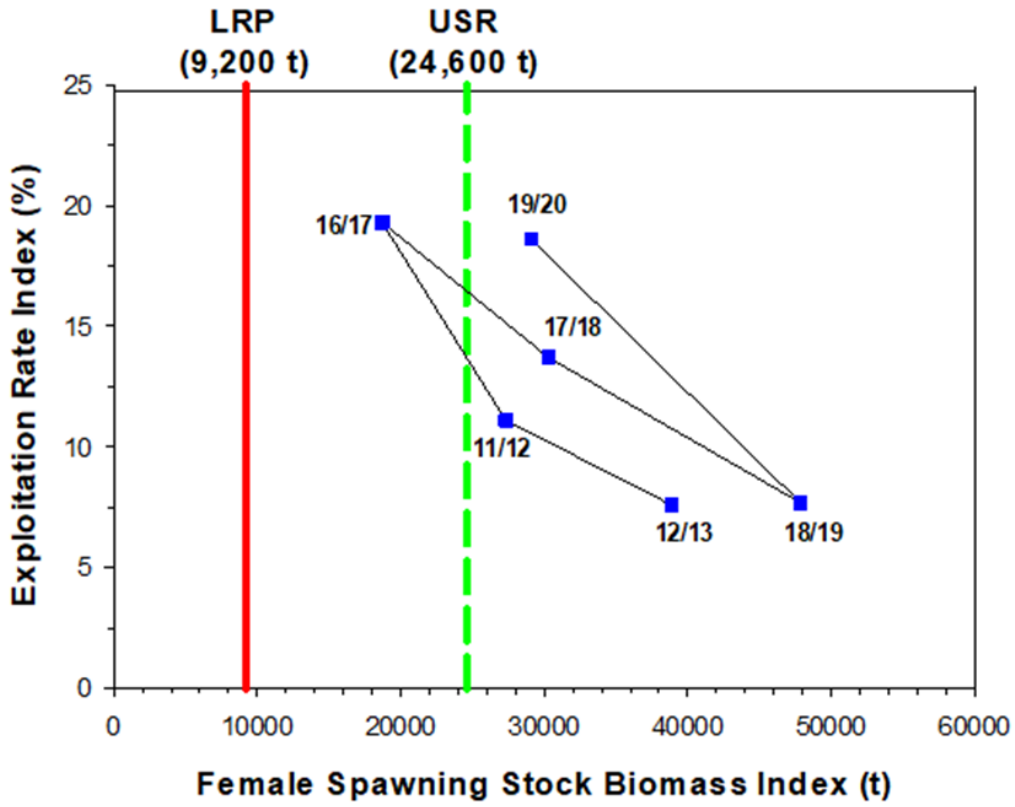

Figure 19. PA Framework for Striped Shrimp in the WAZ based on the LRP (red line) calculated as 30% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

Approach 2: LRP=40% SSB Index

The LRP for Northern Shrimp in the WAZ calculated at 40% of the geometric mean of the SSB index is 4,100 t (Figure 20). The USR, if established at 80% of the geometric mean for SSB index, would be 8,200 t. Plotting SSB as a function of exploitation rate indicates that the stock has been in the Healthy Zone in 4 out of 6 years of the survey time series.

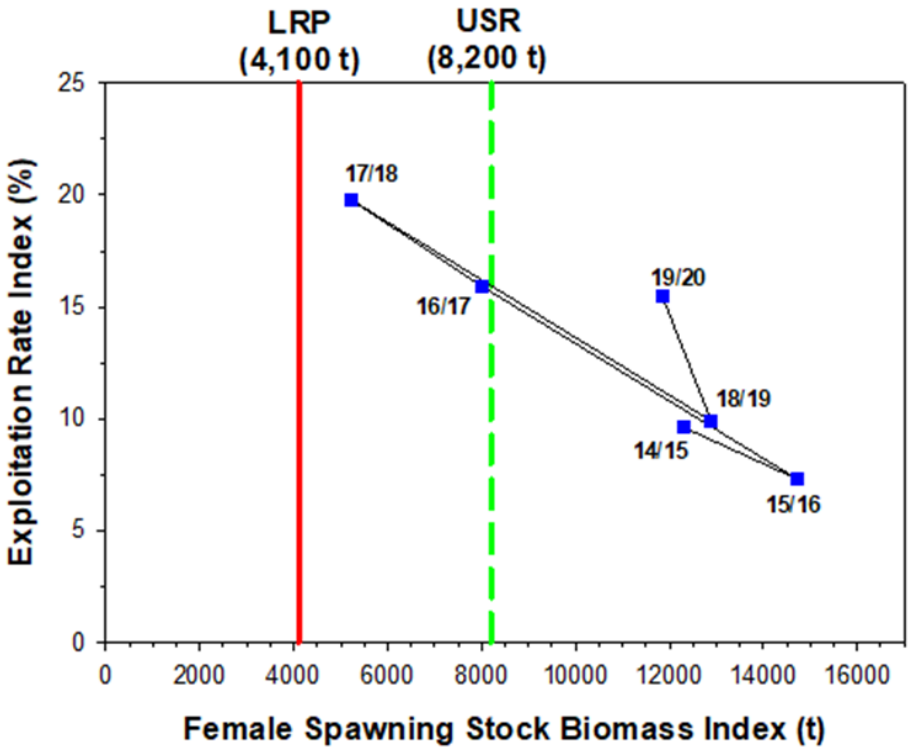

Figure 20. PA Framework for Northern Shrimp in the WAZ based on the LRP (red line) calculated as 40% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

The LRP for Striped Shrimp in the WAZ calculated at 40% of the geometric mean of the SSB index is 12,300 t (Figure 21). The USR, if established at 80% of the geometric mean for SSB index, would be 24,600 t. Plotting SSB as a function of exploitation rate indicates that the stock was in the Healthy Zone in 5 out of 6 years of the survey time series.

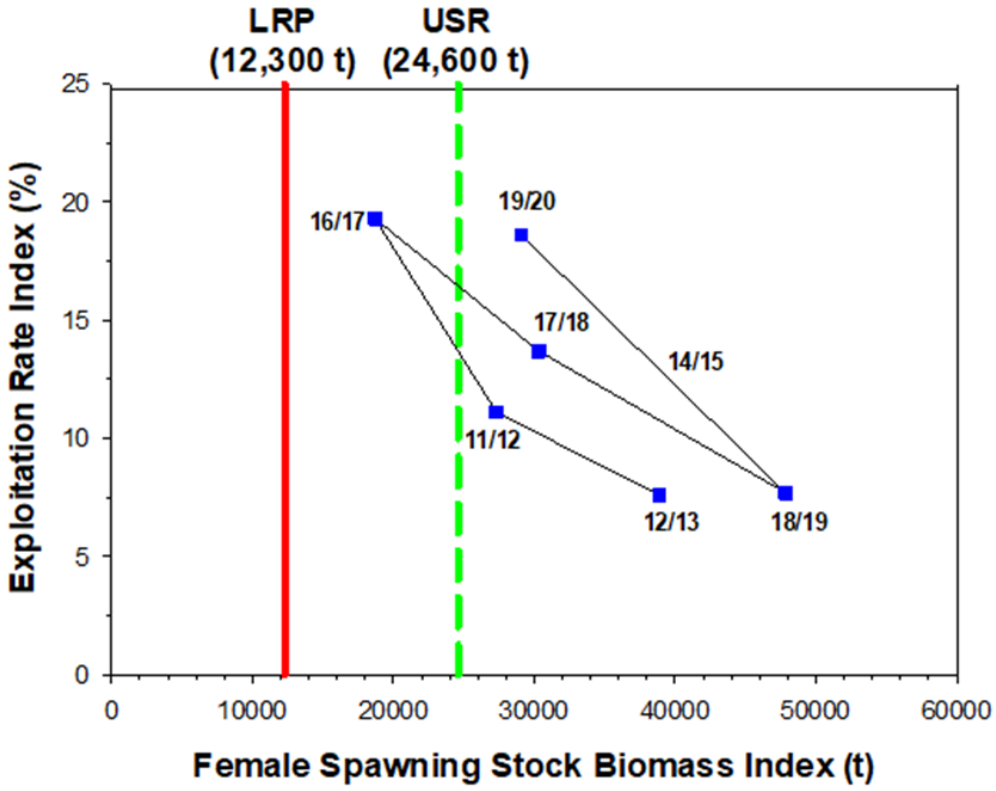

Figure 21. PA Framework for Striped Shrimp in the WAZ based on the LRP (red line) calculated as 40% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

PROPOSED UPDATED LIMIT REFERENCE POINTS FOR EASTERN ASSESSMENT ZONE

Approach 1: LRP=30% SSB Index

The LRP calculated using 30% of the geometric mean of the SSB index for Northern Shrimp in the EAZ (11,800 t) based on an 11-year data series (2009–2019) is higher than the current LRP (6,800 t; Figure 22) that was also calculated based on a 30% scenario but using a 3-year data series (2006–2008) for a different geographic area and survey range. When comparing the old Framework and the proposed updated Framework, it appears that the recent 11 biomass data points, with the exception of one, had SSB values that are above the new proposed USR. This could be an indication of a relatively productive period for this stock, which is desirable when establishing a PA Framework (DFO 2018). The proposed USR calculated at 80% of SSB index based on the 11-year data series has increased to 31,600 t from the previously established 18,200 t using the 80% scenario with a 3-year data series. If the revised higher value is adopted for the USR, the 2017/18 stock status falls into the Cautious Zone. All other data points would remain within the Healthy Zone.

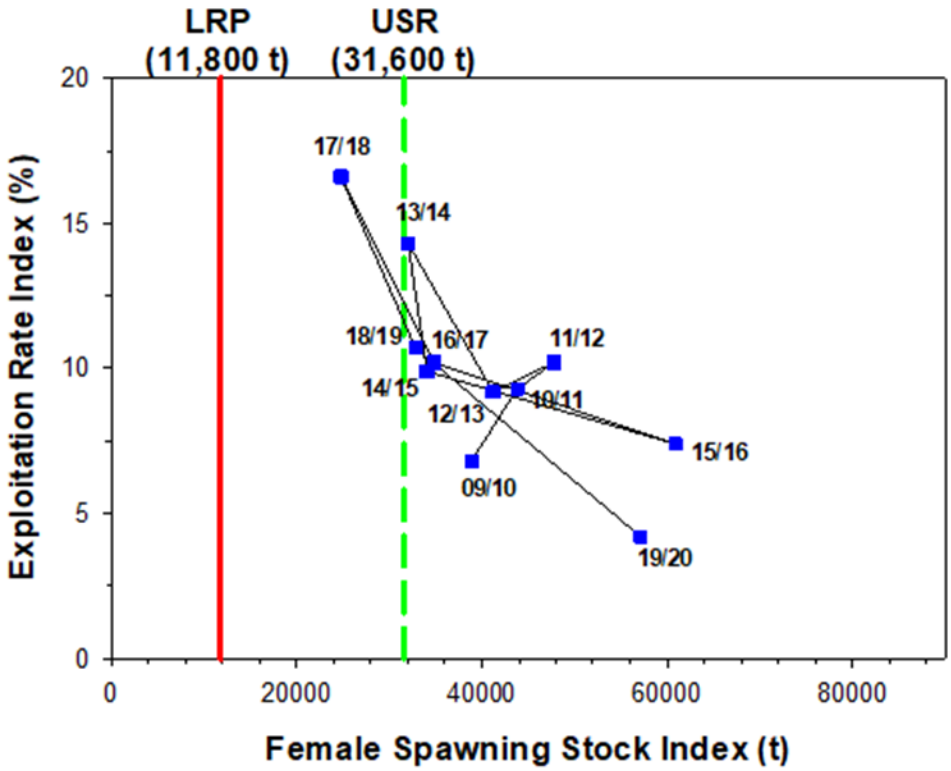

Figure 22. Updated PA Framework for Northern Shrimp in the EAZ based on the LRP (red line) calculated as 30% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

Calculation of the updated LRP and proposed updated USR for Striped Shrimp in the EAZ, based on an 11-year data series, yielded the same values as were established in the original Framework (i.e., LRP of 2,300 t and USR of 6,100 t; Figure 23). This consistency is attributed to the wide SSB variability of this stock and consequently unchanged mean, which fluctuated between the Cautious and Healthy Zones. While the large variability cannot be explained without more comprehensive environmental data, it is expected that thermal habitat contraction and expansion might be one of the causes.

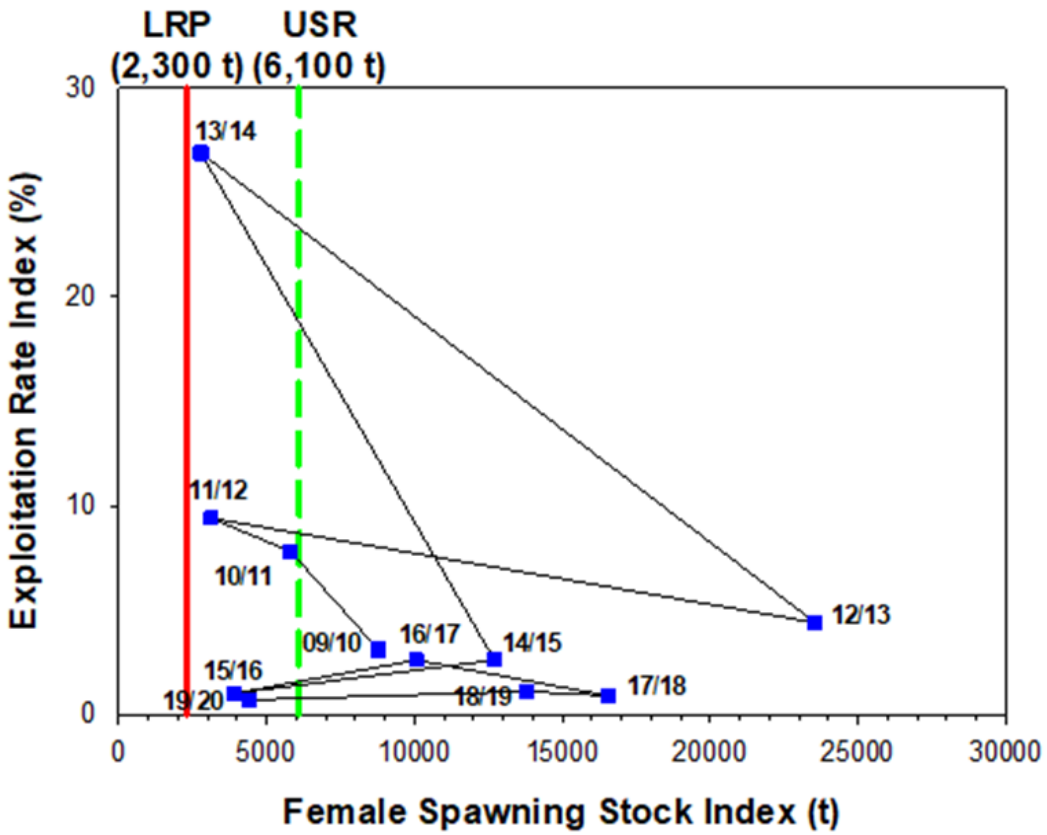

Figure 23. Updated PA Framework for Striped Shrimp in the EAZ based on the LRP (red line) calculated as 30% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

Approach 2: LRP=40% SSB Index

The LRP calculated using 40% of the geometric mean of the SSB index for Northern Shrimp in the EAZ (15,800 t) based on an 11-year data series (2009–2019) is higher than the current LRP (6,800 t; Figure 24) that was calculated based on a 30% scenario using a 3-year data series (2006–2008) for a different geographic area and survey range. When comparing the old Framework and the proposed updated Framework, it appears that the recent 11 biomass data points, with the exception of one, had SSB values that are above the new proposed USR. Similar to the 30% calculation, this could be an indication of a relatively productive period. The proposed USR calculated at 80% of SSB index has increased from what was previously established at 18,200 t to 31,600 t based on the 3-year and 11-year data series, respectively. If the revised higher value is adopted for the USR, the 2017/18 stock status falls into the Cautious Zone. All other data points would remain within the Healthy Zone.

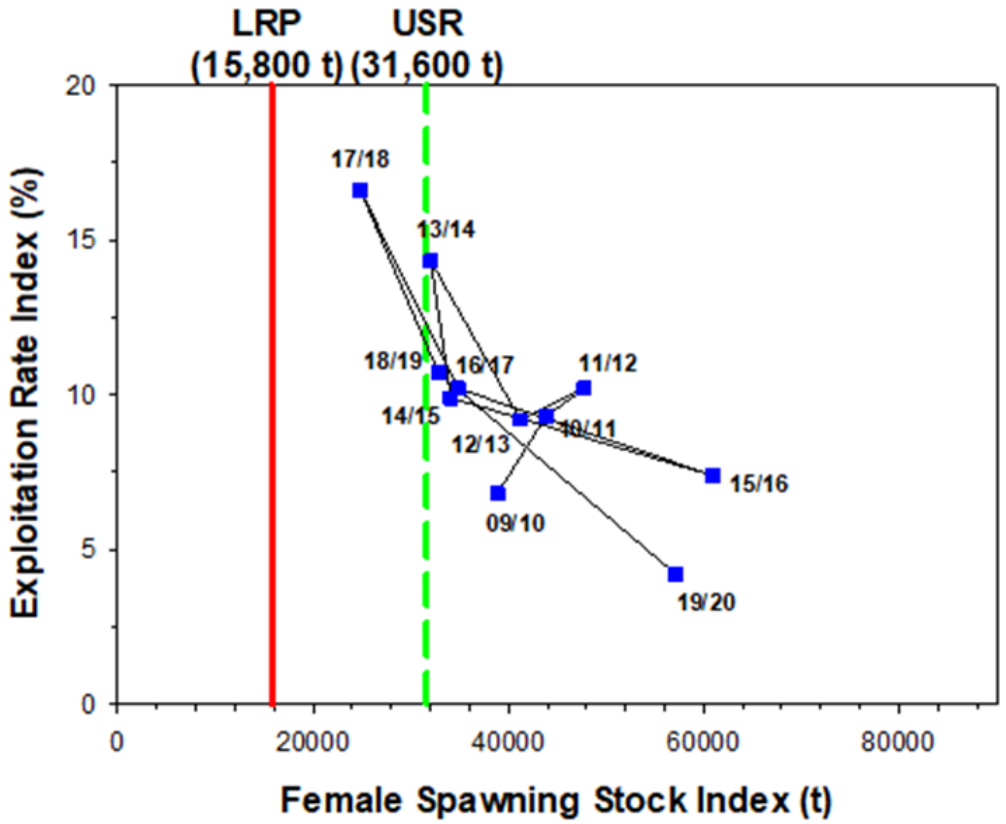

Figure 24. Updated PA Framework for Northern Shrimp in the EAZ based on the LRP (red line) calculated as 40% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

Calculation of the updated LRP for Striped Shrimp in the EAZ from 40% of the geometric mean of the SSB index based on an 11-year data series resulted in a higher LRP (3,100 t vs. 2,300 t) than in the original Framework), while calculation of the proposed USR at 80% of the geometric mean of the SSB resulted in the same USR value (i.e., 6,100 t; Figure 25). If the revised higher value is adopted for the LRP, the 2013/14 stock status falls into the Critical Zone, four data points would fall into the Cautious Zone, and the remaining six data points would be within the Healthy Zone. Large interannual variability cannot be explained at present due to the lack of comprehensive environmental data, however, it is expected that the variability in the suitable habitat (expansion and contraction) could play a significant role in shrimp biomass distribution.

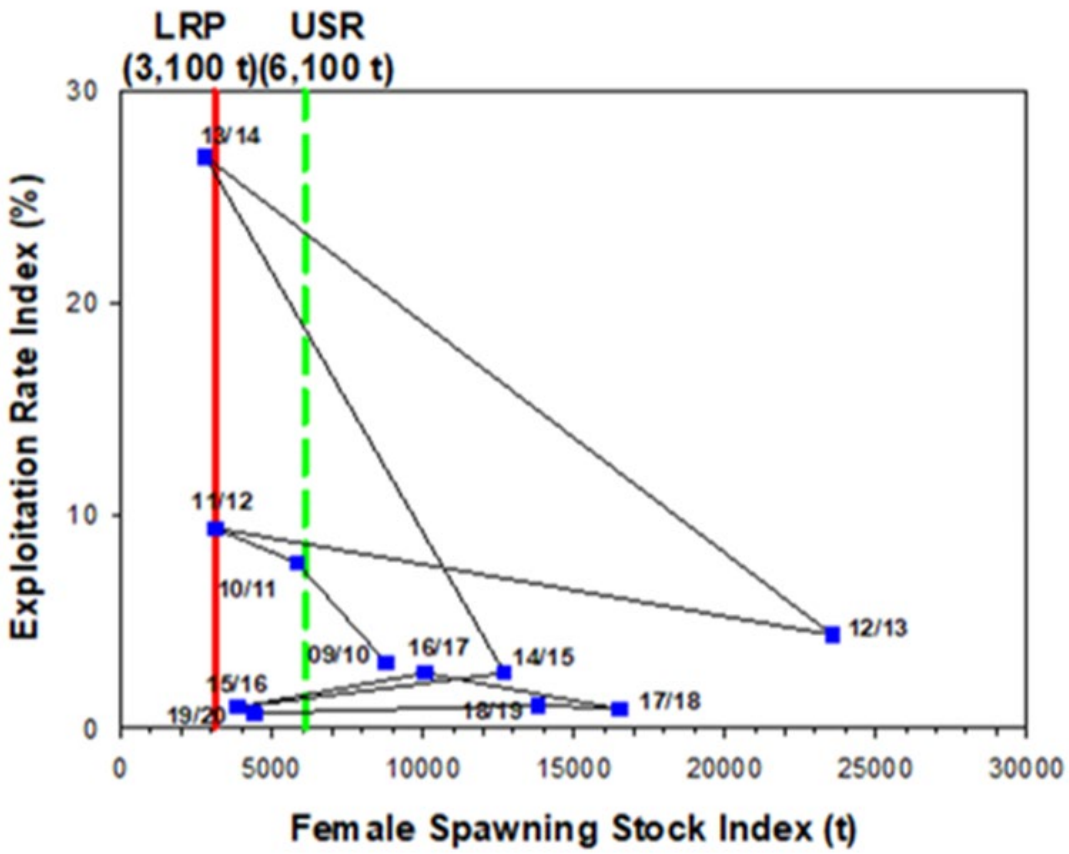

Figure 25. Updated PA Framework for Striped Shrimp in the EAZ based on the LRP (red line) calculated as 40% of the geometric mean for SSB index and the proposed USR (dashed green line) calculated as 80% of the geometric mean for SSB index. Blue symbols are annual stock status values, numbers indicate the fishing season.

CONCLUSIONS

In this document, new LRPs consistent with DFO's PA Policy were developed for Northern and Striped Shrimp stocks in the WAZ, and new USRs were proposed (Table 1). For the WAZ, the proposed PA Framework was based on a six-year data series from a fishery-independent survey. In addition, existing LRPs for Northern and Striped Shrimp stocks in the EAZ were updated, and updates to existing USRs were proposed (Table 1). The proposed EAZ framework was updated based on 11 years of fishery-independent data applied to the entire EAZ (a broader geographic coverage than the initial assessment in SFA 2). It appears that these 11 years represent a relatively productive period, which is desirable for establishing a PA Framework.

For each assessment zone and shrimp fishery, the 30% and 40% LRP of the geometric mean of the SSB index were explored (Table 1). Currently, a 30% LRP is being used as a reference point for many shrimp stocks that are managed by NAFO and those managed in Newfoundland and Labrador Region, therefore adopting a 30% LRP here would be consistent with the management approaches used in adjacent shrimp fishing areas. However, the use of the 30% LRP is not fully substantiated for the WAZ and EAZ given the limited scientific information available for these particular stocks. Furthermore, an LRP of 40% is suggested in the DFO PA Policy (DFO 2009) for instances of data deficiency and uncertainty. Establishing LRPs based on

40% of the geometric mean of the SSB index for the WAZ and the EAZ is recommended as an optimal way forward based on the information available and recent decreases in stock productivity observed in southern SFAs (DFO 2019).

Considerable uncertainty remains with respect to the biomass variability as it relates to environmental changes (e.g., temperature). These variable distributions in shrimp result in occasional large catches and biomass estimates for each of the assessment zones in different years. Other SFAs have longer data sets (e.g., SFA 5 dataset has 25 annual biomass data points) and can justify using 30% LRPs, while the WAZ and EAZ have shorter data sets, large fluctuations in biomass, and a lack of stock trends. Furthermore, the stocks in the WAZ and EAZ appear to recover from a 40% LRP, below this point the ability of the stocks to recover is unknown (DFO 2020b,c).

When the PA Framework for the EAZ was initially established using 30% LRPs, the reference points were based on three years of data, the geographic area of SFA 2 and a different survey range. While this approach was recognized as suboptimal at the time, it was recommended that the initial EAZ PA Framework be revised as soon as possible (Siferd 2015). Other shrimp fisheries are looking into moving towards a dynamic LRP, which follows the pattern of the stock. Since the shrimp stocks in the WAZ and EAZ have limited information with which to design dynamic reference points, the LRPs remain static. The PA Framework should be revised in the future when more data on environmental variables affecting WAZ and EAZ shrimp stocks becomes available.

Table 1. Proposed LRP scenarios (calculated as either 30% or 40% of the geometric mean of the SSB index) and suggested USRs for Northern and Striped Shrimp stocks in the Western and Eastern Assessment Zones.

Shrimp species	LRP 30% SSB	USR 80% SSB	LRP 40% SSB	USR 80% SSB
Western Assessment Zone				
Northern Shrimp	3,100 t	8,200 t	4,100 t	8,200 t
Striped Shrimp	9,200 t	24,600 t	12,300 t	24,600 t
Eastern Assessment Zone				
Northern Shrimp	11,800 t	31,600 t	15,800 t	31,600 t
Striped Shrimp	2,300 t	6,100 t	3,100 t	6,100 t

There are a number of uncertainties related to the process used to calculate reference points presented herein.

- In general, with limited data available and no trends determined in shrimp biomass, it is currently unknown if the reference points, regardless at what level established, would act to prevent the serious harm should the decline in the stock's biomass occur.
- The biomass survey of all stocks discussed in this document is completed in the middle of the fishing season and the impact of that approach on biomass assessment in a given year has never been quantified. Stocks of both species, in both assessment zones, exhibit relatively large inter-annual variability. Since the assessment is done from a static point of view (snapshot approach), there is no consideration of shrimp biomass movement between the two assessed zones and the impact on biomass from movement from outside of the

assessment area. Recent studies show that shrimp fishing grounds are connected via larval drift and that this process is most likely unidirectional (north to south), which greatly adds to the uncertainty of the PA Framework presented herein.

- Since the naturally occurring distribution of shrimp does not reflect administrative management unit boundaries, it is expected that there is one population of shrimp (for each species) inhabiting both assessment zones. From a scientific perspective, pooling the fractions of a larger stock into one larger unit could alleviate the issue of trans-zonal migrations and transport. Siferd (2015) has already suggested that "*Combining the areas of SFA4, the EAZ and WAZ into one large assessment zone would better reflect the "true" stock area for both Pandalid species for the purpose of determining stock status*". Since the survey of all three areas is done at the same time, with the same vessel and the same survey protocol, it would be possible to attempt one larger assessment. It would be advised, however, to gather at least 4 additional years of data to obtain a better understanding of the stocks in the WAZ and be able to infer some trends in the biomass.
- There is limited data being collected, and subsequently available, in regards to the ecosystem variables in the WAZ and EAZ. While the data on shrimp biomass indices and their temporal changes are relatively well recognized, there is a lack of information on ecosystem variables in these areas that determine shrimp productivity. Therefore, any conclusions based on this paper should be considered temporary until sufficient environmental data is collected to provide adequate background information (i.e., model) on shrimp ecology and biology. Once a sufficient amount of supporting information is obtained, the reference points in both the WAZ and EAZ should be revisited.

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