



2023 STOCK STATUS UPDATE OF EASTERN SCOTIAN SHELF NORTHERN SHRIMP (SFAS 13-15)

Context

Advice on the status of the Eastern Scotian Shelf (ESS) Northern Shrimp (*Pandalus borealis*) stock is requested annually by Fisheries and Oceans Canada (DFO) Resource Management to help determine a Total Allowable Catch (TAC) that is consistent with its management plan (DFO 2011). Annual science advice is required because of the potential for rapid changes in abundance, variable recruitment to the population and fishery, and changes in the size of ESS Northern Shrimp available for harvest. This stock is also near the southern limit of the species' distribution where it is thought to be more vulnerable to significant and rapid declines, as observed in the adjacent Gulf of Maine and Gulf of St. Lawrence (GSL) stocks (ASMFC 2018; DFO 2022a). For further comparison, the GSL stocks have declined in their survey abundance since the mid-2000's in three out of four areas (DFO 2022a). The GSL stocks have also been moving to shallower water depths, which has similarly been observed for the ESS Northern Shrimp stock in recent years. This movement to shallower waters in the GSL has been interpreted to be the result of unfavorable environmental conditions dominated by the effect of warming water temperatures (DFO 2022a).

Northern Shrimp exhibit protandrous sequential hermaphroditism, hatching as males and eventually transitioning into females; a unique biological feature linked to the reproductive success. For this reason, faster growth coupled with lower mortality in males increases reproductive success of ESS Northern Shrimp (Henshaw 2018). Under cooler environmental conditions, Northern Shrimp grow more slowly, change sex later, and live longer, reaching a larger maximum size. In contrast, faster growing shrimp under warm environmental conditions initiate an earlier transitional stage and thus reach a smaller maximum size more quickly (Hardie et al. 2018). Flexibility in this growth response, and in the onset of the transitional stage, results in the growth rate being strongly influenced by variable environmental factors throughout all life cycle stages (Koeller 2006).

This Science Response Report provides information on the 2023 fishery and an assessment of considerations for its management in 2024. This report is from the regional peer review held on January 5, 2024, entitled the Stock Status Update of Northern Shrimp on the Eastern Scotian Shelf.

Background

Following a four-year decline (2014-2017), positive changes to the total biomass were observed in 2018. A steady biomass increase was then observed up until 2020. In 2021, however, the biomass subsequently decreased from 29,875 t to 21,167 t and has since continued to decline. In 2023, the total biomass is estimated to be 10,856 t, which marks a decrease of 51% in the last two years (2021-2023). The less abundant 2015-2016 year-classes are providing limited recruitment to the fishable biomass, as they near the end of their expected lifespan (DFO

2022b; DFO 2023). The ESS Northern Shrimp recruitment (Age 1) from 2018-2021 has been at a consistent level near the time-series mean (264 million, 1999-2023) and has been contributing to the fishable biomass in 2023.

In 2016, after two years of Spawning Stock Biomass (SSB) declines, TAC reductions were put in place. The TAC was reduced by 28% to 3,250 t in 2016, with a further TAC reduction of 20% to 2,600 t in 2017. From 2018 until 2021, a status quo TAC of 2,600 t was implemented. Then in 2022, in response to a decrease in both total biomass and SSB, the TAC was further reduced by 11.5% to 2,300 t. Despite the TAC reductions, the stock continued to decline, and subsequently another TAC reduction of 25% to 1,728 t was implemented in 2023.

Stock assessments for ESS Northern Shrimp are typically conducted every two years, with updates on stock health occurring in interim years. Both assessment and update processes are based upon a full analysis of ESS Northern Shrimp stock indicators determined from the DFO-Industry ESS Northern Shrimp collaborative survey (including the main trawl and a small-meshed 'belly-bag' used to capture the smallest size classes), commercial catch, port sampling program, and environmental monitoring data.

Description of the Fishery

The ESS Northern Shrimp fishery consists of 56 licences, 28 of which are DFO Maritimes Region-based mobile licences (mostly less than 65 ft length overall) and 14 of which are DFO Gulf Region-based mobile licences (65-100 ft length overall). All mobile sector licences have been under Individual Transferable Quotas (ITQs) since 1998. There is also a competitive trap fishery with 14 licences, which is largely restricted to Chedabucto Bay, Nova Scotia. The trap sector licences operate under a Competitive Quota (CQ). The quota allocated to the trap fishery is currently 8% of the TAC. As described in the ESS Northern Shrimp Integrated Fisheries Management Plan (IFMP), sectors negotiate annually on temporary transfers of uncaught trap quota to the mobile fleet (DFO 2011). The mobile trawl fishery on the Scotian Shelf occurs primarily during late spring and early summer, with some fishing during fall in the deep offshore ESS Northern Shrimp "holes" and in the inshore area of Bad Neighbour Shoal (Figure 1). In 2023, there were only 11 active mobile¹ sector vessels and two active trap¹ sector vessels, with trap sector activity dramatically decreasing in the last three years. The main fishery management tools include limits on the number of licenses and size of vessels used, minimum codend mesh size (40 mm), use of a Nordmøre separator grate, and a TAC.

Although there has been some ESS Northern Shrimp fishing on the Scotian Shelf since the 1960s, the Nova Scotia fishery began to expand toward its full potential only when groundfish bycatch restrictions were overcome with the introduction of the Nordmøre grate in 1991 (Figure 2). The TAC was first reached in 1994 after individual Shrimp Fishing Area (SFA) quotas were combined into a single TAC. Since that time, there have been some minor shortfalls associated with late re-allocations of uncaught trap quotas to the mobile fleet late in the season, which may not allow for this quota to be fished. The mobile fleet continues to prefer open access to all areas (i.e., no individual SFA quotas) because of the flexibility this offers in obtaining favourable combinations of good catch rates and counts (shrimp sizes). The fishing season is from January 1st to December 31st. As of November 28, 2023, 1,640 t of the 1,728 t TAC for 2023 had been landed. Of these total landings, less than 1 t was landed by the trap fleet.

¹ Number of active vessels for mobile and trap fleets is reported as of November 28, 2023.

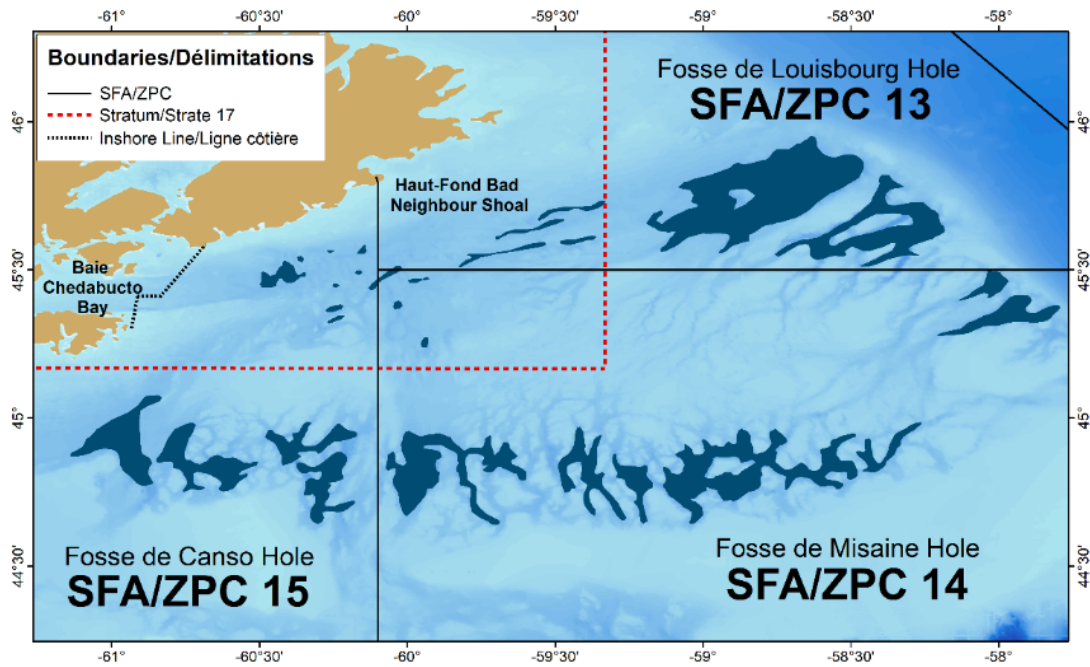


Figure 1. Shrimp Fishing Areas (SFAs) on the Eastern Scotian Shelf. The area within the dashed red line depicts survey stratum 17 (inshore area); survey strata 13-15 are the remaining portions of SFAs 13-15.

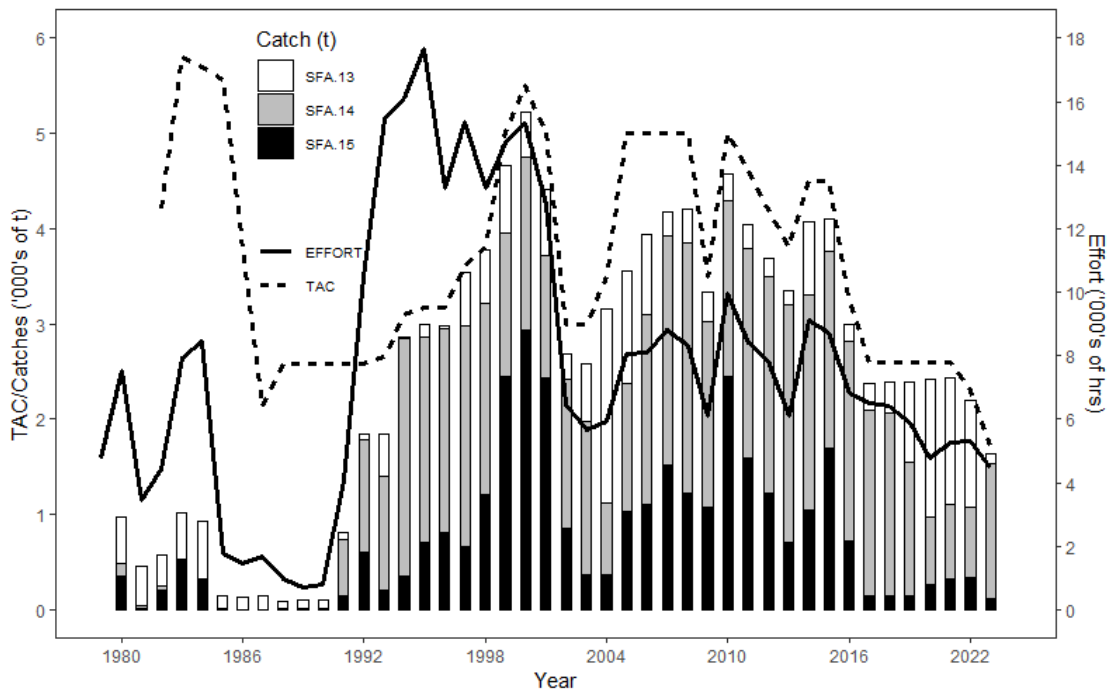


Figure 2. History of ESS Northern Shrimp catches per Shrimp Fishing Area (SFA; 13, 14, and 15), Total Allowable Catch (TAC) (thousands of t), and effort (thousands of hours), from 1979-2023. Effort and catches for 2023 represent data available as of November 28, 2023.

The spatial pattern of the fishery has not significantly changed since 2005, with the bulk of the catch taken from SFAs 14 and 15. Following 2017, fishing activity increased in SFA 13 and decreased in SFA 15. However, COVID-19 restrictions in 2020 and 2021 affected spatial (i.e., fishing increase in SFA 13) and temporal (i.e., fishing later in the season) fishing patterns in the ESS Northern Shrimp fishery. These changes to fishing patterns remained similar up until 2023, when fishing returned to pre-pandemic spatial patterns (not temporal), with over 80% of the 2023 mobile landings being harvested in SFA 14 (as of November 28, 2023).

Analysis and Response

A Traffic Light Analysis (TLA) has been used to assess the status of the ESS Northern Shrimp stock for the provision of science advice since 1999 (Koeller et al. 2000). This holistic, multi-indicator approach considers the current value of each indicator relative to its time series and summarizes individual indicators into four characteristic groupings focused on Abundance, Production, Fishing Effects, and the Ecosystem, as well as an overall Mean summary indicator. The TLA is used to display, summarize, and synthesize many relevant yet disparate data sources into a consensus opinion on the state of the ESS Northern Shrimp stock.

A Precautionary Approach (PA) Framework that has reference points and harvest control rules has been implemented within the Sustainable Fisheries Framework, using the TLA to inform the ESS Northern Shrimp stock status through its assessments. The Limit Reference Point (LRP; 5,459 t) and Upper Stock Reference (USR; 14,558 t) for the ESS Northern Shrimp stock are 30% and 80%, respectively, of the average SSB maintained during the high productivity period of the modern fishery (2000-2010) (Hardie et al. 2018). When the stock is in the healthy z, a maximum removal reference point of 20% female exploitation rate is used to help guide management decisions (Hardie et al. 2018).

Data used in this assessment includes commercial catch data, survey catch data (expanded to total biomass using the swept area method), detailed ESS Northern Shrimp biological data (commercial and survey samples), survey data for other marine species, and various environmental data (Hardie et al. 2018).

Indicators of the Stock Status

The swept area survey biomass index decreased by 30% from 15,610 (+/- 4,055 t 95% Confidence Interval or CI) in 2022 to 10,856 (+/- 2,441 t 95% CI) in 2023. Since 2020, the Maritimes mobile fleet standardized Catch Per Unit Effort (CPUE) has decreased by 21% (9% in 2023), the Gulf mobile fleet unstandardized CPUE has decreased by 35% (5% in 2023), and the survey CPUE has decreased by 64% (30% in 2023) (Figure 3A). The 2023 mobile fleet unstandardized commercial CPUE trends decreased from 2022 in Stratum 13 and 14, but increased in Stratum 17 (Figure 3B). Since 2021, the trap catch index has not been an informative proxy, as it is biased against only a few vessels and has reduced fishing activity, so its value has been omitted in the summary TLA below. Monitoring commercial CPUE indices may not always reflect overall abundance changes in the short term, due to changes in the spatial distribution of the resource and fishing effort. However, in 2022 and 2023, both the survey biomass and commercial catch indices have decreased.

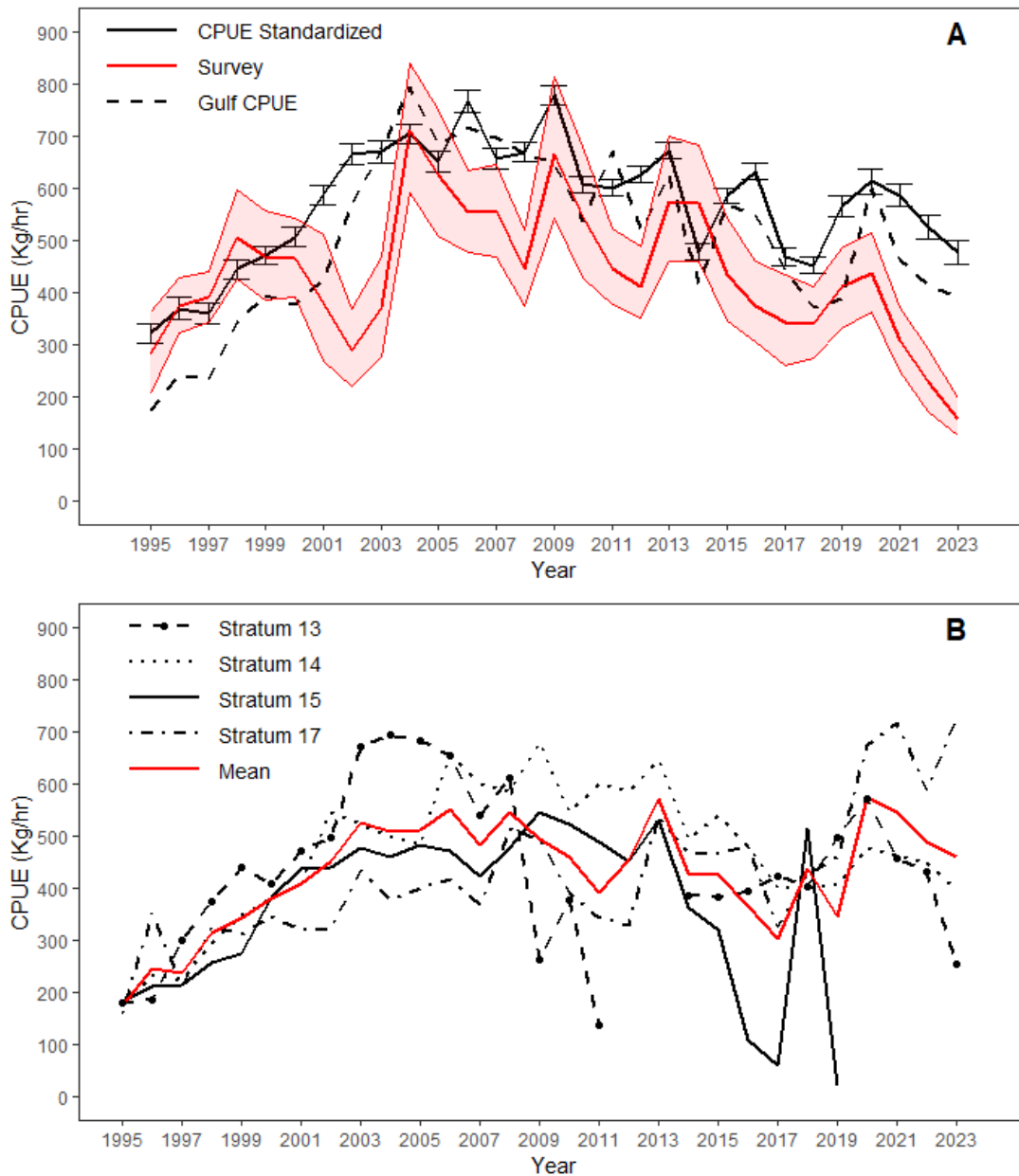


Figure 3. (A) DFO-Industry survey stratified Catch Per Unit Effort (CPUE) with 95% confidence intervals (red), Maritimes mobile fleet standardized commercial CPUE with 95% confidence intervals (solid black line), and unstandardized Gulf mobile fleet CPUE black, dash line; and (B) Unstandardized mobile commercial CPUE for each stratum from 1995-2023 and combined mean across all strata (red) (this figure excludes factory trawlers).

The PA Framework for the ESS Northern Shrimp stock uses SSB (a Production characteristic) as the metric for stock status and female exploitation rate (a Fishing Effects characteristic) as the metric for the removal rate (Figure 4). The 2023 SSB point estimate decreased by 32%, from 10,165 t ($\pm 4,914$ t, 95% CI) in 2022 to 6,883 t ($\pm 3,184$ t, 95% CI) in 2023. It is below the USR of 14,558 t. The spread of the CIs show that the SSB point estimate is between the range of 3,699-10,067 t, where there is a 32% chance that this estimate is potentially in the critical

zone, as it would be below the LRP of 5,459 t. Based on the PA Framework, the ESS Northern Shrimp stock remains in the cautious zone for 2023, where it has been since 2021 (Figure 4). The TAC reductions were anticipated to maintain lower total and female exploitation rates since 2021; however, both rates increased in 2021 and 2022 despite catch level reductions. In 2023, the total exploitation rate decreased to 12% and the female exploitation rate increased to 18%. The 2023 female exploitation rate is now closer to its 20% maximum removal reference when in the healthy zone, as the SSB continues to decline towards the LRP.

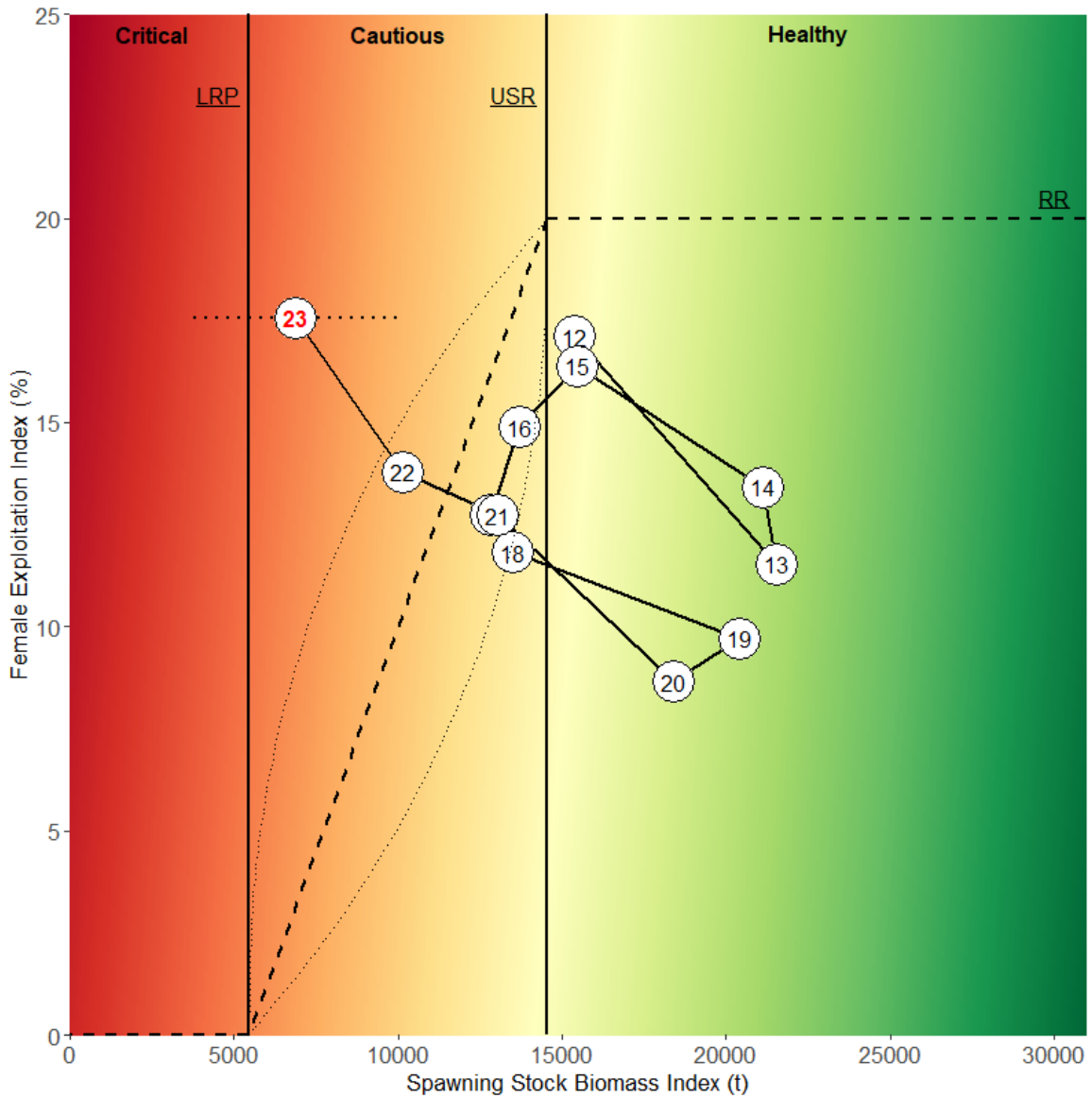


Figure 4. Graphical representation of the Precautionary Approach (PA) Framework for ESS Northern Shrimp. The black vertical lines represent the Limit Reference Point (LRP; 5,459 t) and the Upper Stock Reference (USR; 14,558 t). The horizontal dotted line across the 2023 point estimate represents the 95% CI range. The horizontal dotted line in the healthy zone represents the 20% maximum female exploitation Removal Reference (RR). The dotted lines in the cautious zone represent a range of possible management actions.

Interpretation of year-class strength and longevity can be complicated by several factors, including: low catchability of ESS Northern Shrimp younger than Age 4; strong influence of growth rate on the catchability of Age 4 ESS Northern Shrimp; difficulty in distinguishing and assessing year-classes after Age 3; and, changing longevities and natural mortalities associated with environmental and/or density-dependent influences. The tendency of a single year-class to change sex over a few years, especially relatively large year-classes such as 2013 (first observed in 2014 as 1-year olds; see: Table 1), makes it difficult to distinguish them from adjacent year-classes. Nonetheless, past recruitment pulses have coincided with the maturation of strong year-classes, providing evidence that strong year-classes have produced large SSB estimates.

Cohort tracking through length-frequency distributions from the DFO-Industry survey and commercial samples can help predict upcoming contributions to fishable and spawning biomass. The fishable biomass and SSB have received limited recruitment since 2020, as the low belly-bag (Age 1 abundance) indices from 2016 and 2017 have been contributing fewer commercial-sized individuals and have now reached the end of their expected lifespan in 2023 (Table 1; Figure 5). Belly-bag index values from 2018-2021 show an increase in recruitment relative to 2016-2017. However, in 2023 the abundance index for both Age 2 (2022) and Age 4 (2020) decreased, which is inconsistent with the belly-bag index (Table 1). The 2022 and 2023 Age 1 recruitment estimates were 52 and 77 million ESS Northern Shrimp, respectively, which is a decrease compared to the last four years and the lowest values since the 2012 year-class (as evidenced in the 2013 belly-bag index). The low overall abundance of Age 1 and Age 2 ESS Northern Shrimp observed in the 2023 DFO-Industry survey is consistent with decreasing SSB and the warmer temperature trends observed since 2019.

The 2013 year-class, first observed in 2014 and the second highest belly-bag index in the time series (1999-2023), has been closely monitored and has provided a strong signal in the DFO-Industry survey (Table 1) and commercial fishery data until 2022. The abundance of Age 5+ females and Age 4+ males has been decreasing since 2019, coinciding with lower overall recruitment from the 2015 and 2016 year-classes. Subsequently, there was an increase in maturing contributions from the 2017 year-class, but these did not add to the abundance of Age 5+ females and Age 4+ males as expected (Table 1; Figure 6A).

The age-class abundance based on survey length frequency data on transitional and primiparous (first-time spawner) ESS Northern Shrimp has been decreasing since 2020. The age-class abundance of multiparous (multi-year spawner) ESS Northern Shrimp has also been decreasing since 2019 and substantiates the decreases observed in the SSB index during these years (as demonstrated in Figure 4). Furthermore, the total females estimate for 2023 in Table 1 is at an all-time low for the time series (1999-2023). The 2017 and 2018 year-classes were expected to supplement the SSB in 2022 and 2023; however, continued low belly-bag index values and a small primiparous proportion of total females suggest otherwise (Table 1; Figures 5 and 6B). In 2023, the total abundance of ESS Northern Shrimp from 21 mm carapace length, the size at which primiparous and multiparous trends are discernible in Figure 5, has declined from 2022 values. This reduction highlights that the multiparous portion of the stock is not only declining in abundance but is also limited in its carapace length range (Figure 5).

Table 1. Minimum survey population numbers-at-age of ESS Northern Shrimp (millions of individuals) from modal analysis. Mean and median values are based on data from 1999-2023. The table is representative of numbers across all SFAs.

Age	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Mean ⁱ	Median ⁱ
1ⁱⁱ	88	94	22	796	288	112	83	267	272	279	244	52	77	264	202
2	58	43	211	26	495	17	166	37	68	72	154	106	62	159	112
3	513	348	302	119	501	193	581	361	195	368	462	309	230	516	362
4	1,105	1,018	1,157	613	690	1,304	1,468	822	392	522	583	687	426	1,182	1,057
5+	2,694	2,688	4,091	4,673	2,956	3,076	1,734	2,231	3,155	3,000	2,109	1,341	889	2,838	2,856
TOTAL	4,458	4,191	5,783	6,227	4,930	4,702	4,032	3,718	4,082	4,241	3,552	2,495	1,683	4,821	4,458
Age 4+ malesⁱⁱⁱ	2,003	2,241	2,960	3,831	2,270	2,931	1,859	1,966	2,273	2,137	1,611	1,046	649	2,451	2,270
Primiparous^{iv}	947	371	699	706	521	664	453	433	435	573	398	388	251	726	699
Multiparous	937	1,188	1,611	1,545	1,143	897	973	921	1,111	1,091	927	646	491	971	973
Total females	1,884	1,559	2,310	2,251	1,664	1,561	1,426	1,354	1,546	1,664	1,325	1,034	742	1,696	1,591

ⁱ Mean and median values based on data from 1999-2023.

ⁱⁱ Belly-bag. Time series began in 2002.

ⁱⁱⁱ Total population less Ages 2 and 3 males, transitionals (i.e., males that will potentially change to females the following year) and females.

^{iv} Includes transitionals.

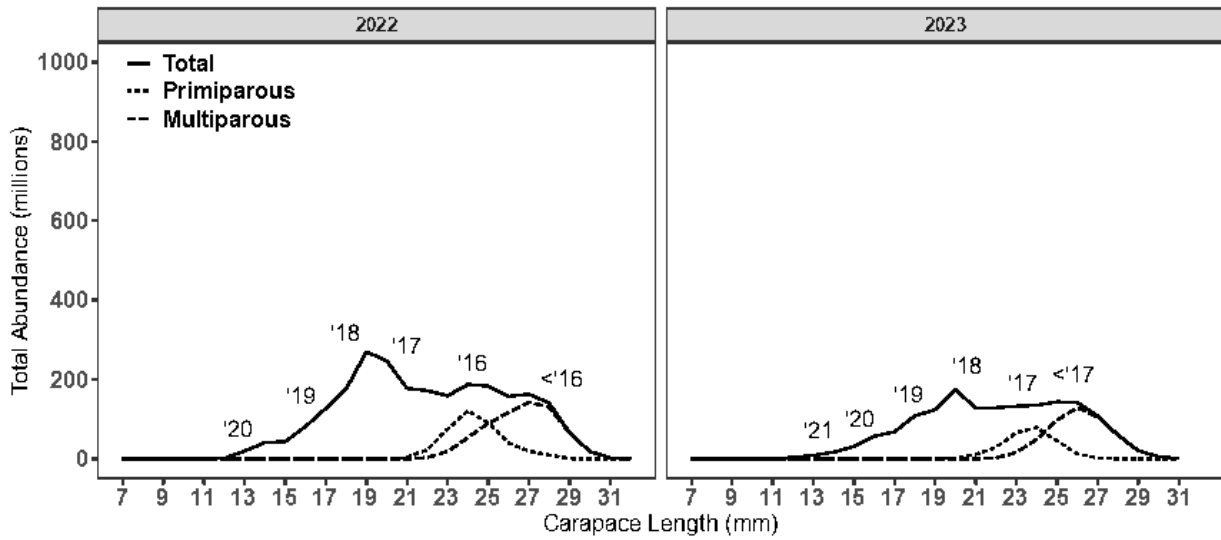


Figure 5. Population estimates of number of shrimp-at-length from the 2022 and 2023 DFO-Industry surveys (solid line). The dotted line in each figure represents transitional and primiparous ESS Northern Shrimp and the dash line represents multiparous ESS Northern Shrimp. Year-classes associated with ESS Northern Shrimp at given carapace lengths are indicated. See DFO 2022b and DFO 2023 for a complete time-series of survey length-frequencies.

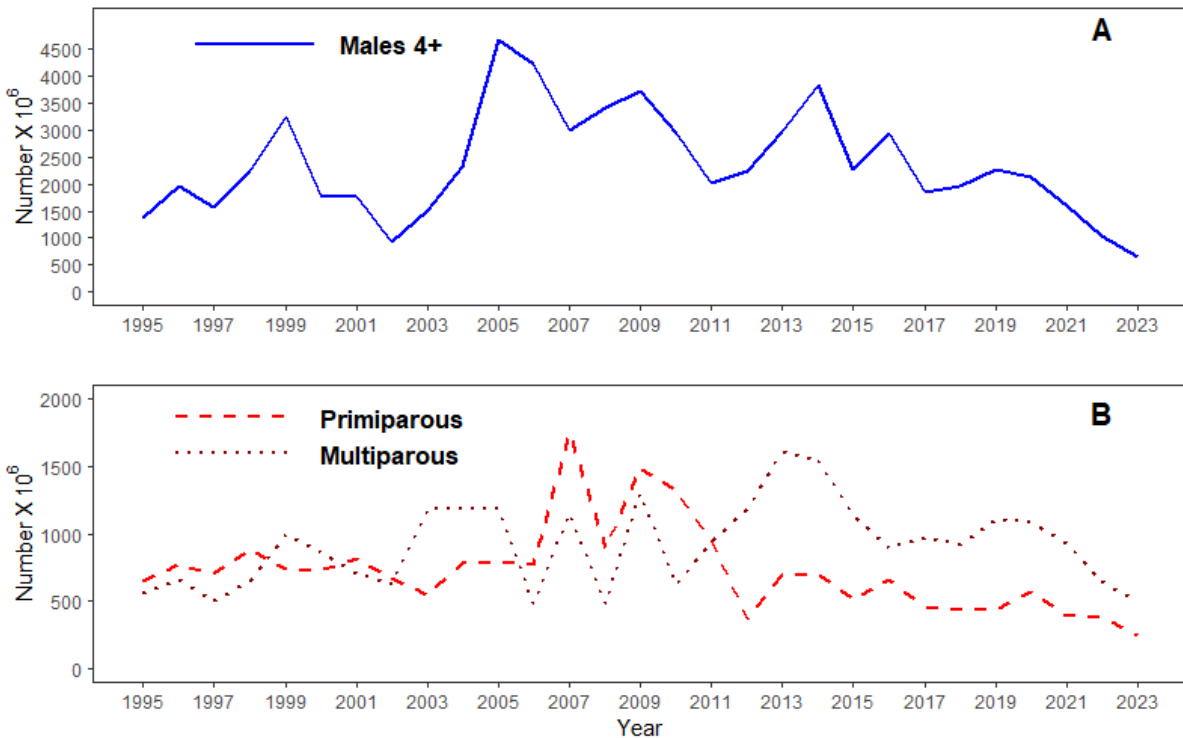


Figure 6. (A) Modal analysis population estimates of Age 4 and older male and (B) Primiparous female (dashed line) and Multiparous female (dotted line) ESS Northern Shrimp from the DFO-Industry survey.

The port sampling program provides a length distribution of commercial catches across SFAs throughout the year. Figure 7 suggests that smaller-sized ESS Northern Shrimp are being retained commercially and at sizes prior to female transition as primiparous (Figure 5). There is no minimum size of capture for this fishery; however, in 2022 the relative proportion of smaller ESS Northern Shrimp in the commercial catch was higher (Figure 7). In 2023, the majority of commercial samples were collected in Stratum 14 (41/47 samples), which provides the only recorded instance of ESS Northern Shrimp larger than 29 mm in carapace length (Figure 7). Abundance trends for Stratum 13 (1 sample) and Stratum 17 (5 samples) were limited by a small sample size; however, a larger proportion of their carapace length range was observed to be within 21-27 mm. Given the continued decreasing numbers since 2022 across all age classes (males, primiparous, multiparous, and total females), the continued removal of immature shrimp, and the continued decrease in magnitude of annual recruitment, the total abundance is at a time-series low.

The 24 indicators relating to the health of the ESS Northern Shrimp stock are grouped into categories of Abundance, Production, Fishing Effects, and Ecosystem characteristics. The aggregated trends across each characteristic, as well as an overall mean summary across all characteristics, are shown in Figure 8. Individual indicator trends within each of these characteristics are displayed in Figure 9. After four years of steady increases, the Abundance characteristic decreased in 2022 and again in 2023. This characteristic remains in the red zone for 2023, as all of its indicators are trending negatively from 2022.

The Production characteristic declined sharply in 2022, while in 2023 another decline was observed. Annual contributions from recruitment were similar from 2018-2021 and consistent with the time-series mean; however, these contributions remained lower than higher recruitment pulses such as those observed in 2014 (year-class 2013), which previously resulted in a stronger supplement to the SSB portion of the stock. The anticipated replenishments for 2022 and 2023 have not improved any of the age-class stock productivity indicators described in Table 1, and as a result, the stock productivity remains in the red zone.

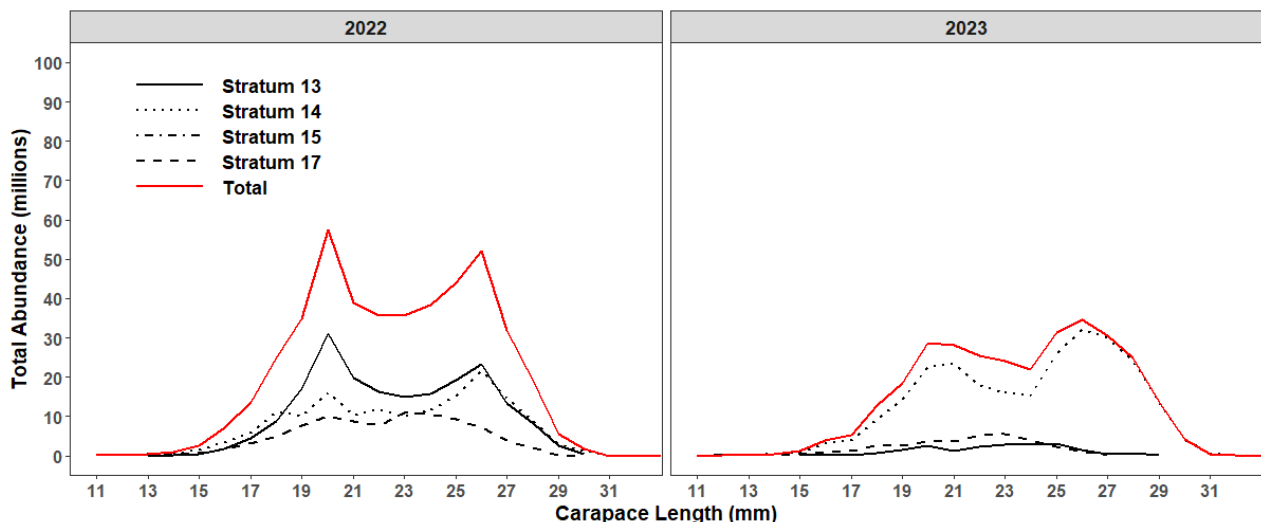


Figure 7. Catch-at-length from commercial sampling by stratum for 2022 and 2023.

The Fishing Effects characteristic was steadily improving up until 2019, after which it began to decline. In 2023, an improvement in the overall indicators was observed. Despite the two reductions in the TAC (11.5% in 2022 and 25% in 2023), female exploitation has been

increasing. The average commercial count of ESS Northern Shrimp per pound has decreased to 55 in 2023 (58 per pound in 2022). While this suggests an increase in the presence of larger shrimp, a stipulation of this indicator is its reliance on the spatial extent from which the volunteer information was provided. In comparison with other size indicators, where a decrease in the proportion of large females is observed, this trend is not substantiated.

In 2021, the Ecosystem characteristic was primarily influenced by temperature indices, since the Snow Crab, Greenland Halibut, and Atlantic Cod recruitment trends were not included in the 2021 assessment due to a lack of data (DFO 2022b). The Ecosystem characteristic improved slightly in 2022, with the addition of the Snow Crab recruitment index, even though the value has decreased since 2020. In 2023, all five indices were accounted for and provided a better weighted perspective across indicators; however, the overall trend remains in the red zone.

Two out of four characteristic summaries in 2023 show decreases from the 2022 values, although the overall mean value is consistent with 2022 and remains in the red zone. There are 15 out of 24 indicators that are describing negative trends for 2023, which supports the resulting PA Framework outcome (see: Figure 4) that the stock continues to be in the cautious zone.

Bycatch

The introduction of the Nordmøre separator grate in 1991 led to a significant reduction in bycatch and allowed the fishery to expand to its present size. Bycatch estimates are extrapolated from at-sea observer sampling during commercial trips. Target coverage is up to 6 trips annually (6% coverage based on trips). There were two observer trips in 2023, which represents 2.2% of the overall commercial effort for 2023, following two years without observer coverage. Total bycatch amounts represent less than 0.5% of the mobile fleet catch. This is based on the summary of 20 sets in May-June 2023, which occurred only in SFA 14. The three most abundant bycatch species from these two trips were Atlantic Halibut, Silver Hake, and Sand Lance. With minimal bycatch interactions from commercial fleets, the ESS Northern Shrimp fishery currently poses little risk in terms of bycatch amount or species composition.

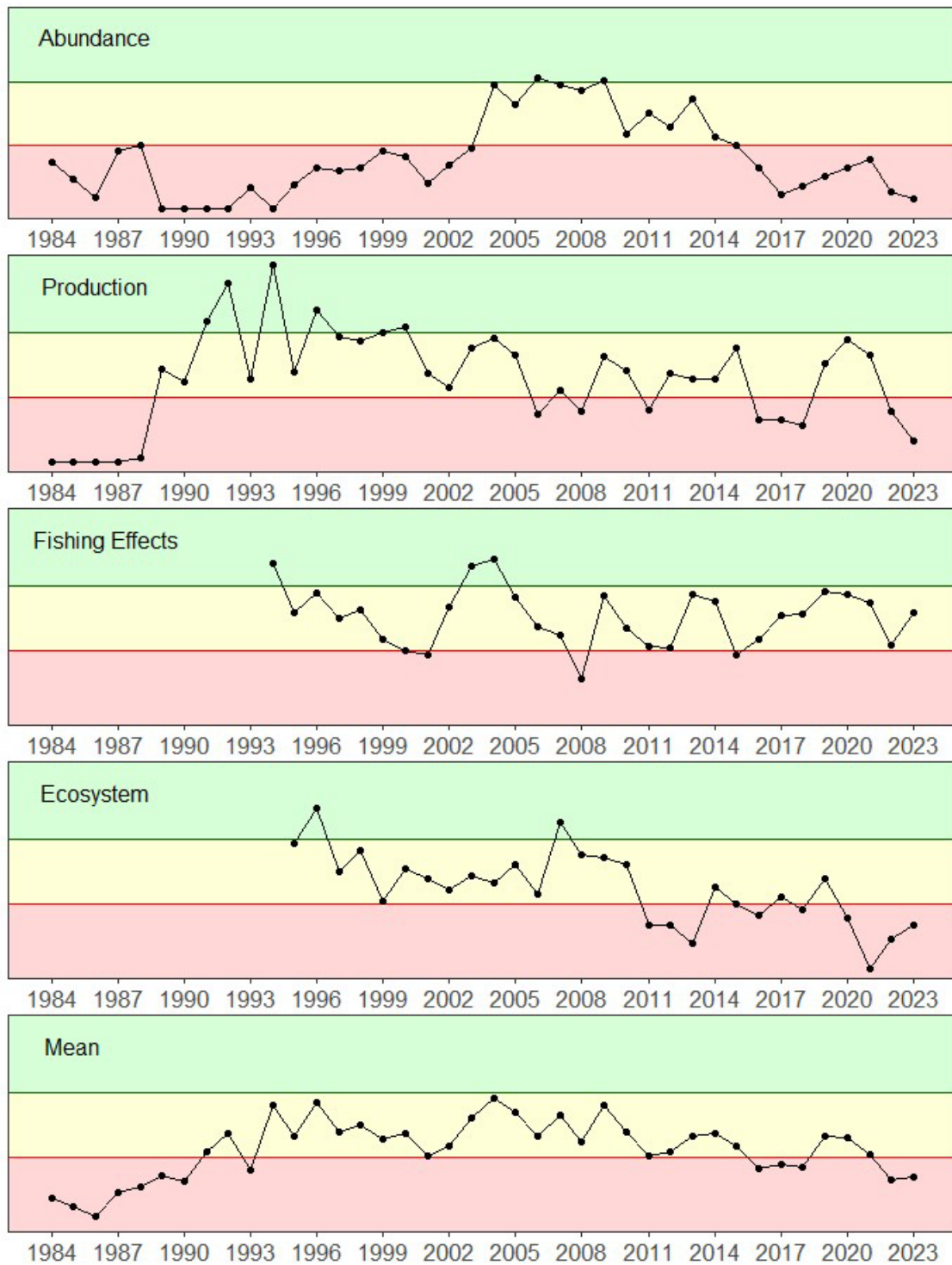


Figure 8. Time series of all available ESS Northern Shrimp indicators grouped into four characteristics (top four panels) and the mean (overall) indicator (bottom panel) from 1984-2023. Thresholds between red, yellow, and green are at the 33rd and 66th percentile of the 2000-2010 data series for each indicator. Not all indicators in the summary above are discussed in the text. See Hardie et al. (2018) for a detailed description of indicators.

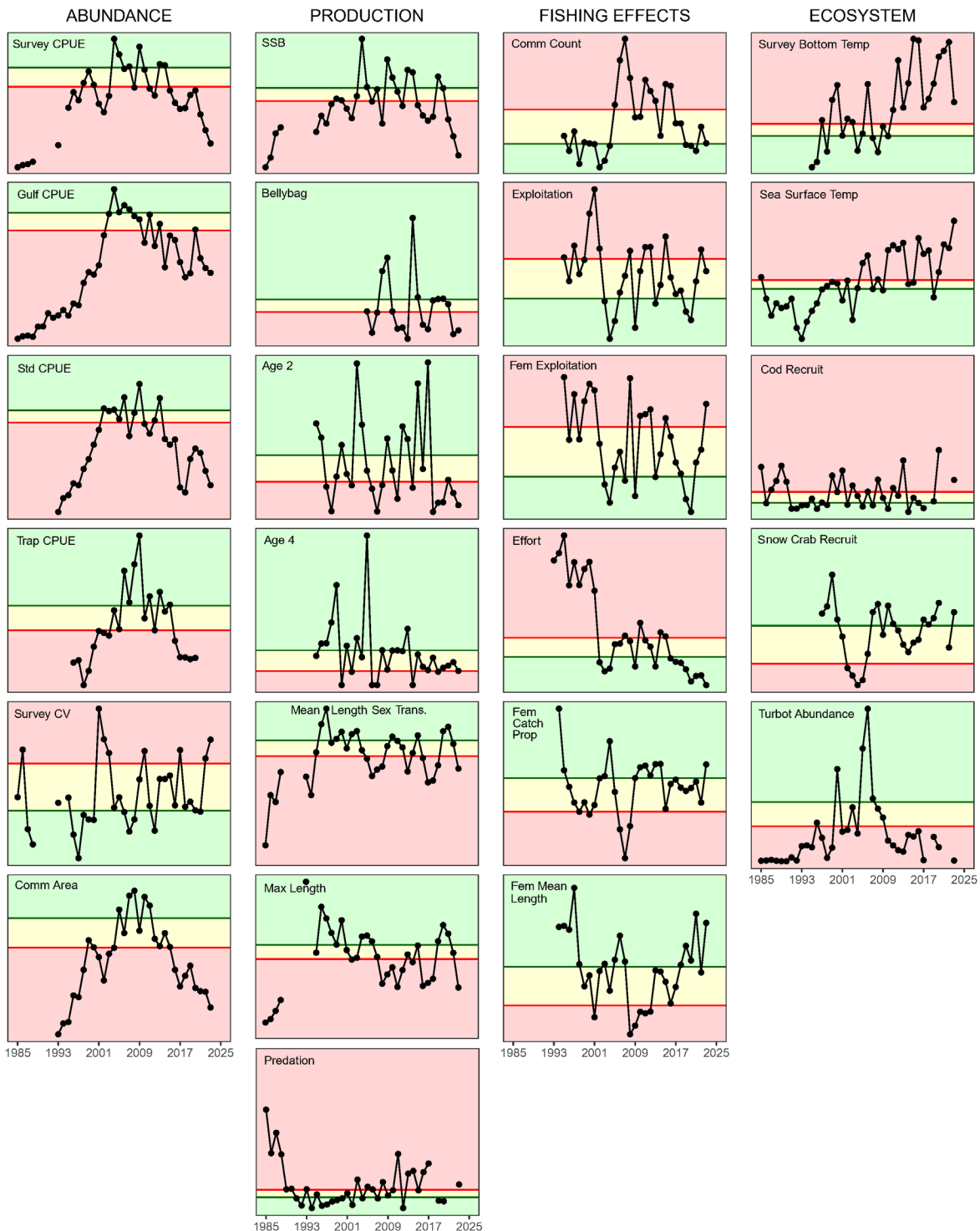


Figure 9. Time series of individual ESS Northern Shrimp indicators. Note that not all indicators are discussed in the text. Refer to past Canadian Science Advisory Secretariat Research Documents for detailed description of indicators (e.g., Hardie et al. 2018). SST = Sea Surface Temperature; Std CPUE = Maritimes mobile fleet standardized catch per unit effort index; Comm count = commercial counts of shrimp per pound.

Conclusions

The 2023 DFO-Industry survey stratified mean biomass estimate shows a decrease to 10,856 t +/- 2,441 t. The point estimate of the 2023 SSB (6,883 t ± 3,184 t, 95% CI) decreased by 32% from 2022, and is below the USR point of 14,558 t, placing this stock in the cautious zone for a third consecutive year and approaching the critical zone. It is further noted that although the 2023 point estimate remains within the cautious zone, its lower bound confidence interval falls below the LRP. In addition, the 2023 total female abundance estimate is the lowest observed in the 1999-2023 time series.

The belly-bag Age 1 abundance index from 2018 to 2021 suggests consistent recruitment and is within the time series mean of 264 million individuals. The abundance of Age 4 ESS Northern Shrimp decreased in 2023 and is inconsistent with the increase observed in the Age 3 value of 2022. The abundance estimates for Age 4+ males, primiparous, multiparous, and total females have decreased in both 2022 and 2023, suggesting a less than expected contribution from the 2017-2018 year classes.

Although some voluntary industry sampling indicates that larger females are present in commercial catches, this differs from other fishery-independent data that indicate fewer younger age-classes, leading to uncertainty that there are actually more larger females in the population and that the larger females observed in voluntary sampling may be an artifact of fishing selectivity.

Recent observations have shown an increase in the retention of smaller, immature shrimp in fishery catches, declines in both total biomass and SSB estimates, as well as declining abundance estimates across mature female sizes. Such trends could decrease the proportion of the total shrimp population becoming mature females. If the SSB continues to decrease, the long-term sustainability of the fishery could be at risk.

All Ecosystem indicators were available in 2023; however, only the Snow Crab recruitment index (known sympatric species) and the Cod recruitment index (allopatric species) had positive trends. An increasing temperature trend in the last few years suggests unfavorable conditions for cold-water species such as the ESS Northern Shrimp. However, a decrease of 1.5°C in bottom temperatures from the 2023 June survey could be advantageous to spawning success in 2023.

The overall mean summary encompassing the 24 stock health indicators remains consistent with 2022 and remains in the red zone for the second consecutive year (see: Figure 8). This is due to decreases in two of the four summaries representing Abundance, Production, Fishing Effects, and Ecosystem characteristics. Fifteen out of the 24 TLA indicators describe adverse results for the ESS Northern Shrimp stock health. According to DFO's PA Framework, the stock remains in the cautious zone for the third consecutive year and is closer to the critical zone than it has ever been.

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