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Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2022/033

2021 ASSESSMENT OF NORTHERN SHRIMP ON THE EASTERN SCOTIAN SHELF (SFAS 13–15)

(J. Domm 2006).

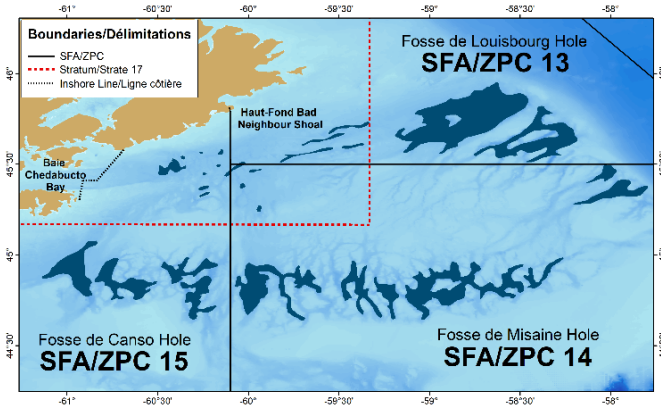

Figure 1. Note - Shrimp Fishing Areas (SFAs) on the Eastern Scotian Shelf.

Context:

Advice on the status of the Eastern Scotian Shelf (ESS) Northern Shrimp stock is requested by DFO Resource Management to help determine a Total Allowable Catch (TAC) that is consistent with the management plan. Annual science advice is required because of rapid changes in abundance, variable recruitment to the population and fishery, and changes in the size of Northern Shrimp available for harvest. The resource is near the southern limit of the species' distribution where it is thought to be more vulnerable to significant and rapid declines, as has been observed in the adjacent Gulf of Maine (GoM) stock. The current report provides information and advice for management of the 2022 fishery.

The trawl fishery on the Scotian Shelf occurs primarily during late spring and early summer with some fishing during fall, in the deep offshore Northern Shrimp "holes", and on an inshore area near the Bad Neighbour Shoal. The main management tools are 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. This sector (about 15 active vessels) is divided into two fleets, a midshore fleet consisting of vessels 65–100' Length Over All (LOA) based in New Brunswick in the Gulf Region, and an inshore fleet consisting of vessels mainly < 65' LOA based in the Maritimes Region. A trap fishery, currently consisting of 7 active vessels, is restricted to Chedabucto Bay. All mobile sector licenses operate under Individual Transferable Quotas (ITQs). Annual stock assessments are conducted bi-annually with interim year updates on stock health. Both assessment and update processes are based upon a full analysis of Northern Shrimp stock indicators determined from the DFO-Industry collaborative survey, commercial landings, and environmental monitoring data.

This Science Advisory Report is from the December 13–14, 2021 regional advisory meeting of the Eastern Scotian Shelf Northern Shrimp Assessment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- As of November 19,2021, 2,429 mt of the 2,600 mt Eastern Scotian Shelf (ESS) Northern Shrimp Total Allowable Catch (TAC) for 2021 had been landed.
- The total biomass estimate for ESS Northern Shrimp decreased by 29% from 29,875 mt in 2020 to 21,67 mt in 2021.
- The 2021 Spawning Stock Biomass (SSB; females) point estimate decreased by 29% to 13,041 mt and it is now below the Upper Stock Reference (USR, 14,558 mt). Based on the precautionary approach, the ESS Northern Shrimp stock is considered to be in the Cautious Zone.
- The TAC (2,600 mt) has been at the same level since 2017 to reflect declining fishable biomass (larger shrimp) and SSB (females only) resulting from the low recruitment contributions from the 2015 and 2016 year classes. The precautionary TAC helped to maintain both total and female exploitation since 2017; however, they have both increased in 2021 to values of 12% and 13%, respectively.
- Belly-bag index (Age 1 abundance) values for 2016 and 2017 were the lowest in the time series, suggesting future poor recruitment contributions. However, the values since 2018 show an increase in recruitment relative to these, and suggest better contributions in the next four years.
- The abundance index for both Age 2 and Age 4 ESS Northern Shrimp increased in 2021, which is consistent with the higher belly-bag Age 1 abundance index values found in 2020 (i.e., 2019 year class) and 2018 (i.e., 2017 year class).
- Ecosystem indicators were primarily influenced by temperature trends, as all three sympatric species trends (Snow Crab, Greenland Halibut, and Atlantic Cod recruitment) were not updated for 2021. The consistent increase in both bottom and sea-surface temperatures suggest that conditions are currently reaching unfavorable levels for cold-water species such as Northern Shrimp.
- The overall mean summary indicator decreased in 2021 and is in the yellow zone due to decreases in all four characteristic summaries representing abundance, productivity, fishing effects, and ecosystem characteristics. Twelve out of 24 indicators (4 not updated in 2021) describe adverse results for Northern Shrimp stock health.
- The 2021 SSB index places the stock in the Cautious Zone according to the DFO Precautionary Approach (PA). Further reduction of removal rates could stabilize catch rates, protect incoming recruitment essential to the fishery, and allow commercial biomass to rebuild.

BACKGROUND

Species Biology

The Northern Shrimp, *Pandalus borealis*, is the only shrimp species of commercial importance in the Maritimes Region. This crustacean has a life cycle similar to other decapods, characterized by several stages including egg, larva, juvenile, and adult, moulting its exoskeleton to grow and develop through each subsequent stage. Typically, mature females mate in late summer/early fall soon after moulting, while mature male shrimp fertilize the eggs that are oviposited on the female's abdomen to form an external clutch (Shumway et al. 1985).

Females carrying an egg clutch are referred to as ‘ovigerous females’, and this period lasts until spring (approximately 8 months of the year). Newly hatched Northern Shrimp spend 2 to 3 months as pelagic larvae, feeding near the surface before settling to the bottom as post-larvae (Ouellet and Allard 2006). In order to interpret shrimp sizes as age categories, age-based estimates are produced from a mixture analysis using the ‘mixdist’ R package (MacDonald and Du 2018), using modes in length distribution to allocate ages from length metrics. On the Scotian Shelf, Northern Shrimp first mature as males at Age 2, and they generally change sex at Age 4, to spend another 1 to 2 years as females. However, Northern Shrimp may live up to 8 years, depending on environmental conditions and population dynamics. Northern Shrimp concentrate in deep "holes" (> 100 fathoms) on the ESS (Figure 1), but nearshore concentrations along the coastline were discovered in 1995 by the DFO-Industry collaborative survey. This inshore area is defined as Stratum 17. Portions of the Shrimp Fishing Areas (SFAs) outside the Stratum 17 boundaries are redefined as SFA subsets of each SFA and referred to as Stratum 13–15. In general, Northern Shrimp prefer temperatures of 2–6 ºC and a soft, muddy bottom with a high organic content.

The Fishery

There are 56 licenses distributed across three fleets: 28 are individually owned licenses by the Maritimes mobile fleet (8 active vessels during 2021), 14 are owned by the Gulf mobile fleet (7 active vessels during 2021), and 14 are owned by the Maritimes trap fleet (1 active vessel during 2021). Furthermore, First Nations own 13 of the Maritimes mobile fleet licenses and 2 of the trap fleet licenses. There have been no changes to the number of permanent licenses in the fishery since 2005 (Hardie et al. 2018). All mobile sector licenses have been under Individual Transferable Quotas (ITQs) since 1998. The trap sector is a competitive fishery and largely restricted to Chedabucto Bay (Figure 1). The trap sector allocation is currently 8% of the yearly Total Allowable Catch (TAC). As described in the ESS Northern Shrimp Integrated Fisheries Management Plan (IFMP), sectors negotiate annually on transfers of uncaught trap quota to the mobile fleet (DFO 2011).

Although there has been some Northern Shrimp fishing on the Scotian Shelf since the 1960s, the Maritimes fishery began to expand toward its full potential only when groundfish bycatch restrictions were overcome with the introduction of the Nordmøre grate in 1991. The TAC was first reached in 1994 after individual Shrimp Fishing Area (SFA) quotas were combined into a single TAC (Table 1; Figure 2). Since that time, there have been some minor shortfalls associated with re-allocations of uncaught trap quotas to the mobile fleet late in the season. The gap between the TAC and catch has narrowed steadily since 2005 as problems associated with market conditions and quota reallocations have been resolved. 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 favorable combinations of good catch rates and counts (Shrimp sizes).

The fishing season is from January 1st to December 31st. At the time of the assessment (November 19, 2021), 2,429 mt of the 2,600 mt TAC had been landed. The trap fleet landed 57 mt in 2020, and < 1 mt was landed as of November 19, 2021. Fishing activity has been strongly affected by the pandemic, with not only fishing limitations and delays, but also from an unstable market perspective. This has been an additional challenge for all ESS Northern Shrimp fleets in the last two years.

Table 1. Recent Eastern Scotian Shelf Shrimp Total Allowable Catches (TACs) and landings ('000s mt).

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
TAC	5.0	3.5	5.0	4.6	4.2	3.8	4.5	4.5	3.2	2.6	2.6	2.6	2.6	2.6
Landings[1]	4.3	3.5	4.6	4.4	4.1	3.6	4.3	4.4	3.0	2.4	2.5	2.5	2.5	2.4

[1] Landings to November 19, 2021.

The spatial pattern of the fishery has not changed significantly since 2005 (Figure 2), with the bulk of the catch taken from SFAs 14 and 15. However, since 2017 fishing activity has decreased in SFA 15 and increased in SFA 13 in the most recent years. Pandemic limitations in 2020–2021 have affected spatial (fishing increase in SFA 13) and temporal (fishing later in the season) fishing patterns in the ESS Northern Shrimp fishery. As of November 19th, 60% of the 2021 landings were harvested in SFA 14.

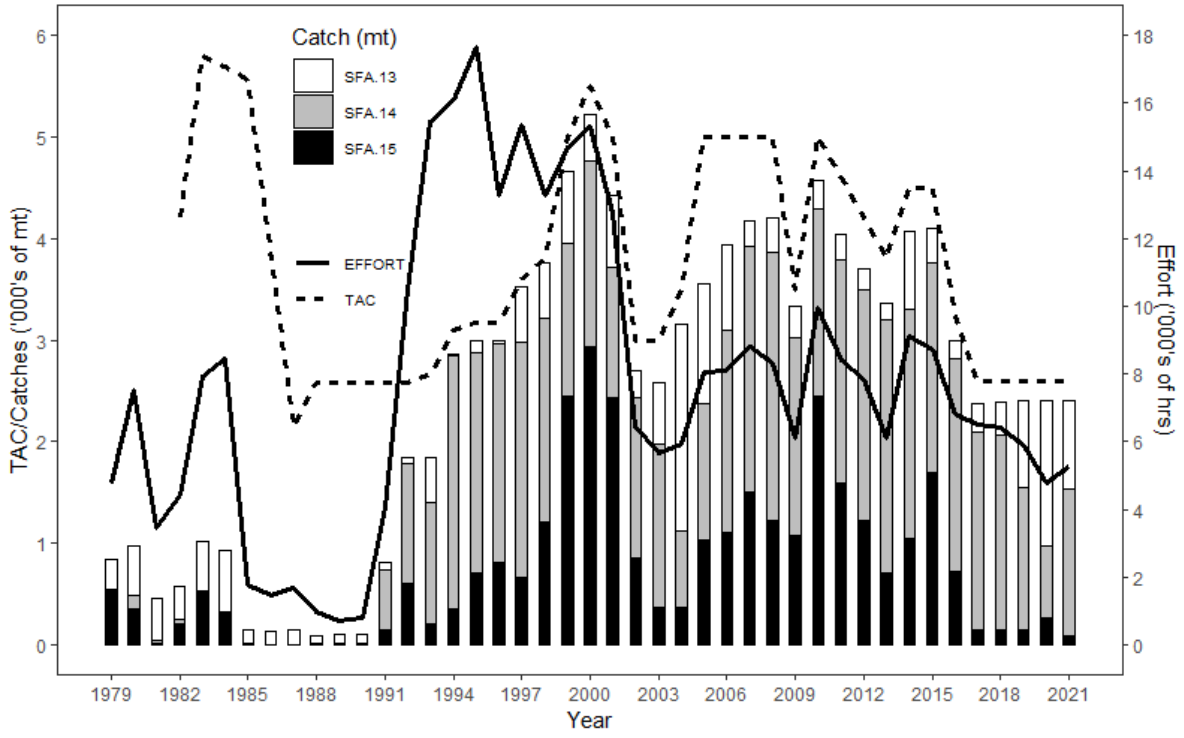

Figure 2. History of Eastern Scotian Shelf Shrimp catches per Shrimp Fishing Area (SFA) (13, 14, and 15), Total Allowable Catch (TAC) (thousands of mt), and effort (thousands of hours), from 1979–2021. Effort and catches for 2021 represent preliminary data as of November 19, 2021.

ASSESSMENT

Stock Trends and Current Status

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 multiple indicator approach considers the current value of each indicator relative to its time series and summarizes individual indicators into four characteristic groupings focusing on Abundance, Production, Fishing Effects, and the Ecosystem, as well as in an overall mean summary indicator. Indicators always represent summary data for the entire area (i.e., all SFAs combined, according to the current practice of managing the fishery as one stock). The TLA is used to

display, summarize, and synthesize a large number of relevant yet disparate data sources into a consensus opinion on the state of the Northern Shrimp stock.

The DFO-Industry survey Catch Per Unit Effort (CPUE) decreased by 29% (Figure 3A). The standardized CPUE and the Gulf vessel CPUE decreased by 2.5% and 23%, respectively (Figure 3A). The unstandardized commercial CPUE (Figure 3B) decreased in strata 13 and 14, while increases were observed in strata 15 and 17. As of November 19, 2021, the trap catch index increased by 57% relative to 2020; however, this index is calculated from a single vessel and with reduced fishing activity. 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. In 2021, CPUE indices support the overall abundance changes observed. The decrease in the DFO-Industry survey CPUE in 2021 is also corroborated by the distribution of commercial catch area index, where decreases have occurred in all catch rate categories. The TAC has been 2,600 mt since 2017 as mixed results from the TLA indicators have suggested a precautionary outlook with variable fishable biomass (larger Shrimp) and Spawning Stock Biomass (SSB; females only) results from the loss of the formerly abundant year classes, and limited subsequent recruitment contributions (2015 and 2016 year classes). The maintenance of this precautionary TAC value has served to limit the fishing effort and reduce overall pressure on a declining resource.

The 2021 ESS Northern Shrimp total biomass estimate decreased by 29% to 21,167 mt (± 3,973 mt, 95% Confidence Interval [CI]) from the 2020 estimate of 29,875 mt (± 4,956 mt, 95% CI) (DFO 2021a). The total biomass has declined since 2020, with consistent annual recruitment; however, year classes 2015–2016 reflect the lowest recruitment values in the time series and are minimally contributing to the SSB. With this limitation, and with larger recruitment contributions (i.e., 2013–2014 year classes) beyond their life expectancy, the 2021 total biomass decrease was expected.

Figure 4A shows that the SSB estimate also decreased by 29% (13,041 mt ± 5,021 mt, 95% CI) in 2021 from the 2020 estimate (18,403 mt). This is the second consecutive decrease for the SSB estimate, and this seems to coincide with a diminished contribution of the larger 2013 year class in the last few years. Consecutive year-class contributions, from 2014–2016 have been, to a lesser extent, supplementing the SSB and, therefore, are deficient at maintaining an SSB at similar 2013 year-class contribution levels.

The Precautionary Approach (PA) uses two indicators, SSB (Production characteristic) and female exploitation (Fishing Effects characteristic), as reference points. The 2021 SSB (females) point estimate decreased by 29% to 13,041 mt (± 5,021 mt, 95% CI) and is now below the Upper Stock Reference (USR, 14,558 mt). Based on the PA, the ESS Northern Shrimp stock is considered to be in the Cautious Zone for 2021 (Figure 4A and Figure 5). The precautionary TAC helped to maintain lower total and female exploitation values since 2017; however, both rates have increased in 2021 to 12% and 13%, respectively (Figure 4B and Figure 5).

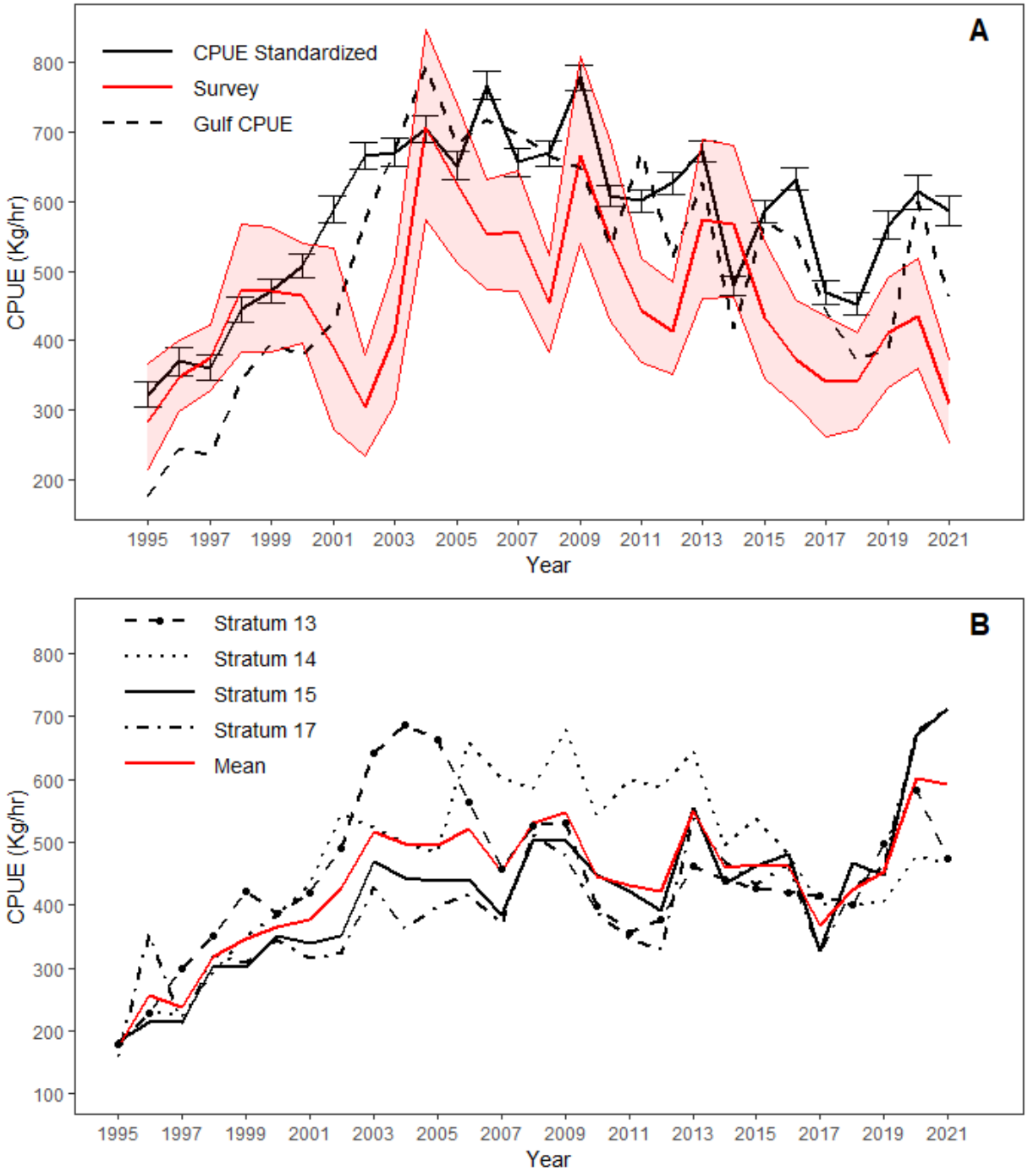

Figure 3. Survey stratified CPUE, standardized commercial CPUE with 95% confidence intervals, and unstandardized Gulf vessel CPUE (A); unstandardized commercial CPUE for each fishing area, from 1995–2021 (B).

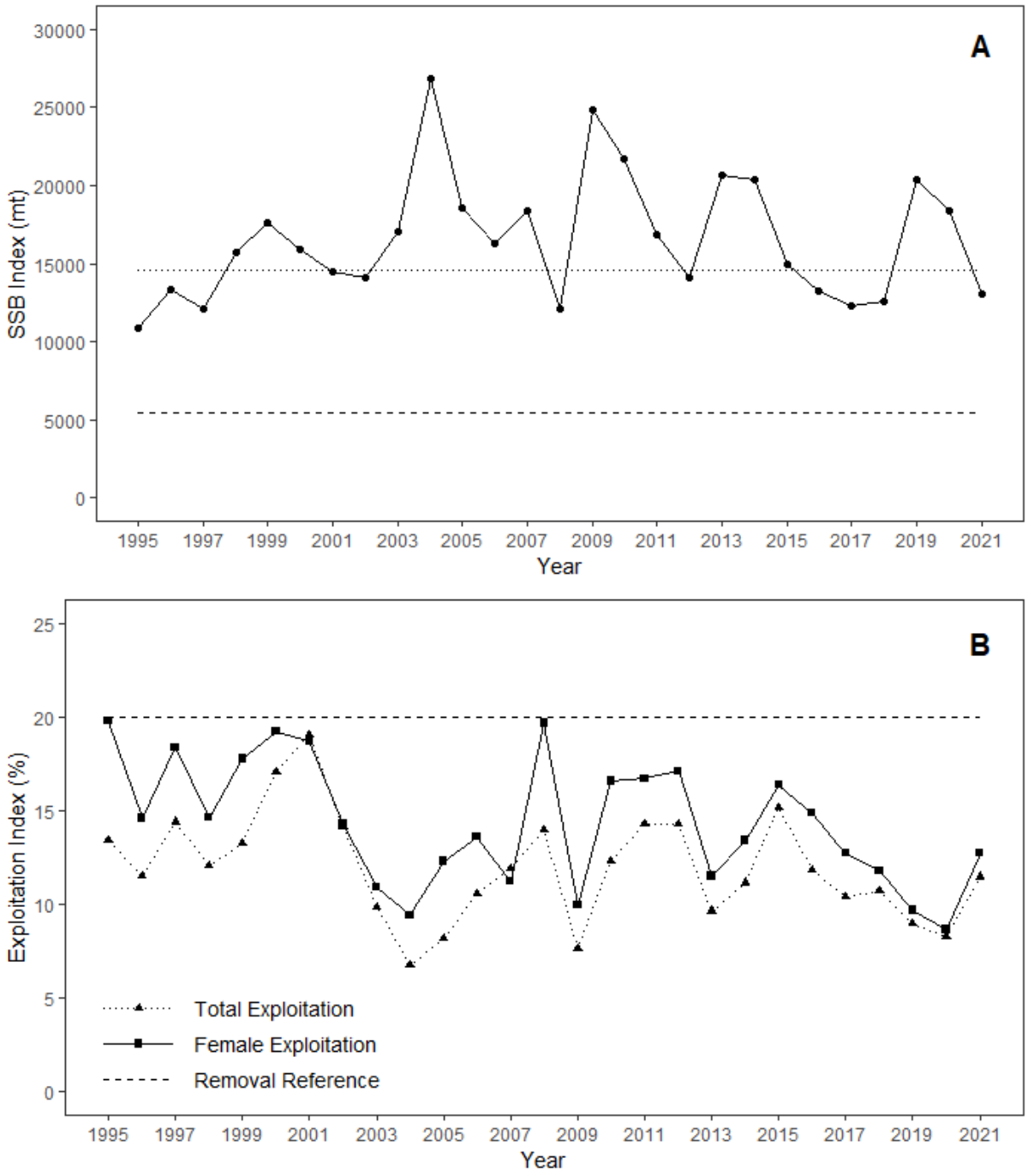

Figure 4. Changes in the Spawning Stock Biomass (SSB) index for the Eastern Scotian Shelf Northern Shrimp population (A). The dashed lines show the Lower Reference Point (LRP) at 30% and Upper Stock Reference (USR) at 80% of the mean SSB during the 2000–2010 high-productivity period. Changes in the exploitation indices for the Eastern Scotian Shelf Shrimp fishery (B). The dashed line shows the removal reference of 20% for the female exploitation index when in the Healthy Zone.

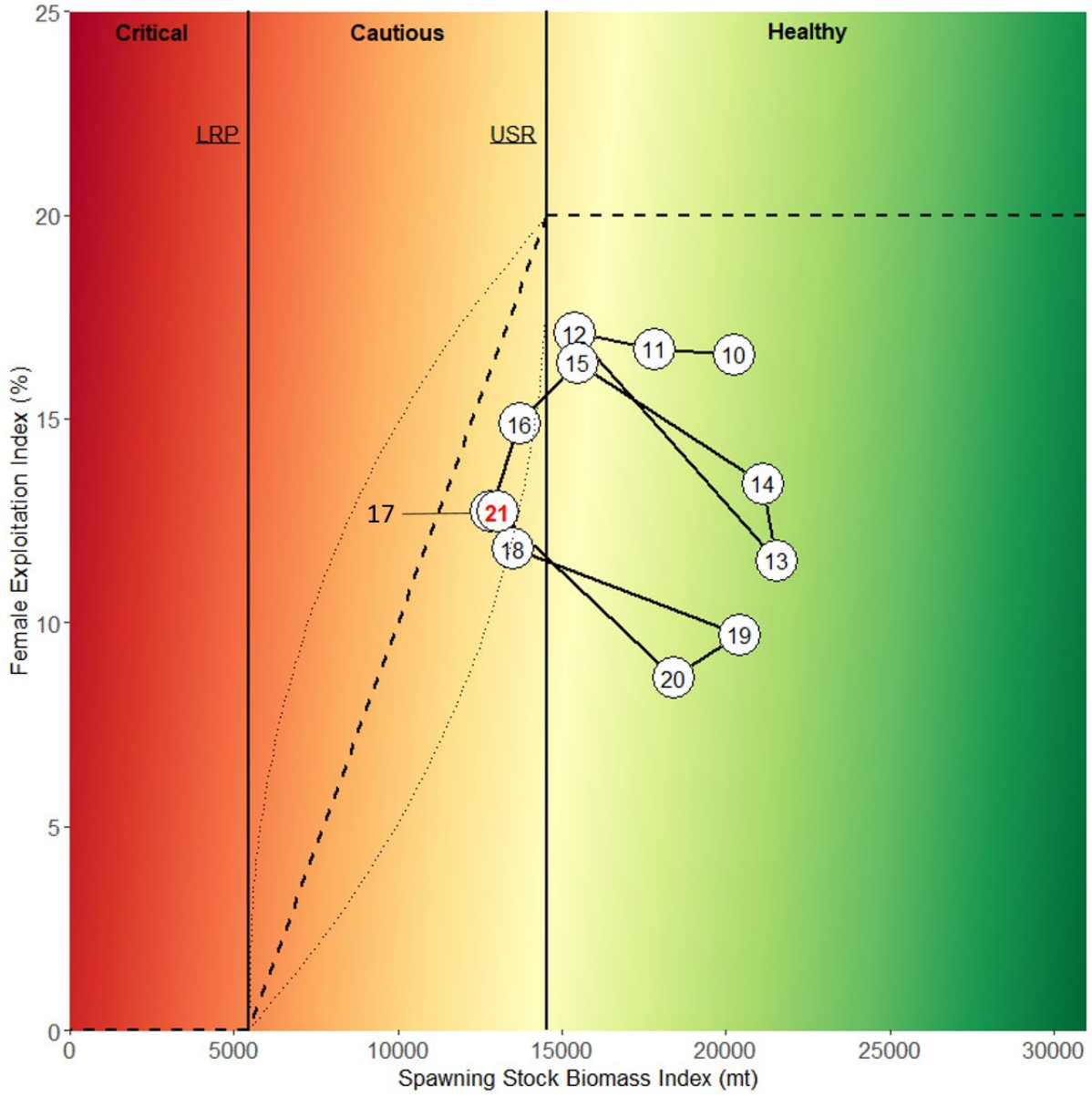

Figure 5. Graphical representation of the Precautionary Approach for Eastern Scotian Shelf Northern Shrimp. The dotted lines in the Cautious Zone represent a range of possible management actions, depending on whether the stock is stable, increasing or decreasing, or on trends in other indicators of stock and ecosystem health. The horizontal dashed line in the Healthy Zone represents the Removal Reference (20%). Values within the circles represent calendar year.

The interpretation of year-class strength and longevity can be complicated by a number of factors, including: the low catchability of Northern Shrimp younger than Age 4; the strong influence of growth rate on the catchability of Age 4 Shrimp; difficulty in distinguishing and assessing year classes after Age 3; and changing longevities and natural mortalities associated with environmental or density dependent influences. The tendency of a single year class, especially relatively large ones such as 2001, 2007–2008, and 2013, to change sex over a number of years makes it difficult to distinguish them from adjacent year classes. Nonetheless,

these recruitment pulses have coincided with the maturation of strong year classes, providing evidence that strong year classes have produced large spawning stock biomass estimates.

As evidenced in the 2017 to 2021 DFO-Industry survey (Figure 6 and Figure 7) and commercial catches (Figure 8), the 2012–2015 year classes have reached the end of their expected lifespan. The remaining fishable biomass and SSB has not been well supported by subsequent recruitment. Cohort tracking through length-frequency distributions from the DFO-Industry survey and commercial samples, corroborated by the low belly-bag (Age 1 abundance) index from 2016–2017, predict low contributions to fishable biomass and SSB from the 2015–2016 year classes (Table 2). Belly-bag index values for 2016 and 2017 were the lowest in the time series, suggesting future poor recruitment contributions. However, the values since 2018 show an increase in recruitment relative to these, and suggest better contributions in the next four years. The 2021 estimate was 244 million Northern Shrimp, which is comparable to the last three years, and is near the long-term average (286 million Northern Shrimp; Table 2). The abundance index for Age 2 and Age 4 Northern Shrimp increased in 2021, which is consistent with the higher belly-bag index values found in 2020 (i.e., 2019 year class) and 2018 (i.e., 2017 year class) (Table 2). The moderate overall abundance of Age 1 and Age 2 Northern Shrimp observed in the 2021 DFO-Industry survey is consistent with the decreasing SSB and increasing temperature indices observed since 2019.

Table 2. Minimum survey population numbers-at-age from modal analysis. Numbers x 10^6 for all SFAs combined.

Age	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average (2002–2020)	Median (2002–2020)
1 [1]	22	796	288	112	83	267	272	279	244	286	205
2	211	26	495	17	166	37	68	72	154	160	109
3	302	119	501	193	581	361	195	368	462	565	368
4	1,157	613	690	1,304	1,468	822	392	522	583	1,183	1,083
5+	4,091	4,673	2,956	3,076	1,734	2,231	3,155	3,000	2,109	3,115	3,076
TOTAL	5,783	6,227	4,930	4,702	4,032	3,718	4,082	4,241	3,552	5,232	4,930
Age 4+ Males [2]	2,960	3,831	2,270	2,931	1,859	1,966	2,273	2,137	1,611	2,694	2,319
Primiparous [3]	699	706	521	664	453	433	435	573	398	780	699
Multiparous [4]	1,611	1,545	1,143	897	973	921	1,111	1,091	927	1,034	1,111
Total Females	2,310	2,251	1,664	1,561	1,426	1,354	1,546	1,664	1,325	1,814	1,664

[1] Belly-bag. Time series began in 2002.
[2] Total population, less ages 2 and 3 males, transitionals (i.e., males that will potentially change to females the following year), and females.
[3] Primiparous Northern Shrimp includes transitionals and are the group of females entering the SSB.
[4] Multiparous Northern Shrimp identifies the group of females that are already contributing to the SSB.

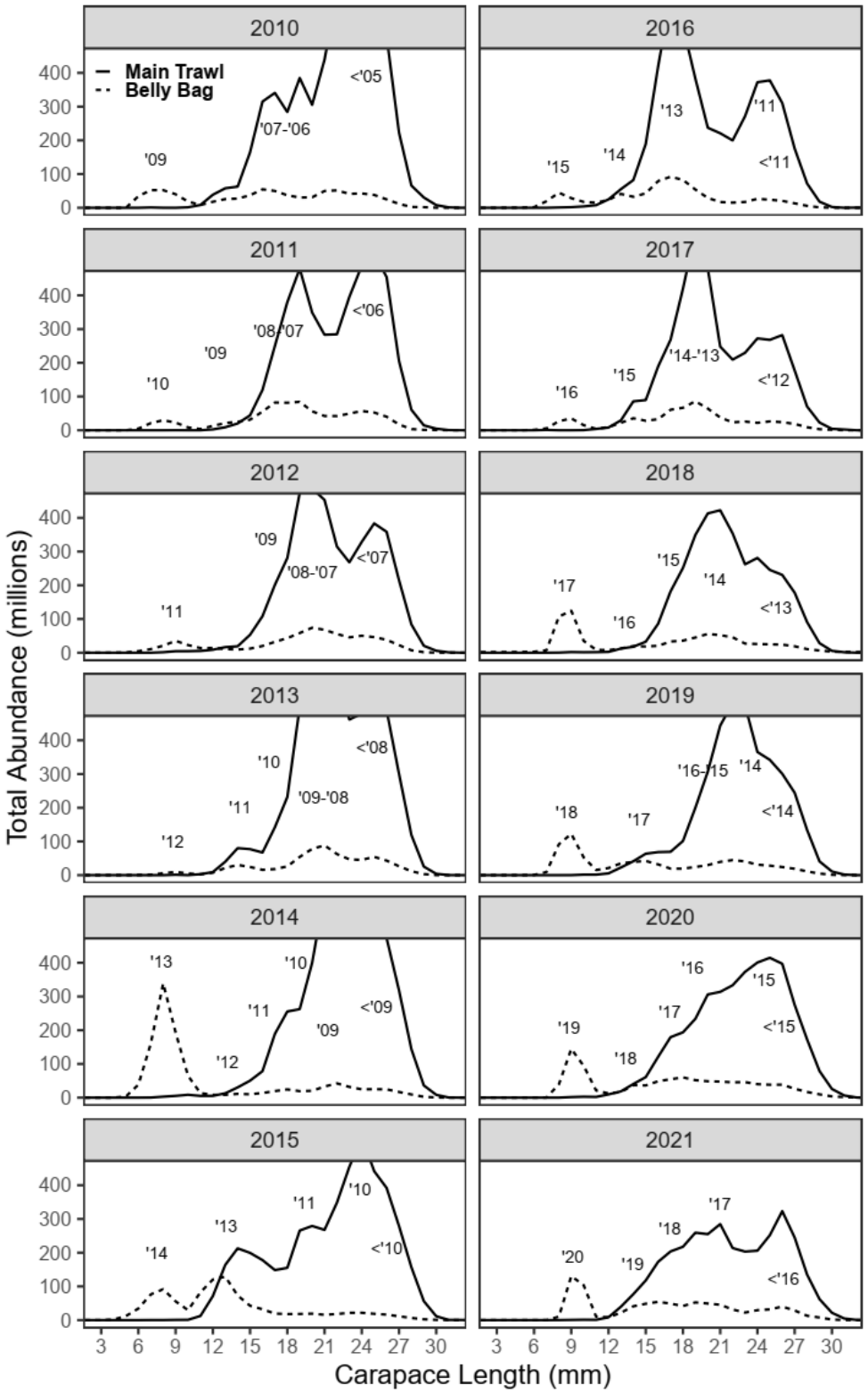

Figure 6. Population estimates from the belly-bag (dashed line) and main trawl catches (solid line) from the DFO-Industry collaborative surveys (2010 to 2021). Year-class labels are added to guide cohort tracking of recruitment as they grow through the system.

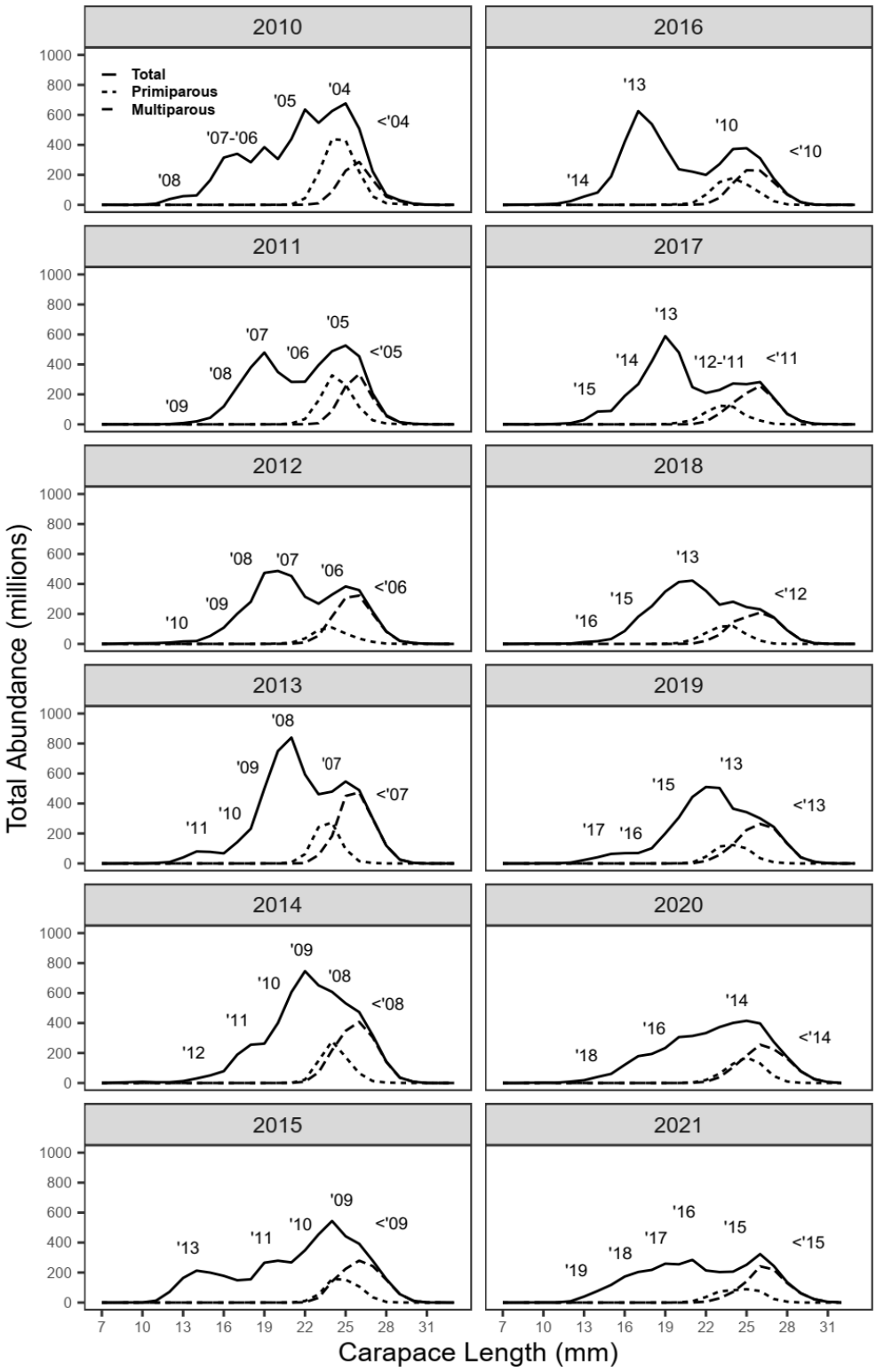

Figure 7. Population estimates-at-length from DFO-Industry surveys 2010–2021 (solid line). The dashed line in each figure represents transitional and primiparous Northern Shrimp, and the dotted line represents multiparous Northern Shrimp. Year-class labels are added to guide cohort tracking of Northern Shrimp as they grow through the system.

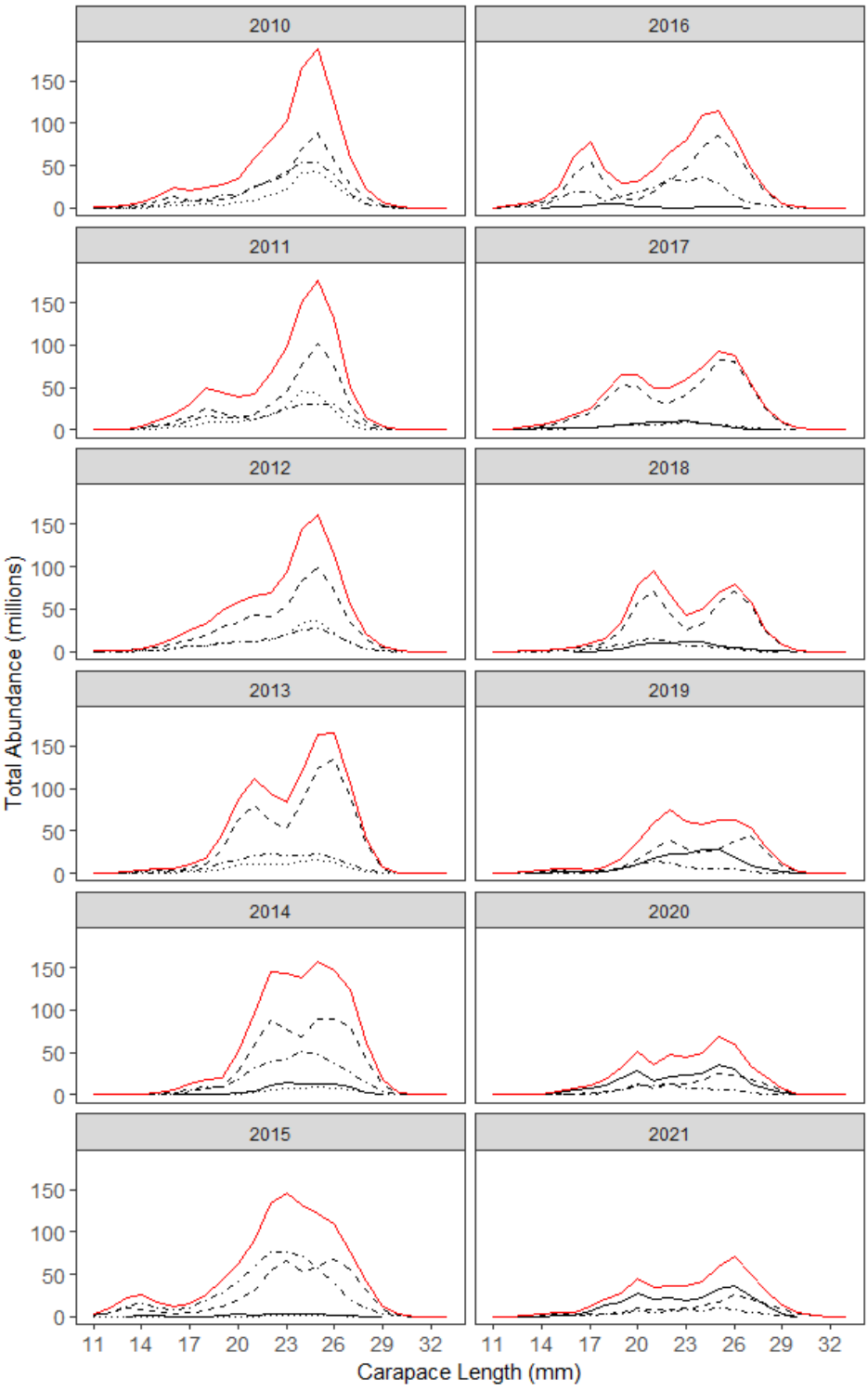

Figure 8. Catch-at-length from commercial sampling by stratum, 2010–2021. Stratum 13 (solid line), Stratum 14 (dashed line), Stratum 15 (dotted line), Stratum 17 (dot-dash line), and total abundance (solid red line).

The year-class monitoring continues to provide a strong signal in the DFO-Industry survey (Table 2; Figure 6 and Figure 7) and commercial fishery data (Figure 8). Commercial count estimates (numbers of Northern Shrimp per pound) slightly decreased in 2021 and have been decreasing since 2015 (Figure 9A). The decreased count index in 2021 relative to 2015–2020 is likely indicative of residual female Northern Shrimp from the previous year classes at the end of their lifespan. The mean maximum length index is calculated from the main trawl samples collected annually from the DFO-Industry survey. This index has been variable but, overall, has shown a decreasing trend since the mid-1990s (Figure 9B); however, increases in 2019–2020 were attributed to sustained abundance of large females from previous year classes. The increase in the mean female size indicator from 2021 further supports the presence of large females within the SSB.

Decreases in mean length-at-sex transition in Northern Shrimp stocks may contribute to population downturns through decreased female fecundity (i.e., smaller Northern Shrimp produce fewer eggs). Length-at-sex transition can be influenced by large year classes, which can delay the timing of sex transition, allowing additional year(s) of growth potential. Size-at-sex transition has been trending in a slow decline toward an average level (for the high-productivity period, 2000–2010) for this stock; however, in 2021, it is the second highest value in the time series at around 24.8 mm (Figure 9D).

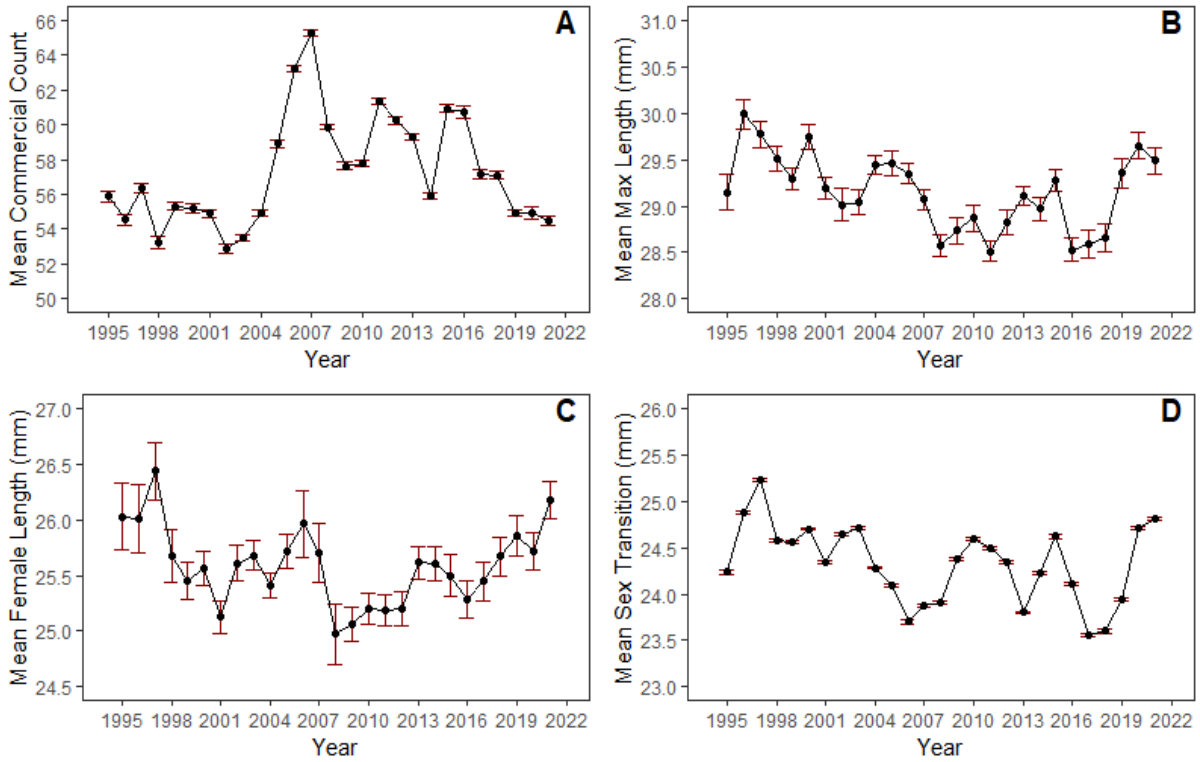

Figure 9. Mean: (A) fishery log commercial count, (B) survey maximum length, (C) commercial port mean female size, (D) commercial port and survey mean size-at-sex transition for all Northern Shrimp Fishing Areas (SFAs) combined for 1995–2021 with 95% confidence interval.

Northern Shrimp has substantial value as a forage species, so the fishery must not threaten the conservation of other species for which it is an important food source. The *Policy on New Fisheries for Forage Species* provides a framework to ensure that fisheries on forage

species are conducted in ways compatible with conservation of the full ecosystem and that their sustainability is evaluated in that larger context. Most groundfish species on the ESS feed on crustaceans at some point in their lives, with Shrimp identified as an important part of the diets of cod, Silver Hake, redfish, various flatfish, and both Atlantic and Greenland Halibut (Shumway et al.1985). Since Northern Shrimp are a forage species, predation is an important aspect of stock health as trends in predation inform on their natural mortality.

Significant negative correlations between Northern Shrimp and finfish abundance have been demonstrated from the Gulf of Maine to Greenland (Parsons 2005). Over the recent high productivity period, the predation index has been variable but remains at a low level relative to the early 1980s, when Northern Shrimp abundance was low. Cod recruitment remained low in 2020. The general index of Northern Shrimp finfish predator abundance has been low in recent years and is unavailable for 2021 (Figure 10B).

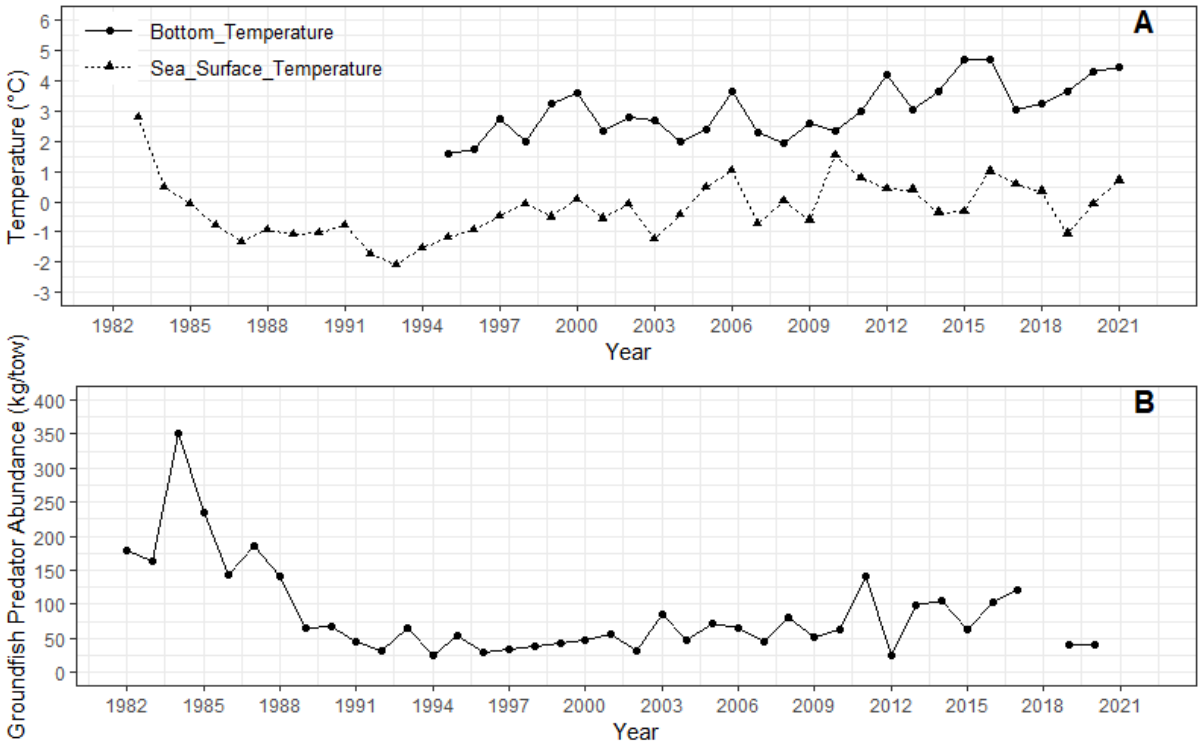

Figure 10. Average bottom and late winter Sea Surface Temperatures (A) and predator abundance on the Eastern Scotian Shelf Northern Shrimp grounds (B).

For some Northern Shrimp stocks near the southern limit of the species' range, abundance is negatively correlated with water temperatures (Shumway et al. 1985). On the ESS, the large population increase that occurred from the mid-1980s to the mid-1990s is associated with colder surface and bottom water temperatures. Colder temperatures can increase the length of the egg incubation period, resulting in later egg hatchings that are closer to the spring phytoplankton bloom and warming of the surface layers where larvae feed and grow (Shumway et al. 1985). Large fluctuations in bottom water temperatures (Figure 10A) may also be associated with the cyclical recruitment pattern experienced since the early 1990s (i.e., 1993–1995, 2001, 2007–2008, and 2013 year classes). Spring sea-surface temperatures increased in 2021, and June survey bottom temperatures increased slightly in 2021 relative to 2020. Since 2017,

bottom temperatures have been steadily increasing but have remained lower than 2015–2016 values, and they are still in a favorable range for Northern Shrimp (Shumway et al. 1985). Colder water conditions, within a level of thermal preference for Northern Shrimp, are thought to have a positive influence on juvenile recruitment. This is supported by the higher recruitment observed in the belly-bag Age 1 abundance index since 2018 (Table 2), coinciding with a downturn in 2017 bottom temperatures. Further, the abundance of Snow Crab, a cold water indicator species, has increased in 2020 relative to previous warmer water years (DFO 2021b). Unfortunately, this index was not able to be updated with a 2021 value as the Snow Crab survey did not occur in 2020.

The 24 indicators relating to the health of the ESS Shrimp stock are summarized in Figure 11. Each indicator was assigned a color for every year data were available according to its percentile value relative to the fixed high-productivity 2000–2010 period. Default boundaries between traffic lights for individual indicators, i.e., transition from green to yellow and from yellow to red, were arbitrarily taken as the 0.66 and 0.33 percentiles (i.e., > 0.66 percentile = green; 0.66–0.33 percentile = yellow; and < 0.33 percentile = red). If an increase in the indicator was considered bad for stock health, the transition between boundaries was reversed. Individual indicators were then grouped into categories of Abundance, Production, Fishing Effects, and Ecosystem characteristics, as well as an overall mean summary indicator (Figure 12). Note that indicators are not weighted in terms of their importance; each of these categories and the overall mean summary indicator are determined as a simple average of individual contributing indicators.

Indicators of abundance have been annually variable, but this characteristic's summary has been on a downward trend since 2004 (Figure 12). The abundance characteristic decreased in 2021 after three years of steady increases, and it remains in the red zone mainly due to declines in the commercial mobile and survey CPUE indices. A decrease was also observed in the number of commercial areas with 250 kg/h catch rates.

Indicators of productivity have been increasing towards a positive level since 2018. Annual contributions of recruitment have been consistent in the last four years; however, they have been lower in magnitude and only starting to supplement the SSB portion of the stock. The SSB is comprised of smaller Northern Shrimp from lower recruitment years and fewer, older, larger individuals. Despite increases in Age 2 and Age 4 productivity indices, a SSB decrease was still observed. Northern Shrimp size indicators show an increase of larger Shrimp, and these contribute as multiparous spawners in the current stock. The current predation index has been low; however, it is based on a limited area of the ESS as only four strata from the summer groundfish survey were available for consideration. Redfish, in particular, has been observed to have increased significantly and are likely consuming an important proportion of Northern Shrimp as prey.

The fishing effects characteristic has been improving and can be attributed to declines in total and female exploitation due to the precautionary reductions/maintenance of TAC since 2016. In 2021, both indices show an increase to levels higher than observed in the last three years. Fishing effort that was adopted in response to predicted declines in total and spawning stock biomass has been consistently decreasing and has increased in 2021 from the lowest level in the time series in 2020. Female-size indicators show increases from 2020 values and support the delay in the contribution of smaller Shrimp into the SSB.

Ecosystem indicators were primarily influenced by temperature trends as all three sympatric species (Snow Crab, Greenland Halibut and Atlantic Cod recruitment) trends were not updated for 2021. The time series in each temperature index shows increasing trends since the late

1990s. Bottom temperatures from the survey have been increasing since 2017 and are reaching the highest levels in the time series in 2021. Sea-surface temperatures have only been increasing in the last two years; however, the increase in 2021 is also nearing the highest values in the last decade.

All characteristic summaries in 2021 show decreases from the 2020 values, resulting in an overall mean decrease, suggesting that the ESS Northern Shrimp stock health is negatively influenced. The fact that 12 out of 24 indicators (4 indicators outstanding) describe adverse outcomes also supports the PA analysis that the stock is in the Cautious Zone.

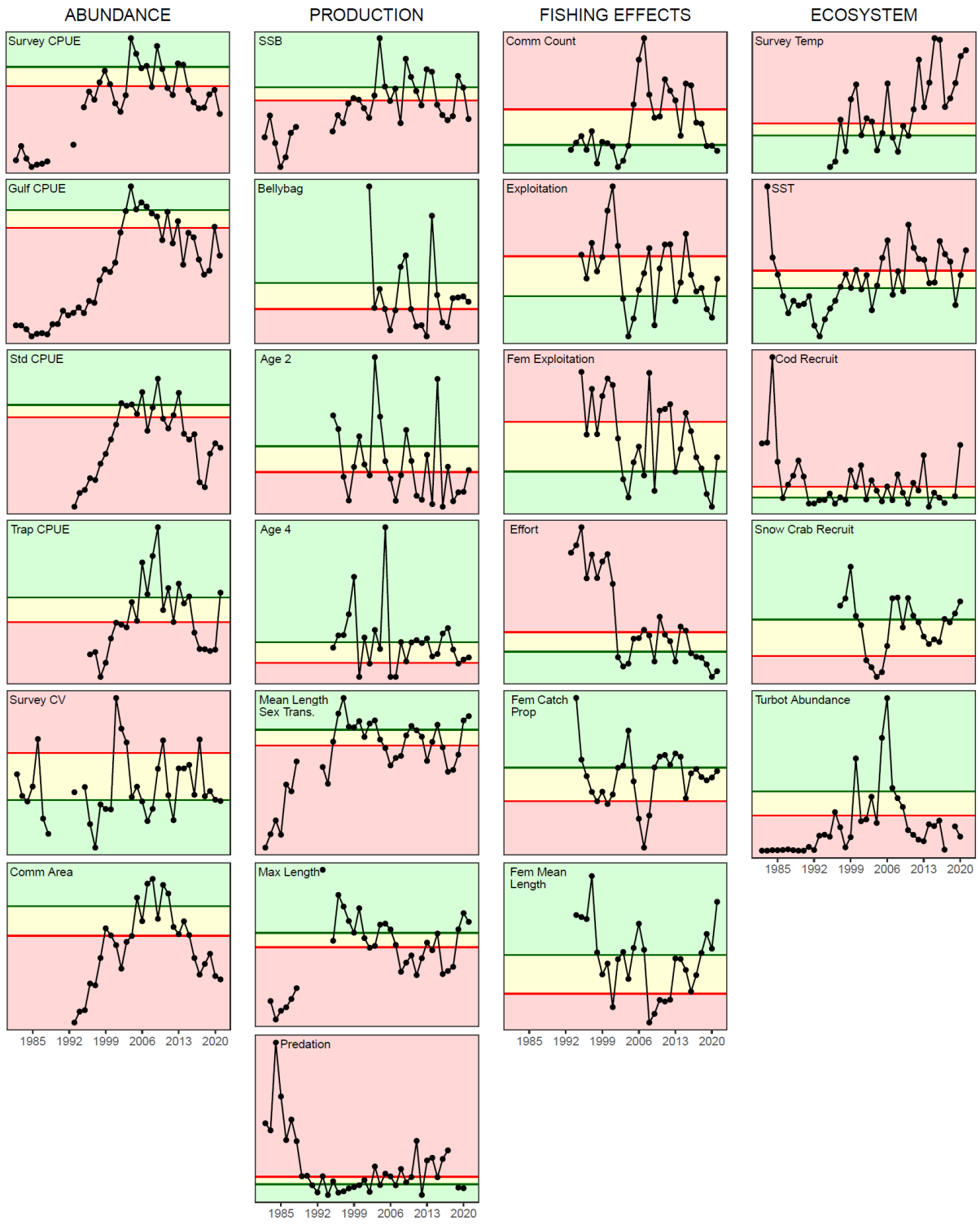

Figure 11. Time series of individual Northern Shrimp indicators. Note: not all indicators are discussed in the text. Please consult past CSAS Research Documents for detailed description of indicators (e.g., Hardie et al. 2018). Note that the Predation indicator (Production), the Cod Recruitment (Ecosystem), and the Turbot Abundance (Ecosystem) cannot be updated for 2018 and 2021, as well as the Snow Crab recruitment indicator for 2021.

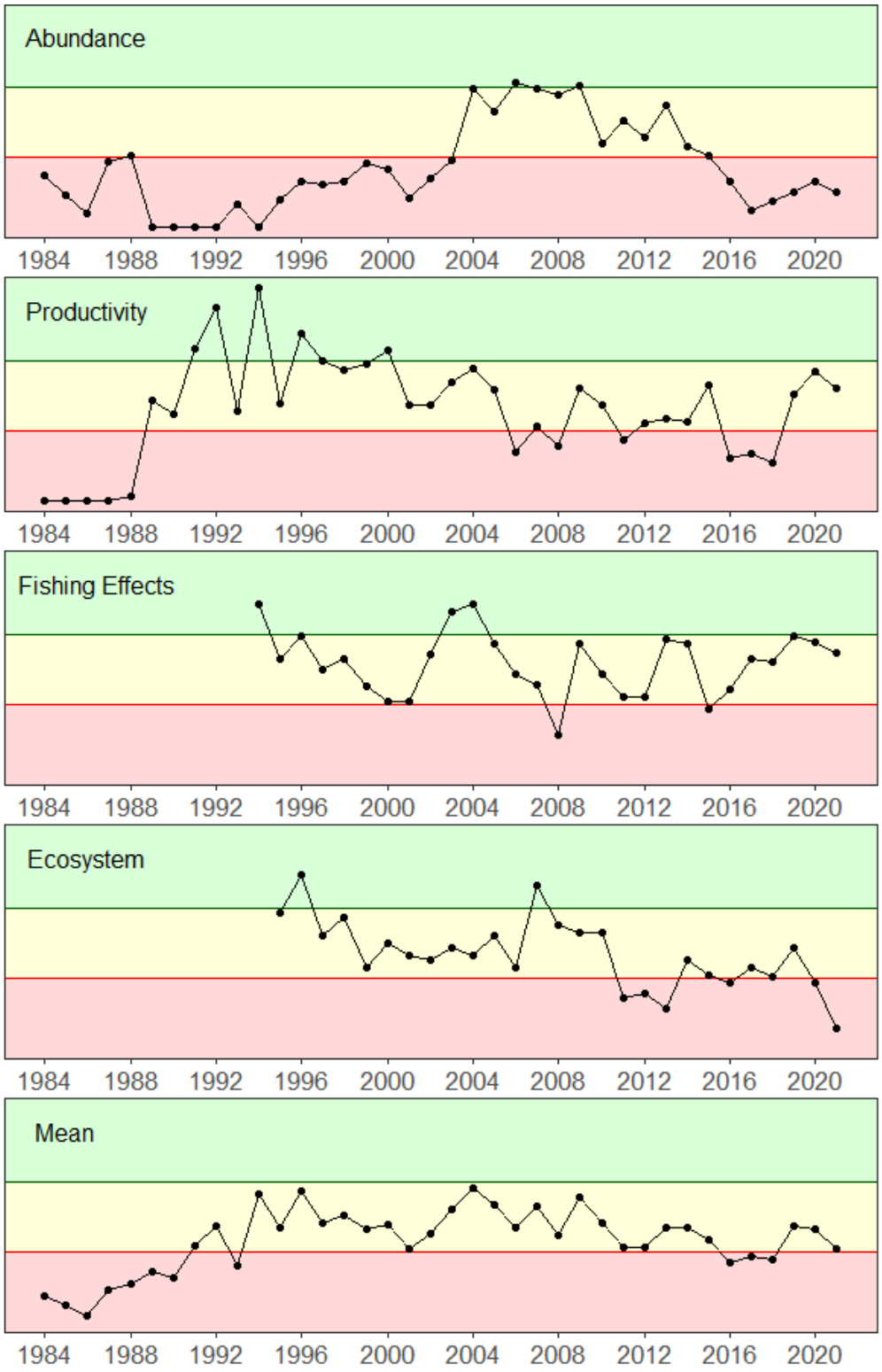

Figure 12. Time series of the characteristic summaries and overall mean summary Eastern Scotian Shelf Northern Shrimp indicator. Note that the Productivity and Ecosystem summary characteristics have missing indicators in 2018 and 2021; this will affect their overall mean differently than in previous years.

Bycatch

Introduction of the Nordmøre separator grate in 1991 reduced 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 6 trips annually (6% coverage based on trips). There were no trips observed for 2021; however, low bycatch amounts (< 1%, 2019 and 2020) from the mobile fleet are expected. The consistency of the fleet's trawl configurations, including the use of the Nordmøre separator grate, continue to ensure low total bycatch by weight, and would likely show a similar trend in 2021. Since 2018, the trap fleet has also been providing at-sea observer sampling during commercial trips. Their fishing activity is seasonal (approximately September to March of the following year), and they have provided data for two seasons showing low (< 1%, 2018–2019) to nil (2019–2020) bycatch amounts. There were no trips observed for 2021. With minimal bycatch interactions from both commercial fleets, the Northern Shrimp fishery currently poses little risk in terms of bycatch amount or species composition.

Sources of Uncertainty

The reliance on external sources to provide essential information into our analysis assumes the risk that if there are interruptions in that time-series, we would not be able to update our indicators for one or more years. There are two identifiable sources of information under this criterion: the Snow Crab and the Summer Research Vessel (RV) Surveys. In 2018, three indicators were unable to be updated due to the reduced coverage of the DFO Summer RV Survey. The operational limitations experienced by the Summer RV Survey created a break in a 36-year time-series. Additionally, in 2021, four indicators were unable to be updated due to the reduced coverage of the DFO Summer RV Survey and the Snow Crab survey not going forward. Since indicators are summarized into characteristic groupings, the failure to have a value for each indicator could bias the summary result by informing only on the available indicator values.

The DFO-Industry Northern Shrimp survey results are associated with high variances and biases associated with survey-gear changes. Spatial and temporal variability in the distribution of Northern Shrimp is a source of uncertainty with regard to the accuracy of survey estimates; the survey is conducted consistently during early June to try to mitigate this effect. In 2007–2008, problems with NetMind distance sensors and data logging required the use of historical average instead of actual wing-spread data to calculate swept areas and abundance. Since 2019, new vessels have been used to collect survey data. With pandemic limitations and the retirement of our survey vessel in 2020, a new survey vessel, the Nannie Bessie, was used for the 2021 data collection.

Given the inability to accurately age Northern Shrimp, modal groups are assigned to age classes beyond the first year of growth; this process is subjective, particularly for larger individuals, as length distribution modes are indiscernible beyond the fifth year of growth. Growth rates can change dramatically due to density dependence, as happened with the strong 2001, 2007–2008, and 2013 year classes. Consequently, recruitment to the fishery can be delayed and spread over two to three years.

Commercial abundance indices are susceptible to logistic, economic, analytical, and other factors that influence index values in ways that may be unrelated to Northern Shrimp abundance. For example, periods of bad weather or abundant sea ice can cause low CPUEs, as can fishing vessels targeting large Northern Shrimp for market reasons. The standardized commercial CPUE index subsamples the data for vessels that meet certain criteria; this can also

result in particularly successful, or particularly unsuccessful, vessels influencing this index in ways that may be unrelated to Northern Shrimp abundance in any given year.

Unforeseen changes in the ecosystem (specifically predator abundance) and the environment (specifically water temperature) increase the difficulty of making long-term projections for this stock. This is particularly challenging when increased predator abundance and water temperature co-occur.

Finally, because of the timing of the Northern Shrimp assessment relative to the collection and analysis of commercial samples, advice provided during past assessment processes (prior to 2012) may have been based on only a portion of the samples. However, steps have been taken to expedite the analysis of samples such that for 2021, all 120 survey samples and 50 commercial samples were included.

CONCLUSIONS AND ADVICE

The 2021 DFO-Industry survey stratified mean biomass estimate shows a decrease at 21,167 mt (± 3,973, 95% CI). The point estimate of the 2021 SSB (13,041 mt ± 5,021 mt, 95% CI) decreased by 29%, below the USR point of 14,558 mt, placing this stock within the Cautious Zone for 2021. As predicted by recent assessments, these declines are consistent with the expectation of a lag between the complete mortality of the long-lived 2013–2014 year classes and the recruitment of the 2015–2016 year classes. A decrease in both the survey abundance index and the commercial CPUEs were observed (standardized CPUE decreased 2.5%, Gulf-based vessels declined by 23%), and the distribution of areas representing various catch-rate categories has decreased for 2021. Since four out of the six indicators of abundance show declining trends across this characteristic, the resulting summary also results in an undesirable outlook.

Belly-bag Age 1 abundance indices since 2018 highlight consistent recruitment from the 2017–2020 year classes and are consistent with the expectation that lower temperature conditions are promoting favorable recruitment. The abundance of Age 2 and Age 4 Shrimp also increased in 2021 and is consistent with the larger belly-bag index values from 2018–2021 (representing the 2017–2020 year classes). The more abundant 2017 year class increased the index of abundance of Age 4 male Northern Shrimp in 2021. Assuming continued growth and survival, this age class will be recruiting to the spawning stock biomass during 2021–2022.

Three of the size-based indicators (size at sex-transition, female size, count) demonstrate that the size of Northern Shrimp has been increasing in recent years. This is consistent with matured age classes that still have larger than average females present in the SSB. Less abundant subsequent age classes have provided little to no replacement by smaller, younger Northern Shrimp. With the growth of the 2017–2020 Northern Shrimp age classes, and their sustained survival, their contribution will provide a replenishment benefit to the SSB.

Ecosystem indicators were primarily influenced by temperature trends as all three sympatric species (Snow Crab, Greenland Halibut, and Atlantic Cod recruitment) trends were not updated for 2021. The increases in temperatures in the last few years suggest that conditions are currently nearing unfavorable for cold-water species such as Northern Shrimp.

The overall mean summary indicator, summarizing the 24 stock health indicators, decreased in 2021 and is in the yellow zone due to decreases in all four characteristic summaries representing abundance, productivity, fishing effects, and ecosystem characteristics. Twelve out of 24 indicators (4 not updated in 2021) describe adverse results for Northern Shrimp stock health. Additionally, the 2021 SSB index places the stock in the Cautious Zone according to the

DFO PA. Further reduction of removal rates could stabilize catch rates, protect incoming recruitment essential to the fishery, and allow commercial biomass to rebuild.

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SOURCES OF INFORMATION

This Science Advisory Report is from the December 13–14, 2021 Regional Advisory Meeting on the Eastern Scotian Shelf Northern Shrimp Assessment. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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