Fisheries and Oceans Canada | Pêches et Océans Canada
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Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2024/032

ASSESSMENT OF SCOTIAN SHELF SNOW CRAB FROM 2022

Snow Crab (Chionoecetes opilio)

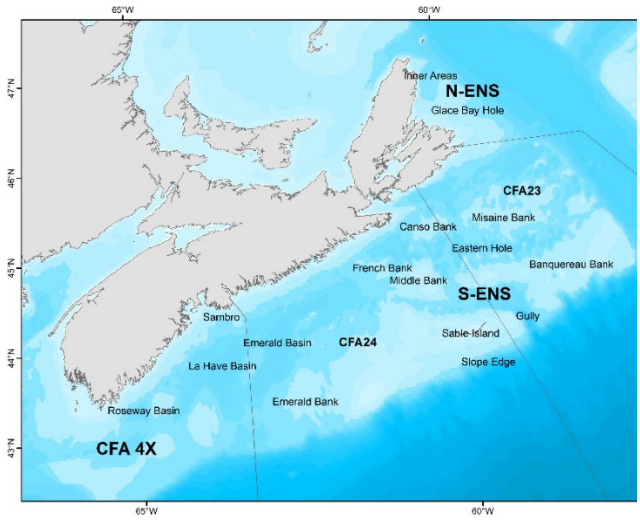

Figure 1. Map of the Scotian Shelf Ecosystem and Crab Fishing Areas (CFAs) as delineated by the dashed lines: 4X, south-eastern Nova Scotia (S-ENS), and north-eastern Nova Scotia (N-ENS). The stippled line in the S-ENS area delineates the former CFAs, 23 &24, that are now combined as S-ENS.

Context:

*Snow Crab (*Chionoecetes opilio*, O. Fabricius) have been a dominant macro-invertebrate in the Scotian Shelf Ecosystem (SSE) since the decline of groundfish stocks. They are observed in large numbers in deep, soft-bottom substrates ranging from 60 to 300 m and at temperatures generally less than 6°C. The SSE Snow Crab are in the southern-most extreme of their spatial distribution in the Northwest Atlantic.*

The Snow Crab fishery on the Scotian Shelf has been in existence since the early 1970s. It occurs annually throughout the year dependent upon the crab fishing area (CFA). In 2005, many CFAs and subareas were merged with the resulting divisions being north-eastern Nova Scotia (N-ENS; formerly CFAs 20–22), south-eastern Nova Scotia (S-ENS; formerly CFAs 23 and 24), and Northwest Atlantic Fisheries Organization (NAFO) division 4X.

In support of the fishery, Fisheries and Oceans Canada (DFO) Maritimes Fisheries Management Branch requested that DFO Science Branch assess the status of the resource ahead of the 2023 fishing season.

This Science Advisory Report is from the March 9–10, 2023 regional peer review on the Stock Assessment of Snow Crab in Maritimes Region. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Fishing effort in 2022 was 8,600 trap hauls in north-eastern Nova Scotia (N-ENS), 56,500 trap hauls in south-eastern Nova Scotia (S-ENS), and 2,000 trap hauls in 4X. This represents a change of -2.3%, -30.1% and -35.5%, respectively, relative to the previous year.
- Landings in 2022 were 977 t in N-ENS; 7,323 t in S-ENS; and 35 t in CFA 4X (season ongoing), representing a change of 8.4%, -12.1%, and -68.2%, respectively, relative to 2021. Total allowable catches (TACs) for 2022 were 979 t, 7,345 t, and 125 t in N-ENS, S-ENS, and 4X, respectively.
- Non-standardized fishery catch rates in 2022 were 113 kg/trap haul in N-ENS, 130 kg/trap haul in S-ENS, and 17 kg/trap haul in 4X. This represents a change of 10.8% in N-ENS, 26.2% in S-ENS, and -52.8% in 4X (season ongoing) relative to the previous year. Though the spatial extent of exploitation was smaller, many of the exploited areas showed elevated catch rates.
- The percentage of soft-shelled crab in commercial catches in the 2022 season was 6.4% in S-ENS and 0% in N-ENS; there was no sampling to-date in 4X (season on-going) for the 2022–2023 season. In 2021, the percentage of soft-shelled crab in commercial catches in S-ENS was 11.2% (low sampling intensity); there was no sampling in N-ENS and 4X.
- In 2022, numbers of Snow Crab with carapace condition 5, derived from At-Sea Observer sampling data, were higher in N-ENS and S-ENS than historical trends; however, as At-Sea Observer sampling targets were not met, there is uncertainty in the representativity of the data when comparing to historical trends.
- Bycatch of non-target species is low (<< 1% of total catch) in all Snow Crab fishing areas; however, as sampling targets for At-Sea Observer coverage have not been met in recent years, there is uncertainty in the representativity of the data.
- Egg and larval production is expected to be high in the next year in all areas except N-ENS.
- Average bottom temperatures observed in the 2022 Snow Crab survey were near or above historical highs in all areas. Average viable habitat surface area has declined to historical lows in 2022.
- Based on stomach sampling, Atlantic Halibut, Atlantic Wolffish, Thorny Skate, and other skate species appear to be the predominant predators of Snow Crab on the Scotian Shelf. Overall, higher predation mortality seems likely in N-ENS and S-ENS and lower in 4X. Densities of co-occurring species such as shrimp have declined, possibly due to large-scale environmental change.
- In N-ENS, the modelled biomass (pre-fishery) of Snow Crab in 2022 was 3.69 kt, relative to 3.96 kt in 2021. In 2022 there was a high possibility of mobility of crab and elevated predation in N-ENS. In S-ENS, the modelled biomass (pre-fishery) was 41.93 kt, relative to 44.83 kt in 2021. In 4X, the 2022–2023 season's modelled biomass (pre-fishery) was 0.78 kt, relative to 0.89 kt in the 2021–2022 season. In 2022, 83 of 385 survey stations were not completed (all missing stations were in S-ENS).
- In N-ENS, though recruitment continues at low levels, a gap in future recruitment to the fishery is expected for the next one to three years in N-ENS. Following the Precautionary Approach based reference points for the area, N-ENS is in the healthy zone. However, a

more conservative harvest strategy may support the stock in bridging the expected gap in recruitment.

- In S-ENS, recruitment to the fishery is likely to continue at a moderate rate for the 2023 season. The S-ENS stock remains in the healthy zone. Exploitation rates derived from the fishery model have been declining in recent years. Continuation of the current harvest strategy would support maintenance of stock status of S-ENS in the healthy zone.
- In 4X, low to moderate levels of recruitment are expected for the next two years. The area is also in the southern-most extent of Snow Crab distribution in the North Atlantic and viable habitat has been depressed for many years. Following the Precautionary Approach based reference points for the area, 4X is in the cautious zone. A more conservative harvest strategy is advised.

INTRODUCTION

Snow Crab are a circumpolar, subarctic species. In the Scotian Shelf Ecosystem (SSE; Figure 1), habitat preference is generally for soft mud and sandy bottoms, at depths from 60-300 m and temperatures from -1–6°C. The SSE represents the southern-most part of this distribution and, therefore, is most influenced by environmental variability. More detailed information with regards to Snow Crab life history, habitat requirements, and spatiotemporal distributions of different life stages can be found in Choi et al. (2022) and references therein.

Management of Snow Crab in the Scotian Shelf Snow Crab fishery is inherently precautionary:

- The spawning stock biomass, the mature female component of the stock, is not fished, and so completely protected from the fishery.
- Conservative exploitation strategies have generally been in place since the mid-2000s.
- Spatial refugia (Marine Protected Areas, continental slopes, western inshore portion of Crab Fishing Area (CFA) 24, and western inshore portion of 4X) are inaccessible to commercial fishing.
- Fishing seasons act as temporal refugia
- Most life stages are protected, especially immature, soft-shelled, and females offering biological refugia).
- Attention to minimizing effects upon other species by implementing bycatch reduction measures (season timing, biodegradable closures, area closures).
- Collaborative management that prioritizes scientific, fisheries-independent, evidence-based decision making.

ASSESSMENT

Fishery Performance

Fishing effort in 2022 was 8,600, 56,500, and 2,000 trap hauls in north-eastern Nova Scotia (N-ENS), south-eastern Nova Scotia (S-ENS), and 4X, respectively. Relative to the previous year, this represents changes of -2.3 %, -30.1 %, and -35.5 %, respectively (Tables 1, 2, 3; Figure 2). Fishing effort was consistent between 2022 and 2021 in terms of spatial distribution. However, in S-ENS there was a spatial contraction to inshore areas and away from the boundary between CFAs 23 and 24 (Figure 3).

Table 1. Fishery performance statistics in north-eastern Nova Scotia. Units are: total allowable catch (TAC) and Landings (tons, t), Effort (thousands of trap hauls) and catch per unit effort (CPUE) (kg/trap haul).

Year	Licenses	TAC	Landings	Effort	CPUE
2012	78	603	603	4.9	122
2013	78	783	783	7.0	112
2014	78	783	781	6.9	114
2015	78	620	619	6.2	100
2016	78	286	290	2.7	109
2017	78	825	813	8.8	93
2018	78	784	742	12.2	61
2019	78	627	629	7.5	84
2020	78	847	836	7.8	108
2021	78	890	901	8.8	102
2022	78	979	977	8.6	113

Table 2. Fishery performance statistics in south-eastern Nova Scotia. Units are: total allowable catch (TAC) and Landings (tons), Effort (thousands of trap hauls) and catch per unit effort (CPUE) (kg/trap haul)

Year	Licenses	TAC	Landings	Effort	CPUE
2012	116	11,707	11,707	114.2	103
2013	116	11,311	11,341	105.5	107
2014	116	11,311	11,265	96.3	117
2015	116	11,311	11,295	103.9	109
2016	116	9,614	9,606	87.3	110
2017	116	6,730	6,718	69.9	96
2018	116	6,057	6,063	51.3	118
2019	116	6,663	6,632	61.9	107
2020	116	8,161	7,943	63.9	124
2021	116	8,161	8,332	80.8	103
2022	116	7,345	7,323	56.5	130

Table 3. Fishery performance statistics in 4X. Units are: total allowable catch (TAC) and Landings (tons), Effort (thousands of trap hauls) and catch per unit effort (CPUE) (kg/trap haul). There were no landings or TACs in 2018/2019 due to indications of low abundance. The 2022 season is ongoing.

Year	Licenses	TAC	Landings	Effort	CPUE
2012	9	263	118	9.3	13
2013	9	80	80	5.2	15
2014	9	80	82	2.5	33

Year	Licenses	TAC	Landings	Effort	CPUE
2015	9	150	143	4.4	32
2016	9	80	79	2.9	27
2017	9	110	55	4.4	13
2018	9	0	0	0.0	0
2019	9	55	59	1.1	51
2020	9	80	76	1.6	49
2021	9	110	110	3.1	36
2022	9	125	35	2.0	17

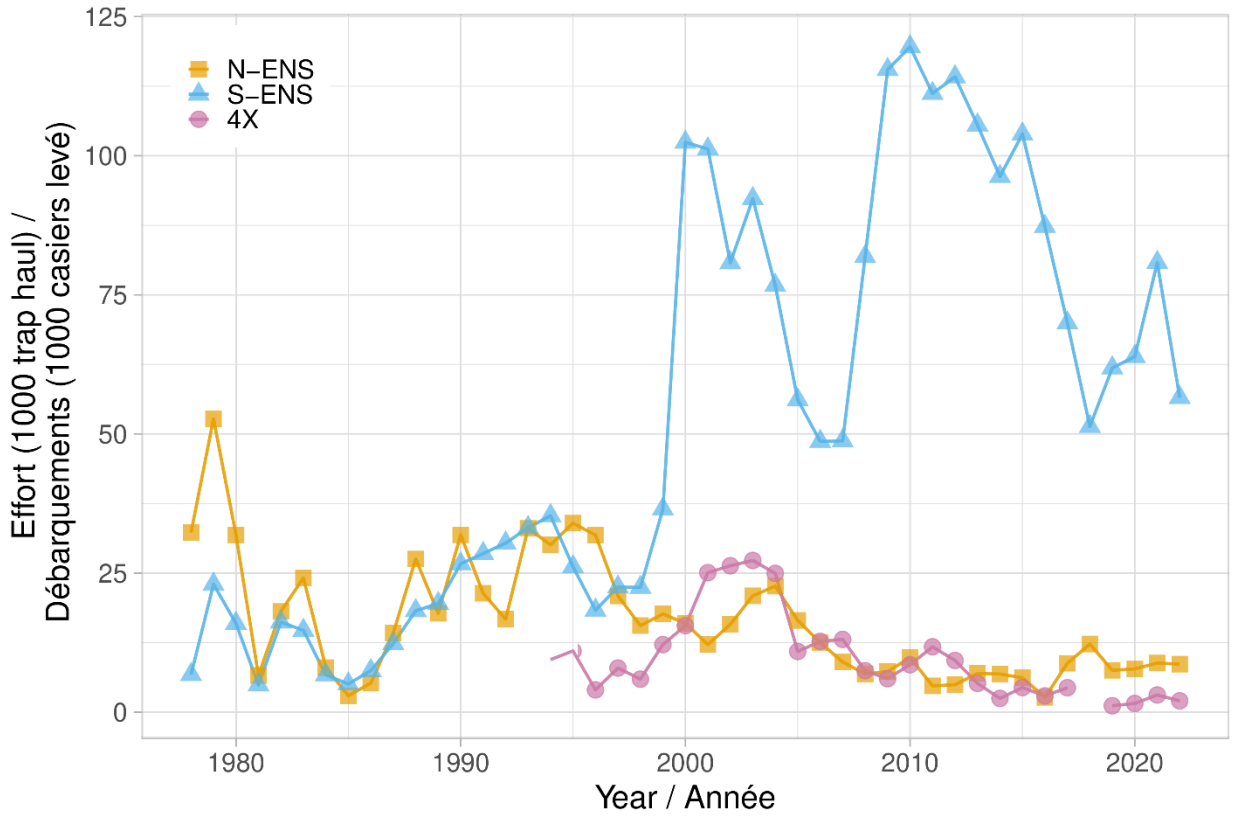

Figure 2. Temporal variations in fishing effort (thousands of trap hauls) in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available.

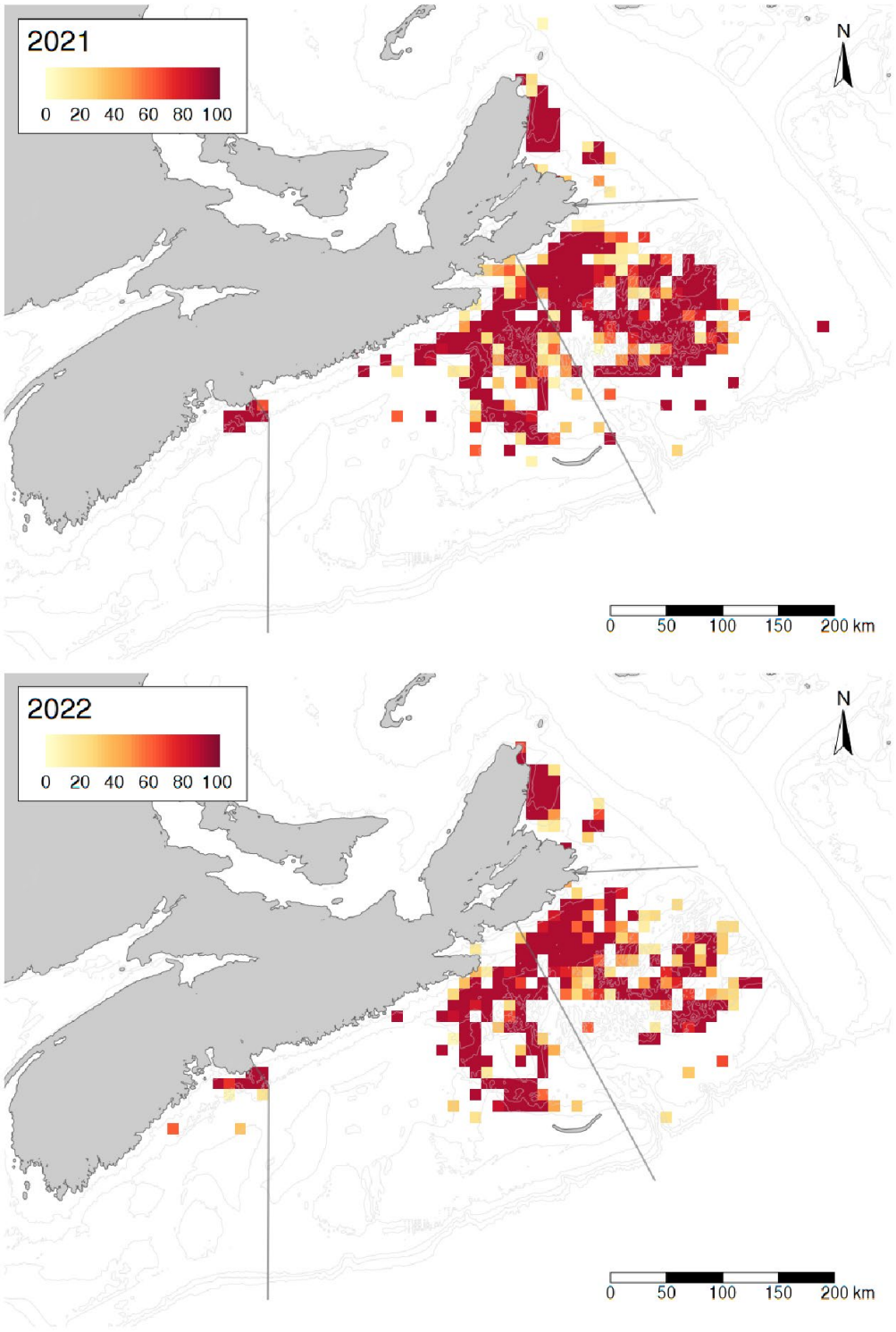

Figure 3. Snow Crab fishing effort from fisheries logbook data for 2021 (top panel) and 2022 (bottom panel). Effort is in thousands of trap hauls per 10 km x 10 km grid. For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available. Grey lines delineate the crab fishing areas as identified in Figure 1.

Landings across time are shown in Figure 4. In 2022, they were 977 t, 7,323 t, and 35 t, in N-ENS, S-ENS, and 4X (season ongoing), respectively. Relative to 2021, they represent changes of 8.4%, -12.1%, and -68.2%, respectively (Tables 1, 2, 3). Total Allowable Catches (TACs) for 2022 were 979 t, 7,345 t, and 125 t in N-ENS, S-ENS and 4X, respectively.

In response to concerns about the ability to safely conduct fishing activities in light of the COVID-19 pandemic, Fisheries and Oceans Canada (DFO) Fisheries Management approved a carry-forward of a portion of the 2020 quota to the 2021 season for all licence holders in the N-ENS and S-ENS Snow Crab fishery. This permitted fishing in excess of the TAC that was otherwise allocated for the 2021 season only. As such, landings beyond the TAC are likely reflective of this additional allowance, rather than over-fishing.

The landings in N-ENS for 2022 and 2021 were similar in their spatial patterns (Figure 5). In N-ENS, most landings occurred in the spring. This has been an ongoing shift in the timing in this area to avoid soft-shell crab and avoid interaction with whales and sea turtles. In S-ENS, landings, as with fishing effort, shifted slightly inshore and away from the boundary between CFAs 23 and 24 (Figure 5). There were no landings on the continental slope areas of S-ENS in 2022. This area, at present, continues to serve as a refugia for Snow Crab from fishing. The landings in 4X for 2022, as with 2021, were primarily in the area just south of Sambro, bordering CFA 24.

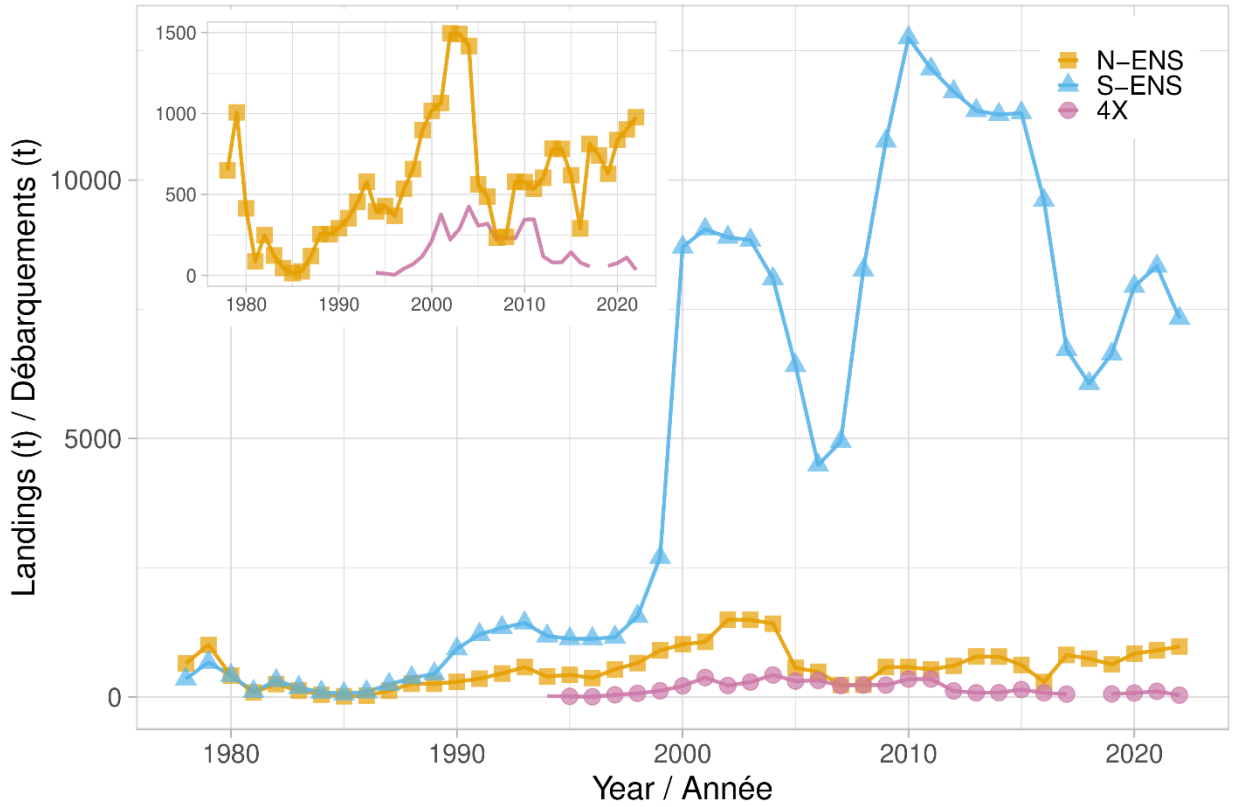

Figure 4. Landings (t) of Snow Crab on the SSE in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available. Inset is a closeup view of the timeseries for N-ENS and 4X.

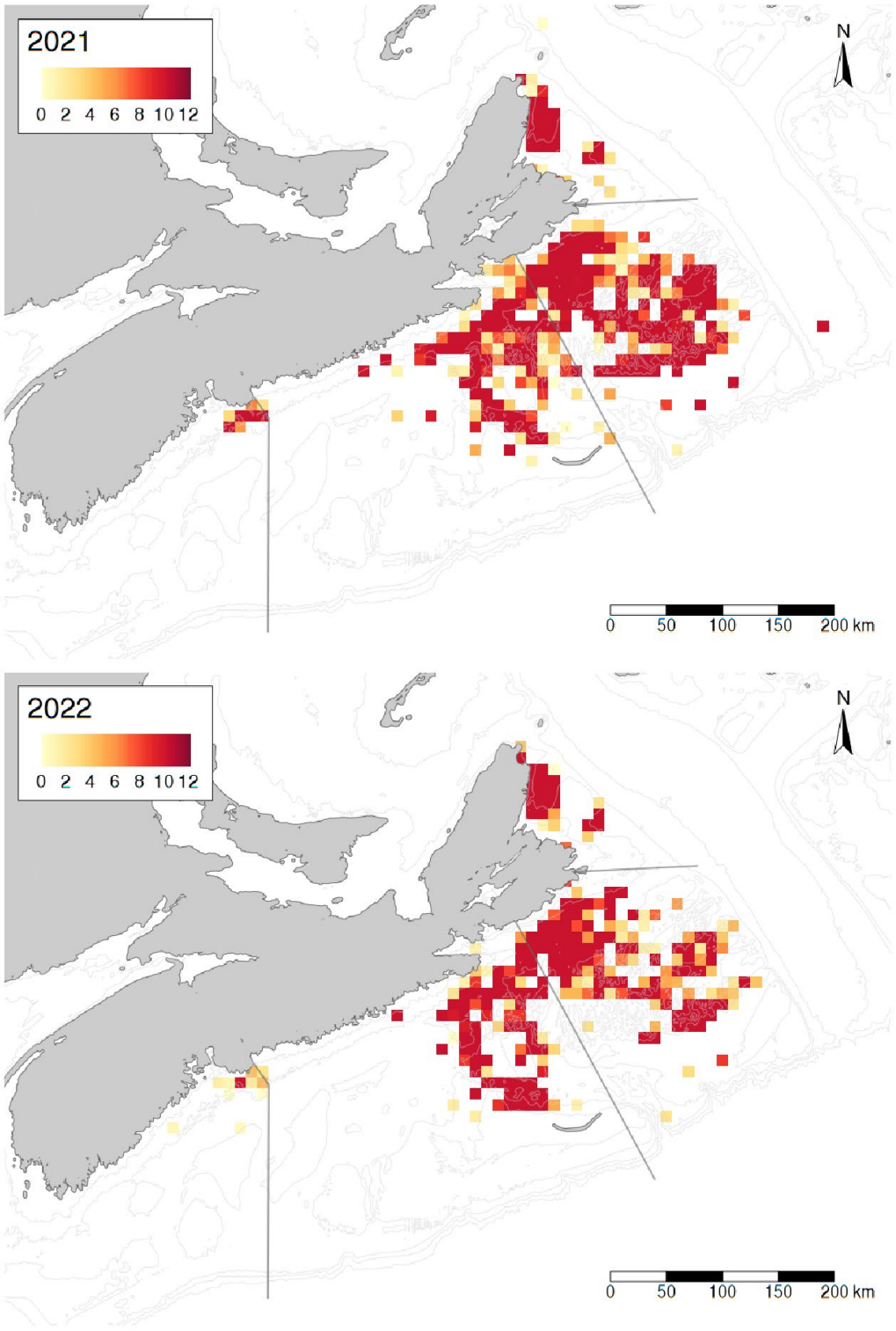

Figure 5. Landings (t) of Snow Crab on the SSE for 2021 (top panel) and 2022 (bottom panel). For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available. Grey lines delineate the crab fishing areas as identified in Figure 1.

Non-standardized fishery catch rates in 2022 were 113, 130, and 17 kg/trap haul in N-ENS, S-ENS, and 4X, respectively. This represents a change of 10.8 %, 26.2 %, and -52.8 % (season ongoing), respectively, relative to the previous year (Tables 1, 2, 3, Figure 6). Though the spatial extent of exploitation in all areas was smaller, many of the exploited areas showed elevated catch rates (Figure 7).

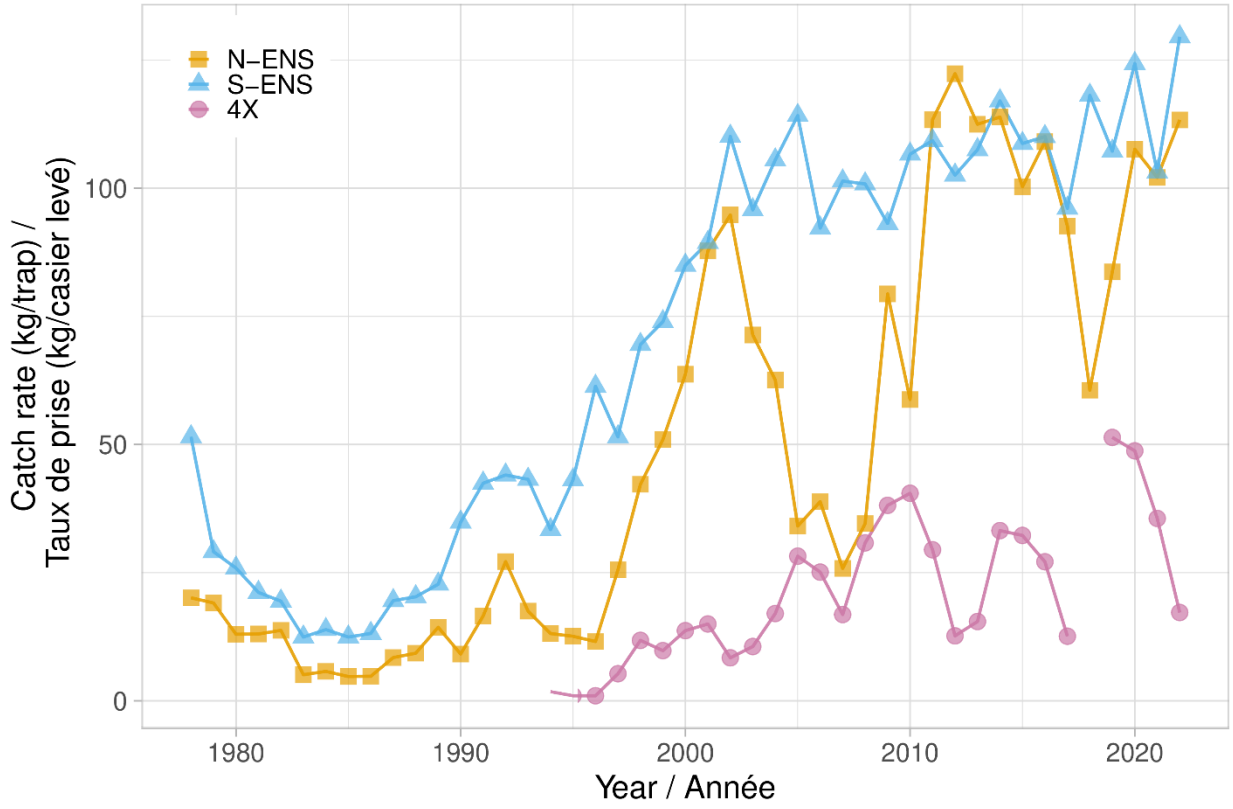

Figure 6. Temporal variations in crude catch rates of Snow Crab (kg/trap haul) in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available.

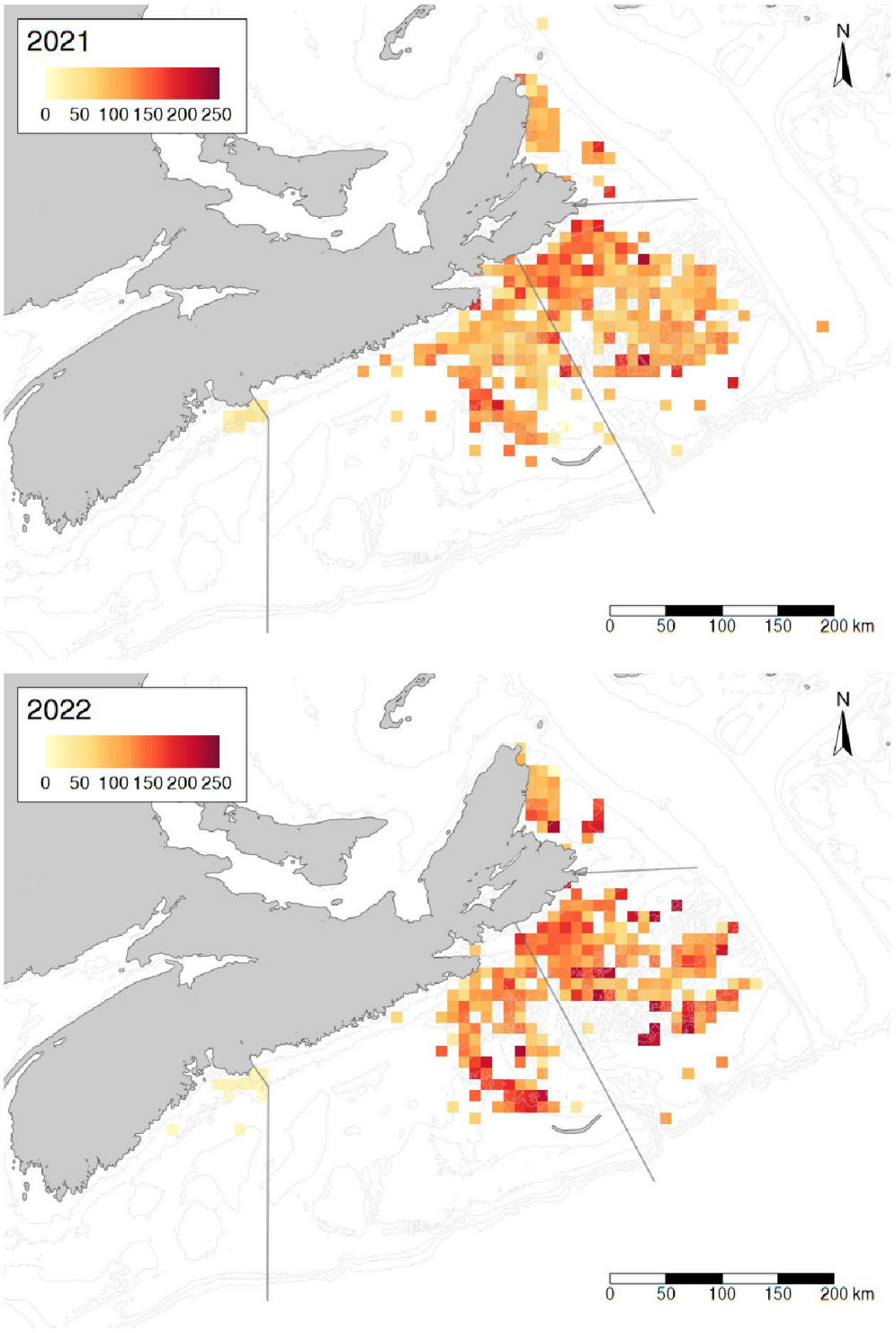

Figure 7. Snow Crab catch per unit effort (cpue; kg/trap haul) calculated from fisheries logbook data for 2021 (top panel) and 2022 (bottom panel). For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available. Grey lines delineate the crab fishing areas as identified in Figure 1.

Carapace condition of the fished component is determined from at-sea observer (ASO) sampling during the commercial fishery. ASO coverage targets for the commercial fishery have not been achieved since 2019 beginning with restrictions due to COVID-19 and continuing due to ongoing issues with ASO companies' ability to provide observers. Estimates of carapace condition since 2020 are unreliable as they represent only small areas of the fishing grounds and short time periods relative to the whole fishing season (Figure 8).

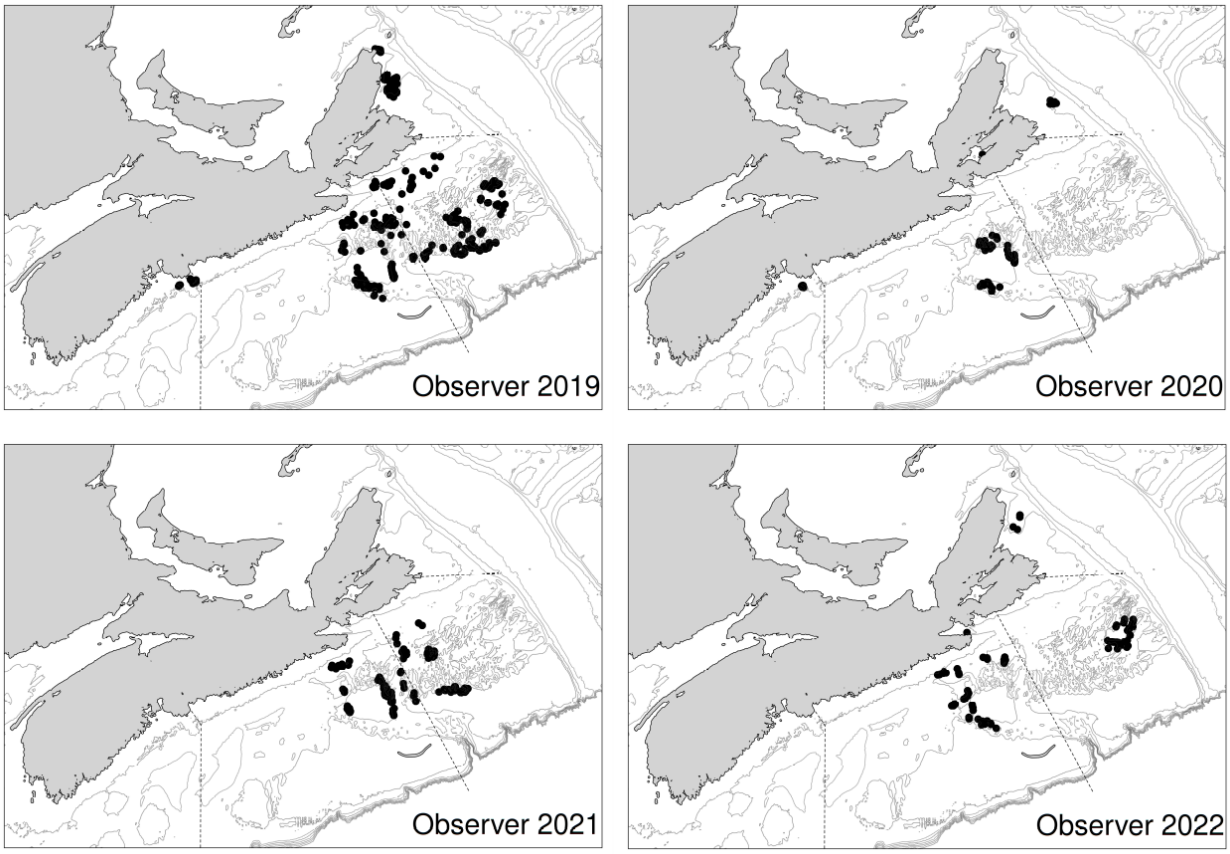

Figure 8. Locations of sampling by at-sea observers on Snow Crab fishing trips. For crab fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available.

In the exploited fraction of Snow Crab, carapace condition (CC) is an index of the approximate time since the last molt, and so describes the relative development and subsequent decay of the carapace. CC1 signifies a newly molted crab, soft-shelled, with no epibiont (e.g., barnacles) growth. CC2 crab have begun to harden, but are still considered to be soft and of no commercial value. CC3 and CC4 represent crab preferred by fishing industry. The oldest carapace condition (CC5) signifies extensive shell decay with no expectation of survival into the next year. In 2022, numbers of Snow Crab with CC5, derived from ASO sampling data, were higher in N-ENS and S-ENS than historical trends; however, as ASO sampling targets were not met, there is uncertainty in the representativity of the data when comparing to historical trends.

The percentage of soft-shelled crab in commercial catches in the 2022 season was 6.4% (low sampling intensity) in S-ENS and 0% (low sampling intensity) in N-ENS; there was no sampling to-date in 4X (season on-going) for the 2022-23 season. In 2021, the percentage of soft-shelled

crab in commercial catches in S-ENS was 11.2% (low sampling intensity); there was no sampling in N-ENS and 4X. Handling of soft-shelled crab can potentially result in handling/discard mortality.

Bycatch in the Snow Crab fishery is also monitored by ASO sampling. Bycatch of non-target species is low (<< 1% of total catch) in all Snow Crab fishing areas; however, as sampling targets for ASO coverage have not been met in recent years, there is uncertainty in the representativity of the data. Historically, bycatch in the Snow Crab fishery has been minimal (Zisserson et al. 2021) with increasing levels as a function of increasing water temperature: bycatch is higher in warmer conditions, primarily other crustacea (crab and lobster). Low bycatch has been attributed to trap design (top entry conical traps), the large mesh size (5.25 inches, knot to knot), and the passive nature of the gear (Hebert et al. 2001).

Stock Status

Survey catch rates are confounded by numerous factors that vary across space and time. Adjustment for these confounding influences were completed with Conditional AutoRegressive SpatioTemporal Models (CARSTM; Choi 2023a). The survey was not conducted in 2020 due to COVID-19 restrictions. In 2022, the survey was not completed due to mechanical issues with the survey vessel; inshore areas of S-ENS were most affected (Figure 9). A total of 302 out of 385 planned stations were completed.

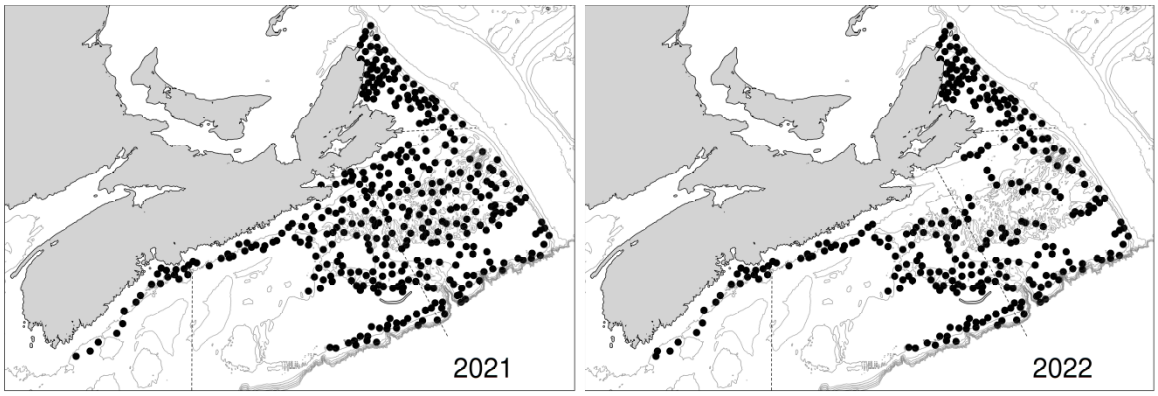

Figure 9. Snow Crab survey locations.

Based on size-frequency histograms of the male Snow Crab population, little to no recruitment is expected for the next 1–3 years in N-ENS (Figure 10). In S-ENS, continued moderate levels of recruitment are expected. In 4X, low to moderate levels of recruitment are expected for two years.

In all areas, there was substantial and continued recruitment of female crab into the mature (egg-bearing) stage of the population from 2016–2022 (Figures 11 and 12). However, in N-ENS, a decline in numerical densities of both the mature and adolescent components was observed in 2022. Egg and larval production is expected to be moderate to high in the next year in all areas except N-ENS.

The sex ratios (proportion female) of the mature component are particularly important as unbalanced ratios can impact reproductive success (Figure 13). In the SSE, there is generally a lack of females. The exception being in inshore areas and areas with high bottom slopes (Figure 14). A decline in sex ratios has been observed since 2017 in N-ENS. In S-ENS the sex

ratio increased from 20% in 2021 to just under 35% in 2022. In 4X, mature sex ratios are more stable and balanced and currently near the 50% level.

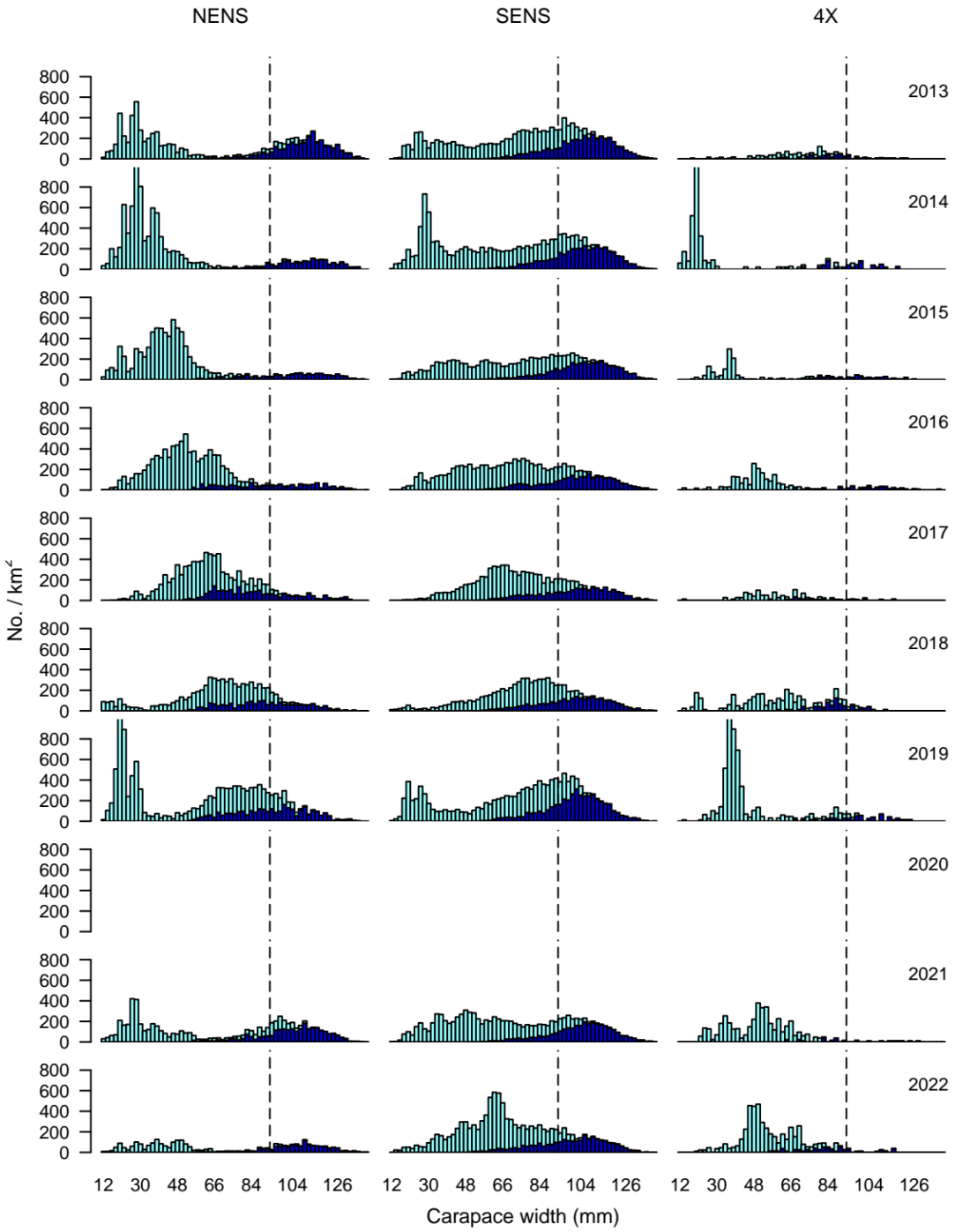

Figure 10. Size-frequency (areal density; no/km^2) histograms by carapace width of male Snow Crab in fishing areas north-eastern Nova Scotia (N-ENS), south-eastern Nova Scotia (S-ENS), and 4X. The vertical line represents the legal size (95 mm). Immature animals are shown with light-coloured bars, mature with dark. There was no survey in 2020.

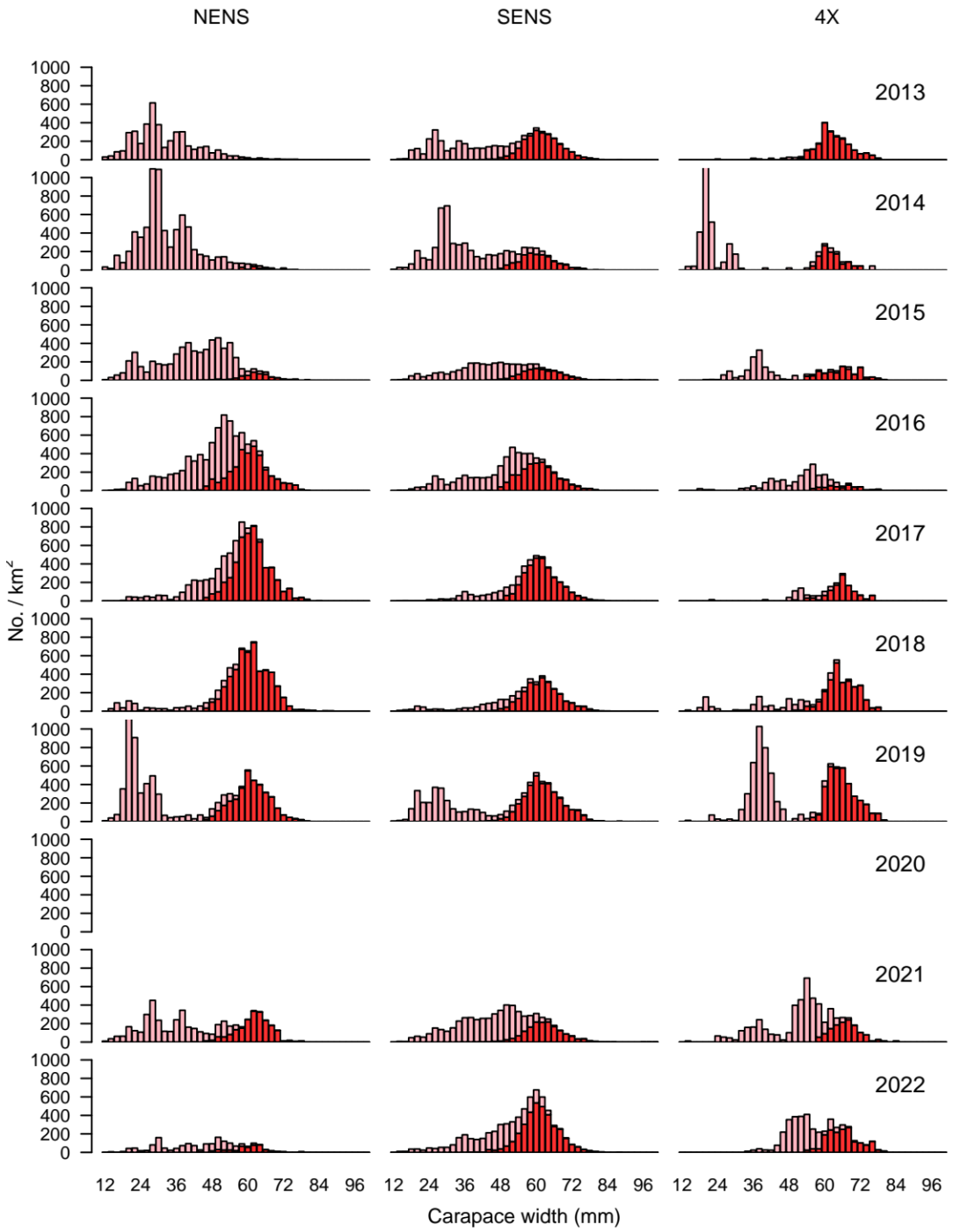

Figure 11. Size-frequency (areal density; no/km^2) histograms by carapace width of female Snow Crab in fishing areas north-eastern Nova Scotia (N-ENS), south-eastern Nova Scotia (S-ENS), and 4X. Immature animals are shown with light-coloured bars, mature with dark. There was no survey in 2020.

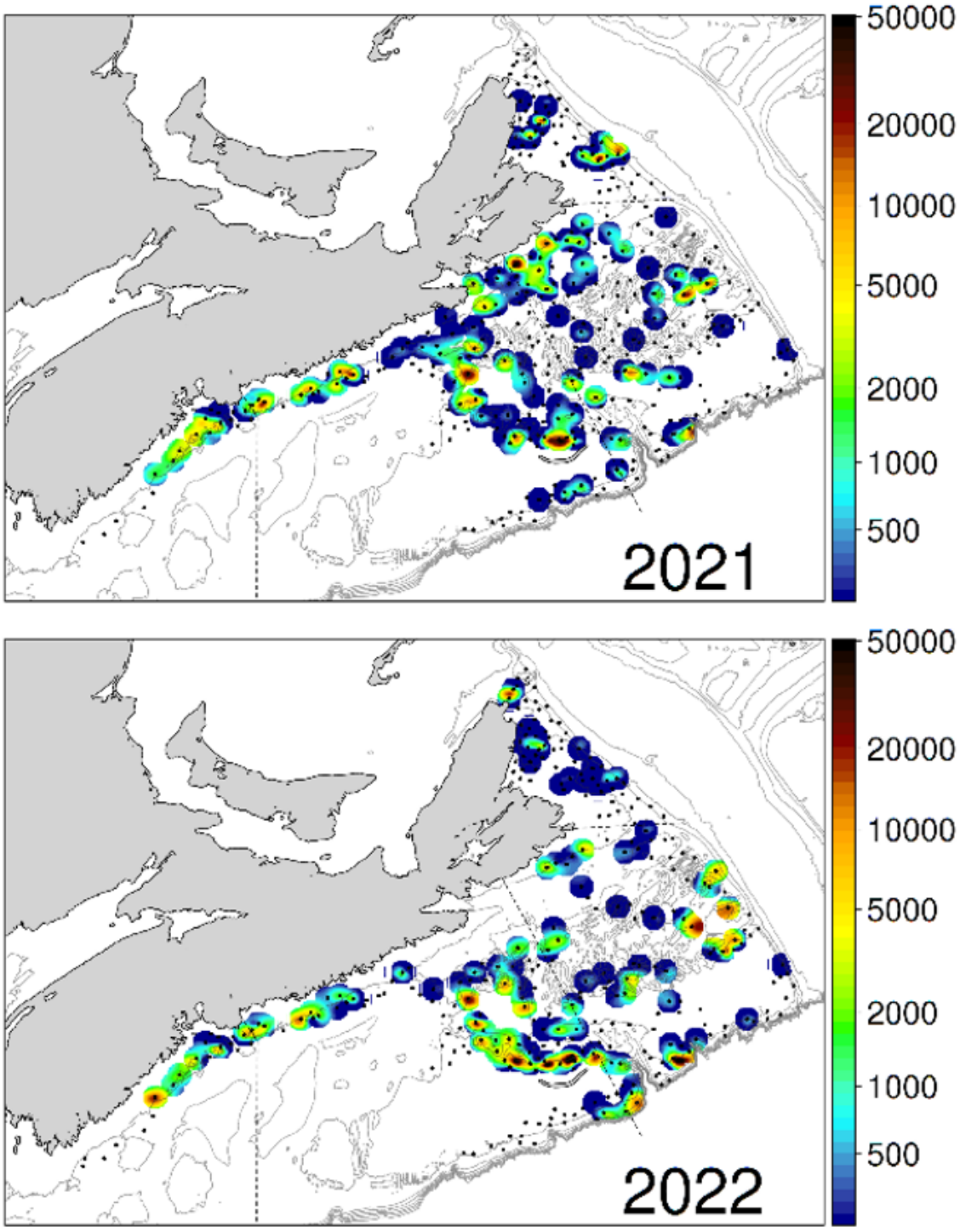

Figure 12. Mature female density (no/km^2) from the Snow Crab survey. Dashed lines delineate the crab fishing areas as identified in Figure 1.

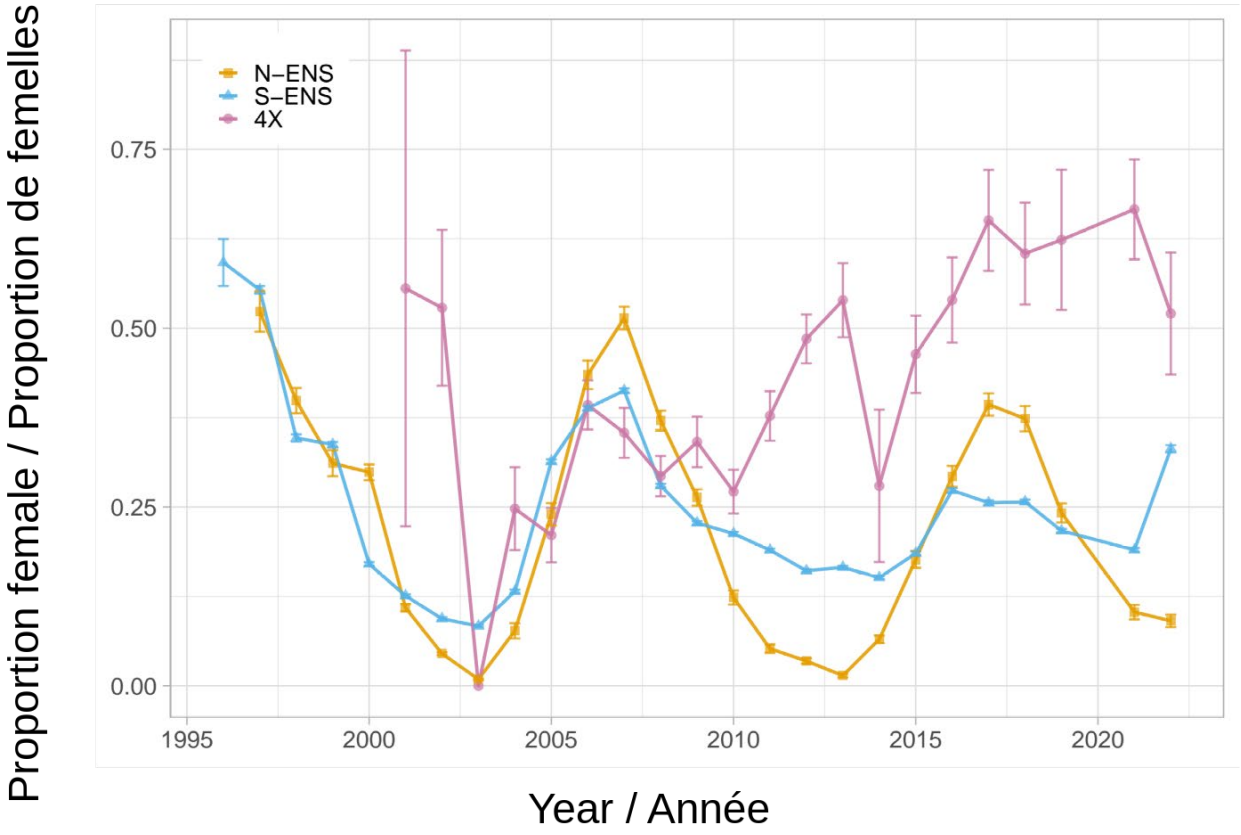

Figure 13. Timeseries of sex ratios (proportion female) of mature Snow Crab for fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). Points are means and vertical bars are 95% confidence intervals.

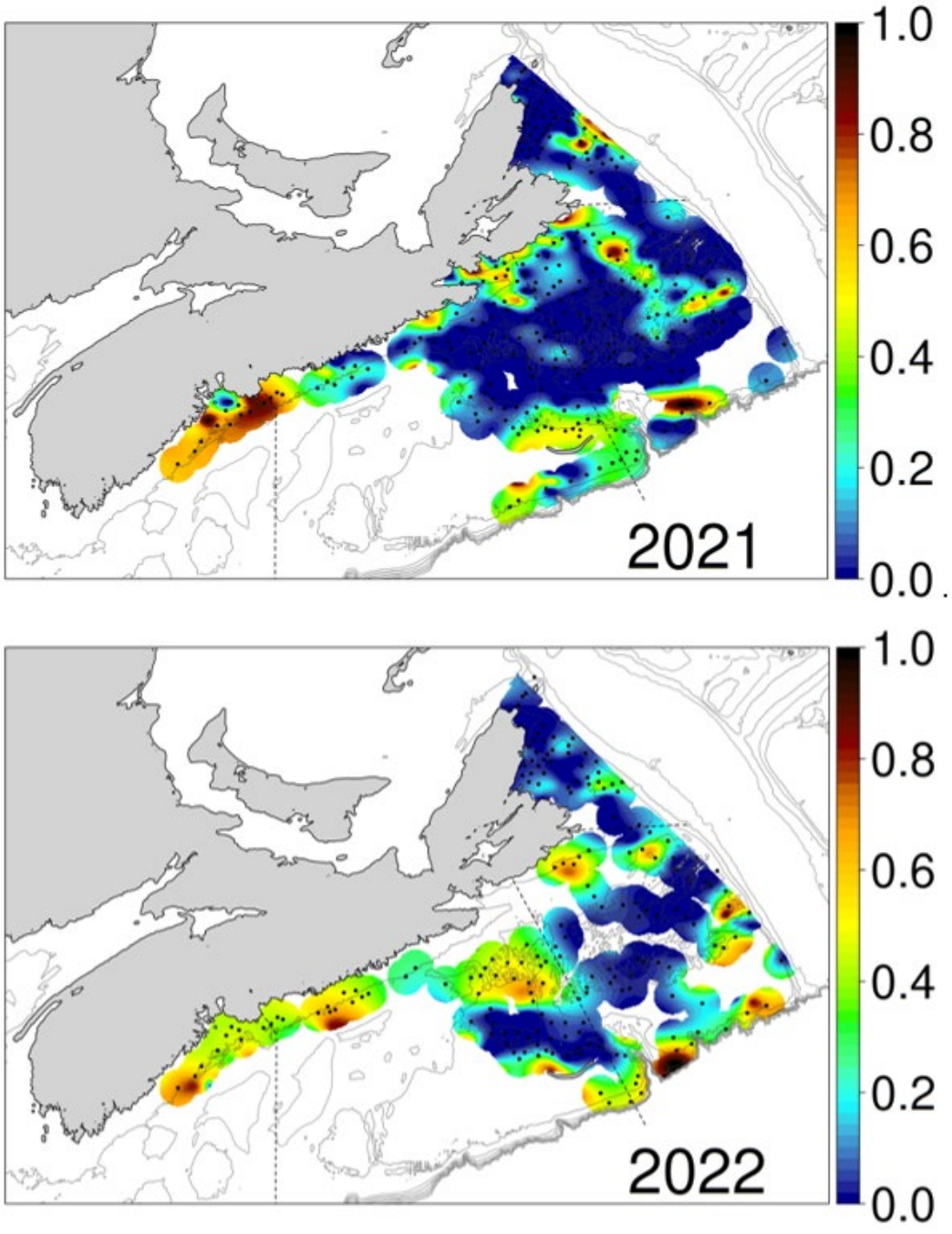

Figure 14. Map of sex ratios (proportion female) of mature Snow Crab. Dashed lines delineate the crab fishing areas as identified in Figure 1.

The fishable component is defined as Snow Crab that are male, mature, and larger than 95 mm carapace width (CW). The crude, unadjusted, geometric mean fishable biomass density (per unit swept area by the trawl) is shown in Figures 15 and 16. A peak in crude biomass densities was observed in 2009 up to 2014, but has since been declining in all areas. Note that high and low biomass density areas fluctuate with time (Figure 16). However, biomass density does not

equate to total biomass as the areas occupied by crab can contract, expand, and shift with environmental conditions and ecosystem change.

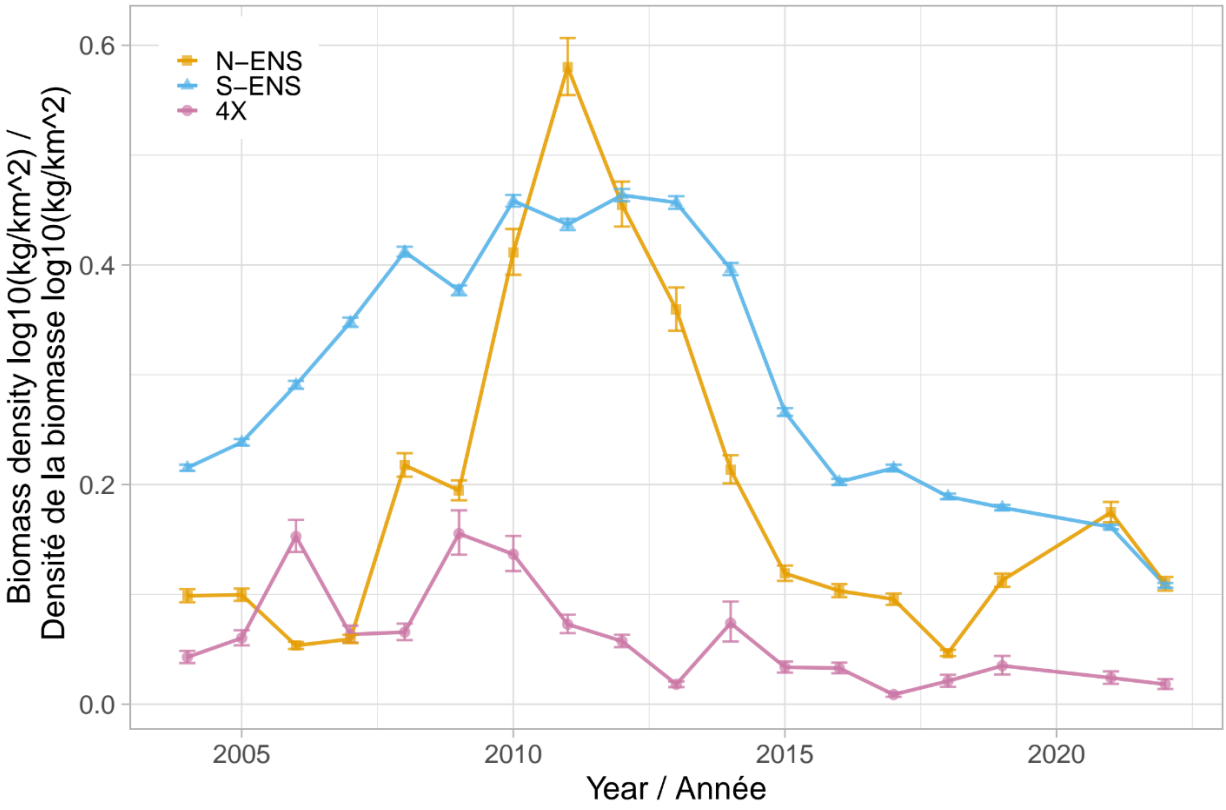

Figure 15. The crude, unadjusted geometric mean fishable biomass density $log_{10}(kg/km^2)$ from the Snow Crab survey in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). Points are geometric means and vertical error bars represent 95% confidence intervals. Note the absence of data in 2020. Prior to 2004, surveys were conducted in the spring.

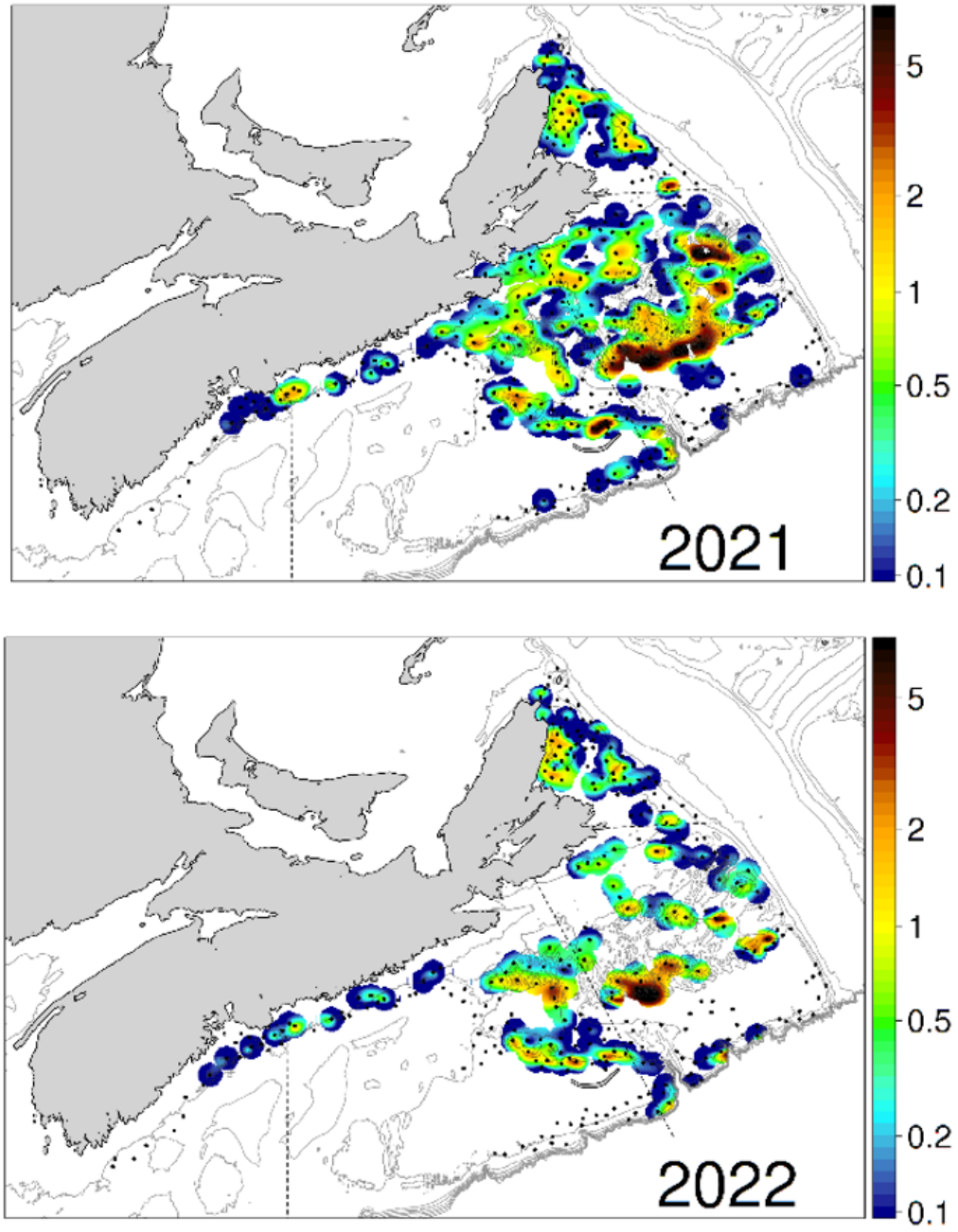

Figure 16. Snow Crab survey fishable component biomass density $log_{10}(kg/km^2)$. Dashed lines delineate the crab fishing areas as identified in Figure 1.

The fishable biomass index (statistically adjusted for covariates and autocorrelation; Figure 17) was computed using conditional auto-regressive spatiotemporal models (Choi 2023a). This approach models Snow Crab numerical abundance and mean size with environmental (depth, substrate, temperature) and biological factors (species composition) as covariates. Upon aggregation we see that the overall biomass has had several cycles (Figure 18). Further, the biomass index model infers the spatiotemporal distribution of the biomass density of the fishable component from the covariates measured in that year; note also the aggregate timeseries with elevated uncertainty for the 2020 estimate (Figure 18).

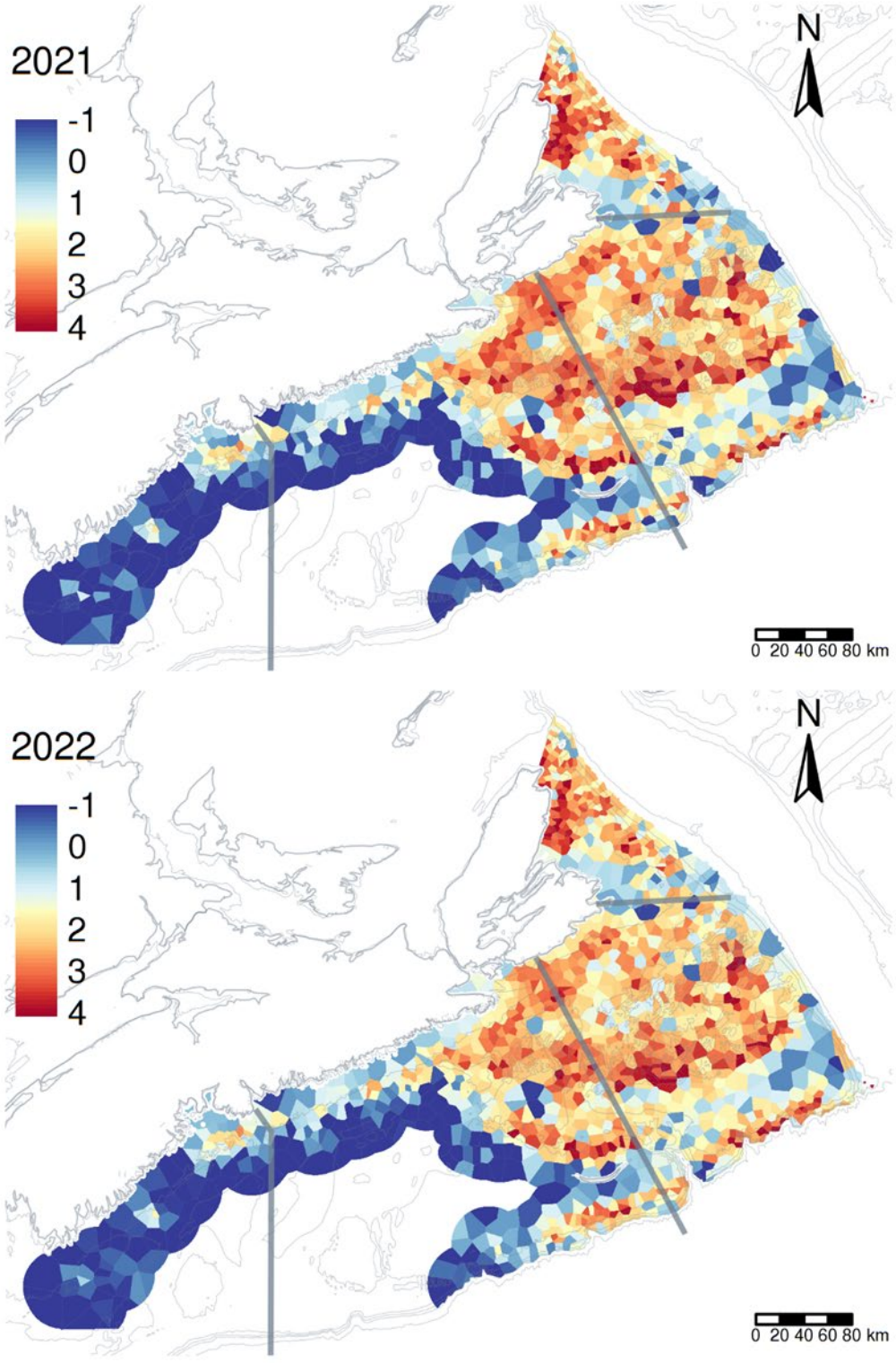

Figure 17. Biomass index $log_{10}(kg/km^2)$ predicted from the Snow Crab survey. Grey lines delineate the crab fishing areas as identified in Figure 1.

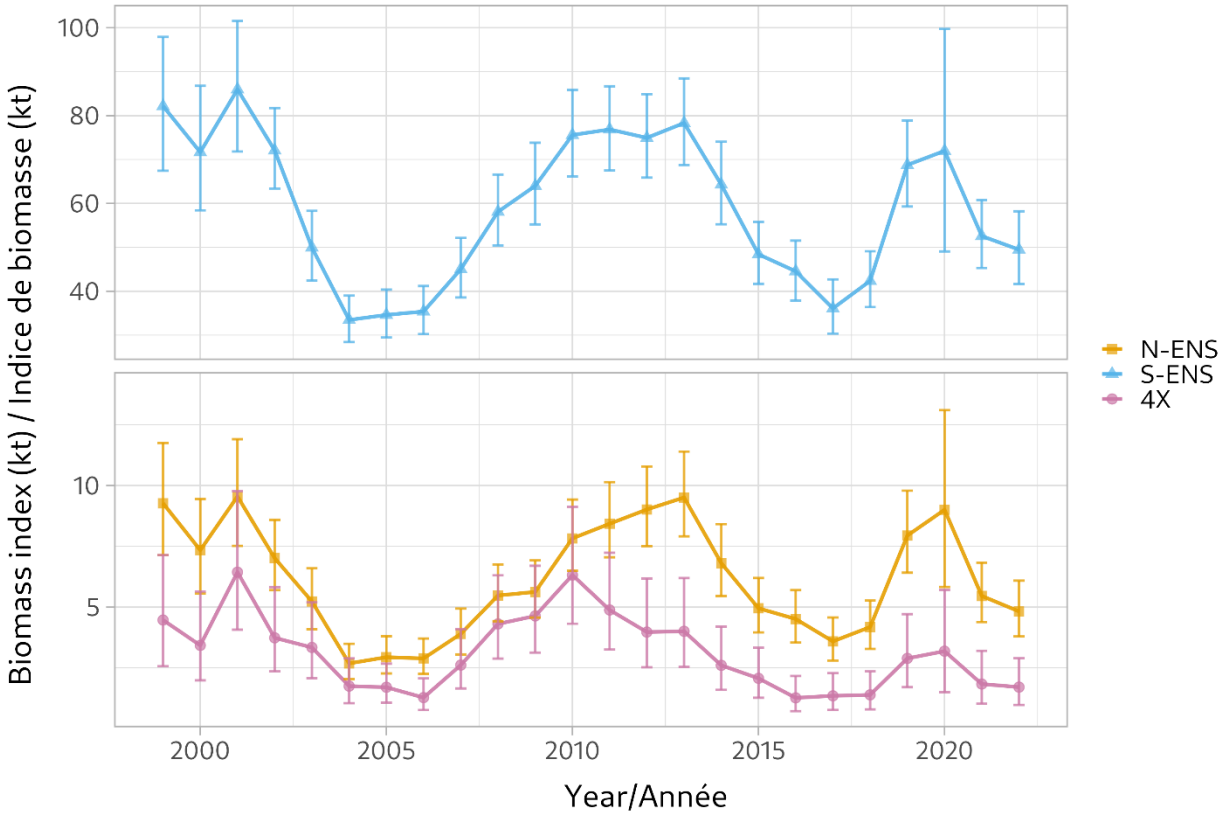

Figure 18. The fishable biomass index (kt) predicted from the Snow Crab survey in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). Points represent posterior predicted means and vertical error bars represent Bayesian 95% credible intervals. Note large errors in 2020 when there was no survey.

The magnitudes of the biomass index are optimistically high as the spatial expansion uses areal units with large surface areas, on average, much larger than the patchiness of Snow Crab distributions (Choi 2023a). The spatial distribution of the biomass index has been consistent over the past six years, with a peak in overall biomass index in 2019 and 2020 (Figure 18). Since then, a reduction in the biomass index was observed throughout the region. Upon aggregation, the predicted biomass index declined marginally in all areas (Figure 18).

The biomass index along with fishery removals are used to fit a logistic biomass dynamics model to determine fishable modelled biomass (Figure 19) and relevant biological reference points (i.e., carrying capacity and fishing mortality at maximum sustainable yield, or F_{MSY}). In N-ENS, the modelled biomass (pre-fishery) of Snow Crab in 2022 was 3.69 kt, relative to 3.96 kt in 2021. In S-ENS, the 2022 modelled biomass (pre-fishery) was 41.93 kt, relative to 44.83 kt in 2021. In 4X, the modelled biomass (pre-fishery) for the 2022-2023 season was 0.78 kt, relative to 0.89 kt for the 2021-2022 season.

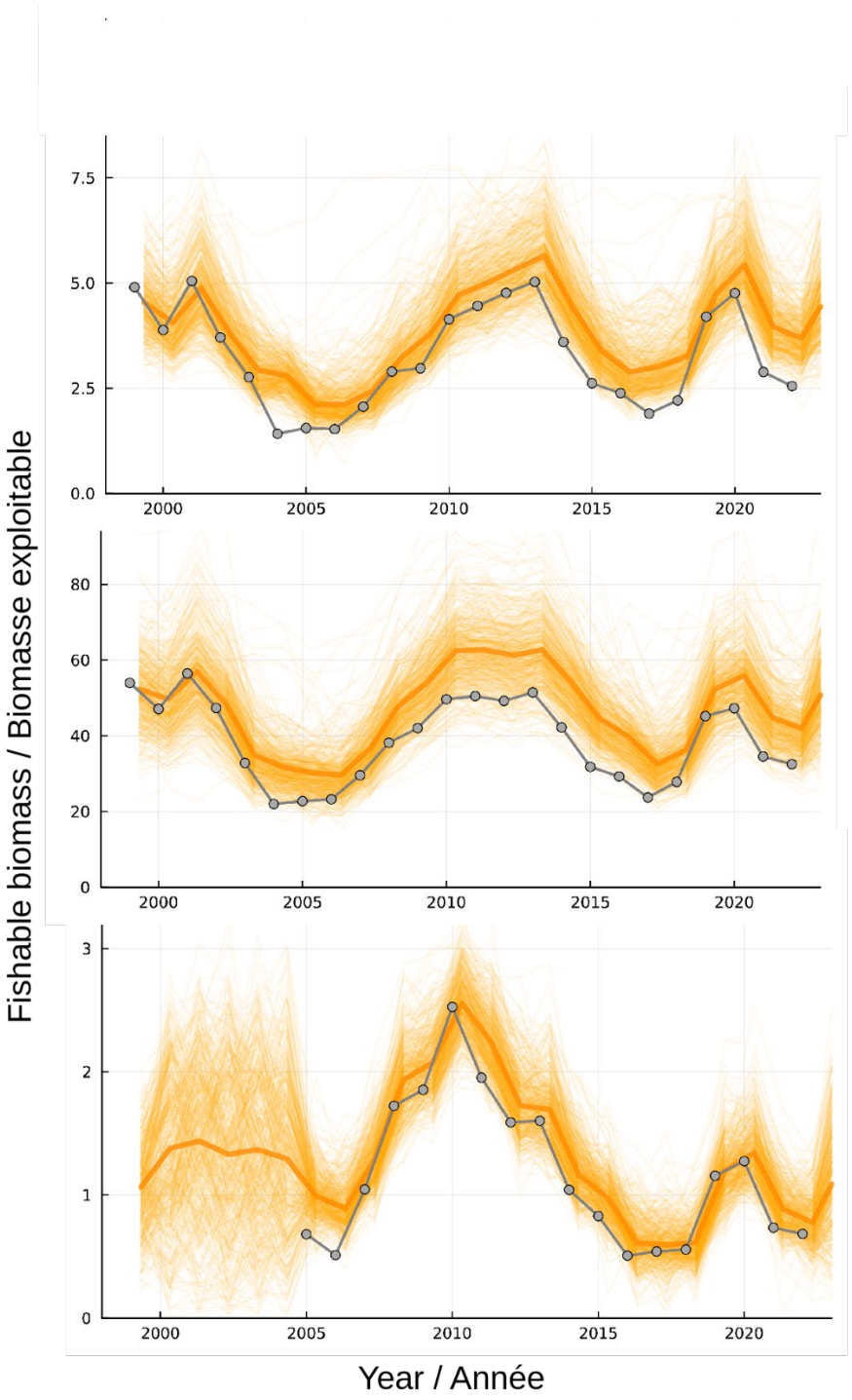

Figure 19. Fishable posterior mean modelled biomass (pre-fishery; kt) are shown in dark orange for fishing areas north-eastern Nova Scotia (top), south-eastern Nova Scotia (middle), and 4X (bottom). Light orange are posterior samples of modelled biomass (pre-fishery; kt) to illustrate the variability of the predictions. The biomass index (post-fishery, except prior to 2004) after model adjustment by the model catchability coefficient is in grey. For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available.

In N-ENS, the 2022 fishing mortality is estimated to have been 0.239 (annual exploitation rate of 26.97%), up from the 2021 rate of 0.208 (annual exploitation rate of 23.2%; Figure 20).

In S-ENS, the 2022 fishing mortality is estimated to have been 0.165 (annual exploitation rate of 17.9%), decreasing marginally from the 2021 rate of 0.174 (annual exploitation rate of 19.1%; Figure 20). Localized exploitation rates are likely higher, as not all areas for which biomass is estimated are fished (e.g., continental slope areas and western, inshore areas of CFA 24).

In 4X, the 2022-2023 season (ongoing), fishing mortality is estimated to have been 0.048 (annual exploitation rate of 4.9%), decreasing from the 2021-2022 season rate of 0.123 (annual exploitation rate of 13.1%; Figure 20). Localized exploitation rates are likely higher, as not all areas for which biomass is estimated are fished.

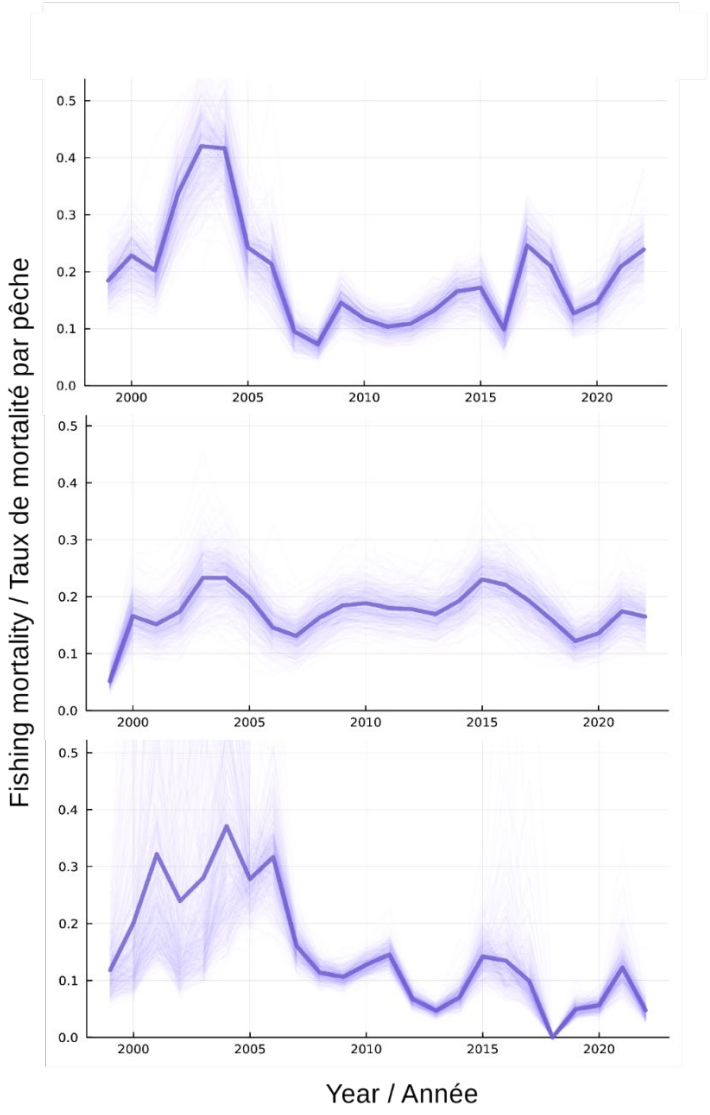

Figure 20. Time-series of modelled instantaneous fishing in north-eastern Nova Scotia (top), south-eastern Nova Scotia (middle), and 4X (bottom). Light purple lines indicate posterior samples of modelled fishing mortality and illustrate the variability of the predictions. The darkest line is the mean posterior fishing mortality. For fishing area 4X, the year refers to the starting year of the fishing season. Season was ongoing in the 4X fishing area for 2022; therefore, the complete data set was not available.

Reference points are used to guide harvest strategies (Canada Gazette 2022; DFO 2013; Figures 21-24). Limit and upper stock reference points are 25% and 50% of carrying capacity which delineate critical, cautious, and healthy zones. The upper removal reference point is the exploitation rate that the fishery tries to stay below; it is defined in terms of the fishing mortality associated with maximum sustainable yield (F_{MSY}). In the model, F_{MSY} is equivalent to half of the intrinsic rate of increase (r). As r is approximately equal to 1 for snow crab (Table 6), F_{MSY} of approximately 0.5 is expected.

The operational target exploitation changes depending upon the zone in which a population lands. These targets are outlined in the harvest control rules (HCRs) for the fishery, which are defined in the Integrated Fisheries Management Plan (DFO 2013). Under these HCRs, when the stock is in the healthy zone, annual exploitation rates are to target between 10% to 30% of the fishable biomass (F=0.11, 0.36, respectively). In the cautious zone, target exploitation rates are to target below 20% (F=0.22). In the critical zone, removals are to be kept to the lowest possible levels, and therefore fishery closure is considered until recovery is observed. Recovery, at a minimum, is indicated when the modelled biomass is greater than the stock limit reference point. Other biological and ecosystem considerations, such as, recruitment, spawning stock (female) biomass, size structure, sex ratios, and environmental and ecosystem conditions, provide additional guidance within each range.

Table 6. Reference points from the logistic biomass dynamics fishery model: K is carrying capacity (kt); and r is intrinsic rate of increase (non-dimensional). Note that F_{MSY} (fishing mortality associated with maximum sustainable yield) is r/2. Similarly, B_{MSY} (biomass associated with maximum sustainable yield) is K/2. SD is posterior standard deviation.

Area	K [SD]	r [SD]
north-eastern Nova Scotia (N-ENS)	5.61 [0.67]	0.92 [0.67]
south-eastern Nova Scotia (S-ENS)	67.42 [8.36]	0.87 [8.36]
4X	2.13 [0.2]	0.93 [0.2]

The current estimates of key reference points are shown in Table 6 and Figures 22-24. The related precautionary approach thresholds can be computed as: Lower Stock Reference (LSR): K/4; Upper Stock Reference (USR): K/2; and Removal Reference (RR): keep fishing mortality below F_{MSY}=r/2. The current state of the fishable components using the above reference points (Figure 21) suggests that:

- N-ENS is in the healthy zone
- S-ENS is in the healthy zone
- 4X is in the cautious zone

However, the range of variability in all parameters are quite large (Figures 22–24) and so status determined from reference points alone are not definitive.

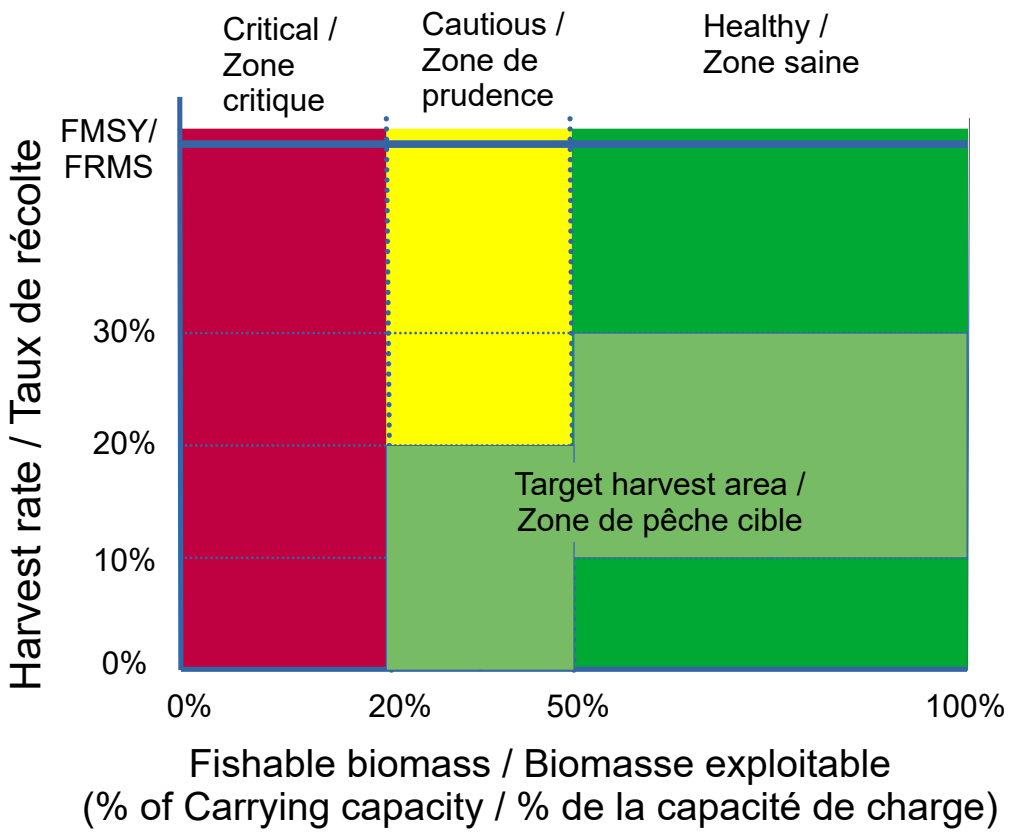

Figure 21. Harvest control rules for the Scotian Shelf Snow Crab fisheries. FMSY/FRMS is the fishing mortality associated with maximum sustainable yield.

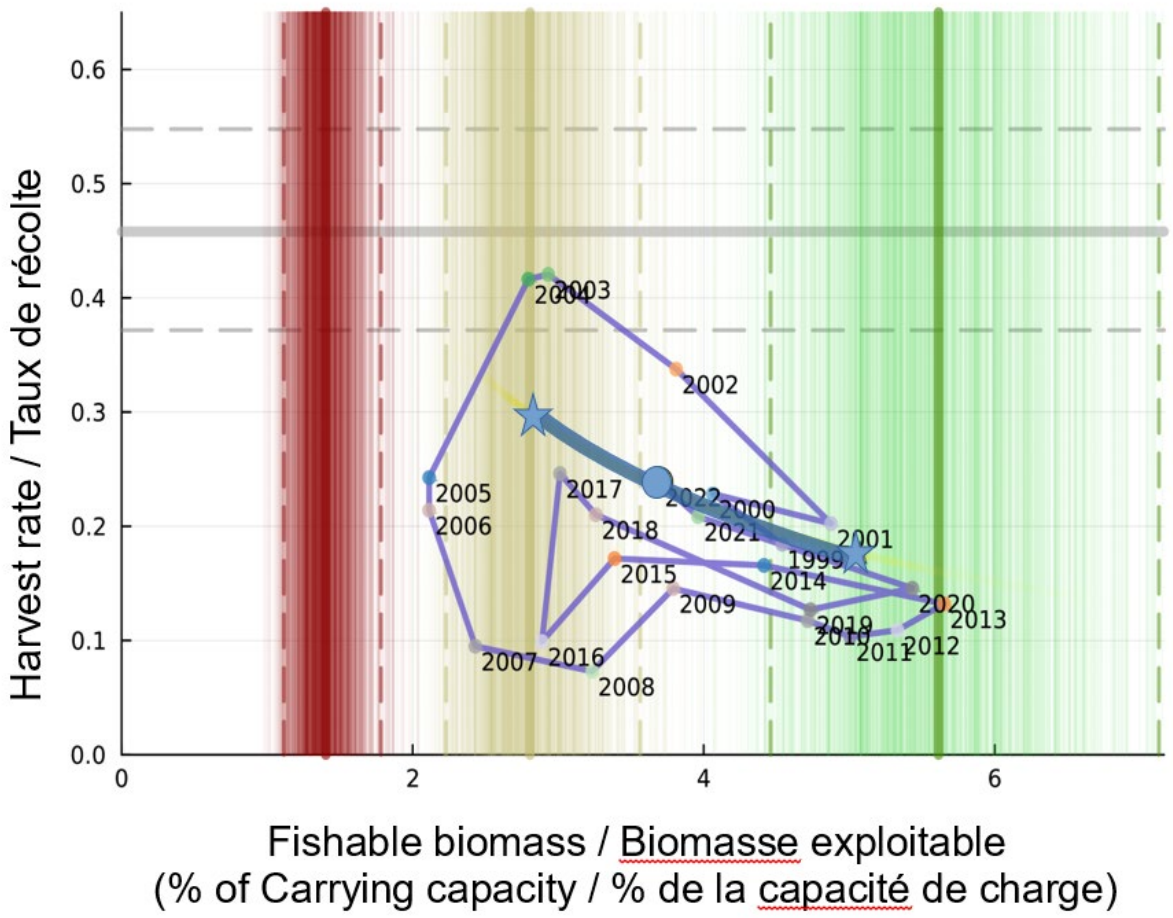

Figure 22. Reference Points (fishing mortality and modelled biomass) in north-eastern Nova Scotia. Coloured circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large blue dot, and the 95% credible intervals are presented by blue stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick blue line and fall upon a line as fishing mortality is computed from fishable biomass with no error assumed in catch. The grey solid horizontal line identifies the F_{MSY} estimated for each area and the stippled horizontal lines identify the 95% credible intervals. The solid-coloured vertical lines identify the estimates of the 25%, 50% and 100% carrying capacity for each region and the stippled lines delimit the 95% credible intervals for each threshold. The lighter-coloured vertical lines are posterior samples to demonstrate the variability associated with each parameter.

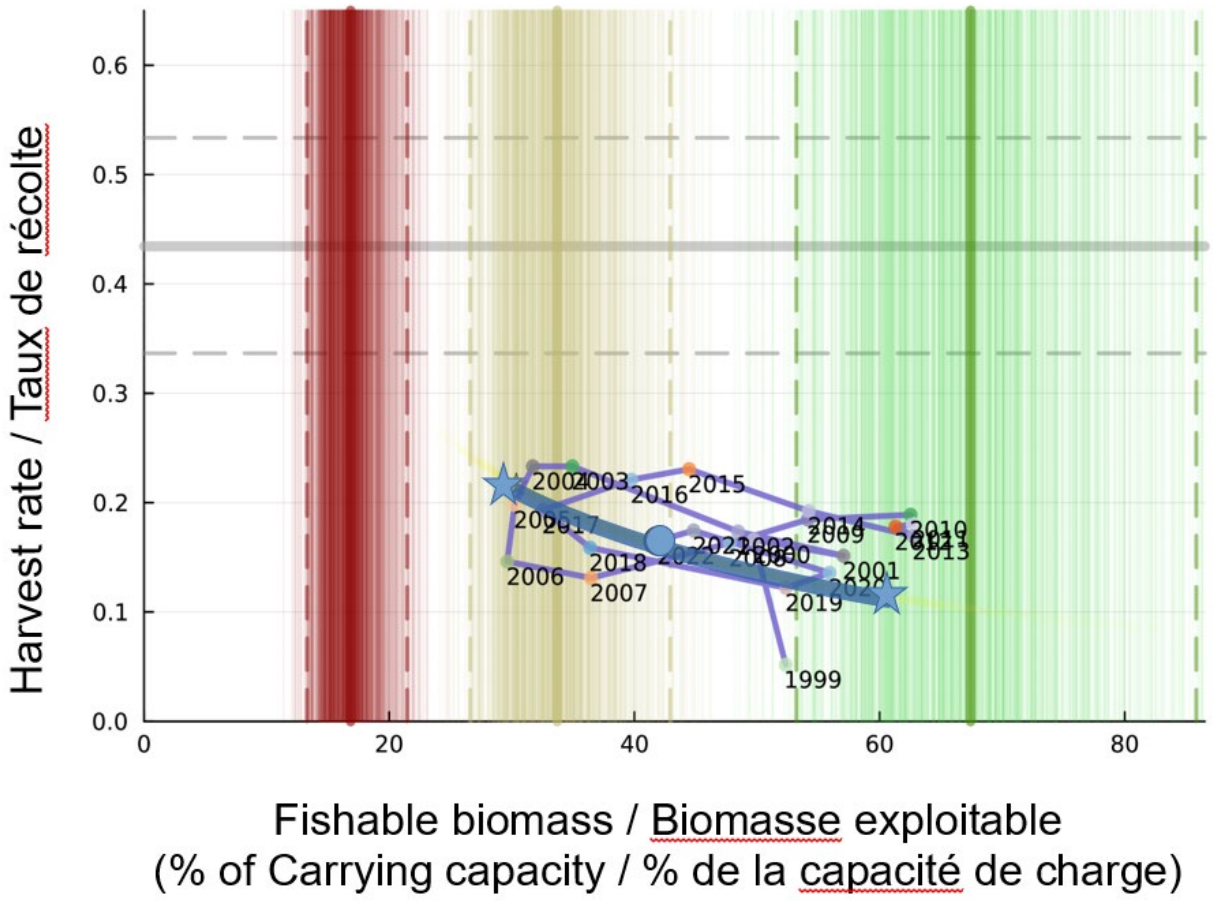

Figure 23. Reference Points (fishing mortality and modelled biomass) in south-eastern Nova Scotia. Coloured circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large blue dot, and the 95% credible intervals are presented by blue stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick blue line and fall upon a line as fishing mortality is computed from fishable biomass with no error assumed in catch. The grey solid horizontal line identifies the F_{MSY} estimated for each area and the stippled horizontal lines identify the 95% credible intervals. The solid-coloured vertical lines identify the estimates of the 25%, 50% and 100% carrying capacity for each region and the stippled lines delimit the 95% credible intervals for each threshold. The lighter-coloured vertical lines are posterior samples to demonstrate the variability associated with each parameter.

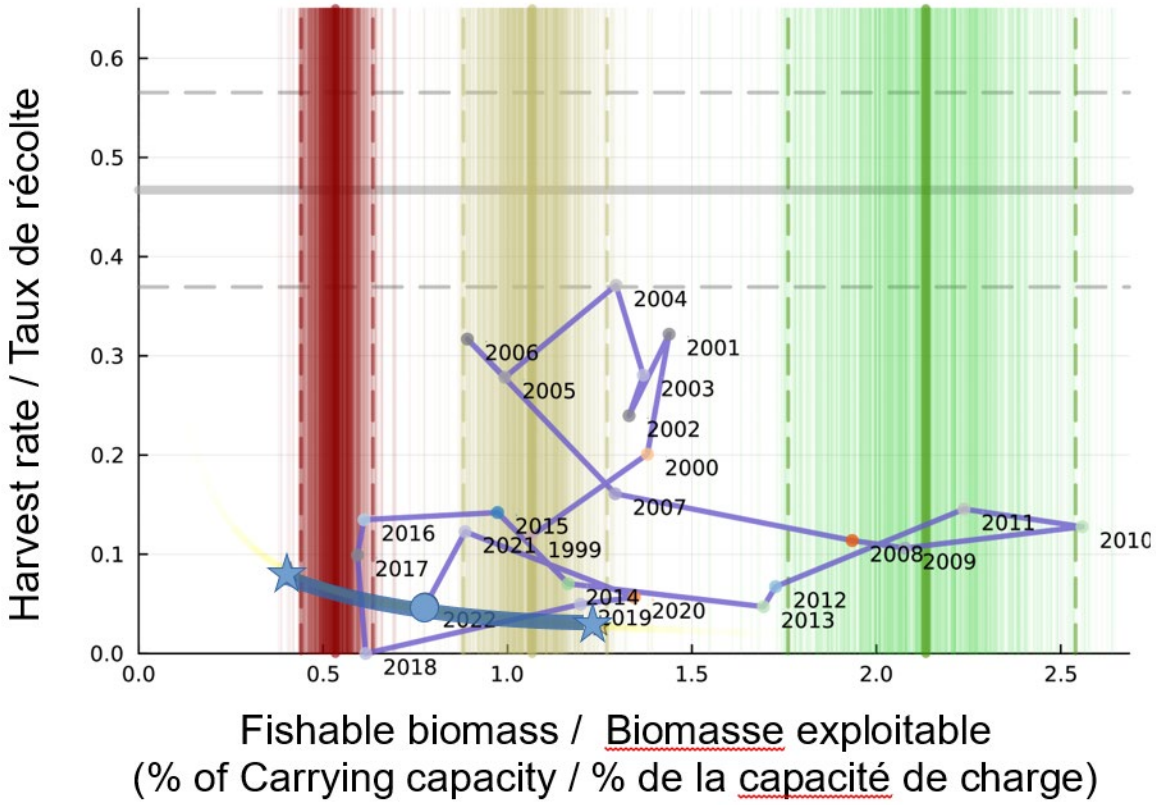

Figure 24. Reference Points (fishing mortality and modelled biomass) in 4X. Coloured circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large blue dot, and the 95% credible intervals are presented by blue stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick blue line and fall upon a line as fishing mortality is computed from fishable biomass with no error assumed in catch. The grey solid horizontal line identifies the F_{MSY} estimated for each area and the stippled horizontal lines identify the 95% credible intervals. The solid-coloured vertical lines identify the estimates of the 25%, 50% and 100% carrying capacity for each region and the stippled lines delimit the 95% credible intervals for each threshold. The lighter-coloured vertical lines are posterior samples to demonstrate the variability associated with each parameter. For fishing area 4X, the year refers to the starting year of the fishing season.

It should be noted that using these parameters assumes that the population dynamics are well described by the fishery model. This is, of course, not true. For example, the observation of fisheries landings in the model is assumed to be known without error. This is not true, as unauthorized and unreported exploitation is not quantified. These and other unaccounted factors can easily bias parameter estimates. As such, caution is required in using these reference points. Other contextual indicators should be used in conjunction, such as:

- Strength of recruitment (short-term, long-term)
- Strength of spawning stock (females)
- Ecosystem variability (predator and prey trends and distributions) within norms
- Habitat viability within norms

- Availability of spatial and temporal refugia within norms

Sources of Uncertainty

Bottom Temperature

A general warming trend has been observed in the Snow Crab survey since the early 1990s on the Scotian Shelf (Choi 2022, Choi et al. 2022). Temperatures are more stable in N-ENS than S-ENS; 4X exhibits the most erratic and highest annual mean bottom temperatures. The average temperature is found to have increased well beyond the 7℃ threshold in 4X. N-ENS and S-ENS also continued to experience historical highs in bottom temperature and elevated spatial variability of bottom temperatures (Figures 25 and 26).

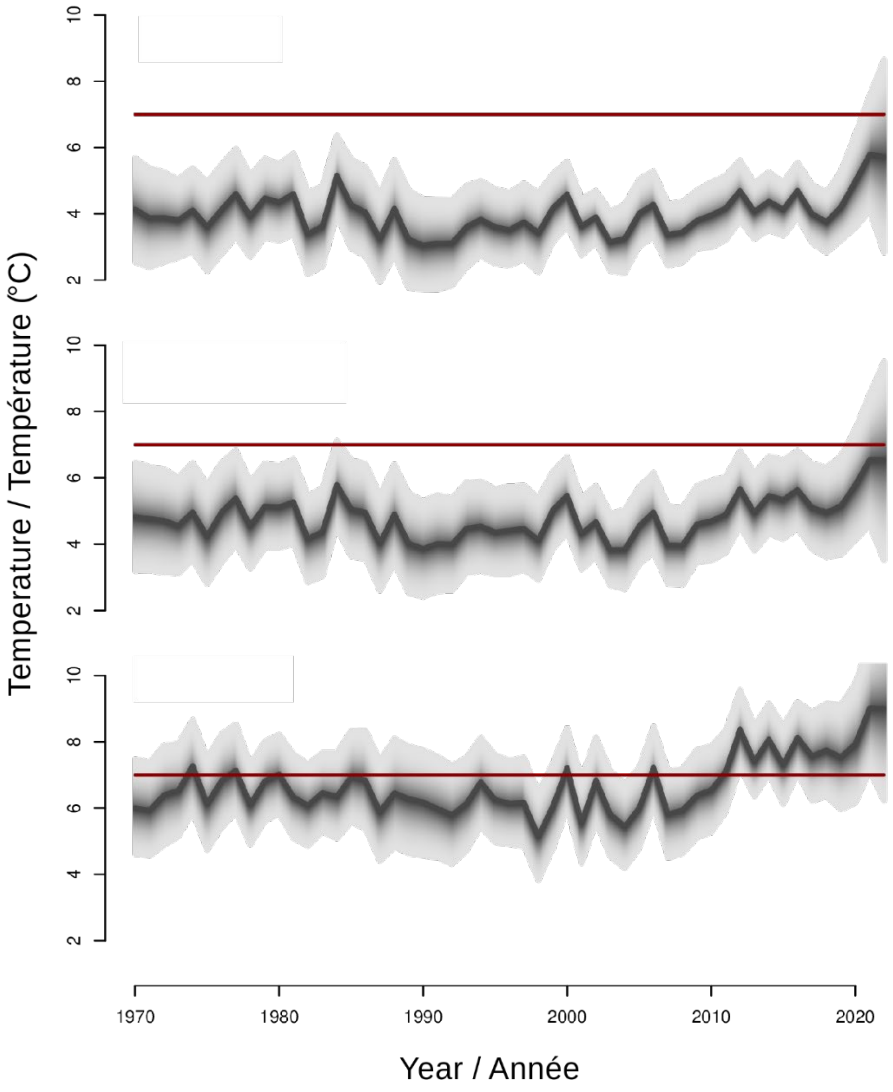

Figure 25. Temporal variations in bottom temperature estimated from a Conditional AutoRegressive Space-Time Model analysis of historical temperature data in fishing areas north-eastern Nova Scotia (top), south-eastern Nova Scotia (middle), and 4X (bottom). Red horizontal line is at 7°C, considered to be the upper metabolic bound for Snow Crab. Presented are posterior samples (light grey) and the posterior mean (dark line) of the spatial variability of temperature at each time slice, after adjustment for spatiotemporal autocorrelation.

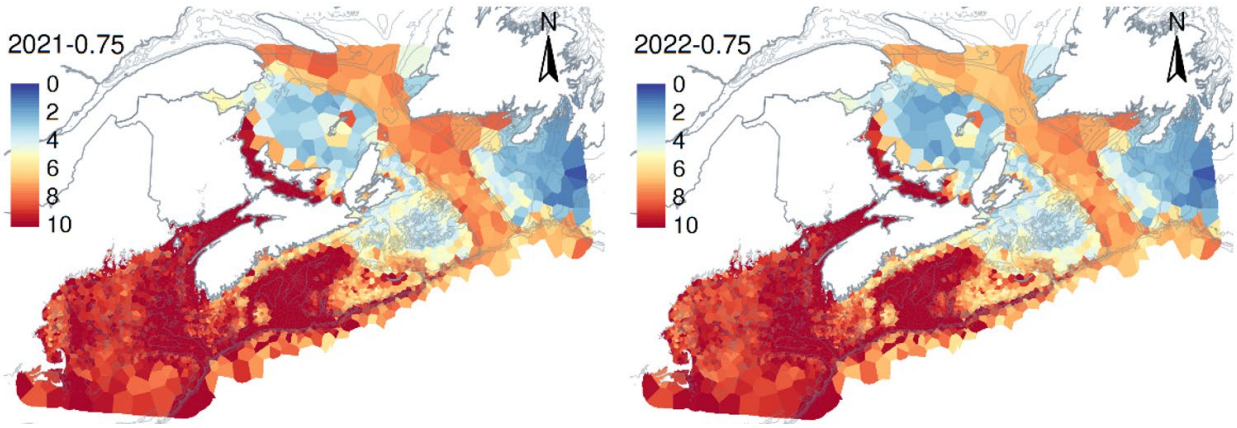

Figure 26. Spatial variations in bottom temperature (°C) estimated from a Conditional AutoRegressive Space-Time Model analysis of historical temperature data and predicted for September 1st.

Viable habitat

For Snow Crab, being cold water stenotherms, stability of environmental conditions is critical for their survival. The Maritimes Region, being at the confluence of many oceanic currents, renders the area highly variable. Rapid climate change and uncertainty exacerbates this situation (Choi 2023b). The viable habitat estimated for each area across time has shown some variations (Figures 27 and 28) in the historical record. As can be seen, 4X showed a significantly lower average viable habitat level relative to the N-ENS and S-ENS. A peak in average probability of observing fishable Snow Crab (viable habitat) was observed in 2010 for 4X, 2011 for N-ENS, and 2012 for S-ENS. Since 2015, the average viable habitat has declined to historical lows in 2022.

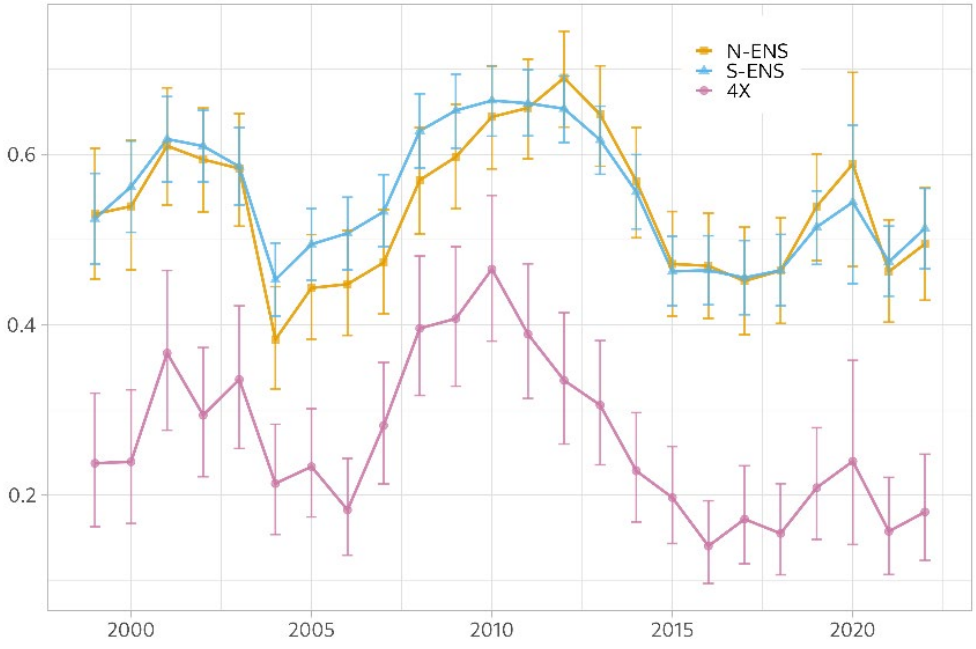

Figure 27. Habitat viability within the model domain as measured by the probability of observing fishable Snow Crab from the conditional auto-regressive spatio-temporal model in fishing areas north-eastern Nova Scotia (N-ENS; yellow line with squares), south-eastern Nova Scotia (S-ENS; blue line with triangles), and 4X (pink line with circles). Points are means and vertical bars are 95% credible intervals.

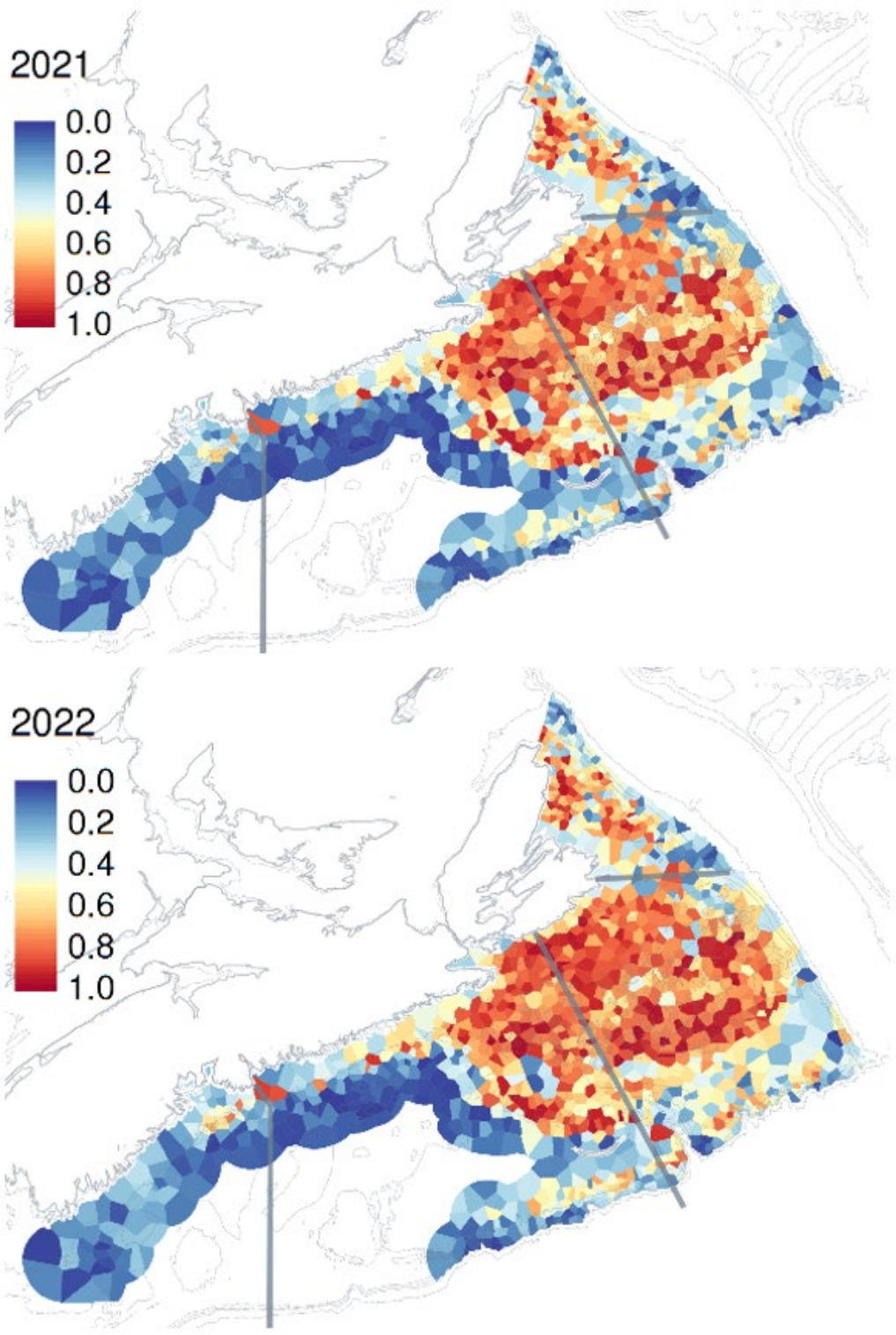

Figure 28. Habitat viability quantified as the posterior predicted mean probability of observing fishable Snow Crab from conditional auto-regressive spatio-temporal model. Grey lines delineate the crab fishing areas as identified in Figure 1.

Predators, Prey, and Competitors

Being long-lived, the influence of predators can be significant. Especially important are predators of the smaller immature and female Snow Crab. Increasing predation not only lowers the abundance and recruitment, but it can also reduce the reproductive potential of Snow Crab, and therefore, long-term population cycles. N-ENS and S-ENS are well known to have skewed sex ratios with few mature females for extended periods of time, quite possibly linked to differential predation mortality (mature females being much smaller and full of fat-rich gonads and eggs).

Based on stomach sampling, Atlantic Halibut, Atlantic Wolffish, Thorny Skate, and other skate species are known predators of Snow Crab. Large Atlantic Halibut with mature female Snow Crab in their stomachs have been reported. There is anecdotal information of some seals having fed upon Snow Crab. Some of these predators (e.g., Halibut; DFO 2018) have significantly increased in abundance in the Maritimes Region. However, for all predators, the abundance and encounter rates in areas overlapping with Snow Crab habitat is more important, but this is not known. We do know from the bycatch in the Snow Crab survey that there are elevated areal densities with many Snow Crab trawl samples. This means that encounter rates will also likely increase and so too potentially predation mortality. However, high density does not equate to high abundance, nor high total predation mortality; but this remains unknown and requires further analysis.

Atlantic Halibut densities have increased rapidly since 2010 (Figure 4.7; DFO 2023) on Snow Crab grounds. Most of these increases were towards The Gully, Slope Edge, and near Sable Island (4.8).

Other Sources of Uncertainty

- Bycatch of other species in the Snow Crab fishery cannot be reliably computed as they are derived from ASO data.
- Bycatch of Snow Crab in other fisheries remains an area requiring attention. Anecdotal information from fishers suggest illegal retention of sublegal and female Snow Crab as bycatch and their use as bait. Illegal removals are also known to occur; however, the scale of such activities is not known.
- Undersea, high-voltage cables is a source of concern. Many marine organisms are known to be sensitive to electromagnetic fields. As such, distribution of predators, prey, and Snow Crab can be affected, potentially creating bias in density estimates considered in the stock assessment.
- Marine Protected Areas (MPAs) continue to be developed (e.g., Canada Gazette 2016). The presence of a refuge from fishing activities is potentially positive for Snow Crab. However, positive effects upon other organisms (predators or prey) can have counter-balancing effects. The overall long-term effects of MPAs upon Snow Crab are unknown.
- Capture of soft-shell Snow Crab is always a concern. Prompt and careful return of immature (small-clawed, non-terminally molted) crab to the water is an important conservation measure that will enhance the 2–3 year productivity of the fishable component. It is not possible to quantify the impact of improper handling on the growth and mortality of captured soft-shell Snow Crab which therefore leads to uncertainty in the fishery model parameters.
- Unreported landings have the potential to hinder the application of a precautionary approach to the management of this resource and cause potential bias and uncertainty in the estimation of reference points.

- A decline of adolescent and mature females in N-ENS was evident in the more recent population cycle than historical patterns. This could be due to predation mortality, environmental variability and/or movement.

CONCLUSIONS

The SSE is still experiencing a lot of volatility driven by rapid ecosystem and climatic variations. Under such conditions, it is prudent to be careful (Choi and Patten 2001). Further, the overall indications of population status suggest that Snow Crab are still able to persist under extreme conditions if they are episodic, albeit, with some shifts in spatial distribution towards cooler and deeper waters.

- In N-ENS, though recruitment continues at low levels, a gap in future recruitment to the fishery is expected for the next one to three years in N-ENS. Following the Precautionary Approach based reference points for the area, N-ENS is in the healthy zone. However, a more conservative harvest strategy may support the stock in bridging the expected gap in recruitment.
- In S-ENS, recruitment to the fishery is likely to continue at a moderate rate for the 2023 season. The S-ENS stock remains in the healthy zone. Exploitation rates derived from the fishery model have been declining in recent years. Continuation of the current harvest strategy would support maintenance of stock status of S-ENS in the healthy zone.
- In 4X, low to moderate levels of recruitment are expected for the next two years. The area is also in the southern-most extent of Snow Crab distribution in the North Atlantic and viable habitat has been depressed for many years. Following the Precautionary Approach based reference points for the area, 4X is in the cautious zone. A more conservative harvest strategy may be advised.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 9–10, 2023 regional peer review on the Stock Assessment of Snow Crab in Maritimes Region. 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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