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Maritimes Region

Assessment of Scotian Shelf Ecosystem Snow Crab in 2024

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Canada

Foreword

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

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TABLE OF CONTENTS

ABSTRACT

In the Maritimes Region, Snow Crab (*Chionocetes opilio*) are managed as three fishing areas: north-eastern Nova Scotia (N-ENS; formerly crab fishing areas [CFA] 20-22), south-eastern Nova Scotia (S-ENS; formerly CFAs 23, 24), and Northwest Atlantic Fisheries Organization (NAFO) Division 4X (CFA 24W).

Results from an annual fishery independent survey suggest that recruitment into N-ENS and 4X continues to decline while that of S-ENS builds in strength. Poor recruitment in N-ENS and 4X may be due to elevated predation by groundfish and habitat reduction. Reproductive potential continues to be comparable to 2023, though it is expected to decline in both N-ENS and 4X. Environmental conditions (bottom temperature) have reverted to a cold-water phase in all areas; however, snow crab habitat viability still declined, especially in N-ENS and 4X. Elevated mortality and poor recruitment of immature male crab will continue to be an issue in these two areas for at least the next three years.

Fishable biomass densities also declined in 2024 in both N-ENS and 4X while they increased in S-ENS. The fishable biomass indices are near historical lows in each area. In N-ENS, the modelled biomass (pre-fishery) of Snow Crab in 2024 was 2.7 kt, relative to 3.4 kt in the previous year. In S-ENS, the 2024 modelled biomass (pre-fishery) was 41.5 kt, relative to 40.6 kt in the previous year. In 4X, the modelled biomass (pre-fishery) for the 2024-2025 season was 0.18 kt, relative to 0.14 kt in the previous season. There is a continuing decrease in modelled biomass in N-ENS since 2021 and 2019 in S-ENS and 4X.

Fishing mortality in N-ENS in 2024 was estimated to have been 0.32 (annual exploitation rate of 37%), up from 0.26 (annual exploitation rate of 30%) in the previous year. In S-ENS, the 2024 fishing mortality is estimated to have been 0.17 (annual exploitation rate of 18.6%), while in the previous year it was 0.18 (annual exploitation rate of 19%). 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 2024–2025 season (ongoing) fishing mortality is currently estimated to be 0.052 (annual exploitation rate of 5%), while in the previous season it was 0.27 (annual exploitation rate of 31%). Localized exploitation rates are likely higher, as not all areas for which biomass is estimated are fished.

INTRODUCTION

The Snow Crab fishery in Nova Scotia on the Scotian Shelf ecosystem (SSE; Figure 1), has been active since the mid-1970s. The fishery is managed as three main areas: North-Eastern Nova Scotia (N-ENS), South-Eastern Nova Scotia (S-ENS), and NAFO Division 4X. S-ENS is further subdivided into two fishery management areas: crab fishing area (CFA) 23 and CFA 24. The fishing season in N-ENS and S-ENS starts in the spring, while the 4X fishing season starts in the fall extending over the winter into the next year (Table 1). Management measures include effort controls, individual boat quotas (IBQs), total allowable catches (TACs), 100% dockside monitoring, mandatory logbooks, and at-sea monitoring by certified observers. Additionally, the following management measures and other aspects within the Maritimes Region snow crab fishery demonstrate the precautionary nature of this fishery:

- Females (i.e., the spawning stock) are not fished and therefore, completely protected.
- Immature crab are not fished and soft-shelled crab are avoided.
- In general, most exploitation rates since the mid-2000s have been conservative.
- There are spatial refugia in the marine protected areas (MPAs; DFO no date) and continental shelf edge.
- Implementation of bycatch reduction measures (season timing, biodegradable mesh, and area closures) to minimize effects on other species.
- A collaborative management style that prioritizes scientific, fisheries-independent, evidence-based decision making.

This document provides information and an assessment of the Maritimes Region snow crab fishery to address a request for science advice from Fisheries and Oceans Canada (DFO) Maritimes Region Resource Management to support the decision-making process for management of this fishery. Specifically, the objectives addressed herein include advice on:

- Stock status and trends, including the historical and recent trajectory of both stock and fishing indicators (e.g., total biomass, fishable biomass, recruitment, fishing mortality, distribution, other relevant biological characteristics);
- Environmental and climate change considerations affecting the stock including relevant summaries of oceanographic conditions, biological community structure and trends, and pertinent knowledge of ecological interactions (e.g., predator, prey), where data are available; and,

Evaluation of:

- Bycatch of non-target species in the 2024 Snow Crab fishery, where data are available.
- Major sources of uncertainty, where applicable.

METHODS

The SSE Snow Crab (*Chionoecetes opilio*) are found on soft mud or sandy bottoms at depths of 60–300 m and temperatures from −1–6°C. More information on the SSE Snow Crab fisheries history, management and life history can be found in Christie et al. (2025) and Choi (2023) and references therein. The SSE is the southern-most extreme of Snow Crab's distributional range in the northwest Atlantic, influenced by the convergence of numerous oceanic currents, bathymetric complexity and rapid ecosystem and climate change. All approaches, therefore,

attempt to address the high temporal and spatial variability in their distributions and can be found in the "bio.snowcrab" R-Library (Choi 2023) which leverages the statistical computing language and environment of R (R Development Core Team 2023) and Julia/Turing (Bezanson et al. 2017, Ge et al. 2018). More details on methods can be found in Christie et al. (2025).

FISHERIES DATA

Due to important differences in the spatial and temporal distribution of Snow Crab and fishing effort, complexities of crab behavior (movement, aggregation), fishers' behavior (knowledge, experience, bait and trap types), and variability of environmental conditions, fishery catch rates are biased indicators of Snow Crab abundance and so not used as an abundance index.

Mandatory commercial fishing logbooks (completed onboard fishing vessels by the captain) provide information on location, effort (number of trap hauls), landings (verified by 100% dockside monitoring), and interactions with at risk species. The data are stored in the Maritimes fisheries information system (MARFIS) database (DFO Maritimes Region, Policy and Economics Branch, Commercial Data Division).

At-sea-observer data collected from a random subset of fishing events provides information on biological characteristics of the catch, including bycatch information (Figure 2). The target coverage is set at 5% in S-ENS and N-ENS, and 10% for 4X of total landings. In 2024, realized coverage was 1.3%, 2.4% and 0%, respectively. The data are stored in the industry survey database (ISDB).

More information on fisheries data processing and methods can be found in Christie et al. 2025.

MARITIMES REGION SNOW CRAB TRAWL SURVEY DATA

This assessment focuses upon data collected from the annual Maritimes snow crab trawl survey supported by funding from the snow crab fishing industry through a collaborative agreement with DFO. All planned survey stations were completed in 2024 (Figure 3). The data are stored in the ISDB. Data checking and quality control analyses are conducted using the open-sourced "bio.snowcrab" R-Library. More details on methods, survey design, ecosystem indicators, and data sources can be found in Choi (2023) and Christie et al. (2025).

RESULTS

FISHERY

Effort

Fishing effort in 2024 was 11,400, 78,600 and 100 trap hauls in N-ENS, S-ENS, and 4X, respectively. Relative to the previous year, this represents an increase of 20%, 26.6%, and a decline of 90%, respectively, (Table 2–4). The 4X fishery is ongoing at the time of assessment. Fishing effort was spatially more dispersed in 2024 relative to 2023 (Figures 4–5) in most areas; however, some contraction was apparent in 4X.

Landings

Landings in 2024 were 934 t, 7,314 t, and 5 t in N-ENS, S-ENS, and 4X (season ongoing), respectively. Relative to the previous year, this represents a decline of 3.9%, 0.4%, and 78.3%, respectively (Tables 2–4). TACs for 2024 were 938 t, 7,345 t, and 20 t, respectively. As with effort, landings were spatially dispersed in most areas with the exception of 4X (Figures 6–7).

Catch Rates

Non-standardized fishery catch rates in 2024 were 82, 93, and 39 kg/trap haul in N-ENS, S-ENS, and 4X (season ongoing), respectively. Relative to the previous year, they represent decreases of 20.4% in N-ENS and 21.2% in S-ENS, and an increase of 77.3% in 4X (season ongoing) relative to the previous year (Tables 2–4). Declines in catch rates were notable in the inshore areas of N-ENS, and in CFA24 (Figures 8–9).

Discard of Snow Crab

Discards of Snow Crab (sublegal, immature, soft-shelled and females) have been increasing in N-ENS and S-ENS since 2022, though still within the historical range (Figure 10). There are no data for discards in 4X.

Discard of soft-shelled Snow Crab

Generally, higher catches of soft-shelled crab indicate incoming recruitment to the fishery. Though a good sign of strong biological production, their handling can cause unnecessary mortality. Commercial catch of soft-shelled crab was 0% in N-ENS and 16.5% in S-ENS for 2024. However, at-sea-observer sampling was low. For 4X, there was no sampling, with the season ongoing; however, they have been historically low, due largely to their winter season and low recruitment in general (Tables 5–7, Figure 11).

Discard of non-target species (Bycatch)

The bycatch in this fishery are primarily other crustaceans, Atlantic Cod, Halibut and Sea Cucumber, but at very low levels (Tables 8–10). On average, 0.02% and 0.03% of landings were bycatch in N-ENS and S-ENS, respectively. In 4X, there are no current data, but historically they have been, on average, 0.87% of landings.

Bitter crab disease

Bitter crab disease is caused by a *Hematodinium* dinoflagellate and is observed world-wide. In the SSE, they are found at low-levels of prevalence, with an infection rate of < 0.1% (Christie et al 2025).

ECOSYSTEM

Bottom temperatures

Average bottom temperatures observed in the 2024 snow crab trawl survey have returned to historical ranges, after worrisome highs in 2022 (Figures 12–14). Bottom temperatures are more stable in N-ENS than S-ENS. 4X exhibits the most erratic and highest annual mean bottom temperatures.

Interspecific interactions

The potential prey items (Figure 15) seen in the context of multivariate ordinations indicate that prey species occur in colder temperatures (right of Snow Crab in Figure 15). In contrast, potential predators (Figure 16) are found in warmer and deeper associations (left and bottom of Snow Crab in Figure 16). The warm water incursions since 2012, and especially 2022, resulted in predators co-occupying formerly Snow Crab habitats while simultaneously losing access to cold water preferring prey. Figures in Appendix C (C27–C30) provide more details on axes interpretations.

As Snow Crab are 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).

The temporal and spatial co-occurrence of some of these key predators, prey, and competitors in Snow Crab habitat are shown in Appendix C.

Viable habitat

Snow Crab being cold water stenotherms, stability of environmental conditions is critical for their survival. However, it is not just temperature that is in control, but rather, where the temperature is good in combination with substrate, depths, co-occurring species, etc. The SSE is at the confluence of many oceanic currents that render the area highly variable. Rapid species composition change, rapid climate change, and climatic uncertainty, in general, exacerbate this situation. The viable habitat is an index that accounts for these additional factors (Figures 17, 18). Habitat viability is highest in S-ENS, even though temperatures are more stable in N-ENS (Figure 17). Even with ameliorations in temperatures in 2024, overall habitat viability has declined (Figure 18). CFA 4X showed a slight improvement, however, the overall trend has been downwards since 2010. Even with amelioration of bottom temperatures in 2024, previous habitat space seems to have been overtaken by competitors and predators in 4X. Favourable habitat in 2024 was found in the inner trench and Glace Bay Hole of N-ENS, north of Sable Island and south of Misaine Bank in S-ENS, and south of Lunenburg in 4X (Figure 18).

STOCK STATUS INDICATORS

Growth

Growth patterns have been updated and shown in Figure 19. They identify a clear growth pattern in both males and females. Work continues towards a size-structured fishery model.

Recruitment

Using the growth information, the minor recruitment mode of immature male crab in N-ENS (Figure 20) centered on 85 mm carapace width (CW) is approximately an instar 10-11 (Figure 19b, 19d). This group should begin to recruit into fishable size in 1–3 years. In S-ENS, a stable stage size structure exists, and continued recruitment is expected for the upcoming years. In 4X, erratic inter-annual patterns of growth stages are evident with minimal to low recruitment. The small mode near 68 mm CW is in the range of instar 10 and so this recruitment can be expected to begin in 3 years.

Reproduction

In all areas, continued recruitment of female crab into the mature (egg-bearing) stage of the population was observed (Figure 21). However, in N-ENS and 4X there has been a decline in numerical densities of both the mature and adolescent females since 2017. In S-ENS there has been an increase since 2021. Egg and larval production are expected to be moderate to high in the next year in all areas except N-ENS (Figure 22). Spatially, female crabs tend to be found in shallower water (Figure 23). The immature mode at 24 mm CW in Figure 21 represents instar 6 crab and will likely enter the mature female population in another 3 to 4 years. A notable

absence of immature females is evident in 4X (Figure 21). Note that females are not exploited and as such this absence may be due to elevated mortality caused by predation and habitat loss.

Sex Ratios

When sex ratios are extremely out of balance, there is a possibility of reproductive limitation. Females can mate with multiple males but there are dangers in that males will fight with each other and result in harm to the female in the process. Mating with large males is protective and likely responsible for the selection of sexual dimorphism. As the longevity of males is a few years longer than females, and females mature a few years earlier than males, a strong year-class will generate a natural cycle in sex ratios. We observe such cycles in the SSE, especially in N-ENS (Figures 24–25). S-ENS cyclicity has subsided, suggesting the influence of multiple strong year classes. 4X is now dominated by mature females, a condition that is also commonly observed in the Southern Gulf of St. Lawrence population. The differential (elevated) mortality of immature males indicates either predation (e.g., lobsters, groundfish), cannibalism (by females), competition/movement for ideal habitat space (which is limited) or human over-exploitation.

The spatial patterns of the sex ratios are generally distinct: mature males are found in greater proportion (blue) in central areas in ENS, whereas females (red) are found in greater proportion in areas bordered by warm water, on the outer geographical margins of Snow Crab distributions on the SSE (Figure 25). When such spatial segregation is observed, the sexes are likely exposed to differential predation effects. Curiously, based upon co-occurrence of predators with Snow Crab (Figure 16), the females should be exposed to greater predation effects. Yet, in 4X the immature males seem disproportionately vulnerable to natural mortality. Competition for limited habitat space and female cannibalism of males are the leading hypotheses for this observation in 4X at present.

Biomass density

The fishable component is defined as Snow Crab that are male, mature, and larger than 95 mm CW. The crude, unadjusted, geometric mean fishable biomass density (per unit swept area by the snow crab survey trawl) are shown in Figures 26–27. The historical record suggests a single peak in density in all areas: 2011 in N-ENS, 2010–2016 in S-ENS, and 2009 in 4X. Currently, densities are in the historical range for N- and S-ENS, but at historical lows in 4X. Biomass density, however, does not equate to total biomass as the areas (Figure 18) occupied by Snow Crab can contract, expand, and shift with environmental conditions and ecosystem change. In 2024, highest densities were found in Glace Bay Hole in N-ENS, south of Misaine Bank in S-ENS, and south of Lunenburg in 4X (Figure 27).

Biomass index

The fishable **biomass index** (adjusted for covariates and autocorrelation and expanded to total habitat surface area; Figure 28) shows three peaks in N-ENS and S-ENS with an approximately 10-year separation, and a single peak in 4X in 2009. Currently, biomass indices are near historical lows in all areas. The spatial distribution of the fishable biomass suggests high biomass clusters in the same areas as biomass density (Figure 29).

Modelled Biomass

In N-ENS, the **modelled biomass** (pre-fishery) of Snow Crab in 2024 was 2.7 kt, relative to 3.4 kt in the previous year (Figure 30). In S-ENS, the 2024 modelled biomass (pre-fishery) was 41.5 kt, relative to 40.6 kt in the previous year. In 4X, the modelled biomass (pre-fishery) for the

2024–2025 season was 0.18 kt, relative to 0.14 kt in the previous season. There is a continuing decrease in modelled biomass in N-ENS since 2021, and since 2019 in S-ENS and 4X.

Fishing Mortality

In N-ENS, the 2024 fishing mortality is estimated to have been 0.32 (annual exploitation rate of 37%), up from 0.26 (annual exploitation rate of 30%; Figure 31) in the previous year.

In S-ENS, the 2024 fishing mortality is estimated to have been 0.17 (annual exploitation rate of 18.6%), while in the previous year it was 0.18 (annual exploitation rate of 19%; Figure 31). 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 2024–2025 season (ongoing) fishing mortality is currently estimated to be 0.052 (annual exploitation rate of 5%), while in the previous season it was 0.27 (annual exploitation rate of 31%; Figure 31). Localized exploitation rates are likely higher, as not all areas for which biomass is estimated are fished.

REFERENCE POINTS AND HARVEST CONTROL RULES

The application of a precautionary approach in DFO's fishery decision-making framework is based on reference points and harvest control rules (DFO 2009). In the context of natural resource management, the precautionary approach (PA) identifies the importance of care in decision making by taking into account uncertainties and avoiding risky decisions. Natural ecosystems being intrinsically complex, unexpected things can and often do happen. The primary tools of fishery management are the control of fishing effort and removals. Generally, by reducing catch and effort, stock status and/or ecosystem context is expected to improve, though of course, the failure of the groundfish moratoria indicates other factors can be more important. (Smith et al. 2012; DFO 2023).

The operationally defined reference points associated with the 4VWX Snow Crab fishery are as follows (Figure 32):

- **Limit reference point (LRP):** 25% of estimated carrying capacity (K)
- **Upper stock reference (USR):** 50% of estimated carrying capacity (K)
- **Removal reference (RR):** $F_{MSY} = r/2$

The current estimates of these parameters are shown in Table 11.

Harvest control rules

The operational target exploitation varies as a function of stock status within the established stock status zones (Figure 32). Annual exploitation rates between 10% to 30% of the available biomass are targeted in the healthy zone. In the cautious zone, annual exploitation rates between 0% to 20% have been targeted. In the critical zone, fishery closure is considered with the intent to keep removals from the stock at the lowest possible level and promote stock growth. Other biological and ecosystem considerations such as recruitment, spawning stock (female) biomass, size structure, sex ratios, and environmental and ecosystem conditions provide additional context within each range.

The above thresholds are represented in Figure 33. They suggest that:

- N-ENS is in the cautious zone, though with some important overlap with other zones
- S-ENS is in the healthy zone, though with some overlap with other zones

- 4X is in the critical zone.

It should be noted that using these parameters assume that the population dynamics are well described by the fishery model. This is, of course, not true. The SSE Snow Crab population, nor the encompassing SSE is not at, nor near, any equilibrium state. As a result, the parameter estimates derived from the logistic model provide, at best, first order estimates of the true biological reference points. Further, the observation of fisheries catch is assumed to be known without error. This is not true as incorrect data entries, spikes in mortality due to handling of soft-shelled crab, as well as illegal and unreported exploitation occur. These and other unaccounted factors can easily bias parameter estimates.

SOURCES OF UNCERTAINTY

Marine protected areas (MPAs) continue to be developed. The presence of a refuge from fishing activities is potentially positive for Snow Crab. However, effects upon other organisms (predators or prey) can have counter-balancing indirect effects. The overall long-term effects of MPAs upon Snow Crab are unknown.

Capture of soft-shell Snow Crab is always a concern and leads to uncertainty related to the survival of these Snow Crab when returned to the water. Prompt and careful return of soft crab to the water is an important conservation measure that will enhance the 2–3 year productivity of the fishable component.

Illegal and unreported fishing activities have the potential to hinder the application of a precautionary approach to the management of this resource and cause potential bias and elevates the uncertainty in the estimation of reference points.

Elevated natural mortality of immature crab in the SSE are likely due to environmental stressors and predation, factors beyond our control.

CONCLUSIONS

The SSE continues to experience rapid ecosystem and climatic variations. Under such conditions, it is prudent to be careful.

NORTH-EASTERN NOVA SCOTIA

In N-ENS, recruitment continues at low levels. Total mortality exceeded recruitment in 2024. The N-ENS stock is in the cautious zone.

SOUTH-EASTERN NOVA SCOTIA

In S-ENS, recruitment to the fishery continues at a sustainable rate for the upcoming season matching total mortality. The S-ENS stock remains in the healthy zone.

AREA 4X

In 4X, low recruitment is expected to continue for another three years. Viable habitat has been minimal for many years. Total mortality is now in approximate balance with recruitment. CFA 4X is in the critical zone.

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TABLES

Table 1. Snow Crab fishing seasons on the Scotian Shelf in 2023. 4X fishing season spans over two calendar years.

Area	Season
North-Eastern Nova Scotia (N-ENS)	10 April 2024 – 18 August 2024
South-Eastern Nova Scotia (S-ENS) crab fishing area 23 (CFA 23)	15 March 2024 – 31 August 2024
South-Eastern Nova Scotia (S-ENS) crab fishing area 24 (CFA 24)	15 March 2024 – 31 August 2024
4X	1 November 2024 – March 31, 2025

Table 2. Fishery performance statistics in North-Eastern Nova Scotia (N-ENS). Units are: total allowable catch (TAC) and landings (tons, t), effort (x10^3 trap hauls) and catch per unit effort (CPUE) (kg/trap haul).

Year	Licenses	TAC (t)	Landings (t)	Effort (1000 th)	CPUE (kg/th)
2014	78	783	781	6.9	114
2015	78	624	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	7.7	108
2021	78	890	901	8.8	102
2022	78	979	975	8.6	113
2023	78	981	972	9.5	103
2024	78	938	934	11.4	82

Table 3. Fishery performance statistics in South-Eastern Nova Scotia (S-ENS). Units are: total allowable catch (TAC) and landings (tons, t), effort (x103 trap hauls) and catch per unit effort (CPUE) (kg/trap haul).

Year	Licenses	TAC (t)	Landings (t)	Effort (1000 th)	CPUE (kg/th)
2014	116	11,311	11,265	96.3	117
2015	116	11,311	11,295	103.9	109
2016	115	9,614	9,606	87.3	110
2017	115	6,730	6,718	69.9	96
2018	115	6,057	6,063	51.3	118
2019	115	6,663	6,612	61.7	107
2020	115	8,161	7,951	63.8	125
2021	115	8,161	8,332	80.8	103
2022	115	7,345	7,323	56.5	130
2023	115	7,345	7,342	62.1	118
2024	115	7,345	7,314	78.6	93

Table 4. Fishery performance statistics in 4X. Units are: total allowable catch (TAC) and landings (tons, t), Effort (x10^3 trap hauls) and catch per unit effort (CPUE) (kg/trap haul).

Year	**Licenses**	**TAC (t)**	**Landings (t)**	**Effort (1000 th)**	**CPUE (kg/th)**
2014	9	80	82	2.5	33
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	-
2019	9	55	59	1.1	51
2020	9	80	76	1.6	49
2021	9	110	110	3.1	36
2022	9	125	38	2.3	17
2023	9	55	23	1	22
2024	9	20	5	0.1	39

Table 5. Soft-shell incidence of male Snow Crab > 95 mm CW in North-Eastern Nova Scotia from snow crab surveys. The two definitions of soft-shelled crab are: (D) based on durometer measurements < 68 on the hardness scale; and (CC) based upon classification of carapace condition.

Year	Soft (D)	Total (D)	Soft (CC)	Total (CC)
2004	2.5	3525	6.7	3724
2005	18.1	4476	14.1	4510
2006	4.4	3270	13.6	3285
2007	38.9	1148	54.1	1151
2008	29.9	3796	32.5	3813
2009	3.3	4680	3.5	4852
2010	1.9	2972	2.9	3001
2011	1.3	1527	1.9	1528
2012	9.2	1680	2.9	1684
2013	1.7	1393	2.7	1405
2014	2.6	1719	18.5	1731
2015	0.5	1375	3	1594
2016	0.2	859	1.3	871
2017	4	2320	9.4	2338
2018	27.8	2557	34.6	2731
2019	3.4	1874	2.5	1884
2020	5	119	27.7	119

Table 6. Soft-shell incidence of male Snow Crab > 95 mm CW in South-Eastern Nova Scotia from snow crab surveys. The two definitions of soft-shelled crab are: (D) based on durometer measurements < 68 on the hardness scale; and (CC) based upon classification of carapace condition.

Year	Soft (D)	Total (D)	Soft (CC)	Total (CC)
2004	2.6	35315	6.5	38162
2005	5.7	33570	16.3	36583
2006	6.6	28144	23.5	29199
2007	9.2	27035	24.6	27153
2008	12.3	41833	18.6	43723
2009	14.6	59055	15.7	60269
2010	8.3	61285	12.3	66016
2011	7.5	43823	9.8	45608
2012	7.4	50269	10.5	52593
2013	1.9	18179	3.1	18639
2014	2.8	18203	16.8	19487
2015	3.3	23184	9.4	23254
2016	2.9	23989	3.5	26519
2017	1.5	20172	6.2	21086
2018	2.7	10335	5.8	10531
2019	2	10285	4.9	10305
2020	7.9	1749	45.2	1749
2021	7.4	5028	11.2	5042
2022	4.3	2961	6.4	2970
2023	2.5	2751	15.9	2759
2024	5.7	5497	16.5	5542

Table 7. Soft-shell incidence of male Snow Crab > 95 mm CW in 4X from snow crab surveys. The two definitions of soft-shelled crab are: (D) based on durometer measurements < 68 on the hardness scale; and (CC) based upon classification of carapace condition.

Year	Soft (D)	Total (D)	Soft (CC)	Total (CC)
2004	0.4	1917	2.1	1926
2005	0	2665	11.8	2672
2006	0.1	2203	0.5	2215
2007	1.2	4362	0.3	4399
2008	1.1	2460	0.5	2515
2009	2.3	2791	0.5	2799
2010	1.6	4432	1.3	4545
2011	0.4	4177	0.2	4193
2012	0.7	1900	0.8	1909
2013	2	1422	4.4	1866
2014	4.5	1552	14.8	1557
2015	3.5	2003	10.8	2013
2016	2.8	863	11.5	968
2017	5.6	447	15.6	821
2020	0.9	455	0.2	456

Table 8. Bycatch (kg/yr) estimated for the North-Eastern Nova Scotia snow crab fishery. Estimates are extrapolated from at-sea observed bycatch, using the ratio of at-sea observed effort and total fisheries effort (trap hauls). Averages are calculated for 2004–2024. Note data are a subset of all logbook data for which georeferencing was valid. Dash indicates no data.

Species	2020	2021	2022	2023	2024	Average (2004–2024)
Atlantic Cod	–	.	576	.	.	34
Witch Flounder	–	–	–	–	–	1
Greenland Cod	–	–	–	–	–	1
Atlantic Rock Crab	–	–	288	–	–	13
Toad Crab unidentified	–	–	–	–	–	18
Hyas coarctatus	–	–	–	–	–	2
Northern Stone Crab	–	–	–	–	–	28
Toad Crab	–	–	–	–	–	21
Asterias rubens	–	–	–	–	–	2
Mud Star	–	–	–	–	–	4
Sand Dollars	–	–	–	–	–	3
Jellyfishes	–	–	–	–	–	18
Total	–	–	864	–	–	145
Fishery Landings (kg)	792,363	857,719	851,383	877,954	906,298	723,303
Fishery Effort (trap hauls)	7,039	7,770	7,195	7,757	10,422	9,136
At sea observed catch-snow crab and bycatch species (kg)	5,584	–	2,638	2,238	11,764	47,257
At sea observed effort (trap hauls)	25	–	24	30	182	401

Table 9. Bycatch (kg/yr) estimated for the South-Eastern Nova Scotia snow crab fishery. Estimates are extrapolated from at-sea observed bycatch, using the ratio of at-sea observed effort and total fisheries effort (trap hauls). Averages are calculated for 2004–2024. Note data are a subset of all logbook data for which georeferencing was valid. Dash indicates no data.

Species	2020	2021	2022	2023	2024	Average (2004-2024)
Atlantic Cod	–	–	–	1022	574	189
Haddock	–	–	–	273	–	12
White Hake	–	–	–	.	–	5
Pollock	–	–	–	68	–	3
Redfish unseparated	–	649	–	170	328	88
Atlantic Halibut	–	–	–	–	–	186
American Plaice	–	–	–	–	55	6
Witch Flounder	–	–	–	–	55	3
Winter Flounder	–	–	–	–	–	2
Flounder unidentified	–	–	–	–	–	2
Striped Atlantic Wolffish	–	–	263	–	219	72
Spotted Wolffish	–	–	–	–	–	79
Northern Wolffish	–	–	–	204	–	13
Wolffish Unidentified	–	–	–	–	–	4
Brill Windowpane	–	–	–	–	–	2
Thorny Skate	–	–	–	–	–	38
Winter Skate	–	–	–	–	–	7
Longhorn Sculpin	–	–	–	–	–	4
Sculpins	–	–	–	–	–	2
Sea Raven	–	–	–	68	–	10
Eelpouts	–	–	–	–	–	1
Pandalus borealis	–	–	–	–	–	2
Jonah Crab	141	.	.	–	2,863	440
Atlantic Rock Crab	–	–	–	–	657	32
Toad Crab unidentified	–	–	–	–	.	201
Northern Stone Crab	141	–	–	–	3,210	462
Spiny Crab	–	–	–	–	383	373
Toad Crab	–	–	–	–	274	43
Green Crab	–	–	–	–	–	1
American Lobster	–	–	–	–	–	236
Paguroidea	–	–	–	–	55	25
Whelks	–	–	–	–	176	11
Asteroidea	–	–	–	–	–	7
Purple Sunstar	–	–	–	–	–	1
Spiny Sunstar	141	–	–	–	–	7
Brittle Star	–	–	–	–	–	2
Basket Stars	–	–	–	–	–	6
Sea Urchins	–	–	–	–	55	5
Sand Dollars	–	–	–	–	55	3
Holothuroidea	–	325	88	–	745	131
Aglantha digitale	–	–	–	–	–	1
Total	422	974	350	1,806	9,730	2,715
Fishery Landings (kg)	778,8053	816,7228	718,2499	711,8097	705,4193	843,9754
Fishery Effort (trap hauls)	64,703	77,380	57,344	66,099	74,957	79,213
At sea observed catch-snow crab and bycatch species (kg)	46,935	89,373	94,465	127,990	16,7731	640,642
At sea observed effort (trap hauls)	367	737	640	761	1,530	4,788

Table 10. Bycatch (kg/yr) estimated for the 4X crab fishery. Estimates are extrapolated from at-sea observed bycatch, using the ratio of at-sea-observed effort and total fisheries effort (trap hauls). Averages are calculated for 2004–2024. Note data are a subset of all logbook data for which georeferencing was valid. Dashes indicate no data. NS – no at-sea sampling; ND – data not recorded.

Species	2020	2021	2022	2023	2024	Average (2004-2020)
Atlantic Cod	–	–	–	–	–	3
Redfish unseparated	–	–	–	–	–	3
Thorny Skate	–	–	–	–	–	4
Sea Raven	–	–	–	–	–	32
Lumpfish	–	–	–	–	–	2
Atlantic Hookear Sculpin	–	–	–	–	–	1
Jonah Crab	–	–	–	–	–	202
Atlantic Rock Crab	–	–	–	–	–	4
Toad Crab unidentified	–	–	–	–	–	161
Northern Stone Crab	–	–	–	–	–	708
Spiny Crab	–	–	–	–	–	61
Toad Crab	–	–	–	–	–	7
Red Deepsea Crab	–	–	–	–	–	215
American Lobster	–	–	–	–	–	73
Total	–	–	–	–	–	1,475
Fishery landings (kg)	73,558	109,324	38,373	22,565	4,205	169,691
Fishery effort (trap hauls)	1,416	3,420	2,269	1,061	110	9,194
At sea observed catch-snow crab and bycatch species (kg)	2,653	NS	378	NS	NS	13,223
At sea observed effort (trap hauls)	62	NS	ND	NS	NS	387

Table 11. Reference points from the logistic biomass dynamics fishery model for snow crab fishing areas.: K is carrying capacity (kt); and r is intrinsic rate of increase (non-dimensional) and q is the catchability coefficient (non-dimensional). Note that FMSY (fishing mortality associated with 'maximum sustainable yield') is r/2 in this model (non-dimensional). Similarly, BMSY (biomass associated with 'maximum sustainable yield'; kt) is K/2. Numbers in parentheses () indicate the posterior standard deviation.

Parameter	North-Eastern Nova Scotia (N-ENS)	South-Eastern Nova Scotia (S-ENS)	4X
q	0.53 (0.12)	0.69 (0.15)	0.23 (0.08)
r	0.95 (0.1)	0.93 (0.12)	0.93 (0.1)
K (kt)	5.74 (0.94)	69 (9.71)	1.83 (0.34)
Prefishery Biomass (kt)	2.72 (0.84)	41.47 (10.48)	0.18 (0.17)
Fishing Mortality	0.316 (0.086)	0.171 (0.038)	0.052 (0.077)

FIGURES

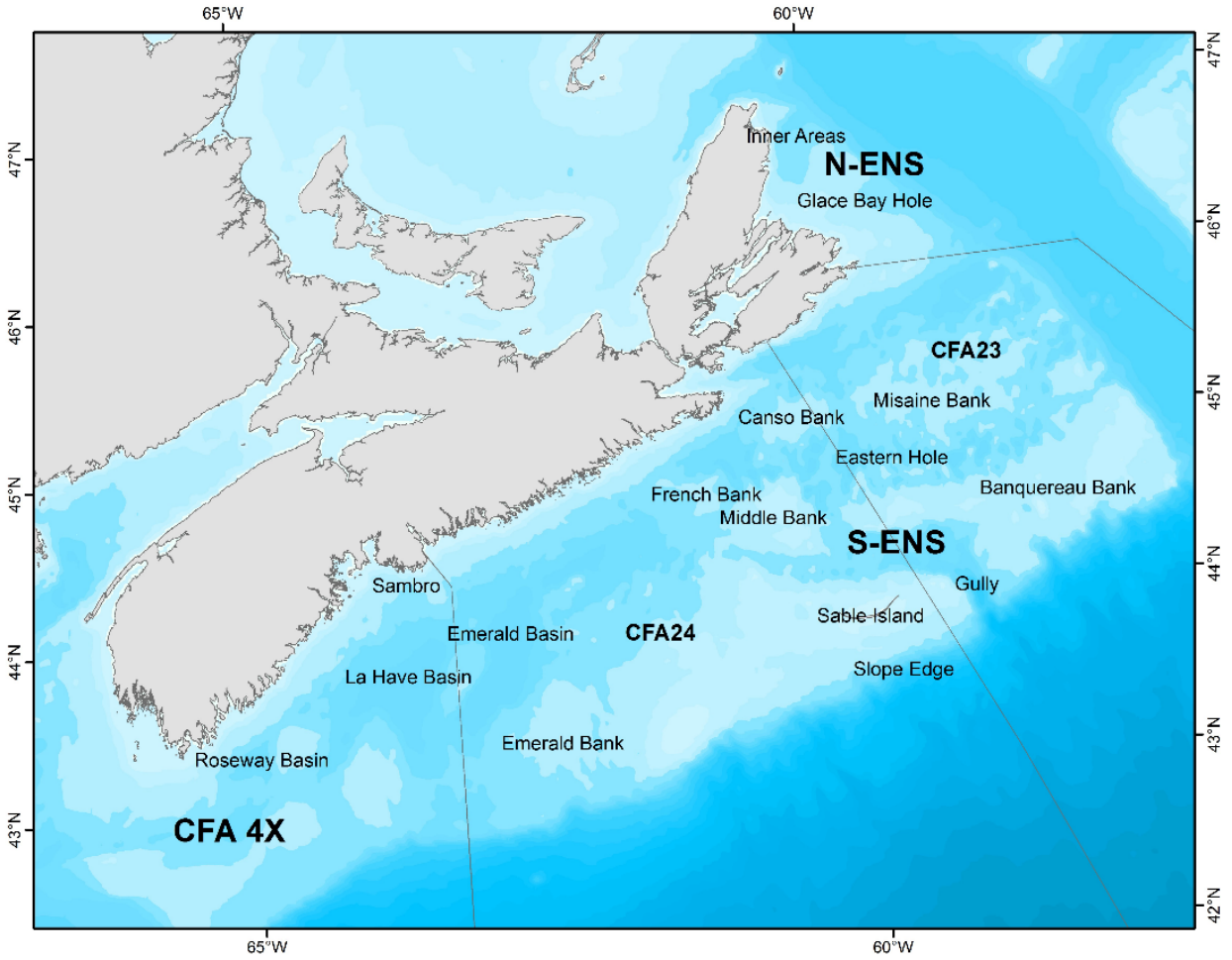


Figure 1. Map of the Scotian Shelf Ecosystem (SSE) and crab fishing areas (CFA). S-ENS is further subdivided for management into CFA 23 to the northeast and CFA 24 to the southwest.

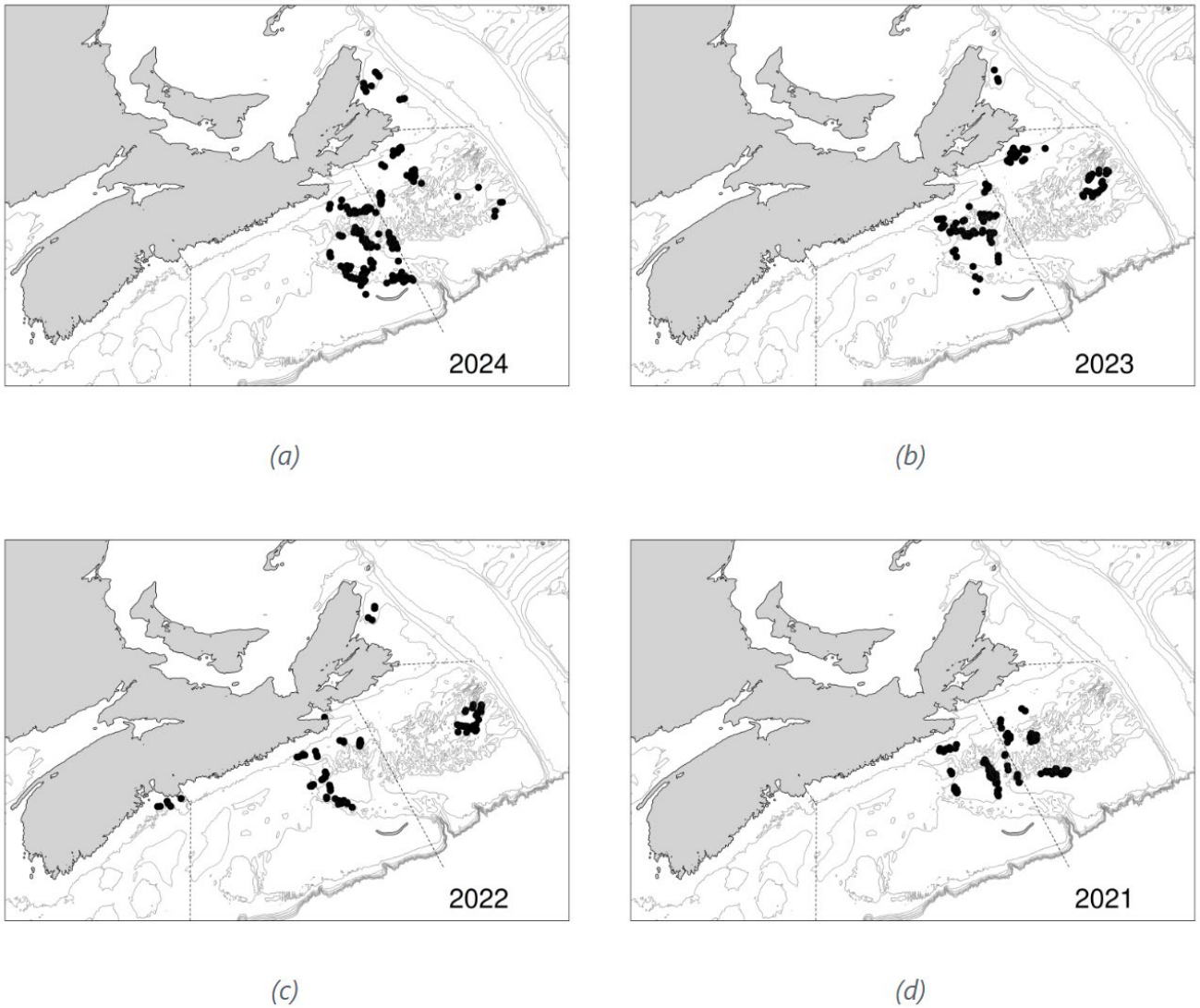


Figure 2. Locations of at-sea observations of snow crab fishing activities from 2021–2024. Numbers indicate year.

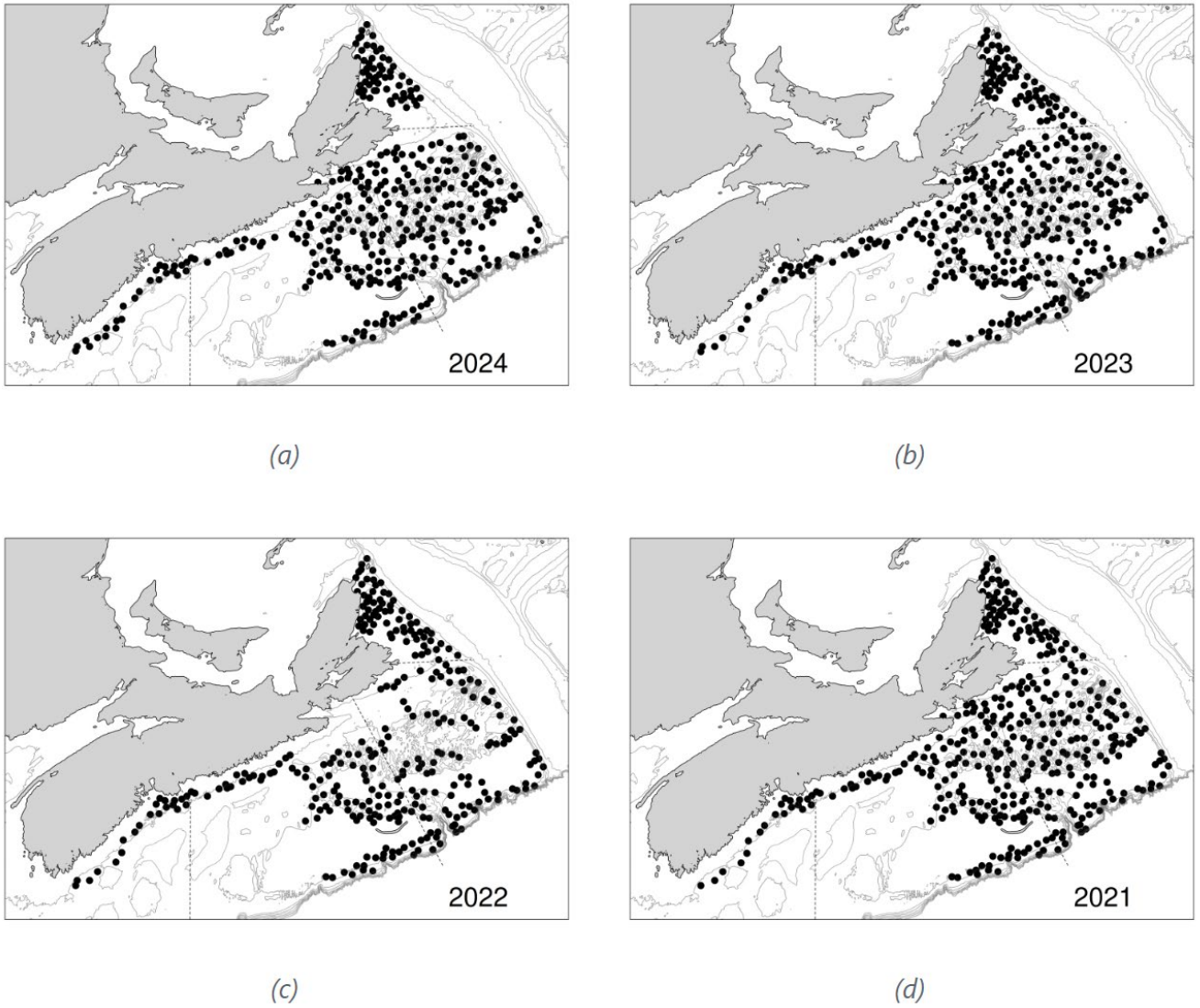


Figure 3. Snow crab trawl survey station locations from 2021–2024. Numbers indicate year.

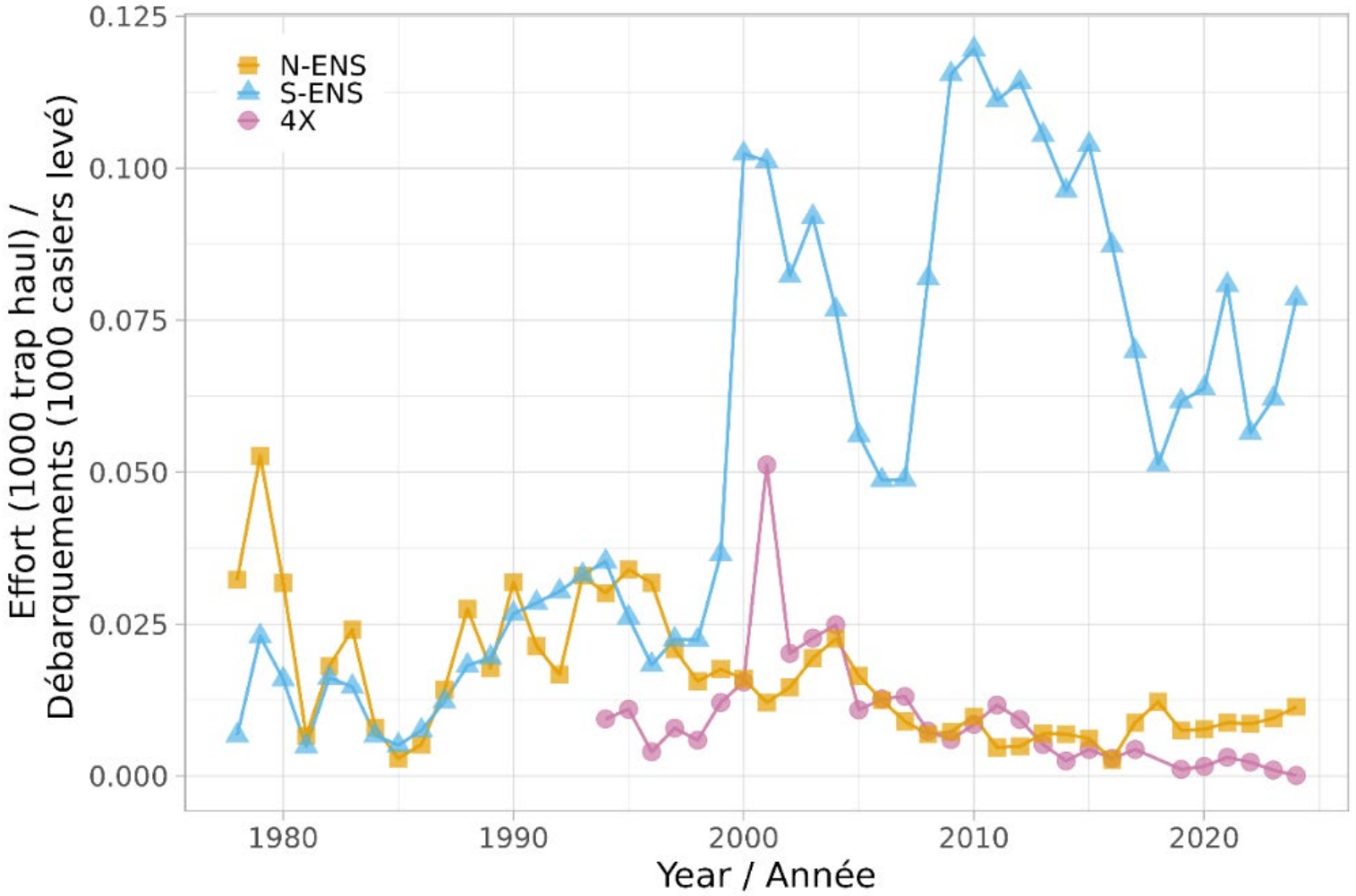


Figure 4. Temporal variations in the fishing effort for Snow Crab on the Scotian Shelf, expressed as the number of trap hauls (x10^3). Year in 4X refers to the year at the start of the fishing season. No fishery occurred in 4X for the 2018 season.

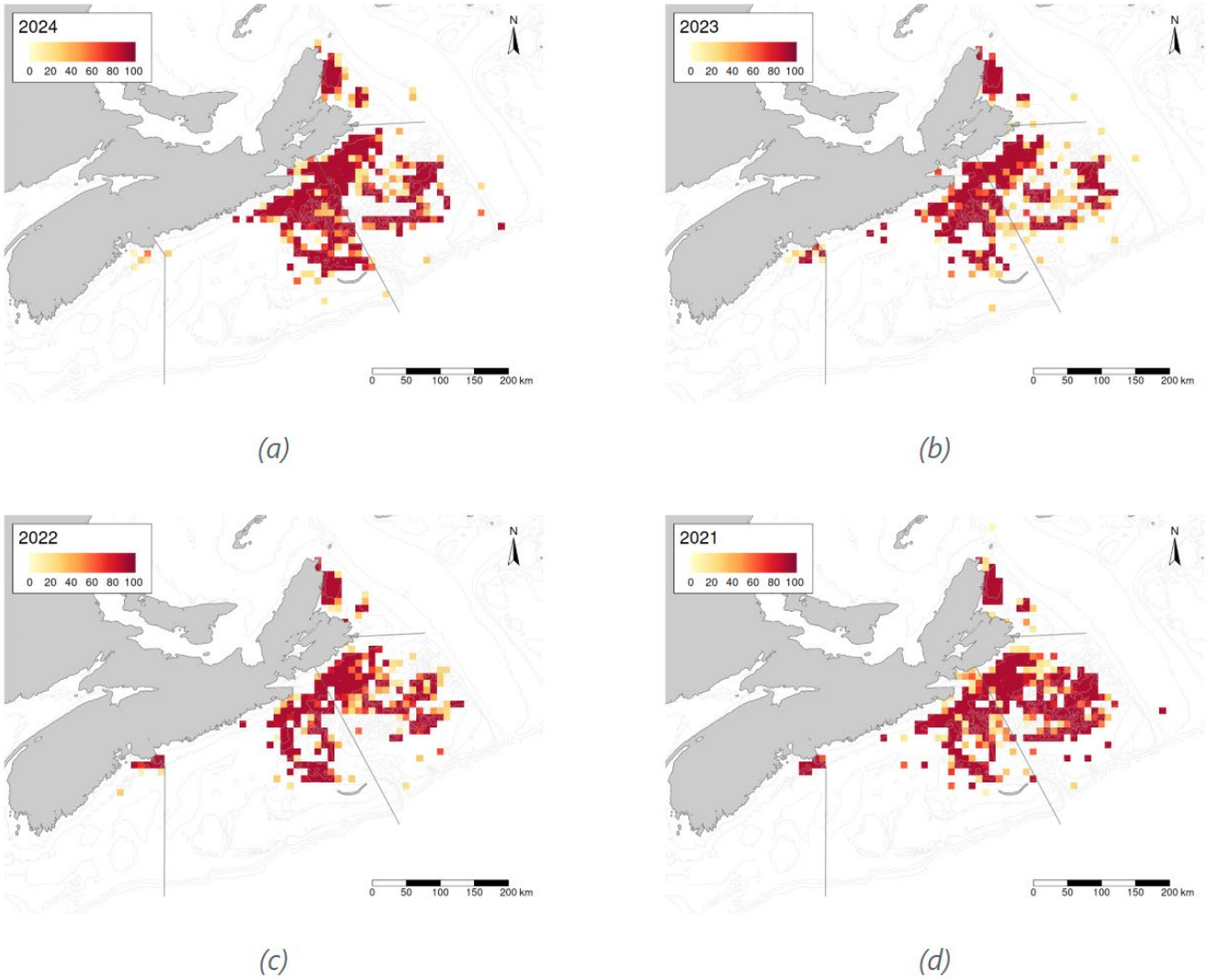


Figure 5. Snow crab fishing effort (number of trap hauls x 10^3 per 10 km x 10 km grid) based on fisheries logbook data for 2021–2024.

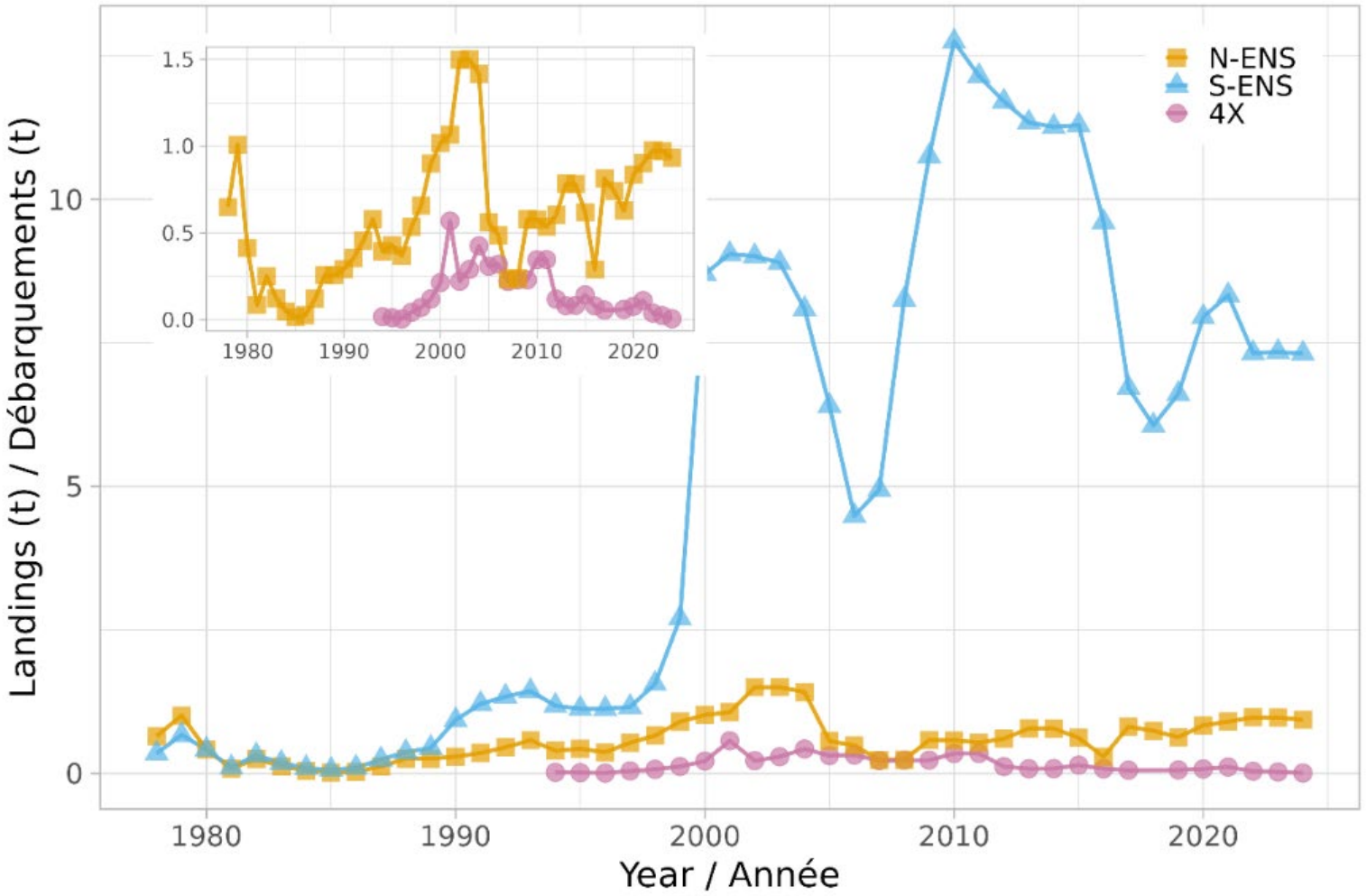


Figure 6. Landings (t) of Snow Crab on the Scotian Shelf (SSE). For 4X, the year refers to the starting year of the season. Inset is a closeup view of the time series of North-Eastern Nova Scotia (N-ENS) and 4X fisheries. Note that there was no quota allotted in 2018 for the 4X fishery. S-ENS – South-Eastern Nova Scotia.

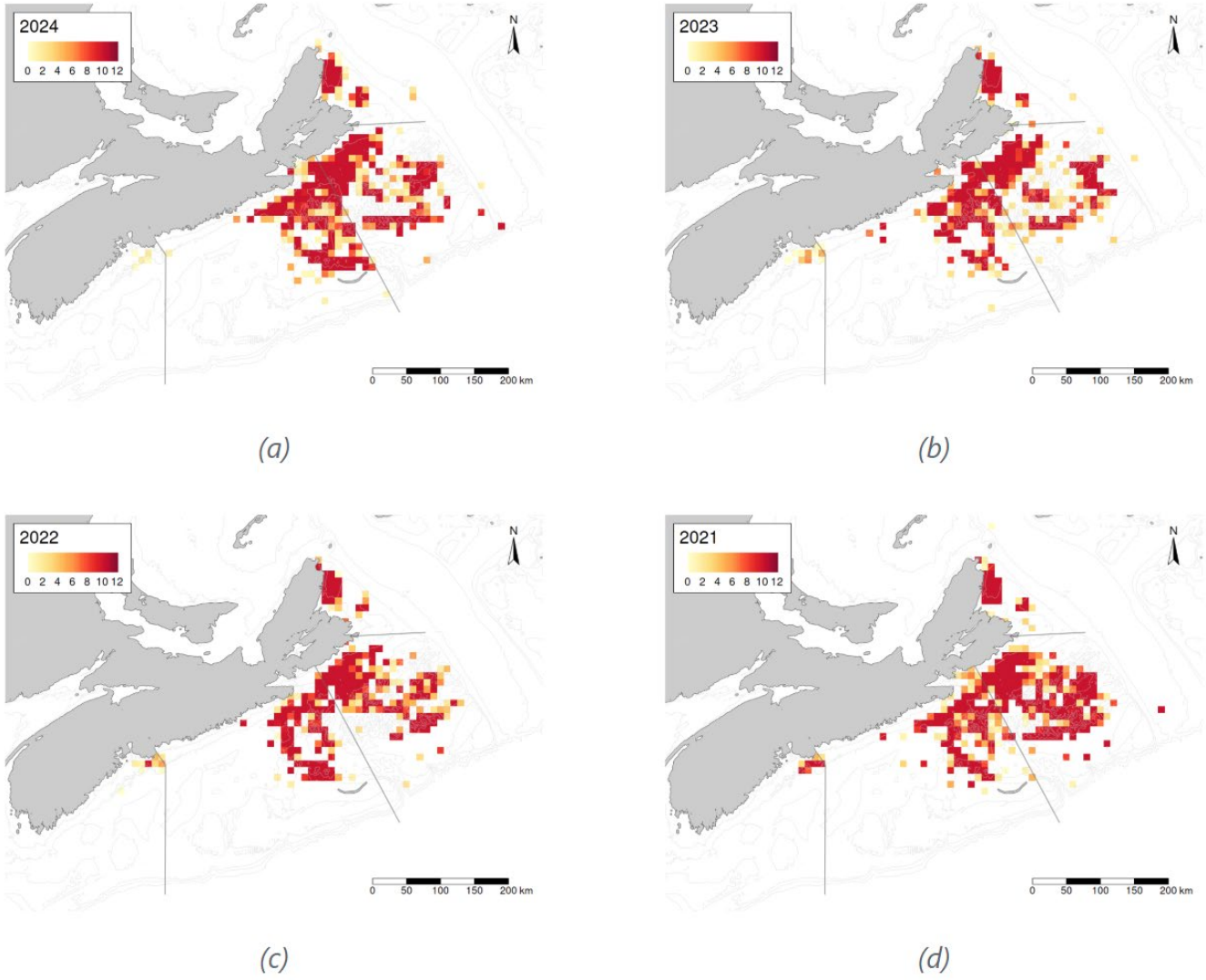


Figure 7. Snow Crab landings (tons per 10 km x 10 km grid) based on fisheries logbook data from 2021–2024.

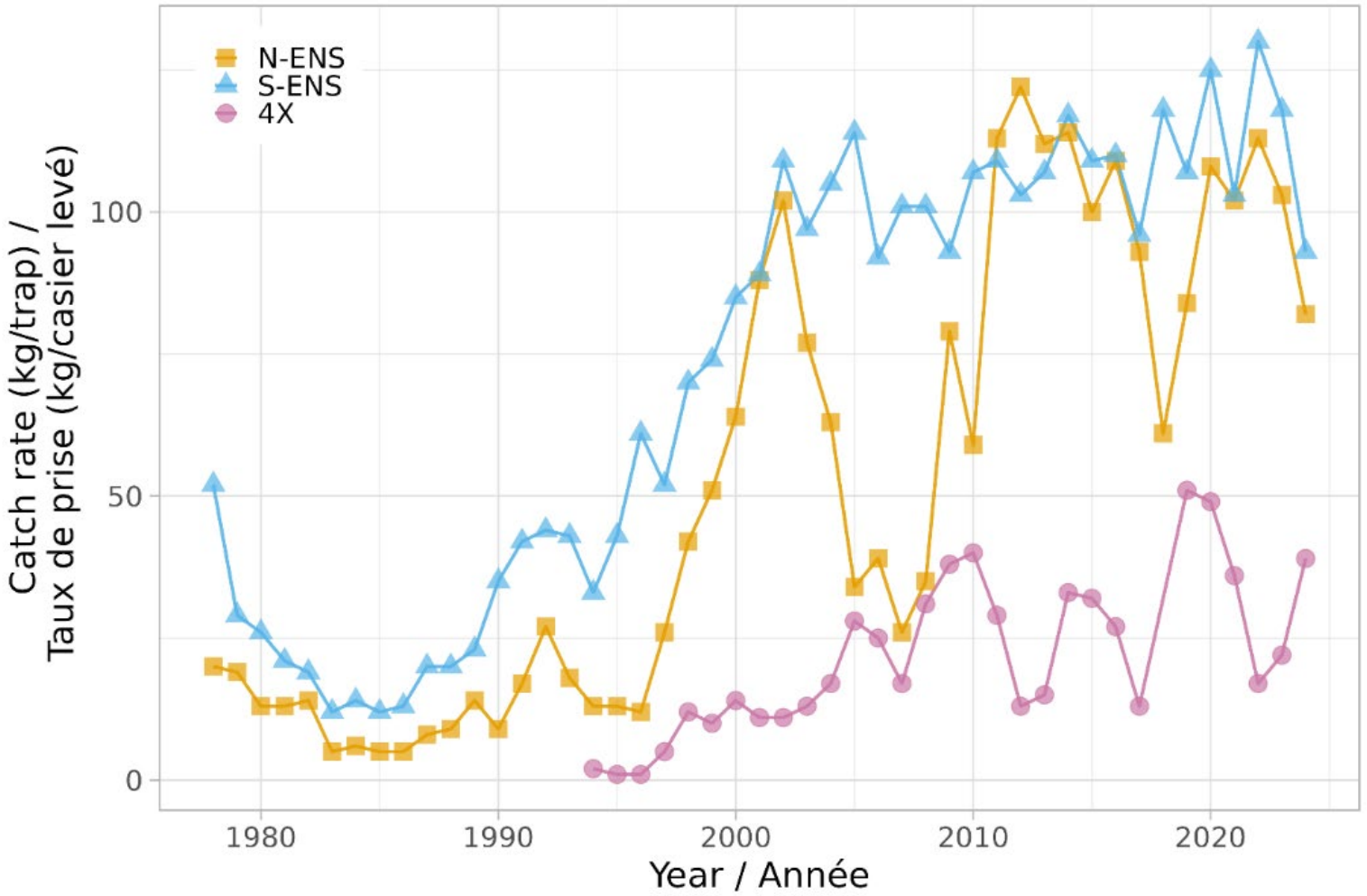


Figure 8. Temporal variations in crude catch rates of Snow Crab in North-Eastern Nova Scotia (N-ENS, yellow), South-Eastern Nova Scotia (S-ENS, blue) and 4X (pink) (kg/trap haul). Note that there was no quota allotted in 2018 for the 4X fishery.

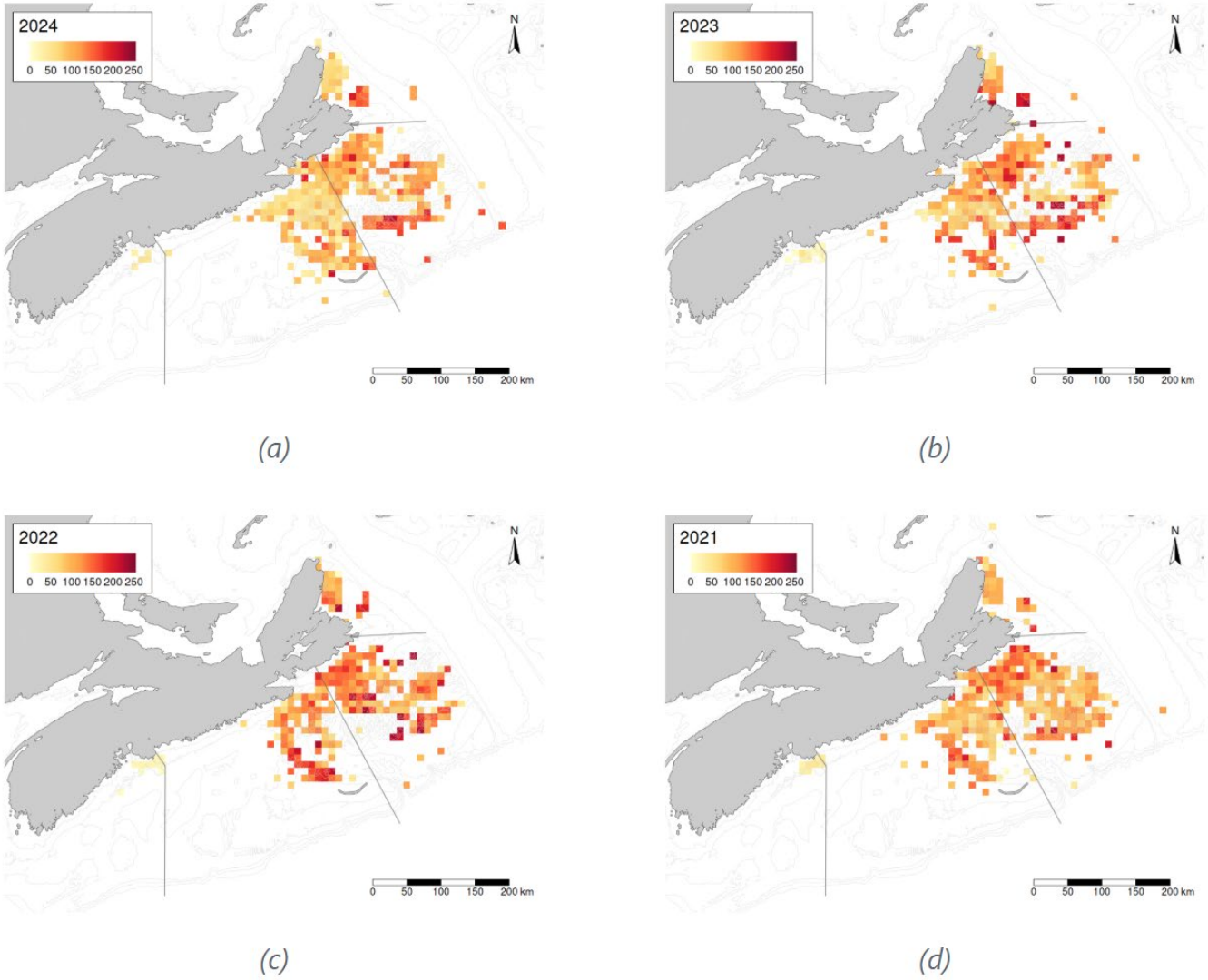


Figure 9. Unstandardized catch rates (kg/trap haul per 10 km x 10 km grid) of Snow Crab on the Scotian Shelf from 2021–2024.

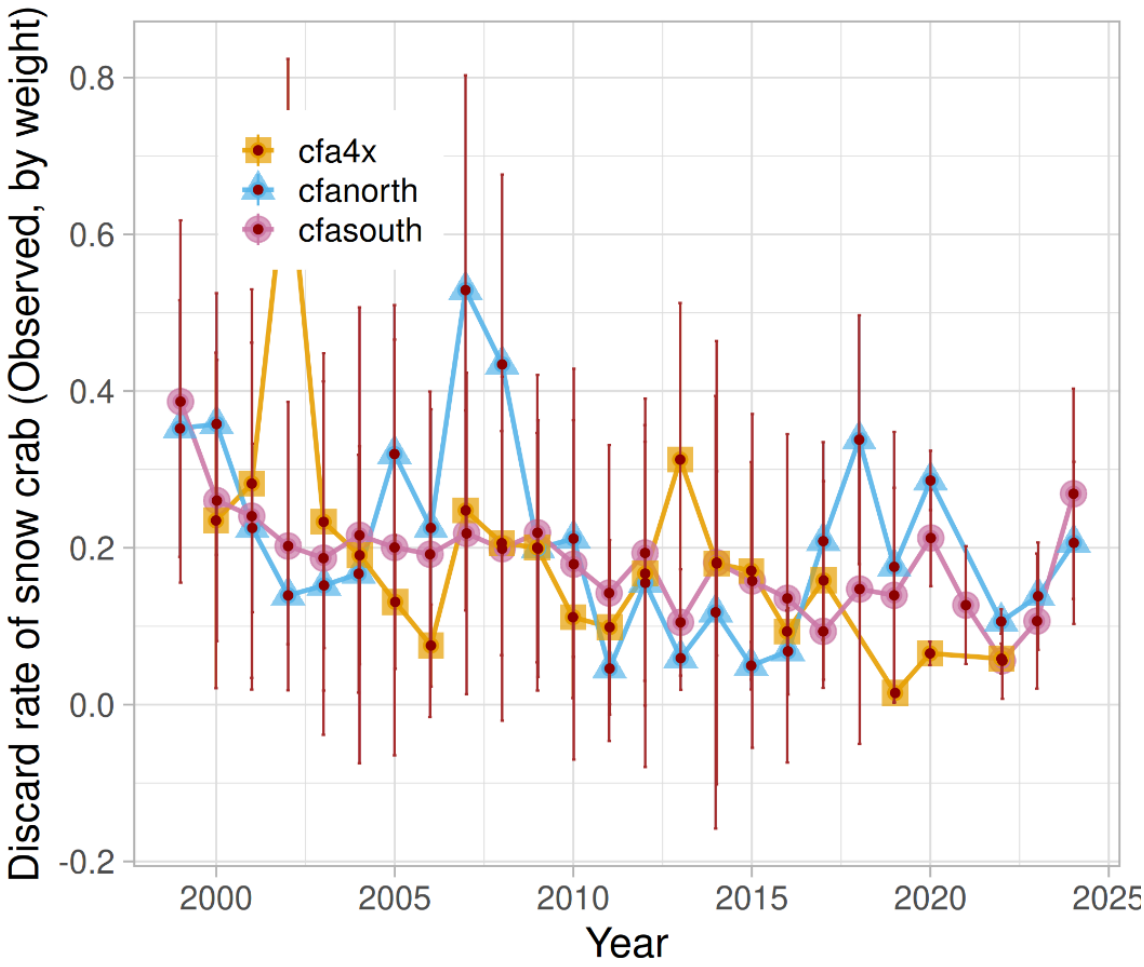


Figure 10. Discard rates of Snow Crab based on at sea-observations (fraction of total catch) on the Scotian Shelf from 2000–2024. Cfa4x – 4X, (yellow), cfanorth – North-Eastern Nova Scotia (blue), cfasouth – South-Eastern Nova Scotia (pink) fishing areas. Points indicate the means and bars are the 95% credible intervals.

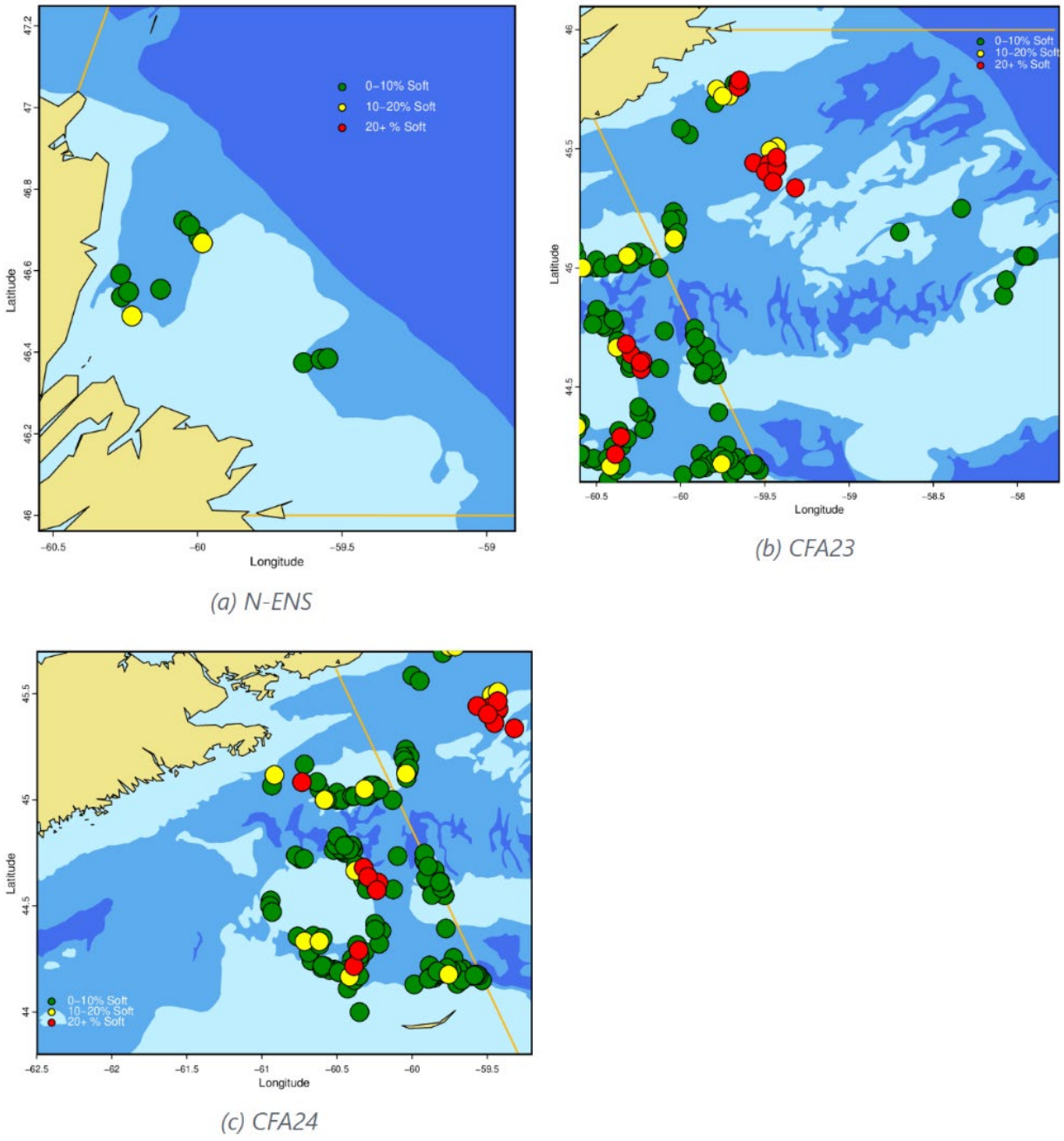


Figure 11. Occurrence of soft-shell Snow Crab in at-sea-observed fishery activities in North-Eastern Nova Scotia (N-ENS), and South-Eastern Nova Scotia (CFA23 and CFA24).

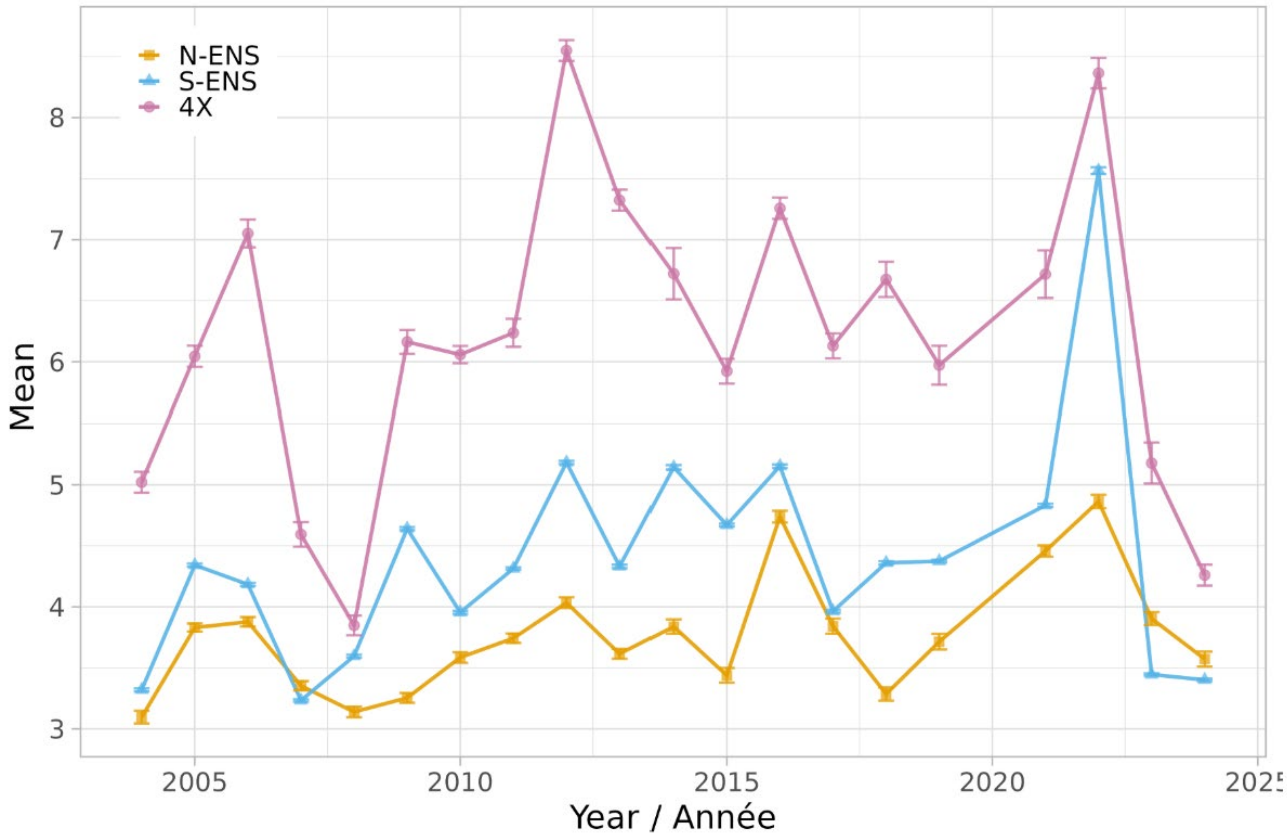


Figure 12. Annual variations in bottom temperatures observed on the Scotian Shelf during the snow crab trawl survey. The horizontal (black) line indicates the long-term, median temperature within each subarea. Error bars represent standard errors. N-ENS – North-Eastern Nova Scotia (yellow), S-ENS – South-East Nova Scotia (blue) and 4X (pink) refer to snow crab fishery areas. Points indicate the means and bars are the 95% credible intervals.

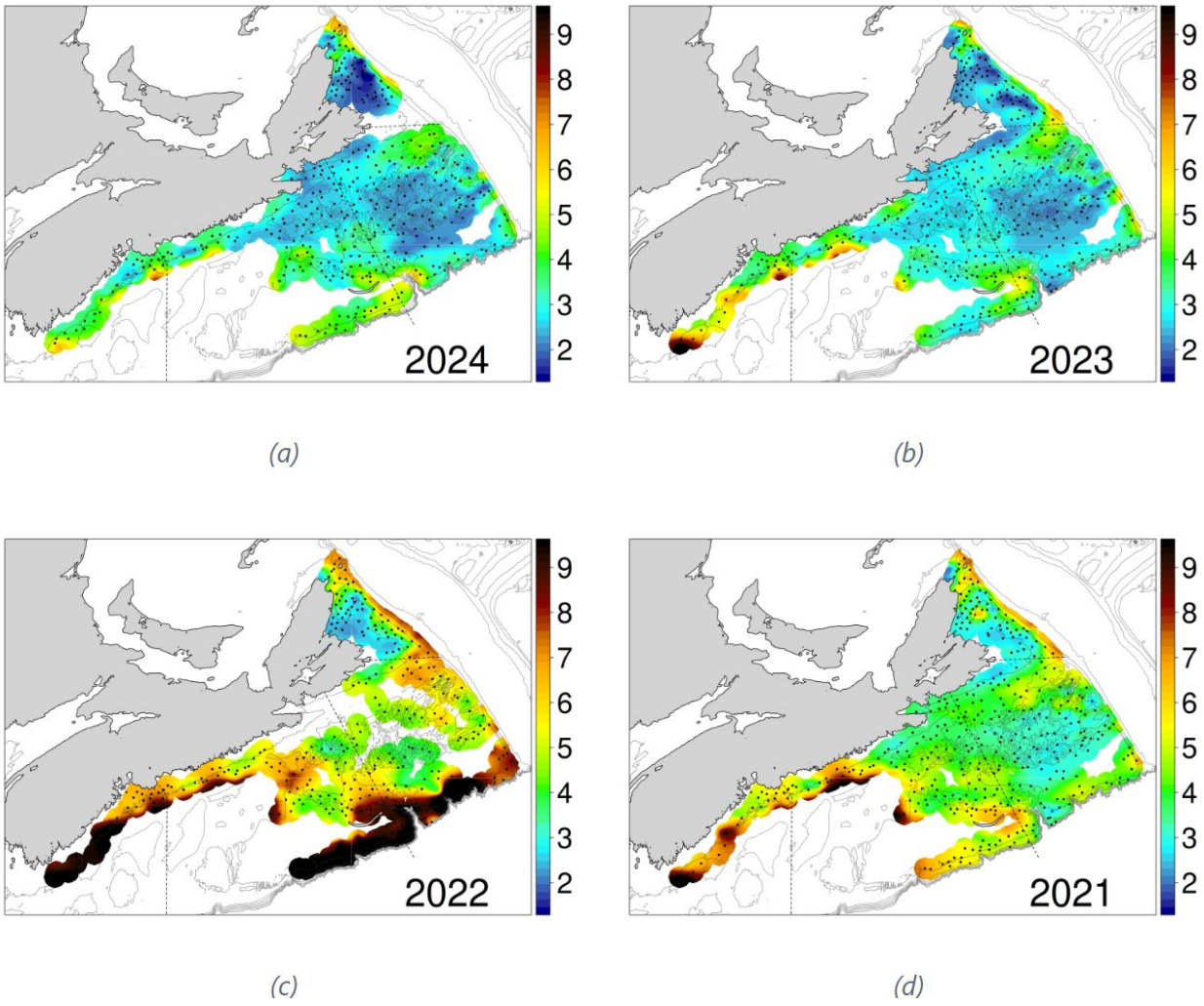


Figure 13. Bottom temperatures (°C) on the Scotian Shelf observed during snow crab trawl surveys from 2021–2024.

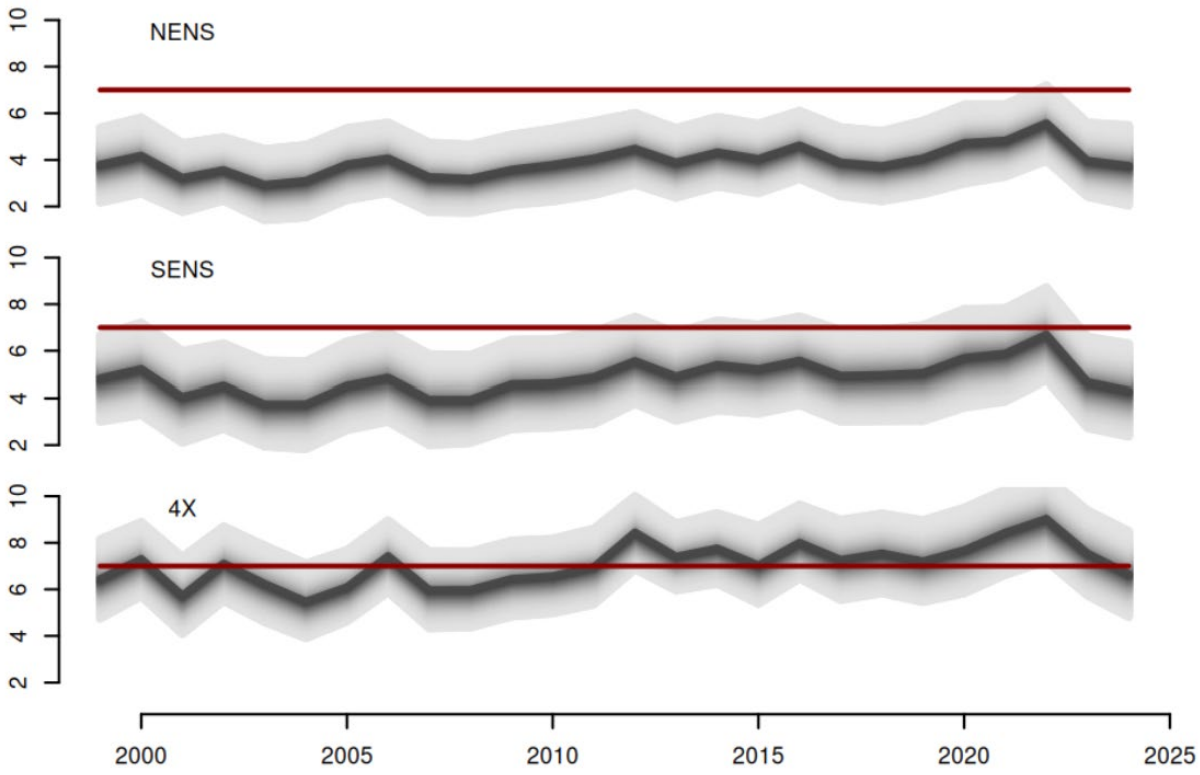


Figure 14. Temporal variations in bottom temperature (y-axis, ºC) estimated from a historical analysis of temperature data (x-axis, years). Red horizontal line indicates 7ºC. Grey zone represents 95% credible intervals of spatial variability in temperature at each time slice, after adjustment for spatiotemporal autocorrelation and sampling time. NENS – North-Eastern Nova Scotia, SENS – South-Eastern Nova Scotia and 4X fisheries.

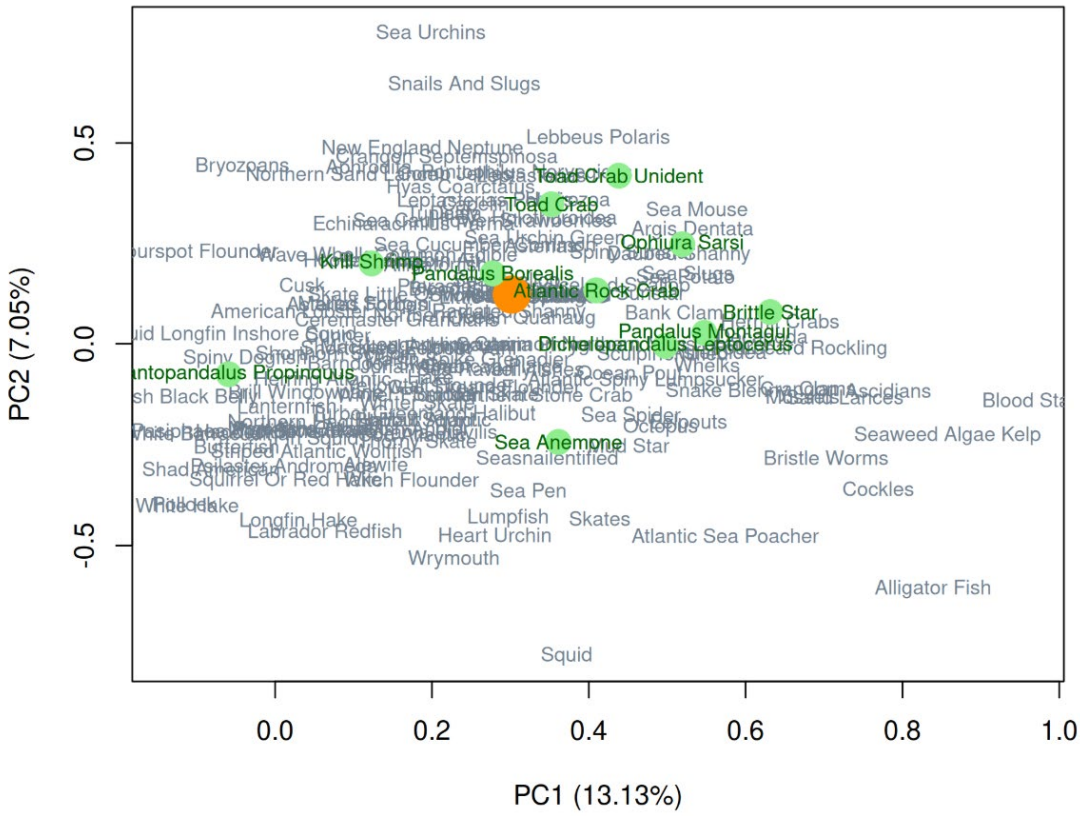


Figure 15. Principle component analyses of occurrence data for Snow Crab (orange) and some potential prey species (green). PC1 is an axis that represents temperature-related species associations: left is warm-water and right is cold-water. PC2 is an axis that represent depth-related species associations: top is shallow and bottom is deep.

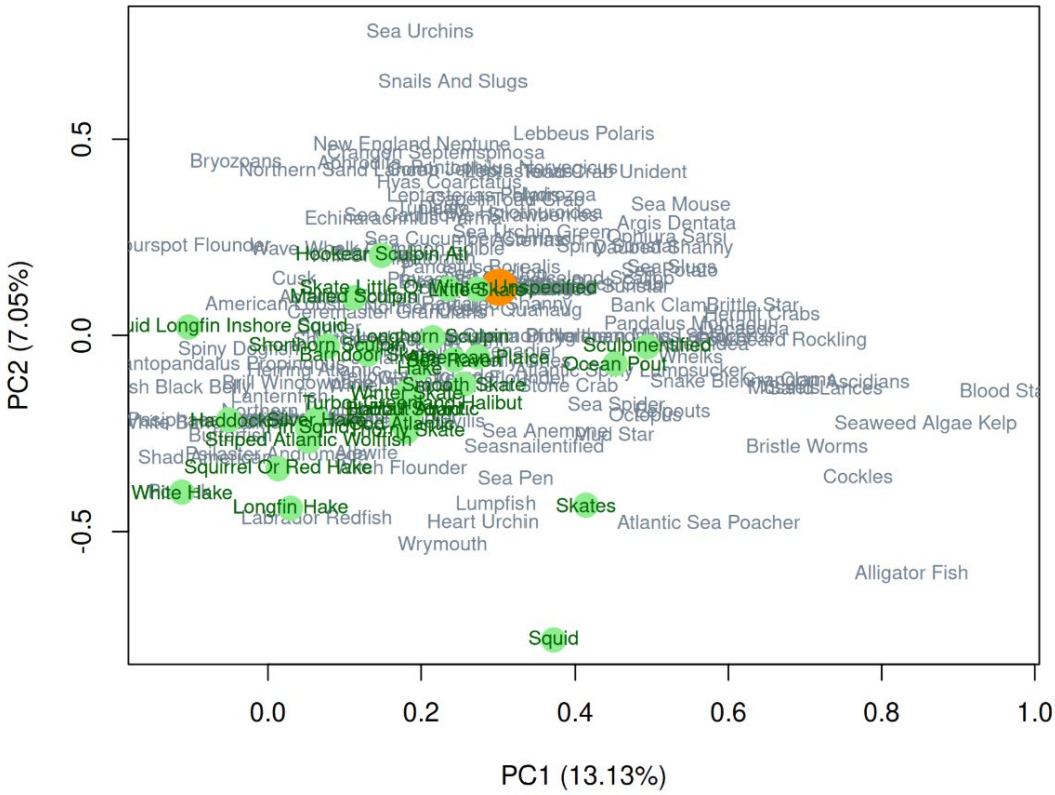


Figure 16. Principle component analyses of occurrence data for Snow Crab (orange) and some potential prey (green). PC1 is an axis that represents temperature-related species associations: left is warm-water and right is cold-water. PC2 is an axis that represent depth-related species associations: top is shallow and bottom is deep.

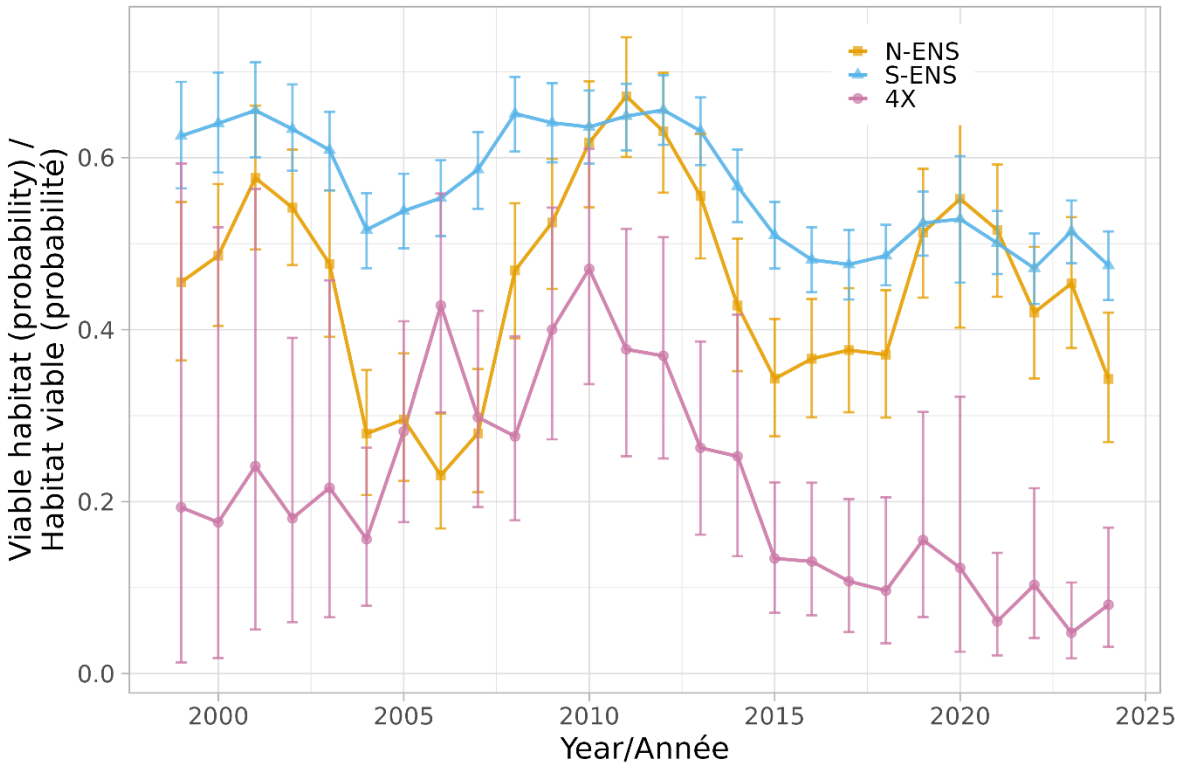


Figure 17. Habitat viability (the probability of encountering harvestable Snow Crab). Points indicate the means and bars are the 95% credible intervals. North-Eastern Nova Scotia (N-ENS, yellow). South-Eastern Nova Scotia (S-ENS, blue) and 4X (pink) fisheries. Points indicate the means and bars are the 95% credible intervals.

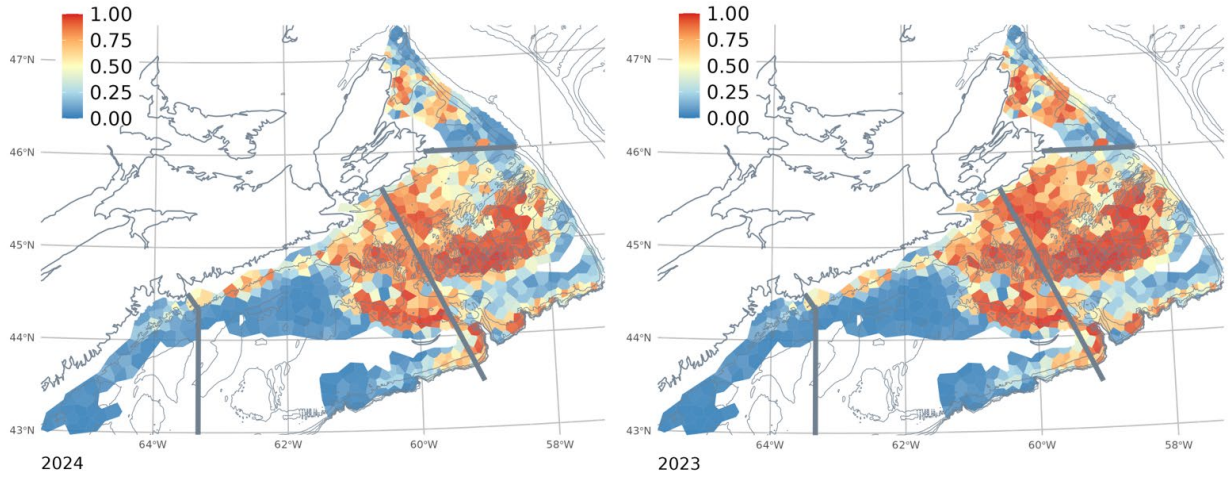
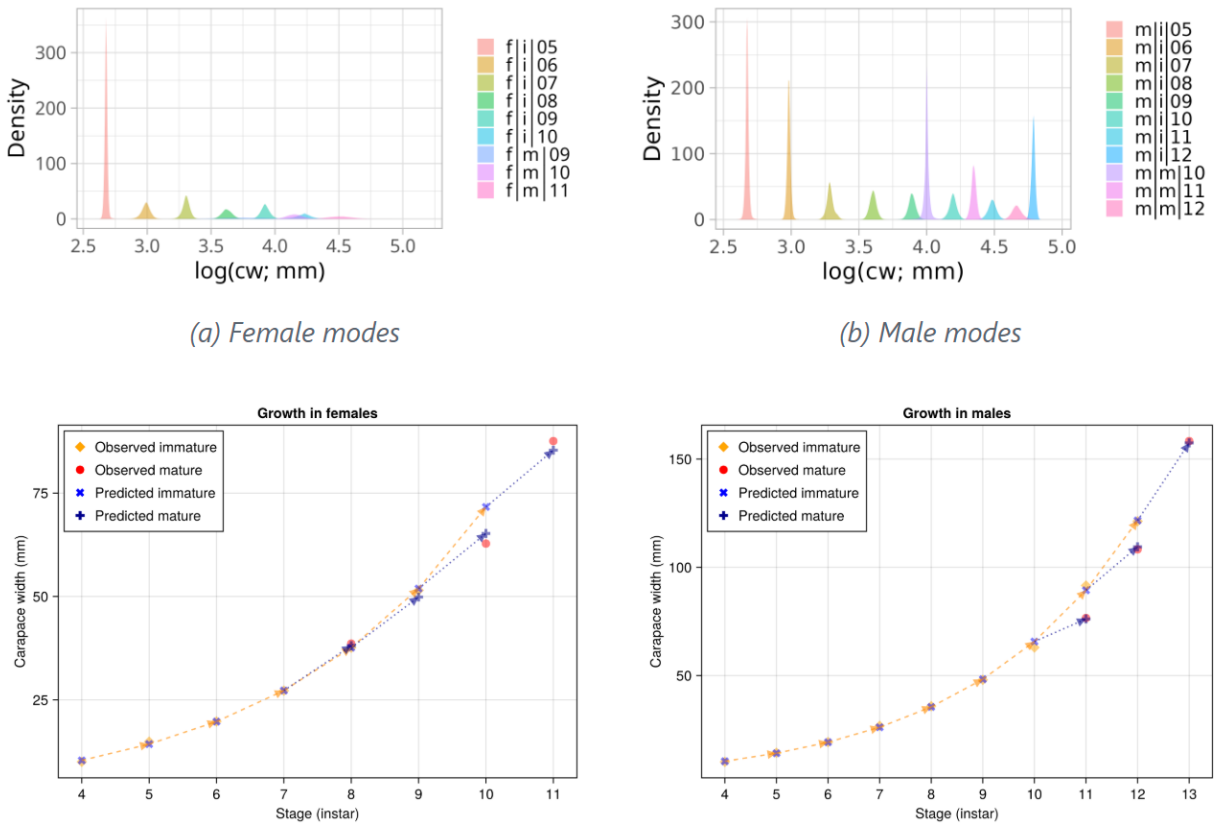


Figure 18. Habitat viability on the Scotian Shelf (the probability of encountering harvestable Snow Crab).Colours are a scale from unlikely (blue) to very likely (red).



(a) Female modes *(b) Male modes*

(c) Female growth trajectory *(d) Male growth trajectory*

Figure 19. Modes identified, ln(cw; mm), from survey data using Kernel Density Estimation of local moving data windows and associated inferred growth derived from Kernel Mixture Models. Legend in (a) and (b): sex|maturity|instar

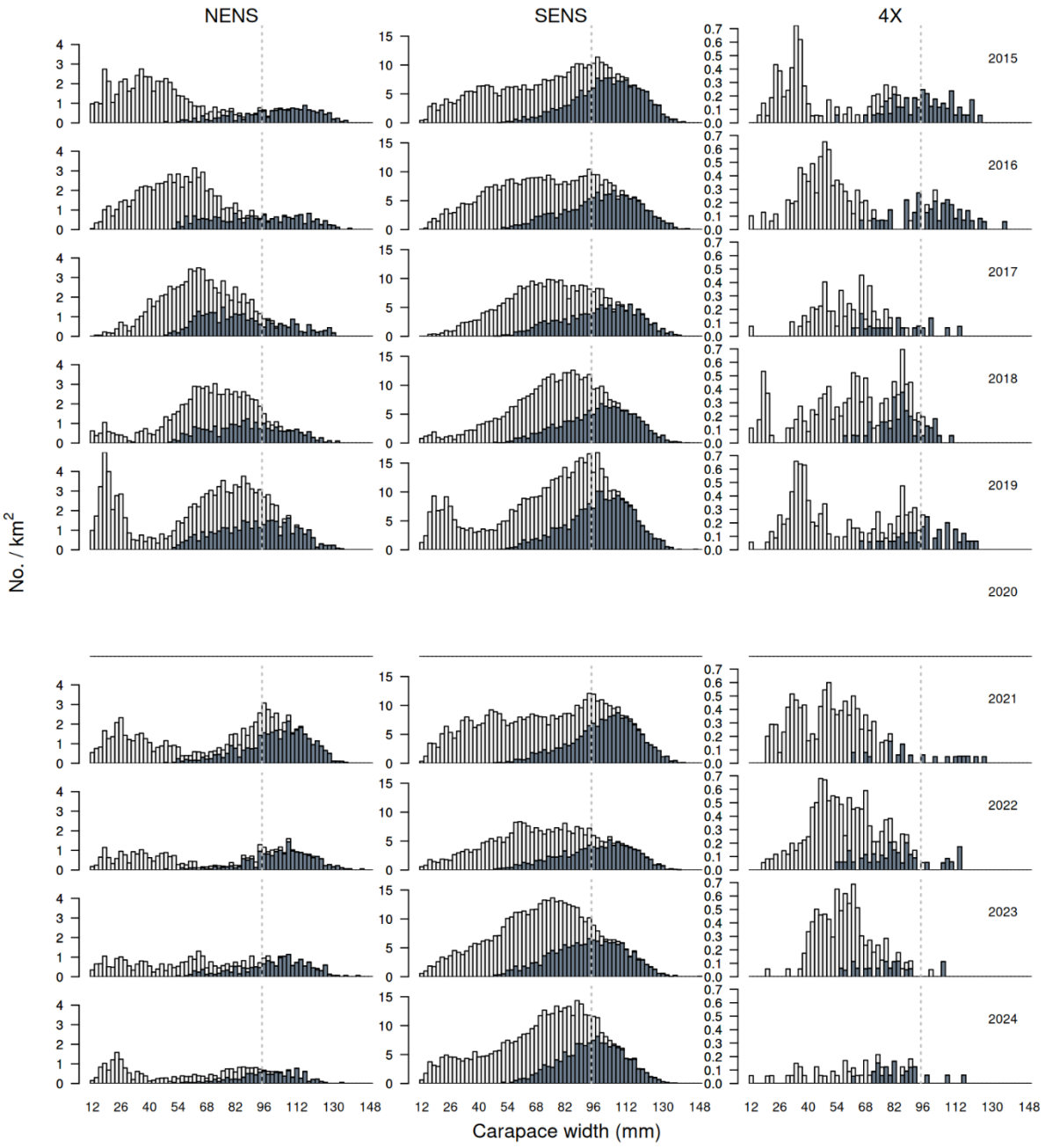


Figure 20. Size-frequency (geometric mean areal density, No./km^2) histograms of carapace width of male Snow Crab (mm) from the snow crab survey by year. The vertical dotted line represents the legal size (95 mm). Immature animals are shown with the lighter bars and mature with darker. The year 2020 is left blank as there was no survey.

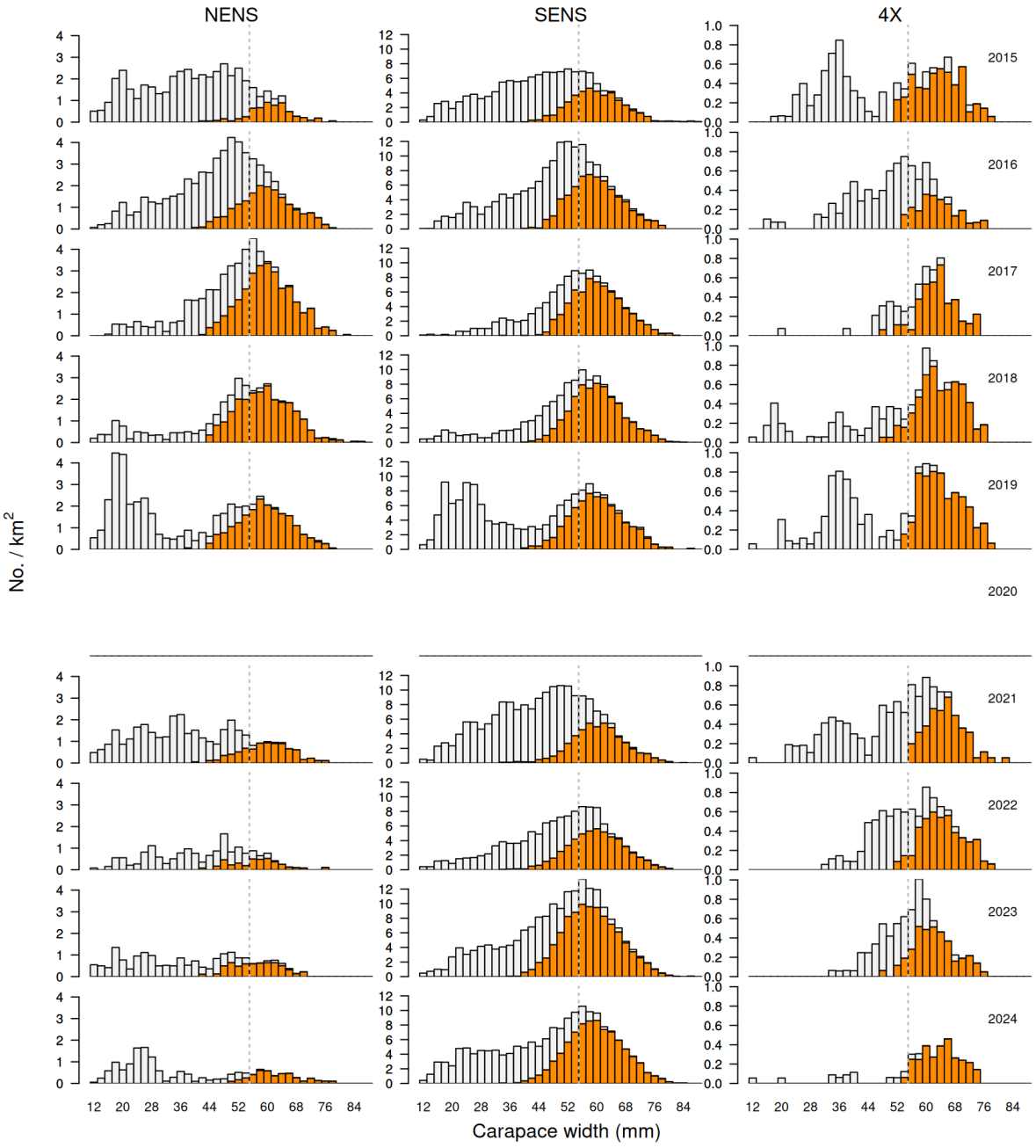


Figure 21. Size-frequency (geometric mean areal density, No./km^2) histograms of carapace width (mm) of female Snow Crab from the snow crab survey by year. Immature animals are shown with the lighter bars and mature with darker. The year 2020 is left blank as there was no survey.

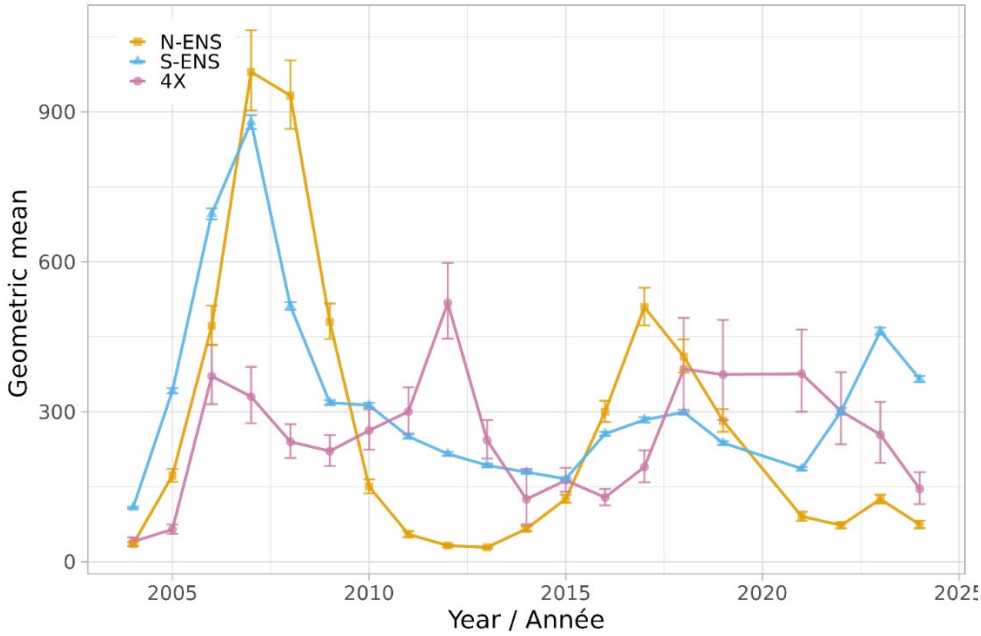


Figure 22. The crude, unadjusted geometric mean of mature female density $log_{10}(no/km^2)$ from the snow crab survey. Error bars represent 95% confidence intervals. Note the absence of data in 2020. Prior to 2004, surveys were conducted in the spring. (N-ENS – North-Eastern Nova Scotia (yellow), S-ENS – South-Eastern Nova Scotia (blue) and 4X (pink) refer to snow crab fisheries).

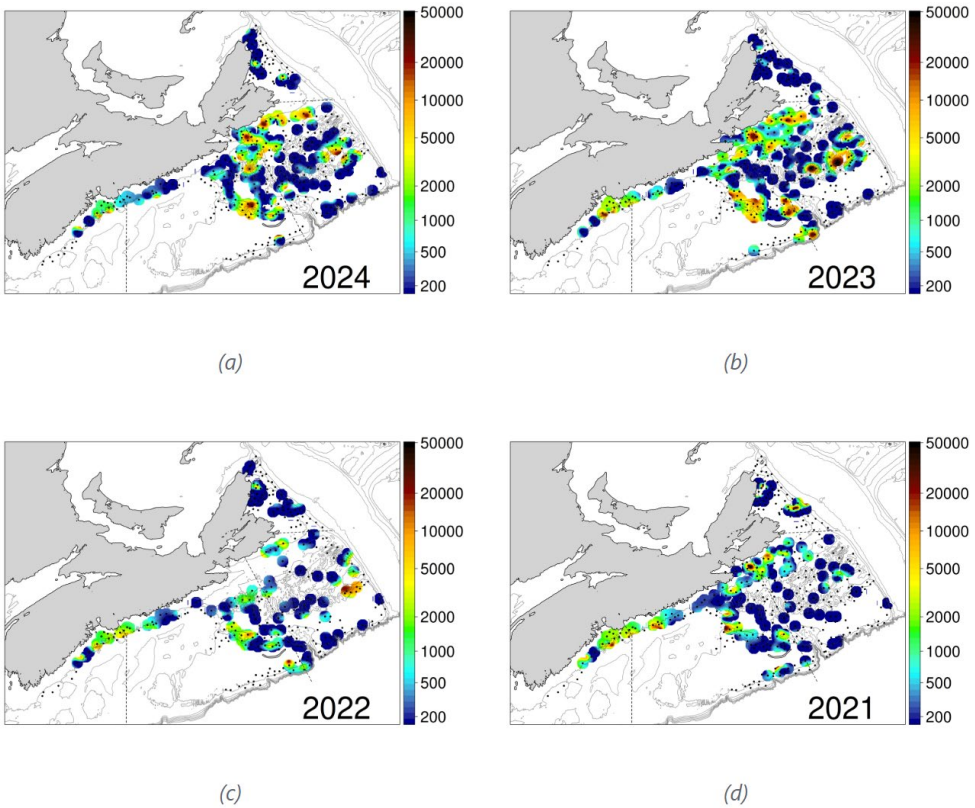


Figure 23. Mature female Snow Crab density (numbers/km²) from the snow crab survey from 2021–2024. The black dots represent the survey station locations where females were not caught.

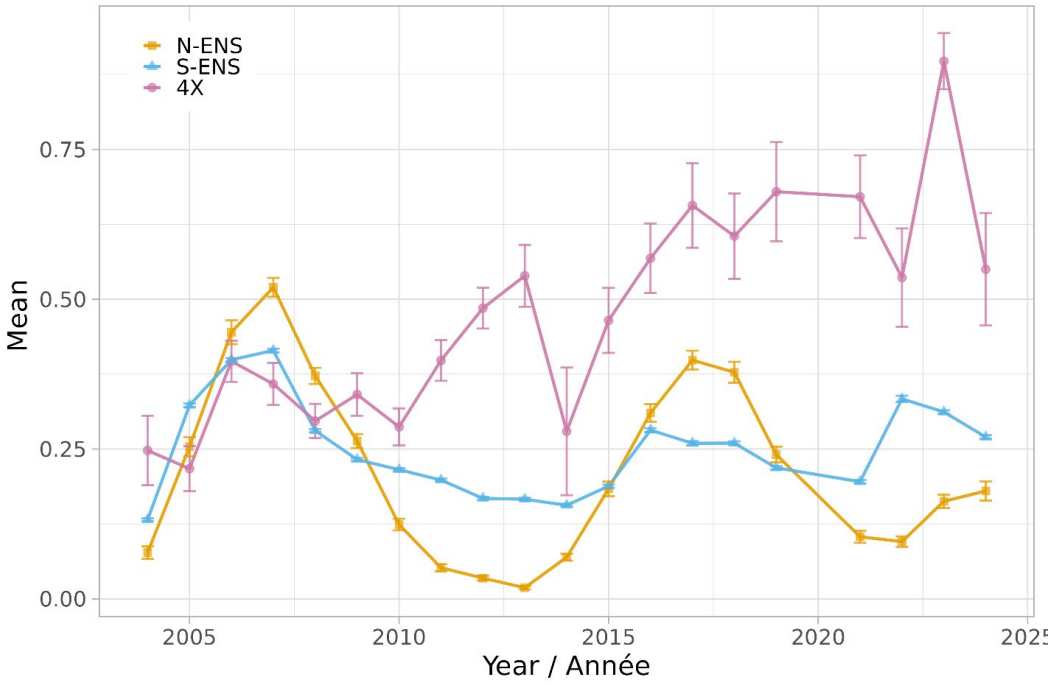


Figure 24. Time series of sex ratios (proportion female) of mature Snow Crab by area. Error bars represent 95% confidence intervals No survey was conducted in 2020. (N-ENS – North-Eastern Nova Scotia (yellow), S-ENS – South-Eastern Nova Scotia (blue) and 4X (pink) refer to snow crab fisheries).

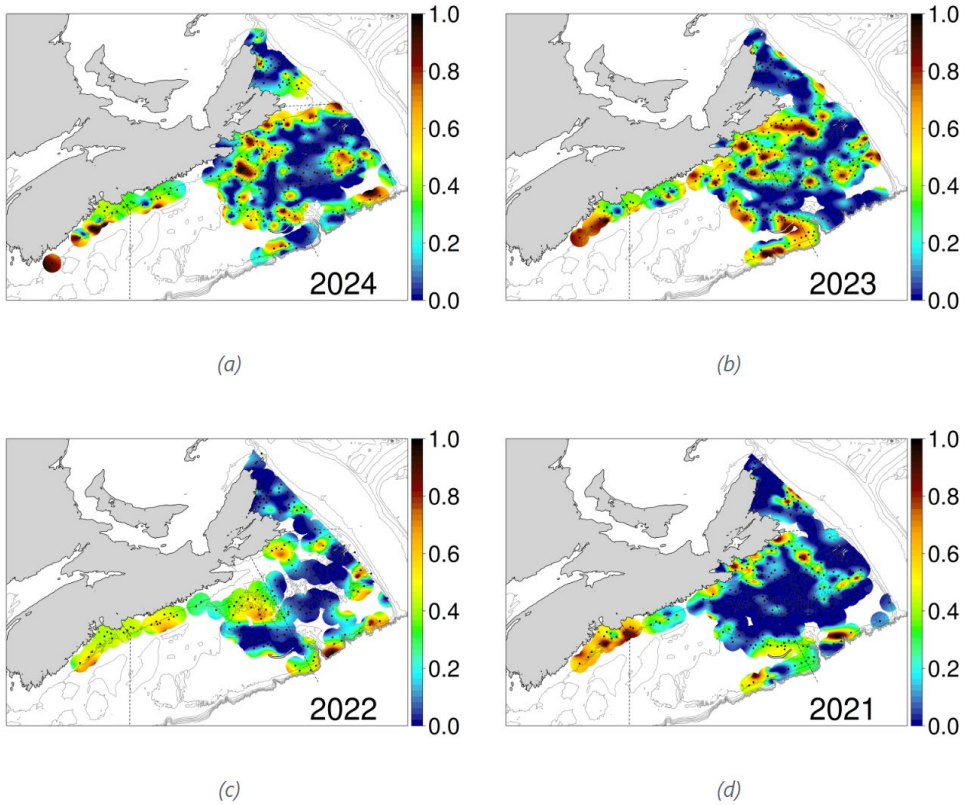


Figure 25. Map of sex ratios (proportion female to male) of mature Snow Crab in the snow crab surveys from 2021–2024.

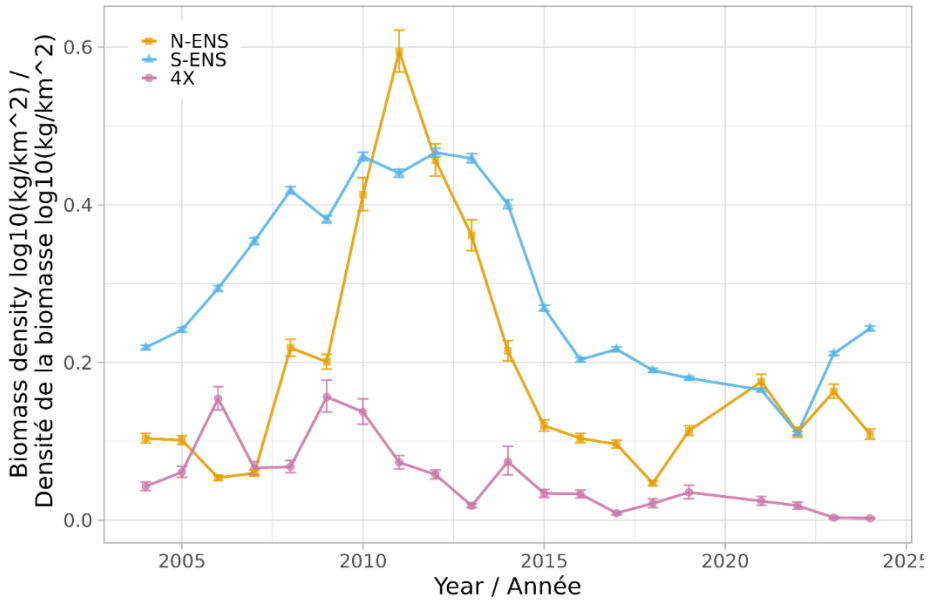


Figure 26. The crude geometric mean fishable biomass density $log_{10}(kg/km^2)$ of Snow Crab from the trawl survey. Error bars represent 95% confidence intervals. Note the absence of data in 2020 due to no survey being conducted. Prior to 2004, surveys were conducted in the spring. (N-ENS – North-Eastern Nova Scotia (yellow), S-ENS – South-Eastern Nova Scotia (blue) and 4X (pink) refer to snow crab fisheries).

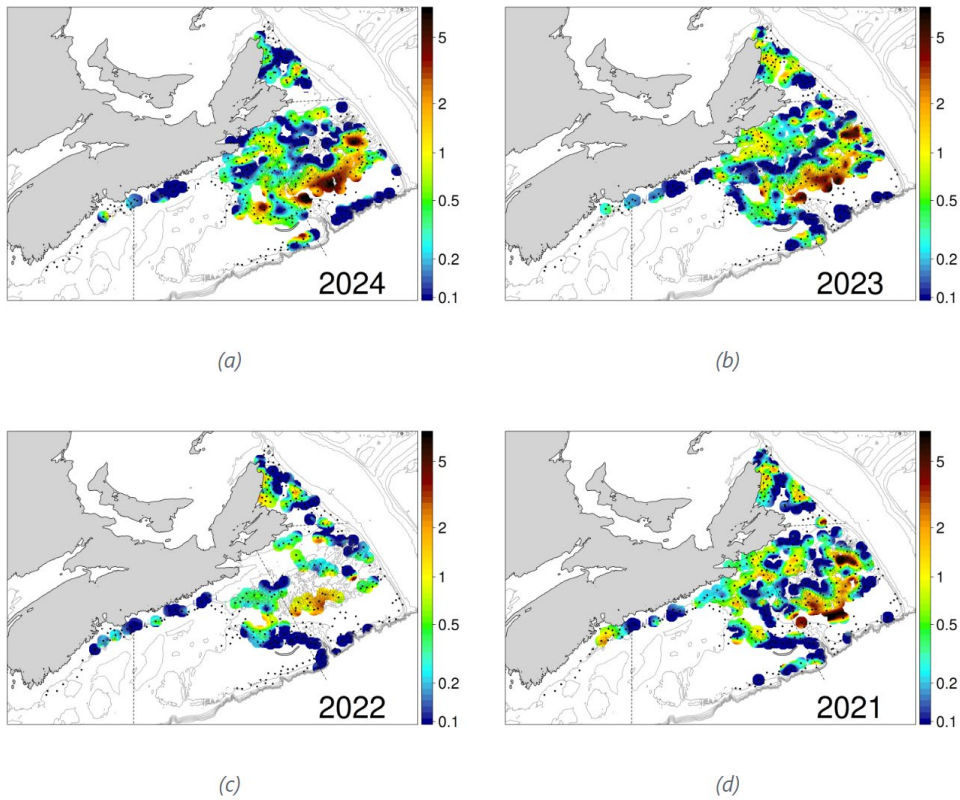


Figure 27. Snow crab survey fishable component biomass density (t/km²) of Snow Crab in the snow crab surveys from 2021–2024. The black dots represent survey station locations with no catch.

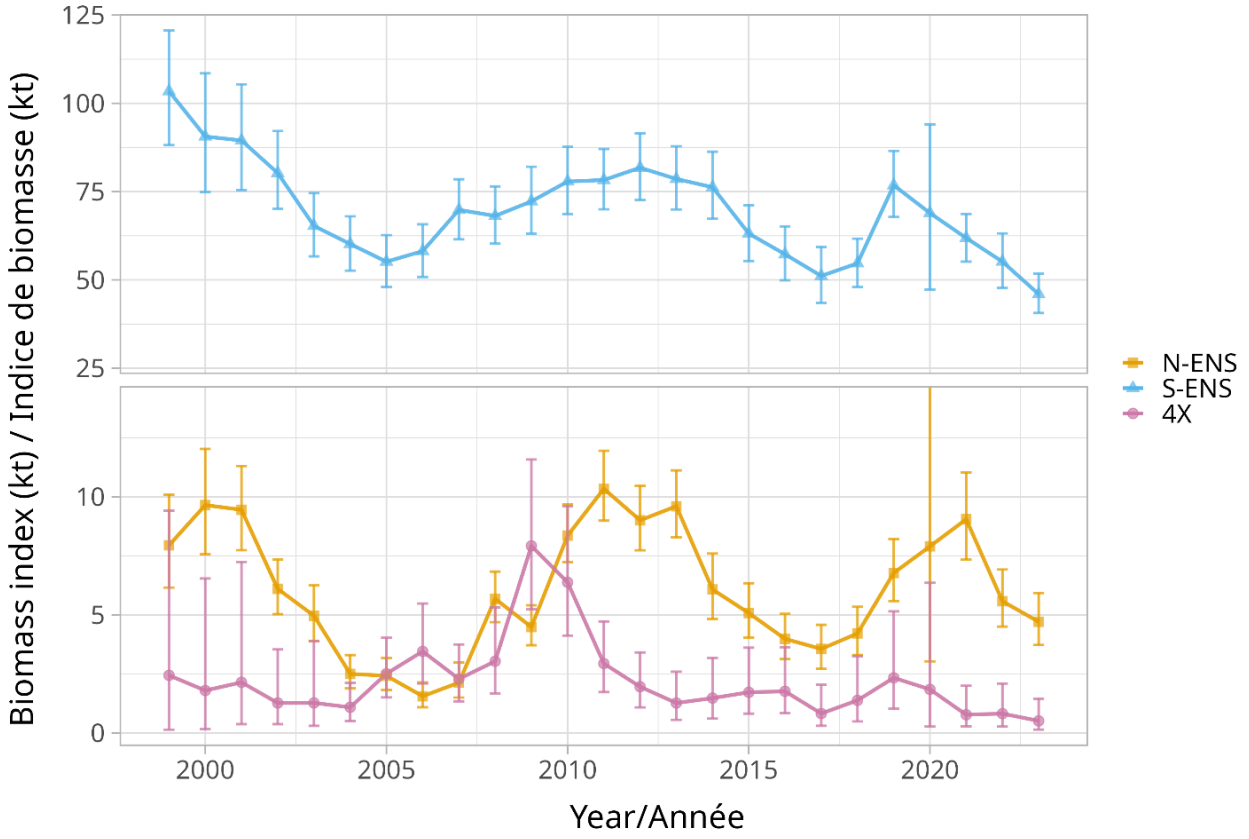


Figure 28. The fishable biomass index (t) predicted from the snow crab survey. Error bars represent Bayesian 95% credible intervals. Note large errors in 2020 when there was no survey completed. (N-ENS – North-Eastern Nova Scotia (yellow), S-ENS – South-Eastern Nova Scotia (blue) and 4X (pink) refer to snow crab fisheries).

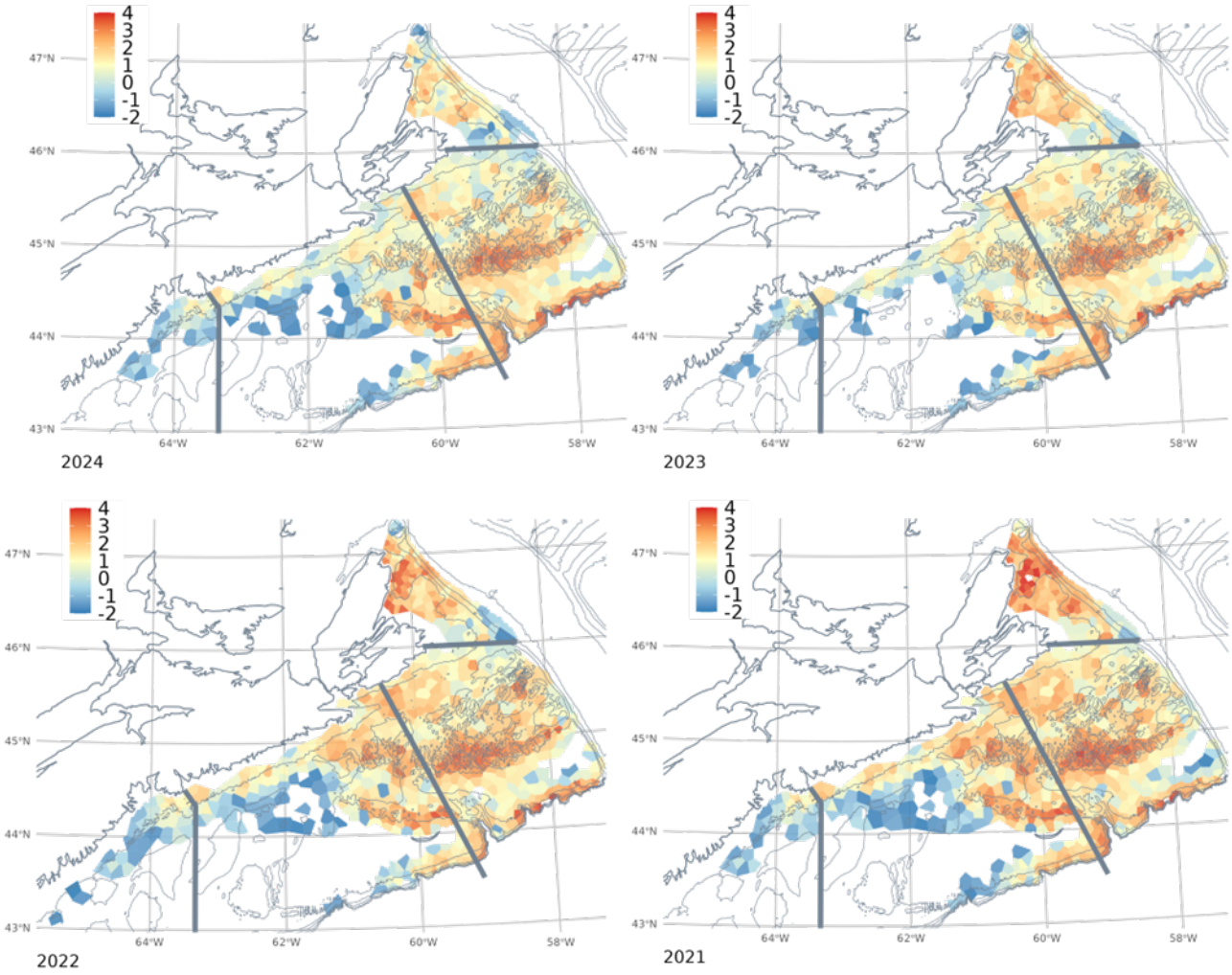


Figure 29. Snow Crab biomass index log_{10} (t/km^2) predicted from the snow crab survey from 2021–2024.Colours represent a gradient from low (blue) to high density (red).

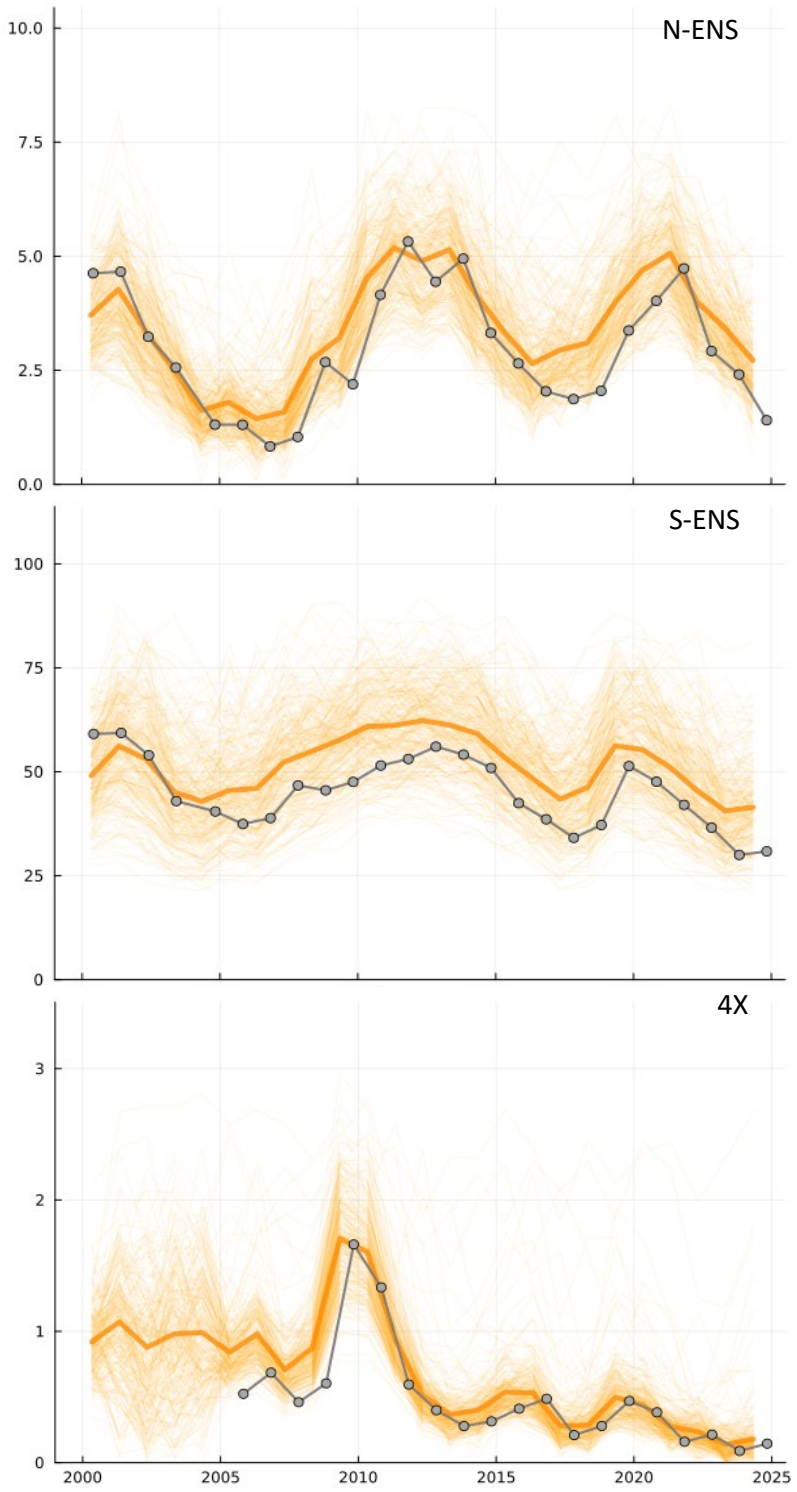


Figure 30. Fishable posterior mean modelled biomass (y-axis, pre-fishery; kt) are shown in dark orange for North-Eastern Nova Scotia (N-ENS), South-Eastern Nova Scotia (S-ENS) and 4X snow crab fisheries. Light orange are posterior samples of modelled biomass (pre-fishery; kt) to illustrate the variability of the predictions. The biomass index (pre-fishery; kt) after model adjustment by the model catchability coefficient is in grey; for 4X, as the fishery is ongoing, this is a during-fishery estimate.

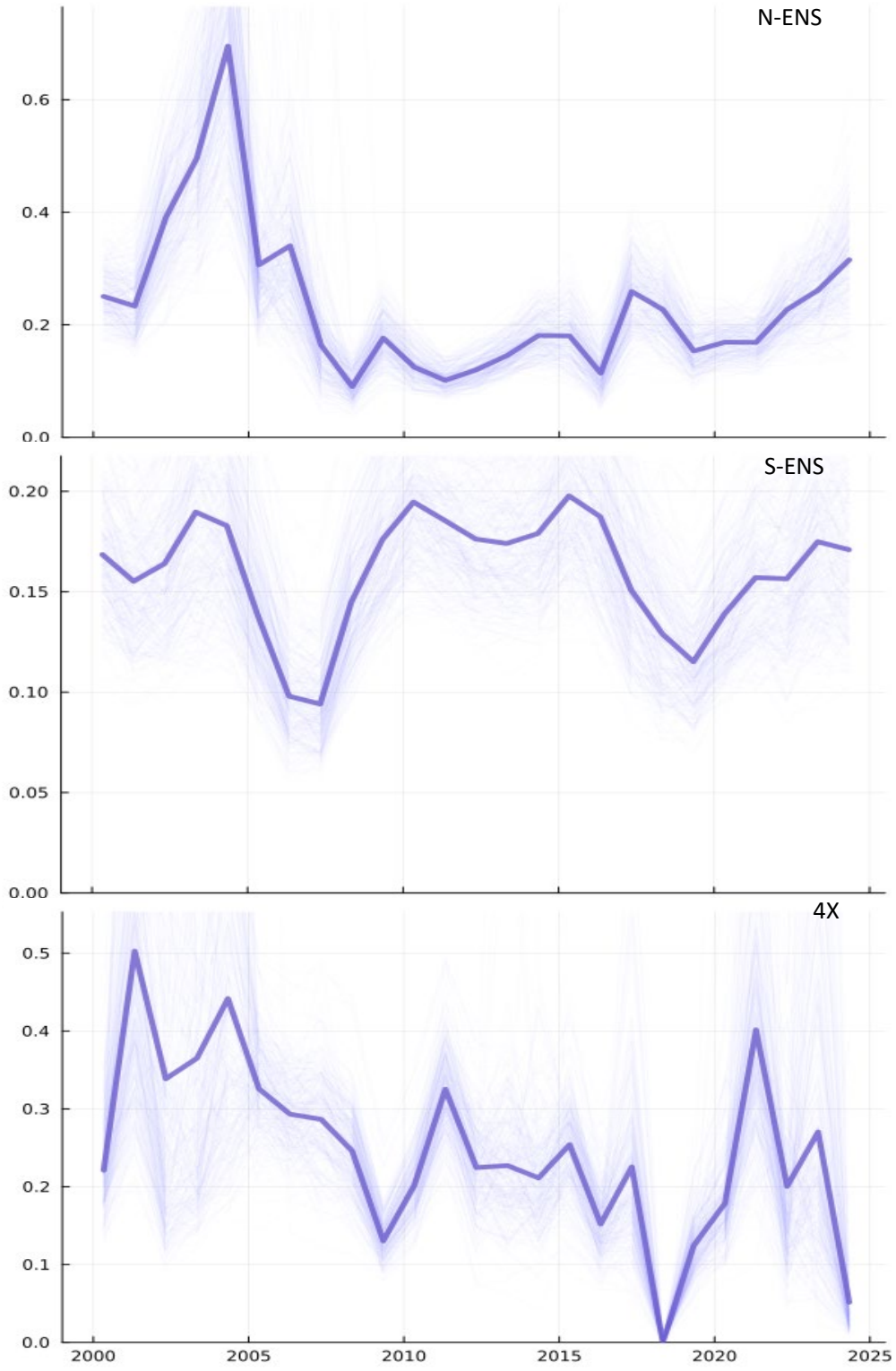


Figure 31. Time-series of modelled instantaneous fishing mortality (y axis) for North-Eastern Nova Scotia (N-ENS), South-Eastern Nova Scotia (S-ENS) and 4X snow crab fisheries . Samples of the posterior densities are presented, with the dark blue representing the mean and the paler areas showing the 95% credible intervals.

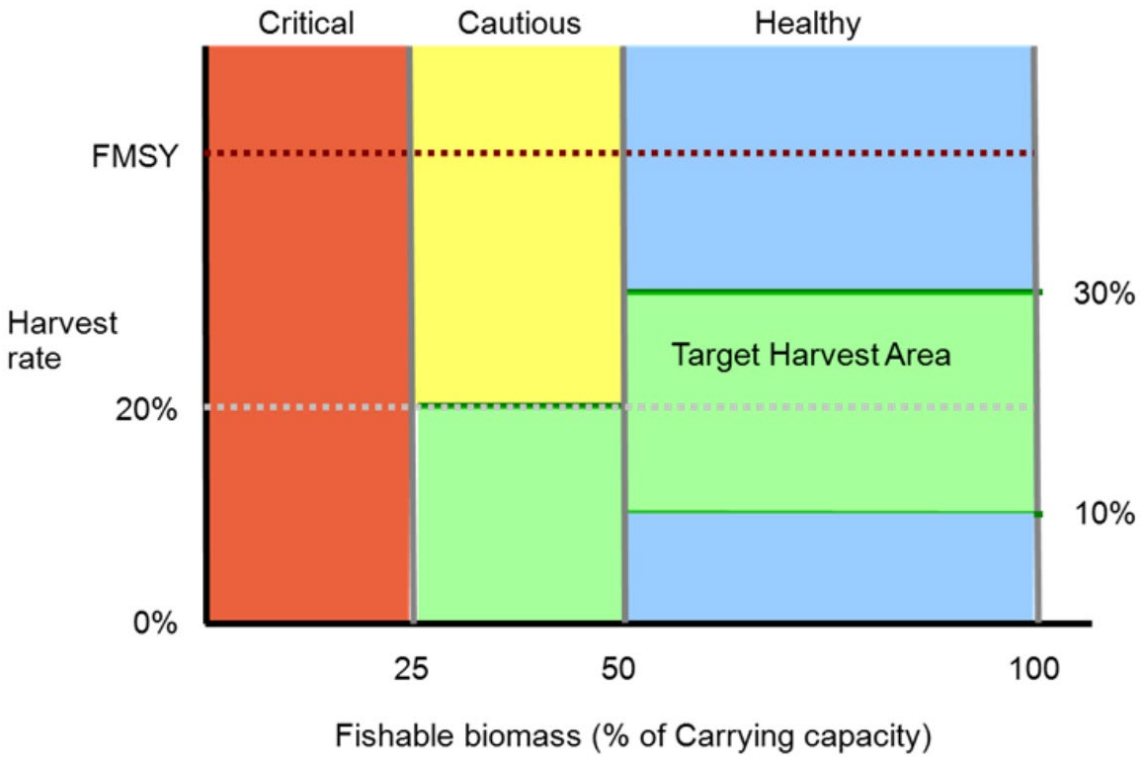


Figure 32. Harvest control rules for the Scotian Shelf snow crab fisheries.

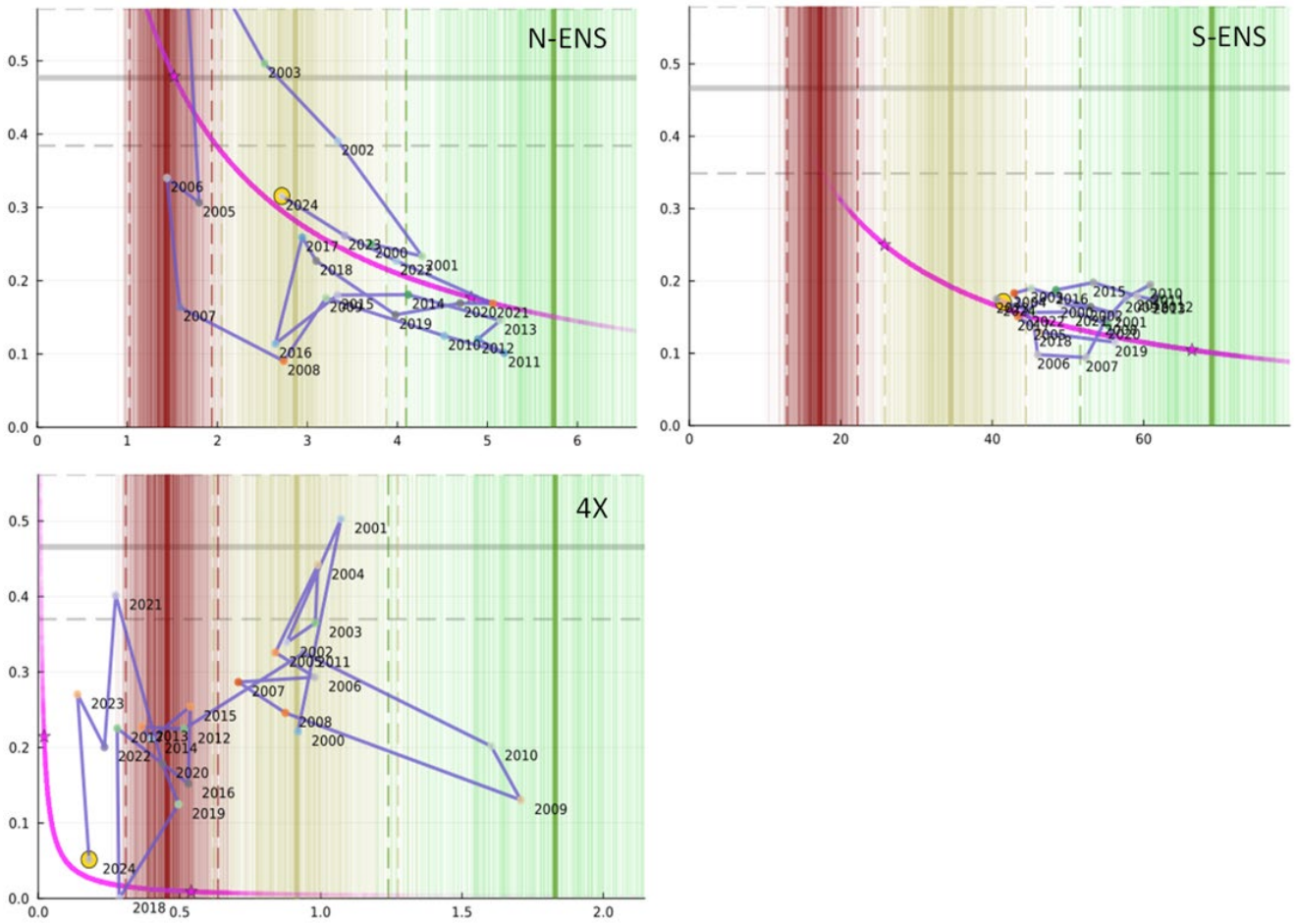


Figure 33. Fishing mortality (F) vs modelled pre-fishery biomass (kt) from 2001–2024 for North-Eastern Nova Scotia (N-ENS), South-Eastern Nova Scotia (S-ENS), and 4X fisheries. The 2024 modelled pre-fishery biomass (yellow dot) and associated 95% credible intervals (pink stars) identify current stock status. The variability associated with fishable biomass and fishing mortality estimates are shown as pink lines (with 95% credible intervals shown with stars). The grey solid horizontal line identifies the removal reference (F_{MSY}) estimated for each area and the stippled horizontal lines identify the 95% credible intervals. The red and yellow solid coloured vertical lines identify the estimates of the limit reference point (LRP) and the upper stock reference (USR), respectively. The green solid line represents the carrying capacity (K) for each region. The dashed lines delimit the 95% credible intervals for the correspondingly coloured reference lines. The lighter coloured vertical lines represent the variability associated with each parameter. For fishing area 4X, the year refers to the starting year of the fishing season; the fishery is ongoing.