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Assessment of Scotian Shelf Snow Crab in 2023

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Foreword

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

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ABSTRACT

In the Scotian Shelf Ecosystem, Snow Crab (*Chionoecetes opilio*) have been a dominant macro-invertebrate since the decline of the groundfish fishery in the 1990s. They are generally observed in deep, soft-bottom substrates ranging from 60-300 m and at temperatures usually less than 6 degrees Celsius. The Scotian Shelf Snow Crab are in the southern-most extreme of their spatial distribution in the Northwest Atlantic Ocean and vulnerable to climate variability. The fishery is made up of 3 fishing areas: north-eastern Nova Scotia (N-ENS), south-eastern Nova Scotia (S-ENS) and 4X.

The Snow Crab assessment is based on a fishery independent survey, the Maritimes Region Snow Crab Trawl Survey, and focuses on indicators of abundance, reproductive potential, recruitment, and exploitation rates. Spatiotemporal models incorporate habitat viability based on ecosystem variables such as depth, species composition and bottom temperatures. At-sea-observer coverage aims to quantify bycatch, and carapace conditions for the crabs in the fishery but has been unreliable since 2020 with minimal observations per year. Fishery data provides catch rates, landings, effort, and monitors historic trends. Total allowable catches (TACs) are generally caught every year (except 4X as the fishery is always ongoing at the time of assessment).

Survey indices indicate recruitment in N-ENS will be minimal with a potential gap for the next 1 to -3 years. In S-ENS, recruitment is likely to continue at a moderate rate in the upcoming season. 4X is expected to see low to moderate levels of recruitment for two years. Fishing mortality was higher than desirable in N-ENS. Bottom temperatures have been continually rising since the early 2000s until a decrease observed during the 2023 survey. This is positive news for the Snow Crab fishery and will be monitored with future surveys in hopes this decreasing trend continues.

The model suggests that N-ENS and S-ENS are in the healthy zone and 4X is in the critical zone.

INTRODUCTION

Snow Crab are a circumpolar, subarctic species. In the Scotian Shelf Ecosystem (SSE), Snow Crab prefer habitat that is generally soft mud or sandy bottoms at depths of 60–300 m and temperatures from −1–6°C. SSE Snow Crab (*Chionoecetes opilio*) stock is managed as three main areas: North-Eastern Nova Scotia (N-ENS), South-Eastern Nova Scotia (S-ENS), and 4X (Figure 1). S-ENS is further subdivided into two fishery management areas: Crab Fishing Area (CFA) 23 and CFA 24. N-ENS and S-ENS start fishing in the spring, while 4X starts in the fall and spans over the winter into the next year (Table 1–4). 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.

The Snow Crab fishery is an important commercial fisheryin both Atlantic Canada and Nova Scotia (DFO 2024). It has been active since the mid-1970s. The earliest records of landings were at levels of less than 1,000 t, mostly in the near-shore areas of ENS. By 1979, landings rose to 1,500 t, subsequent to which the fishery declined substantially in the mid-1980s and was considered a collapsed fishery. Recruitment to the fishery was observed in 1986 and, since that time, landings, effort and catch rates have increased considerably. In 1994, directed fishing for Snow Crab began in 4X, the southern-most range of distribution and continues at low harvest levels.

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

- Females are not fished and therefore, completely protected.
- There have generally been conservative exploitation rates since the mid-2000s.
- There is spatial refugia in the Marine Protected Areas (MPAs) and continental shelf edge.
- Immature and soft-shelled crab are not fished.
- Attempting to minimize effects on other species by implementing bycatch reduction measures (season timing, biodegradable mesh, and area closures).
- With a collaborative management style that prioritizes scientific, fisheries-independent, evidence based decision making.

More information on the SSE Snow Crab fisheries management and life history can be found in Choi (2023a).

FISHERIES DATA

Fishery catch rates are biased indicators of Snow Crab abundance. The spatial and temporal distribution of Snow Crab and the fishing effort are not uniform. There is strong variation with season, bottom temperatures, food availability, timing of spring plankton blooms, reproductive behavior, substrate/shelter availability, relative occurrence of soft and immature crab, species composition, fisher experience, bait type, soak time, and ambient currents. Catch rates have not been adjusted for these influences and are presented here only to maintain continuity with historical records. Fishery catch rates are used as a measure of fishery performance and not necessarily stock performance/abundance.

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

Effort

In N-ENS, a spring season was introduced in 2008 in an effort to reduce soft and white crab capture and handling during the summer season, and now represents the majority of the fishing efforts. This season was in addition to the traditional summer season. Individual fishers were able to fish during either or both seasons. Starting in 2019, there were no longer two distinct seasons.

Observer

At-sea-observer data (Tables 5–7) provides information on 1) the size structure and the carapace condition (CC) of the commercially exploited stock (Tables 8–11) and 2) potential bycatch of non-Snow Crab species by the Snow Crab fishery (Tables 12–13). The data are stored in the Industry Survey Database (ISDB). At-sea-observers are deployed randomly with the coverage being as evenly distributed as possible between vessels through an automated deployment system. The target coverage is set at 5% in S-ENS and N-ENS, and 10% for 4X of total landings. At-sea observer coverage targets for the commercial fishery have not been achieved since 2019 (Tables 5–7). Restrictions due to COVID-19 impacted the at-sea observer companies' ability to provide observers, and this issue has continued. Bycatch estimates are not provided for 4X as there has not been sufficient observer data (Figure 2) since last reported in 2020 (Zisserson et al. 2023).

In the exploited fraction of Snow Crab, CC is an index of the approximate time since the last molt, as it describes the relative development and subsequent decay of the carapace (Table 8). CC1 signifies a newly molted crab, soft-shelled, with no epibiont (e.g., barnacles) growth. CC2 crab have begun to harden, but is still considered to be soft and of no commercial value. CC3 and CC4 represent crab preferred by industry. The oldest carapace condition (CC5) signifies extensive shell decay with no expectation of survival into the next year.

MARITIMES REGION SNOW CRAB TRAWL SURVEY DATA

All planned stations in the Maritimes Region Snow Crab Trawl Survey were completed in 2023. In 2022, not all survey stations were completed due to mechanical issues with the survey vessel, *F/V RS Journey II* (formerly named *F/V Ms. Jessie*; Figure 3). A custom Nephrops trawl, a net originally designed to dig into soft sediments for a lobster species in Europe, was used to sample Snow Crab and other benthic megafauna (headline of 20 m, 27.3 m foot rope mounted with a 3.2 m long, 8 mm chain, with a mesh size of 80 mm in the wings and 60 mm in the belly and 40 mm in the cod-end). Net configuration was recorded with wireless trawl monitoring sensors (MARPORT as of 2021); depth and temperature were recorded with Seabird SBE 39 temperature and depth recorders; and positional information was recorded with a WAAS-enabled global positioning system. Actual duration of bottom contact was assessed from trawl monitoring and Seabird data streams. The ship speed was maintained at approximately two knots for five minutes after the net made contact with the bottom. The warp length was approximately three times the depth. Swept area of the net was computed from swept distance and monitored net width. Detailed descriptions of sampling protocols can be found in Zisserson (2015).

All Snow Crabs were counted, measured with calipers, shell condition determined, and weighed with motion-compensated scales. Captured Snow Crabs were also visually examined for bitter crab disease (BCD; Table 14). Data entry and quality control was provided by Javitech Ltd. and migrated onto the ISDB. For more details on weight estimation, sex ratio calculations, and maturity calculations see Zisserson et al. (2023).

ECOSYSTEM INDICATORS

Movement

The most recent Snow Crab tagging program data has been summarized in Zisserson et al. (2023). It has not continued past January 2019 due to COVID-19 restrictions. It is anticipated that the traditional tagging program will resume in 2024.

Habitat

Bottom temperatures in the distributional centers of S-ENS Snow Crab have been generally increasing since the 1990s (Figure 4). N-ENS shows a relatively more stable bottom temperature field though still exhibits a slight rising trend. In 4X, bottom temperatures are generally warmer and more erratic than the other areas. The potential effects of increasing temperature on Snow Crab populations are detailed in Zisserson et al. (2023).

Predation

Snow Crab predators were determined using data housed in the DFO Maritimes Region Food Habits Database (Cook and Bundy 2010). Diet data of finfish in Scotian Shelf exist from 1999 to 2020. The Snow Crab Trawl Survey data is used to demonstrate temporal trends for some of these predators. More details on predation methods and history can be found in Zisserson et al. (2023).

Resource Limitation

Bottom-up influences refer to changes in a population due to resource (food) availability. Diet studies and field observations (Hooper 1986) indicate that the primary food items of larger (mature) crab are, in order of importance: echinoderms, polychaete worms (*Maldane* sp., *Nereis* sp.) and other worm-like invertebrates, detritus, large zooplankton, shrimps, smaller juvenile crabs (Rock Crab, *Cancer irroratus*; Toad Crab, *Hyas coarctatus*; Lesser Toad Crab, *Hyas araneus*), Ocean Quahog (*Arctica islandica*), bivalve molluscs (e.g., *Mytilus edulis*, *Modiolus modiolus*), brittle stars (*Ophiura sarsi*, *Ophiopholis aculeata*), and sea anemones (*Edwardsia* sp., *Metridium senile*). Smaller Snow Crab have been observed to feed upon, in order of importance: echinoderms, polychaete worms, large zooplankton, detritus, and bivalves (e.g., *Mytilus edulis*, *Modiolus modiolus*, *Hiatella arctica*).

Competition

Lateral (and internal) influences refer to the competitive interactions with groundfish, other crab species, cannibalism and reproduction-induced mortality (direct and indirect). There were no strong negative relationships between Snow Crab and other bycatch species (Choi and Zisserson 2011), suggesting little competitive interaction.

Disease

BCD is observed globally in crustaceans, though most-commonly in the northern hemisphere (Stentiford and Shields 2005). Infected Snow Crab were first observed on the Scotian Shelf in the 2008 Snow Crab Trawl Survey, with a handful of anecdotal reports of infected crab having been seen in the commercial catch in the near-shore areas previous to 2008. The fall survey timing is advantageous to detection as animals infected during the spring molt are expected to show visible signs of infection by the fall. More information on BCD and methods of detection can be found in Zisserson et al. (2023).

Bycatch of Other Species in the Snow Crab Fishery

The bycatch of other species in the Snow Crab fishery, as estimated by at-sea-observers, can be extrapolated to the entire fleet based on landings and the proportion of landings observed (Tables 12–13). Due to restrictions related to COVID-19 and staffing issues with the observer companies, since 2020 there has been minimal observer coverage and therefore, bycatch estimates are not reliable (Figure 2).

There is no updated table for 4X for recent years, as there was minimal observer data collected and there is uncertainty about the validity of the quality of the data collected during this time period.

Marine Protected Areas

St. Anns Bank area has been designated as a Marine Protected Area (MPA) in 2017 pursuant to the *Oceans Act*. The MPA is subdivided into four zones (Figure 5). The majority of the MPA (Zone 1) is a core protection area. The remaining (smaller) three zones are referred to as “adaptive management zones”, which allow limited human activity to occur within their boundaries. The presence of a refuge from fishing activities serves as a fallowing area; however, if the protection is disproportionately beneficial to other organisms (i.e., Snow Crab predators or prey items), the effects upon Snow Crab can be mixed. The long-term effects of an MPA are yet to be determined.

The Gully MPA (Figure 6) is a 2,364 km^2 area east of Sable Island and is the largest marine canyon in the Northwest Atlantic. This area was designated as a protected area in 2004 and is comprised of three distinct management zones, each with specific allowable activities. No Snow Crab fishing is permitted in any of these zones.

The Snow Crab Trawl Survey continues to occur within the St. Anns Bank and the Gully MPAs (through a designated approval process), providing data on the co-occurrence of Snow Crab and other species within these areas. Increased sampling survey catches (fish lengths, weights, and dietary analysis) occur at reference stations within and immediately outside the MPA boundaries.

METHODS

The primary driver of the analytical approaches developed for the assessment of Snow Crab on the SSE is the high temporal and spatial variability in their distributions. This is due to the area being the southern-most extreme of the species’ distributional range in the northwest Atlantic, influenced by the convergence of numerous oceanic currents, bathymetric complexity and rapid ecosystem and climate change.

All data analyses were implemented in the statistical computing language and environment R (R Development Core Team 2023) to allow transparent and open/collaborative development of methods. The Julia/Turing computing environment was used for fishery modelling due to its high performance and flexibility (Bezanson et al. 2017, Ge et al. 2018).

SPACE-TIME MODELLING

Estimation of a fishable biomass index was conducted using an extension of generalized linear models that accounts for spatiotemporal conditional autoregressive random effects in a Bayesian context (Choi 2022, 2023a). This approach models Snow Crab numerical abundance probability of observing Snow Crab, and mean size with environmental (depth, substrate, temperature) and biological factors (species composition) as covariates. Analysis was conducted on numerical counts from the Snow Crab Trawl Survey, assuming a Poisson error distribution with swept area as offsets for the positive valued observations. This was combined with a binomial model of presence and absence and a mean-weight model using the same framework. A fishable biomass index was computed from modelled results by multiplication of posterior simulations of the predicted probability of occurrence, numerical density and body weight in each areal unit, and then aggregation to the relevant management units. The magnitudes of the biomass index are optimistically high (positive bias) as sampling stations have evolved with time to be towable bottoms that generally coincide with good Snow Crab habitat. This positive selection bias (see Choi 2023a) means the index should only be seen as a spatially and temporally consistent relative index of abundance.

STOCK ASSESSMENT MODEL

A discrete time (annual) logistic model of the fishable biomass component is used to fit the biomass index and fishing removals and determine the relevant biological reference points (i.e., carrying capacity and fishing mortality at maximum sustainable yield, or F_{MSY}) associated with the harvest control rules of the Snow Crab fishery (Choi and Zisserson 2011, Smith et al. 2012). Bayesian state-space methods are used to estimate these parameters and implemented in Julia/Turing (see Model 1 referred to in Choi 2023b for more details).

RESULTS

FISHERY

Effort

Fishing effort in 2023 was 9,500, 62,100, and 200 trap hauls in N-ENS, S-ENS, and 4X, respectively. Relative to the previous year, these represent increases of 10.5% in N-ENS and 9.9% in S-ENS (Tables 2-4, Figure 7). The 4X fishery is ongoing, but currently has a reduced effort of 91.3%. Fishing effort was consistent between 2022 and 2023 in terms of spatial distribution. Spatial distribution has expanded in most areas except 4X (Figure 8). This is presumed to be related, in part, to the return of colder bottom temperatures.

Landings

Landings across time are shown in Figure 9. In 2023, they were 972, 7,342 and 7 t, in N-ENS, S-ENS, and 4X (season ongoing), respectively. Relative to 2022, they represent changes of -0.3%, 0.3%, and -84.2% (Tables 2-4). TACs for 2023 were 979 t, 7,345 t, and 55 t in N-ENS, S-ENS, and 4X, respectively.

In 2023, landings in all areas were below respective TACs (Tables 2-4), though the area 4X season is still ongoing.

The landings in N-ENS for 2023 and 2022 were similar in their spatial patterns (Figure 10). In S-ENS, landings, as with fishing effort, was slightly more expanded (Figure 8 and 10). There were no landings on the continental slope areas of S-ENS in 2023; it continues to serve as a “reserve” for Snow Crab from fishing. The landings in 4X for 2023 as with 2022, were primarily in the area just south of Sambro, bordering onto area 24 (Figure 10). In N-ENS, the majority (91%) of the landings occurred in the spring.

Catch Rates

Non-standardized fishery catch rates in 2023 were 103, 118 and 33 kg/trap haul in N-ENS, S-ENS and 4X (season ongoing), respectively. This represents a change of respectively, −8.8%, −9.2% and 94.1% (season ongoing) relative to the previous year (Tables 2–4, Figure 11). Catch rates exhibited a uniform spatial pattern across the majority of areas in 2023 (Figure 12).

OBSERVER

Carapace Conditions of Catch and Soft-Shelled Crab

The percentage of discarded soft-shelled crab (CC1 and CC2) based on observer sampling were 0% (low sampling), 14.81% (low sampling) and unknown (no sampling; season ongoing) in N-ENS, S-ENS and 4X, respectively for 2023. In 2022, it was 12.95% (low sampling), 6.43% (low sampling) and unknown (no sampling), respectively. Current estimates of CC (Tables 9-11) are unreliable as they only represent small areas of the fishing grounds and short time periods relative to the whole fishing season due to lower observations since 2020 (Figure 2).

Old Crab (CC5)

In 2022, CC5 crab levels in N-ENS were 8.4% (n = 143) and decreased to 0% (n = 91) in 2023 (Figure 13). In 2022 for S-ENS, it went from 10.1% (n = 3,347) down to 1.6% (n = 4,452) in 2023 (Figure 14). Low and inconsistent sampling effort makes these numbers uncertain.

SIZE STRUCTURE

Male (Recruitment)

There are many factors that make quantitative determination of recruitment levels into the fishable component of the fishery difficult such as: terminal molt (timing of offset of molting in spring and the survey in fall), inability to accurately age crab, inability to predict the age that male crabs will terminally molt, and survey focusing on fishable component which results in biased under representation of recruitment. The preferred habitat and habitat requirements differ significantly amongst adolescent, larval and mature male crabs, which makes estimating their recruitment level difficult.

In N-ENS, based on the size-frequency histograms of male Snow Crab population, there will be little to no recruitment for the next 1–3 years (Figure 15). In S-ENS, there is continued recruitment expected for the upcoming years (Figure 15). In 4X, there is continued erratic inter-annual patterns with minimal to low recruitment for up to three years (Figure 15).

Female (Reproduction)

In all areas there was continued recruitment of female crab into the mature (egg-bearing) stage of the population from 2016–2023 (Figure 16). However in N-ENS and 4X there has been a general decline in numerical densities of both the mature and adolescent components since 2017. In S-ENS, there has been a general increase since 2021. Egg and larval production is expected to be moderate to high in the next year in all areas except N-ENS (Figure 16). Female crabs tend to be found in more shallow water (Figure 17). In 2022, many survey stations were not completed due to mechanical issues with the survey vessel, resulting in many stations where females would be, not being sampled and not due to a decrease in mature female density necessarily.

SEX RATIOS

When the relative number of mature female crab (as compared to mature male) is high, the possibility of reproductive limitation becomes a conservation issue. This is particularly an issue in heavily exploited areas where there is an absence of large mature males able to mate and protect the more rapidly maturing and smaller females. This is observed in the southern Gulf of St. Lawrence, where male limitation is a known issue. Conversely, with very low relative numbers of female crabs (e.g., cyclically observed circa 2003 and 2013 throughout the SSE) there is low egg and larval production. The reason for extended period(s) of poor reproductive potential in the SSE is not known. Female Snow Crab are not removed by the fishery so it is not directly a fishery-related effect. A potential explanation is different predation pressures for males and female crabs, based on varying habitat preferences for the sexes and the smaller size of mature female Snow Crab. Extreme sex ratios represent an unhealthy reproductive state and a long-term conservation issue. Discontinuity between temporal trends of mature male and mature female population peaks may be a driving force behind large scale immigration or emigration patterns. Crab (particularly large males) may move to find mature females. This appears to have been the case in the early 2010s with mature male crab emigrating from N--ENS to the neighboring Area 19.

There is a high likelihood that sex ratios will naturally fluctuate over time as female Snow Crab of a given year-class will mature two to four years earlier than a male from the same year-class. Females are also believed to have a shorter mature and total life span. Such natural oscillations are particularly evident when strong year-classes dominate a population, as has been the case in the SSE. In the SSE, the sex ratios of mature Snow Crab oscillate with relatively high numbers of females in 1996, 2007, and again in 2017, with a major trough in the early 2000s and again in early 2010s (described in Zisserson et al. 2023). In N-ENS and S-ENS, sex ratio (% female of mature animals) hit a low in 2021 (S-ENS), and 2022 (N-ENS) and have generally been increasing since (Figure 18). Area 4X sex ratios of mature crab have been increasing steadily since 2014 and are now female dominated at almost the 90% level (Figure 18). Female Snow Crab in 4X seem to potentially out-survive the males, a reversal of other areas on the SSE; high exploitation of males may be one cause.

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 Scotian Shelf (Figure 19). When such spatial segregation is observed, the sexes are likely exposed to differential predation effects.

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 20–21. A peak in crude biomass densities was observed in 2009 to 2014 and has since been declining in all areas until 2018 for N-ENS and 2022 for S-ENS. The biomass density in 2023 is increasing. Note that, high and low biomass density areas fluctuate with time (Figures 20–21). Biomass density, however, does not equate to total biomass as the areas (Figure 21) occupied by crab can contract, expand and shift with environmental conditions and ecosystem change.

BIOMASS INDEX

The fishable biomass index (statistically adjusted for covariates and autocorrelation) is shown in Figures 22–23. Upon aggregation it can be seen that the overall biomass has had several cycles (Figure 22). Further, the biomass index model infers the spatiotemporal distribution of the biomass density of the fishable component from the covariates measured in that year (Figure 22); note also the aggregate timeseries with elevated uncertainty for the 2020 estimate due to no survey (Figure 23).

The spatial distribution of the fishable biomass index hit lows in all areas in 2017, began to increase in all areas until hitting highs in 2019 for S-ENS and 4X, 2021 for N-ENS (Figure 22). Since then, a reduction in the biomass index was observed throughout the region. Contraction of spatial range in 4X and the western parts of S-ENS were evident in 2022 to 2023 (Figure 23). Upon aggregation, the predicted biomass index declined marginally in all areas from 2022 to 2023 (Figure 23).

MODELLED BIOMASS

In N-ENS, the modelled biomass (pre-fishery) of Snow Crab in 2023 was 3.27 kt, relative to 3.67 kt in 2022 (Figure 24). In S-ENS, the 2023 modelled biomass (pre-fishery) was 37.91 kt, relative to 42.42 kt in 2022. In 4X, the modelled biomass (pre-fishery) for the 2023-2024 season was 0.08 kt, relative to 0.15 kt for the 2022-2023 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, the 2023 fishing mortality is estimated to have been 0.264 (annual exploitation rate of 30.17%), while in 2022 it was 0.239 (annual exploitation rate of 26.9%; Figure 25).

In S-ENS, the 2023 fishing mortality is estimated to have been 0.18 (annual exploitation rate of 19.7%), while in 2022 it was 0.161 (annual exploitation rate of 17.5%; Figure 25). 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 2023–2024 season (ongoing), fishing mortality is estimated to be 0.077 (annual exploitation rate of 8%), while in 2022–2023 it was 0.236 (annual exploitation rate of 26.6%; Figure 25). Localized exploitation rates are likely higher, as not all areas for which biomass is estimated are fished.

ECOSYSTEM CONSIDERATIONS

For more detailed background on the ecosystem context of Snow Crab in the SSE, please refer to Choi and Zisserson (2011 and the references therein).

Bottom temperature

Being cold-water stenotherms, bottom temperatures are especially important. Temperature driven biomass decreases in local Snow Crab abundance estimates and catch rates in CFA 4X, following a warm water event in 2012/13 (Zisserson and Cook 2017). Temperature changes potentially create new ecosystem regimes that affect Snow Crab's relative role within the benthic community.

A general warming trend has been observed in the Snow Crab Trawl Survey since the early 1990s on the Scotian Shelf until 2022 (Choi et al. 2022, Figure 4). Temperatures are more stable in N--ENS than S-ENS, and 4X exhibits the most erratic and highest annual mean bottom temperatures (Figures 4 and 26). The average temperature is found to have increased well beyond the 7°C threshold in 4X. N-ENS and S-ENS also continued to experience historical highs in bottom temperature and elevated spatial variability of bottom temperatures up to 2022. In 2023, bottom temperatures have returned to the historical range in all three CFAs (Figure 4).

Viable habitat

The Maritimes Region being at the confluence of many oceanic currents renders the area highly variable. Rapid climate change and uncertainty exacerbates this situation. The viable habitat estimated for each area across time has shown some variations (Figures 27–28) in the historical record. 4X showed significantly lower average viable habitat levels relative to the N--ENS and S--ENS levels. 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 and remained low in 2021/22 for all three areas. In 2023, there has been a marginal increase in N-ENS and S-ENS, while 4X decreased again and is at one of its lowest points (Figure 27).

Predation

The capacity of predatory groundfish to opportunistically feed upon Snow Crab, in combination with their numerical dominance prior to the 1990s, suggests that they may have been an important regulating factor controlling the recruitment of Snow Crab (Paine 1966; Worm and Myers 2003). For example, Snow Crab in the size range of 5 to 30 mm CW (with a 7 mm CW mode; that is instars 2 to 7, with instar 7 being strongly selected) were targeted by Thorny Skate and Atlantic Cod (Robichaud et al. 1991). Soft-shelled males in the size range of 77 to 110 mm CW during the spring molt were also a preferred food item. The demise of these predatory groundfish in the post-1990 period, and the resultant release from predation upon the immature and soft-shelled crabs, may have been an important determinant of the current rise to dominance of Snow Crab in the SSE. As the occurrence of Snow Crab (relative to other species) changes within the ecosystem, so does their potential role as both a predator and prey species (Boudreau and Worm 2012). 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, 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). Snow Crab predators were determined using data housed in the DFO Maritimes Region Food Habits.

The most common predators of Snow Crab in the SSE are shown in Table 15. A total of 58,257 finfish stomach samples were analyzed (held in the DFO Maritimes Region Food Habits Database [Cook and Bundy 2010]), and 159 (0.28%) contained Snow Crab. Survey encounter locations of the species with stomach contents containing Snow Crab are displayed in Figure 29, with Atlantic Cod (Figures 30 – 31) and Atlantic Halibut (Figures 32 – 33), Longhorn Sculpin, Thorny Skate (Figures 34 – 35) and Striped Atlantic Wolffish (Figures 36 – 37) being the most common predators of Snow Crab (Table 15).

Atlantic Halibut biomass on Snow Crab grounds have increased since 2010 (DFO 2018, DFO 2022b, DFO 2023, Figure 32) suggesting that the total number of Snow Crab consumed are likely increasing in relation to this predator (Zisserson et al. 2023). Most of these increases have been observed towards The Gully, Slope Edge, and near Sable Island, especially in 2022 (Figure 33). In 2023, in S-ENS there was a decline in the biomass from 2022 observed during the Snow Crab Trawl Survey but still higher than the numbers seen in early 2000s. Only Snow Crab <65 mm CW are typically observed in fish stomachs because maximum span exceeds the predators' mouth gape (Chabot et al. 2008). A proliferation of Halibut, particularly the largest fish with large mouth gapes, could create predation on larger Snow Crab seldom experienced previously. Anecdotal reports of large Atlantic Halibut with multiple mature female Snow Crab in their stomachs support this assertion. Increased predation of mature female crab will impact the reproductive potential of Scotian Shelf Snow Crab. Halibut are likely the largest source of predation of larger Snow Crab on the Scotian Shelf.

Atlantic Cod have been shown to be an important predator (Table 15) of Snow Crab in other regions (Bailey 1982; Burgos et al. 2013; Chabot et al. 2008; Lilly 1984; Orensanz et al. 2004; Robichaud et al. 1989, 1991). Boudreau et al. (2011) suggest that the top-down control effect of Atlantic Cod on Atlantic Canadian Snow Crab is most prevalent on older juvenile and sub-adult Snow Crab. Increased predation upon small immature crabs due to increased predator abundance and changing temperature fields that increase movement and encounter rates represent important issues that need to be monitored (Figures 30–31).

High local densities of predators (such as Thorny Skate, and Striped Wolffish as seen in Figures 34–37) coinciding with high densities of immature crab have been observed. Based upon the observation of Snow Crab predation events in space (Figure 29), higher predation mortality from finfish seems likely in N-ENS and S-ENS and potentially lower in 4X. The latter, however, may be a biased representation as the Maritimes Ecosystem Research Vessel surveys, from which most of the diets database is derived, seldom sampled near shore.

Diet

The distribution of Northern Shrimp (*Pandalus borealis*) on the Scotian Shelf from the Snow Crab Trawl Survey seems to have contracted and SSE stock is in a depressed state (DFO 2022a; Figures 38–39).

Competition

The potential competitors, Lesser Toad Crab (Figures 40–41) and Jonah Crab (Tables 12–13), remain in relatively patchy distributions and, therefore, do not currently appear to pose much threat to the overall health of the Snow Crab stock. Steady increases in near-shore lobster populations in the past 10 years (DFO 2017, DFO 2021) may increase resource competition (and even predation) for juvenile Snow Crab whose habitat preferences overlap those of lobster.

Disease

BCD numbers are still low in 2023, with an infection rate of encountered Snow Crab at 0.014% infected (Table 14). This is the lowest value since 2008. This value may be slightly lower than it should be as observer knowledge of BCD during the survey was limited so not all infected crabs may have been documented.

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). The operational reference points associated with the 4VWX Snow Crab fishery are as follows (Figure 42):

Limit reference point (LRP): defined as 25% of estimated carrying capacity and delineates the critical and cautious zones.

Upper stock reference (USR): defined as 50% of estimated carrying capacity and delineates the cautious and healthy zones.

Removal reference (RR): not to exceed F_{MSY} (where F is the fishing mortality of the legal sized mature male population and MSY is the theoretical Maximum Sustainable Yield).

In the logistic model, $F_{MSY} = r/2$. As r is approximately 1 for Snow Crab, F_{MSY} is expected to be approximately 0.5.

The operational target exploitation changes depending upon the zone in which a population lands. When in the healthy zone, the rule of thumb has been to keep annual exploitation rates between 10% to 30% of the available biomass (F = 0.11, 0.36, respectively). In the cautious zone, the rule of thumb has been to keep annual exploitation rates between 0% to 20% (F = 0, 0.22, respectively). In the critical zone, fishery closure is considered until recovery is observed, where recovery indicates at a minimum, modelled biomass greater than the LRP. 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.

The current estimates of key Reference Points from Model 1 (Choi 2023b) are shown in Table 16 and Figures 42–45). The related PA thresholds can be computed as:

- Limit reference point (LRP): K/4
- Upper stock reference (USR): K/2
- Upper removal reference (URR): keep fishing mortality below FMSY= r/2

The current state of the fishable components and the above landmarks from Model 1 (Choi 2023b; Figures 43–45) suggest that:

- N-ENS is in the healthy zone
- S-ENS is in the healthy zone
- 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 Scotian Shelf Snow Crab population 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 (Choi 2023a, 2023b). Further, the observation of fisheries landings is assumed to be known without error. This is not true as illegal and unreported exploitation occurs. These and other unaccounted factors can easily bias parameter estimates. As such, caution is required in using these reference points**.** Other contextual reference points should and must be used in conjunction:

- Strength of recruitment (short-term, and 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

CONCLUSIONS

The SSE is still experiencing a lot of instability driven by rapid ecosystem and climatic variations. Under such conditions, it is prudent to be careful. 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.

NORTH-EASTERN NOVA SCOTIA

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. N-ENS is in the “healthy” zone.

SOUTH-EASTERN NOVA SCOTIA

In S-ENS, recruitment to the fishery is likely to continue at a reasonable rate for the upcoming season. The S-ENS stock remains in the “healthy” zone.

AREA 4X

In 4X, low recruitment is expected for up to three years. 4X is in the “critical” zone. The area is also in the southern-most extent of Snow Crab distribution in the North Atlantic and experienced an extended period of the harsh conditions for Snow Crab in the region. Viable habitat has been depressed for many years.

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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
N-ENS	April 14^{th} - August 18^{th}
S-ENS (CFA 23)	April 15^{th} – August 31^{st}
S-ENS (CFA 24)	April 15^{th} – August 31^{st}
4X	November 1, 2023 – March 31, 2024

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	Licences	TAC	Landings	Effort	CPUE
2013	I8	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	7.7	108
2021	78	890	901	8.8	102
2022	78	980	975	8.6	113
2023	78	979	972	9.5	103

Table 3. *Fishery performance statistics in south-eastern Nova Scotia (S-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	Licences	TAC	Landings	Effort	CPUE
2013	116	11311	11341	105.5	107
2014	116	11311	11265	96.3	117
2015	116	11311	11295	103.9	109
2016	116	9614	9606	87.3	110
2017	116	6730	6718	69.9	96
2018	116	6057	6063	51.3	118
2019	116	6663	6632	61.9	107
2020	116	8161	7943	63.9	124
2021	116	8161	8332	80.8	103
2022	116	7345	7323	56.5	130
2023	115	7345	7342	62.1	118

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	Licences	TAC	Landings	Effort	CPUE
2013	9	80	80	5.2	15
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[1]	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	38	2.3	17
2023[2]	9	55	7	0.2	33

[1] No fishery (0 TAC) due to low commercial biomass.
[2] As of January 23, 2024 season ongoing.

Table 5. Observer coverage for N-ENS.

Year	Observed (mt)	Traps Sampled	Traps Observed	Landings (mt)	Percent Observed
2019	34	63	354	629	5.4
2020	4	5	25	836	0.5
2021	0	0	0	901	0
2022	2	5	24	975	0.2
2023	2	5	30	972	0.2

Table 6. Observer coverage for S-ENS.

Year	Observed (mt)	Traps Sampled	Traps Observed	Landings (mt)	Percent Observed
2019	332	472	2891	6632	5.0
2020	37	46	379	7942	0.5
2021	78	143	737	8332	0.9
2022	80	116	670	7323	1.1
2023	135	169	850	7342	1.8

Table 7. Observer coverage for 4X.

Year	Observed (mt)	Traps Sampled	Traps Observed	Landings (mt)	Percent Observed
2019	7	16	139	59	11.9
2020	2	12	62	76	2.6
2021	0	0	0	110	0
2022	0	9	0	38	0
2023[1]	0	0	0	7	0

[1] As of January 23, 2024 season ongoing and data is incomplete.

Table 8. Snow Crab carapace conditions (CC) and their description.

Carapace Condition (CC)	Category	Description	Age After Terminal Molt (Approximate)
1	New soft	claws easily bent, carapace soft, brightly coloured, iridescent, no epibionts	0–5 months
2	Clean	claws easily bent, carapace soft, brightly coloured, iridescent, some epibionts	5 months–1 year
3	Intermediate	carapace hard, dull brown dorsally, yellow-brown ventrally, no iridescence, shell abrasion, epibionts	8 months–3 years
4	Old	carapace hard, very dirty, some decay at leg joints, some epibionts	2 – 5 years
5	Very old	carapace soft, very dirty, extensive decay, extensive epibionts	4– 6 years

Table 9. Carapace condition (CC) of crab ≥ 95 mm CW (percent by number) over time for N-ENS from at-sea-observed data. There were no observed trips in 2021 indicated by a dash (-).

Year	CC1	CC2	CC3	CC4	CC5
2008	26.84	4.21	61.33	6.86	0.75
2009	0.23	3.3	92.11	4.35	0.02
2010	1.6	1.56	92.61	3.97	0.25
2011	0	1.9	95.55	2.49	0.07
2012	0	2.99	95.68	1.33	0
2013	0	1.82	73.93	22.52	1.73
2014	0.09	25.65	72.58	1.67	0
2015	0.06	2.89	89.21	7.59	0.25
2016	0	1.26	84.96	13.66	0.11
2017	0.13	9.32	49.23	40.72	0.6
2018	0.15	34.5	45.22	19.74	0.37
2019	0	2.49	75.8	21.66	.05
2020	0.84	26.89	46.22	22.69	3.36
2021	-	-	-	-	-
2022	0	12.95	54.68	25.18	7.19
2023	0	0	69.32	30.68	0

Table 10. Carapace condition (CC) of crab ≥ 95 mm CW (percent by number) over time for S-ENS from at-sea-observed data.

Year	CC1	CC2	CC3	CC4	CC5
2008	10.12	8.57	67.93	12.34	1.03
2009	8.41	7.4	64.77	16.9	2.52
2010	2.5	9.75	79.53	7.25	0.96
2011	0.57	9.22	85.42	4.71	0.09
2012	0.29	10.16	85.28	4.2	0.07
2013	0.25	2.78	94.14	2.81	0.02
2014	1.08	23.48	69.45	5.82	0.17
2015	0.7	8.68	83.77	6.61	0.24
2016	0.03	3.53	80.2	15.88	0.37
2017	0.02	6.3	78.67	14.75	0.26
2018	0.05	5.84	86.33	7.47	0.31
2019	0	4.91	64.1	30.76	0.22
2020	0.06	45.05	51.23	3.66	0.00
2021	0.77	10.39	78.42	10.08	0.34
2022	0.10	6.33	63.70	22.22	7.64
2023	0.21	14.60	74.49	10.28	0.42

Table 11. Carapace condition (CC) of crab ≥ 95 mm CW (percent by number) over time for 4X from at-sea-observed data. Year refers to the starting year of the season (i.e., 2014/15 season is shown as 2014). 2023 season is still in progress indicated by a dash (-).

Year	CC1	CC2	CC3	CC4	CC5
2006	0.05	0.5	98.01	1.44	0
2007	0.18	0.09	78.75	20.75	0.23
2008	0.32	0.16	56.98	42.47	0.08
2009	0.04	0.5	98.89	0.57	0
2010	0.25	1.23	54.28	44.17	0.07
2011	0.05	0.17	94.37	5.32	0.1
2012	0	0.8	81.56	17.16	0.48
2013	0	4.95	89.63	5.37	0.05
2014	0.58	14.19	74.37	10.85	0.00
2015	0.84	10.03	64.83	24.24	0.05
2016	0.41	11.05	60.85	27.69	0.00
2017	0.85	14.74	73.33	10.60	0.49
2018	*	*	*	*	*
2019	0	0	85.82	14.18	0
2020	0	0.22	91.89	7.89	0
2021	**	**	**	**	**
2022	0	0	80.0	20.0	**
2023	-	-	-	-	

**no commercial fishery occurred in 2018/19 due to no TAC.*
*** no observer coverage took place in 2021.*

Table 12. Bycatch (kg) estimates from the N-ENS Snow Crab fishery. Estimates are extrapolated from At-Sea-Observed bycatch and biomass of catch (bycatch = [observed biomass of bycatch species / observed landings of Snow Crab] X total landings of Snow Crab). Species specific data beyond 2019 are considered unreliable. There was one observed trip in 2020 and no observer coverage in 2021(indicated by a dash (-).

Species	2019	2020	2021	2022	2023
Asteroidea	0.7	0.0	-	0.0	0.0
Atlantic Rock Crab	0.0	0.0	-	13.6	0.0
Clams	0.6	0.0	-	0.0	0.0
Cod Atlantic	0.0	0.0	-	26.8	0.0
Flounder Unidentified	2.9	0.0	-	0.0	0.0
Mud Star	3.1	0.0	-	0.0	0.0
Northern Stone Crab	8.7	0.0	-	0.0	0.0
Sand Dollars	0.2	0.0	-	0.0	0.0
Toad Crab Unident	3.4	0.0	-	0.0	0.0
Whelks	0.6	0.0	-	0.0	0.0
Total	**20.3**	**0.0**	**-**	**40.4**	**0.0**

*Table 13. Bycatch (kg) estimates from the S-ENS Snow Crab fishery. Estimates are extrapolated from At-Sea-Observed bycatch and biomass of catch (bycatch = [observed biomass of bycatch species / observed landings of Snow Crab] X total landings of Snow Crab). Species specific data beyond 2019 are considered unreliable. * Indicates one individual of the species was caught during observed trips.*

Species	2019	2020	2021	2022	2023
Asteroidea	0.0	0.0	0.0	0.0*	0.0
Atlantic Rock Crab	28.4	0.0	0.0	0.0	0.0
Cod Atlantic	0.2	0.0	0.0	0.0	109.7
Haddock	0.0	0.0	0.0	0.0	426.6
Jonah Crab	27.3	4.7	0.0	0.0	0.0
Northern Stone Crab	2.2	4.0	0.0	0.0	0.0
Northern Wolffish	0.0	0.0	0.0	0.0	20.6
Pandalus Borealis	22.0	0.0	0.0	0.0	0.0
Pollock	0.0	0.0	0.0	0.0	119.8
Purple Sunstar	0.6	0.0	0.0	0.0	0.0
Redfish Unseparated	1.9	0.0	30.2	0.0	0.0
Sea Cucumber	2.7	0.0	7.1	1.4	0.0
Sea Raven	0.0	0.0	0.0	0.0	4.8
Sea Urchins	0.0	0.0	0.0	0.0*	0.0
Spiny Sunstar	0.0	4.7	0.0	0.0	0.0
Spotted Wolffish	76.3	0.0	0.0	0.0	0.0
Striped Atlantic Wolffish	0.0*	0.0	0.0	6.7	0.0
Toad Crab	43.8	0.0	0.0	0.0	0.0
Toad Crab Unident	51.1	0.0	0.0	0.0	0.0
Witch Flounder	0.0	0.0	0.0	0.0*	0.0
Total	**256.6**	**13.4**	**37.3**	**8.1**	**681.6**

Table 14. Prevalence of bitter crab disease (BCD) on the Scotian Shelf. Total crab refers to the number of crab examined, Visible BCD crab represents those suggested to be positive. Infection rate is the proportion of positives and % male is the proportion of BCD (+) crab that are male. No observations indicated by a dash (-)

Survey Year	Total Crab	Visible BCD (+) Crab	Infection Rate (%)	%Male (BCD +)
2008	31,315	24	0.077	54
2009	29,167	33	0.113	61
2010	31,197	19	0.061	53
2011	24,852	22	0.089	59
2012	20,354	16	0.079	62
2013	21,715	16	0.074	56
2014	23,511	20	0.085	35
2015	19,749	20	0.101	55
2016	20,694	28	0.135	36
2017	15,453	13	0.084	54
2018	15, 430	7	0.045	57
2019	23,502	17	0.072	59
2020	0	-	-	-
2021	25,906	37	0.143	51
2022	18,393	9	0.049	67
2023	21,456	3	0.014	67

Table 15. Frequency of Snow Crab in the diet of predators on the Scotian Shelf of Atlantic Canada. Of 58,257 finfish stomach samples, 159 contained Snow Crab (0.28%).

Species	Frequency
Atlantic Cod	45
Atlantic Halibut	42
Longhorn Sculpin	19
Thorny Skate	12
Striped Atlantic Wolffish	11
Haddock	7
American Plaice	7
Smooth Skate	6
Winter Skate	2
White Hake	2
Shorthorn Sculpin	1
Newfoundland Eelpout	1
Squirrel or Red Hake	1
Sea Raven	1
Ocean Pout	1
Barndoor Skate	1

Table 16. Reference points from the logistic biomass dynamics fishery model (Model 1): K is carrying capacity (kt); and r is intrinsic rate of increase (non-dimensional). Note that FMSY (fishing mortality associated with 'maximum sustainable yield') is r/2. Similarly, BMSY (biomass associated with 'maximum sustainable yield') is K/2. SD is posterior standard deviation.

Area	K [SD]	r [SD]
N-ENS	5.15 [0.44]	0.95 [0.44]
S-ENS	64.41 [5.04]	0.89 [5.04]
4X	1.28 [0.11]	0.94 [0.11]

FIGURES

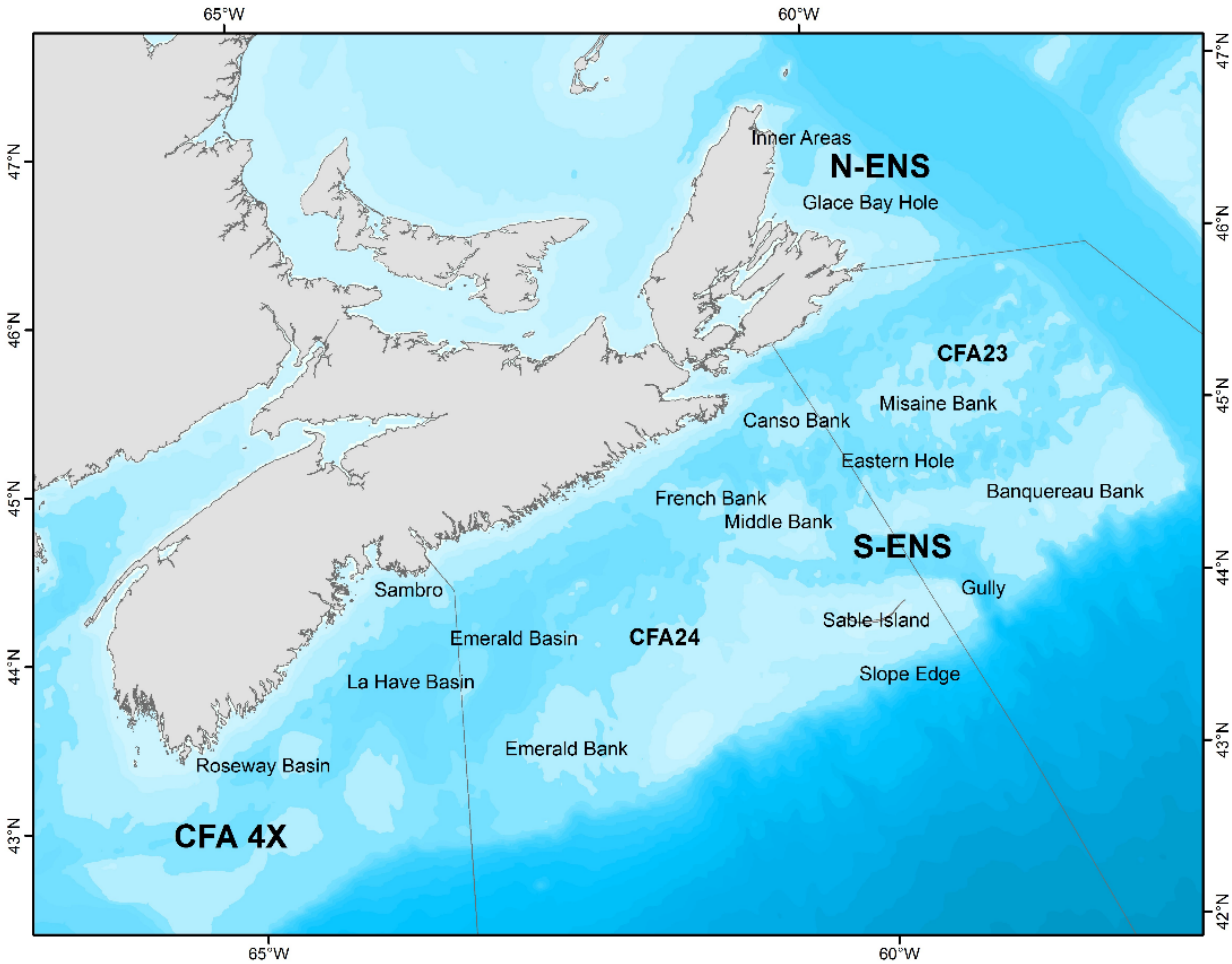

Figure 1. Map of the Scotian Shelf ecosystem (SSE) and crab fishing areas (CFAs). S-ENS is further subdivided for management into Areas 23 to the northeast and 24 to the southwest.

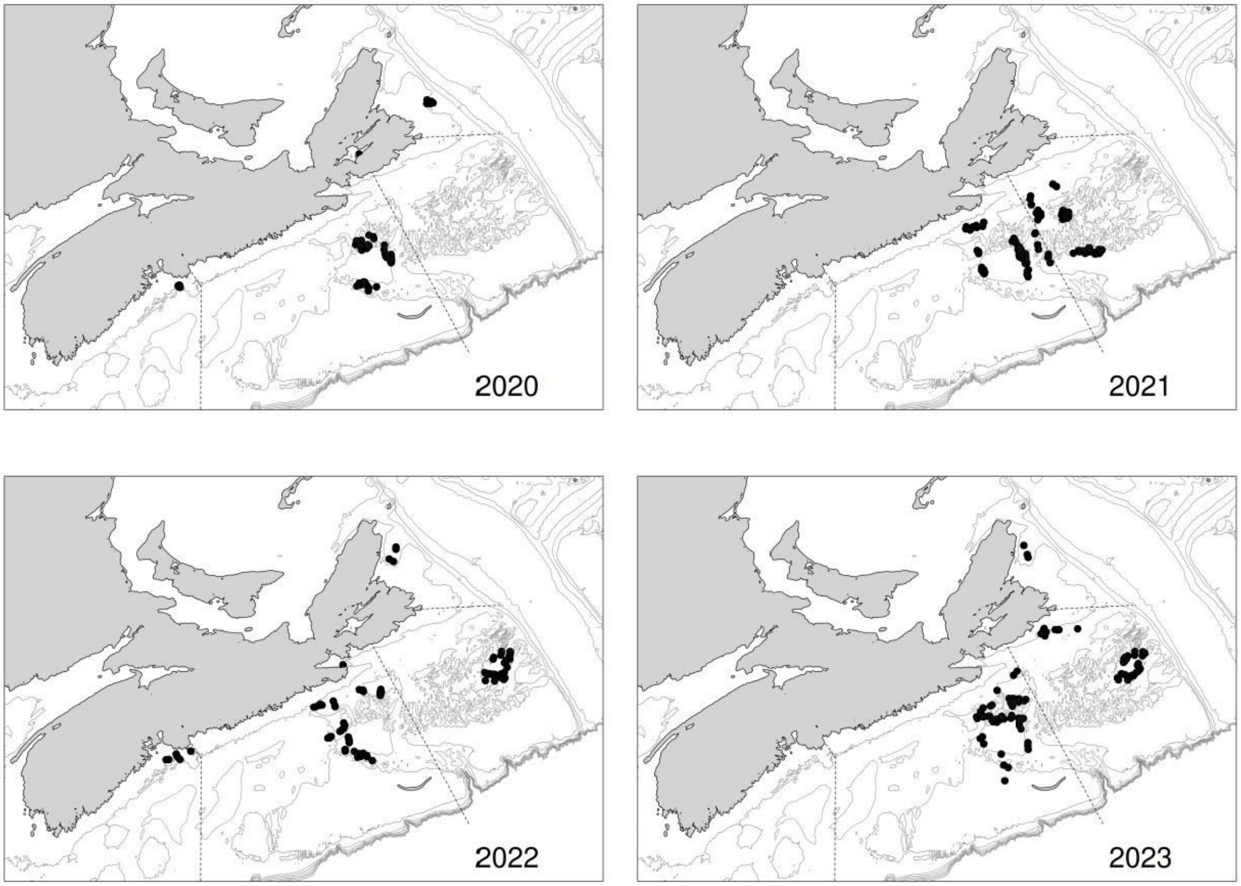

Figure 2. Snow Crab at-sea observer locations from 2020-2023.

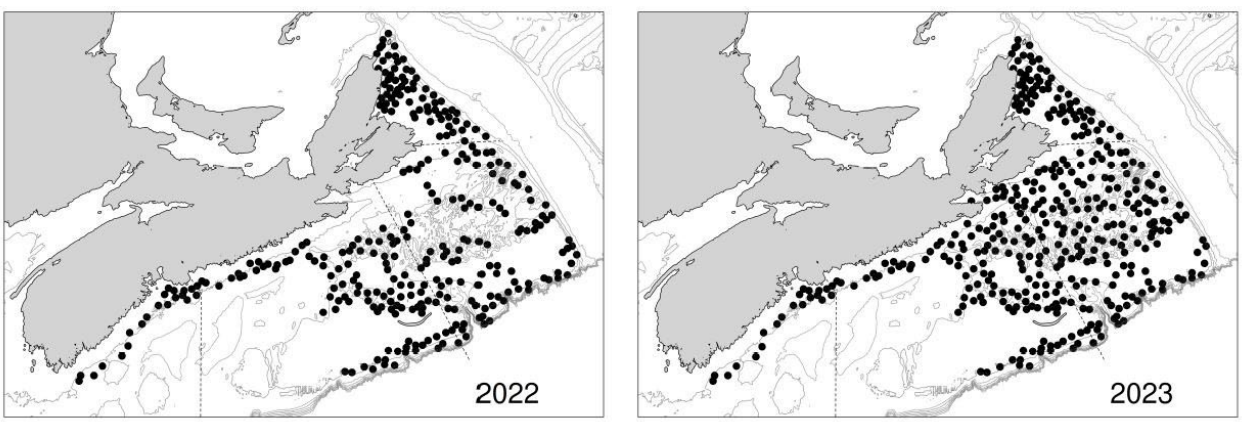

Figure 3. Snow Crab survey station locations from 2022 and 2023.

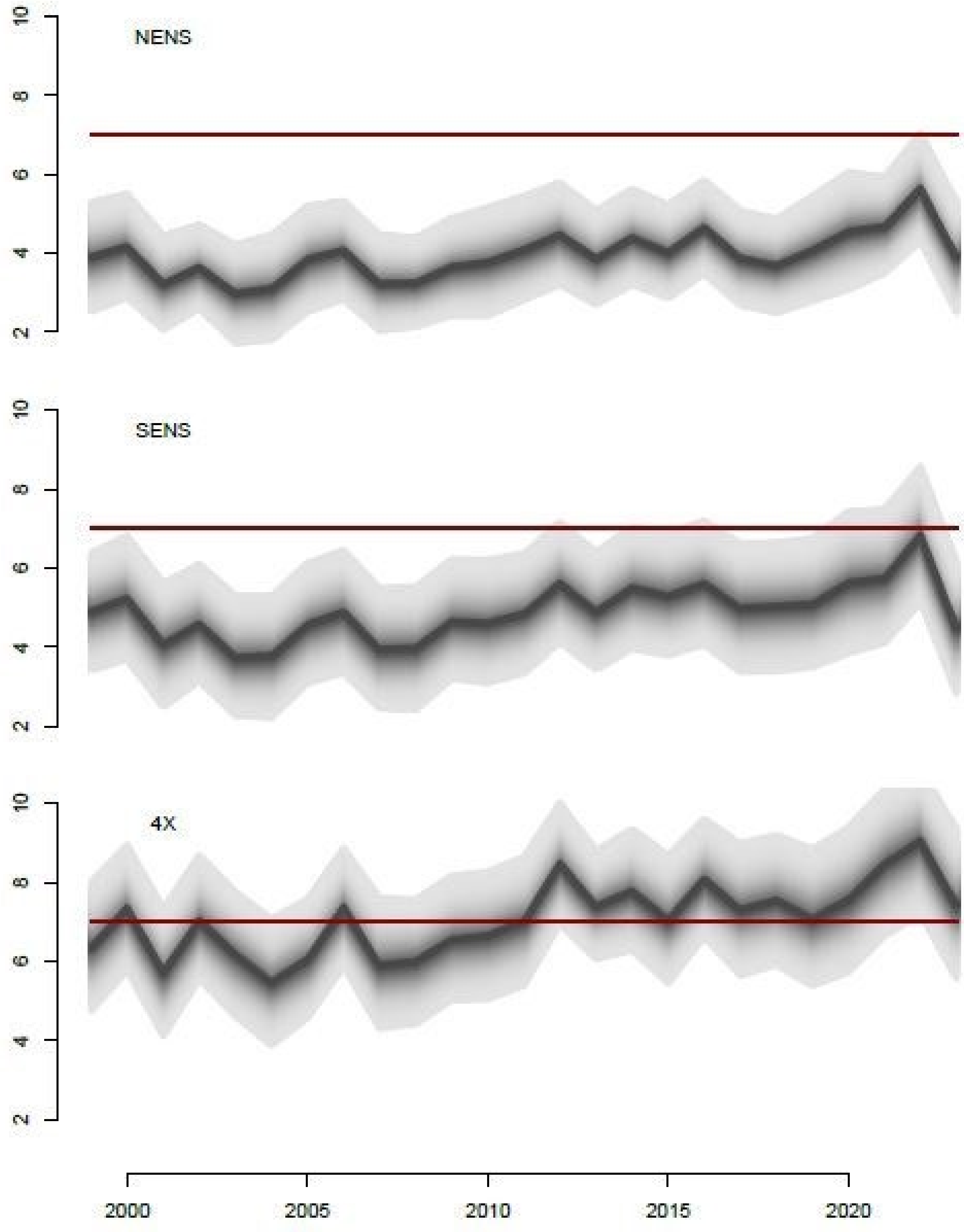

Figure 4. Temporal variations in bottom temperature estimated from a historical analysis of temperature data. Red horizontal line is at 7℃. Presented are 95% credible intervals of spatial variability in temperature at each time slice, after adjustment for spatiotemporal autocorrelation.

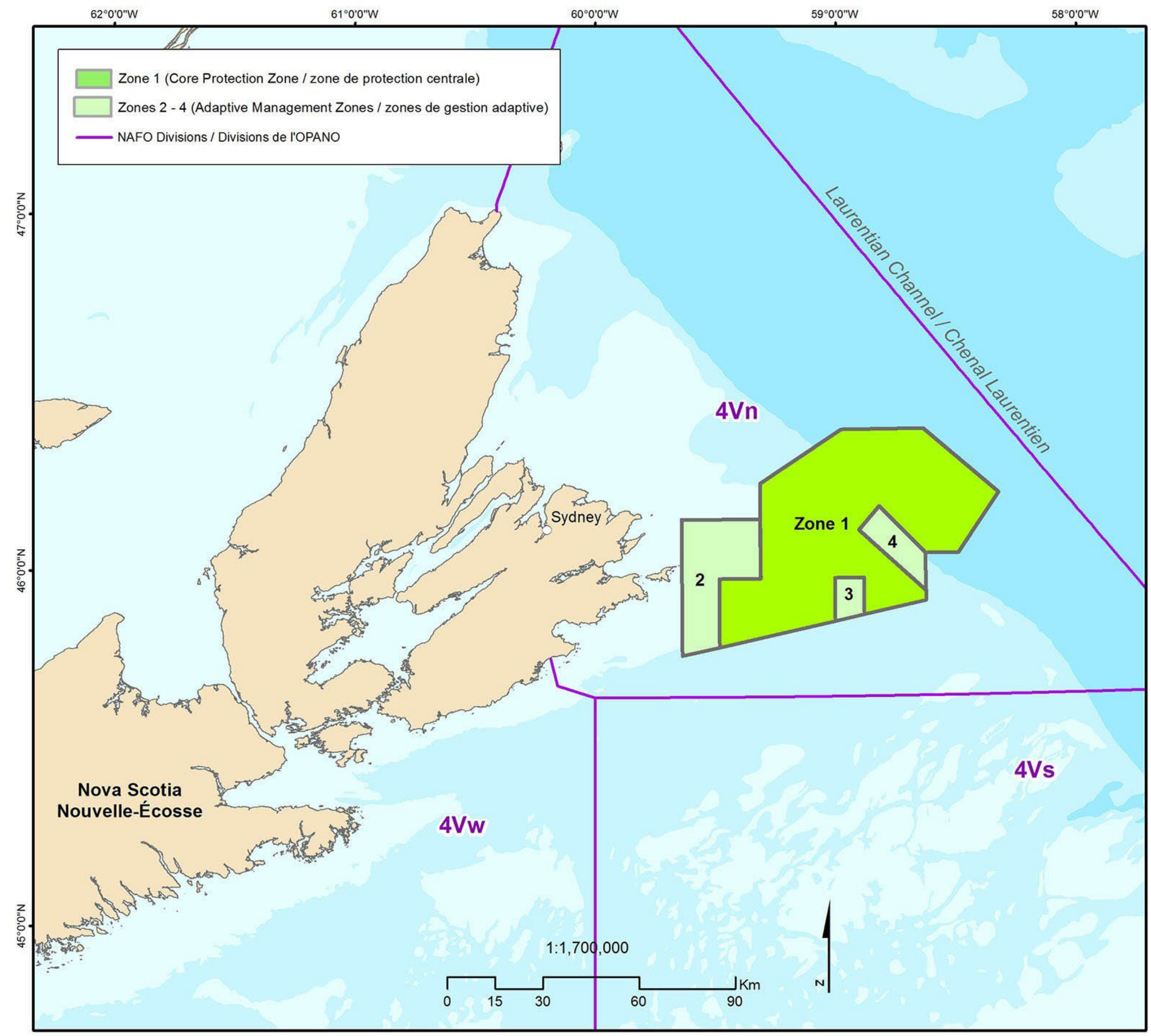

Figure 5. The St. Anns Bank Marine Protected Area (MPA). It is split into four zones.

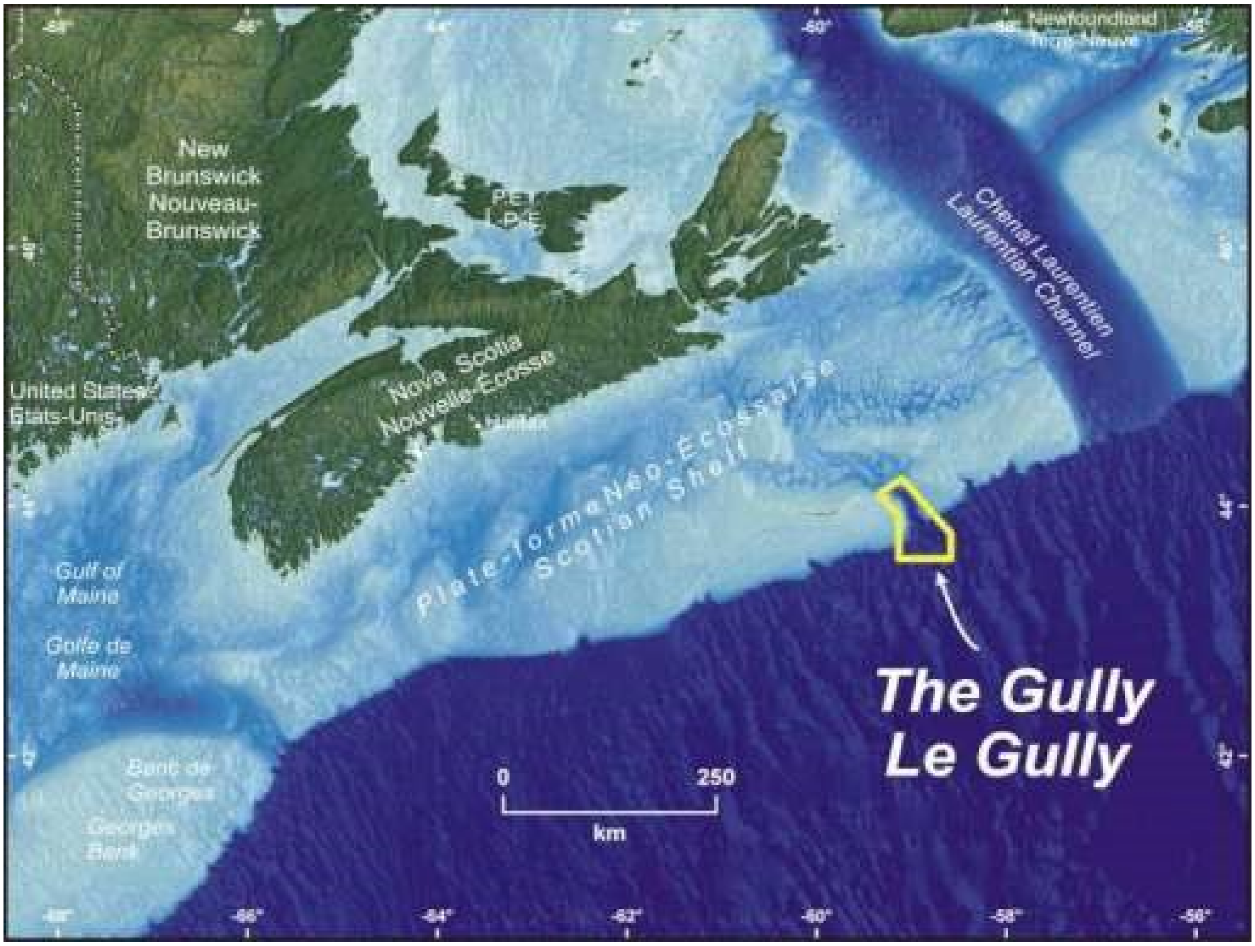

Figure 6. The Gully Marine Protected Area (MPA) located east of Sable Island.

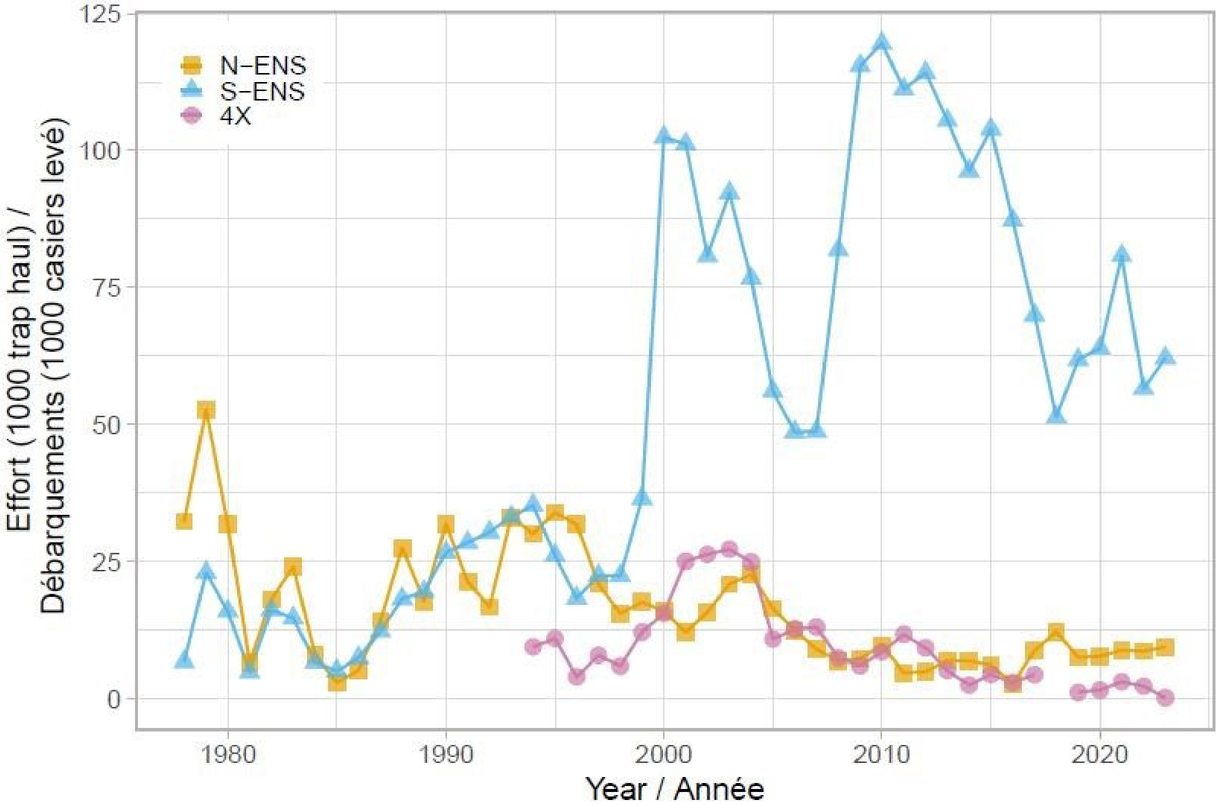

Figure 7. Temporal variations in the fishing effort for Snow Crab on the Scotian Shelf, expressed as the number of trap hauls (x10³). Year in 4X refers to the year at the start of the fishing season. No fishery occurred in 4X for the 2018 season.

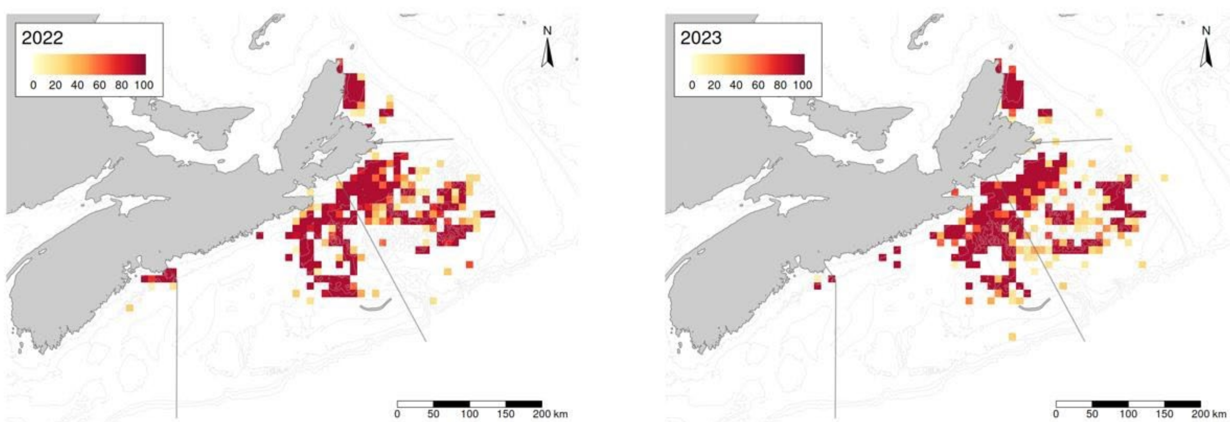

Figure 8. Snow Crab fishing effort from fisheries logbook data for 2022 and 2023 (number of trap hauls x 10³) per 10 km x 10 km grid).

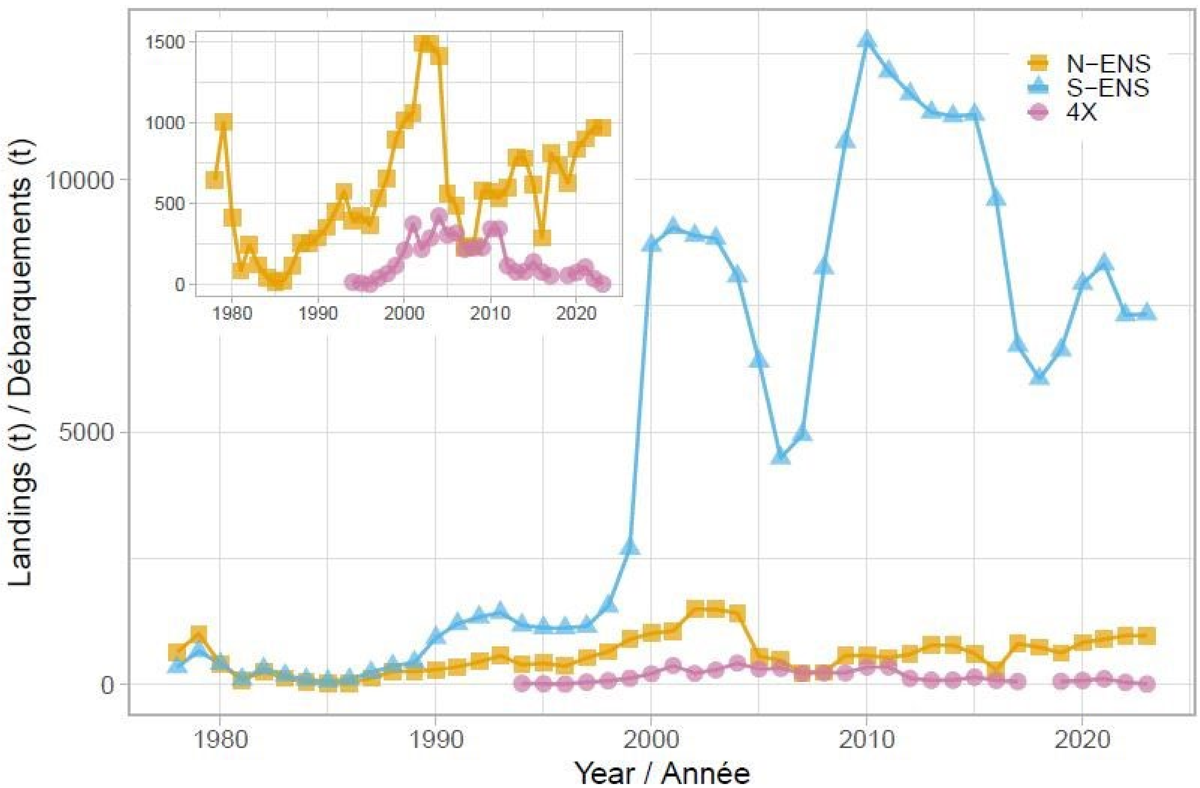

Figure 9. Landings (t) of Snow Crab on the SSE. For 4X, the year refers to the starting year of the season. Inset is a closeup view of the time series of N-ENS and 4X. Note there was 0 TAC in 2018 for the 4X fishery.

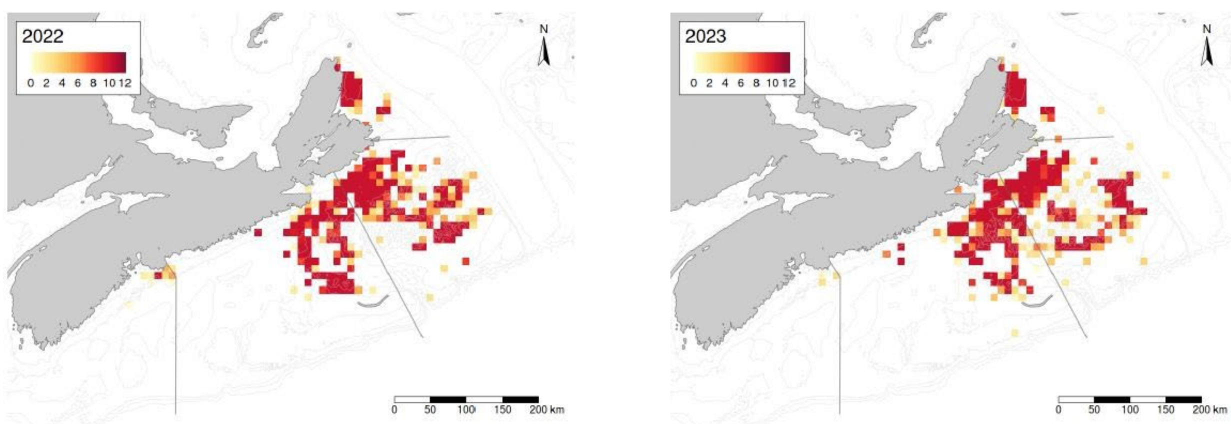

Figure 10. Snow Crab landings from fisheries logbook data for 2022 and 2023 (tons per 10 km x 10 km grid).

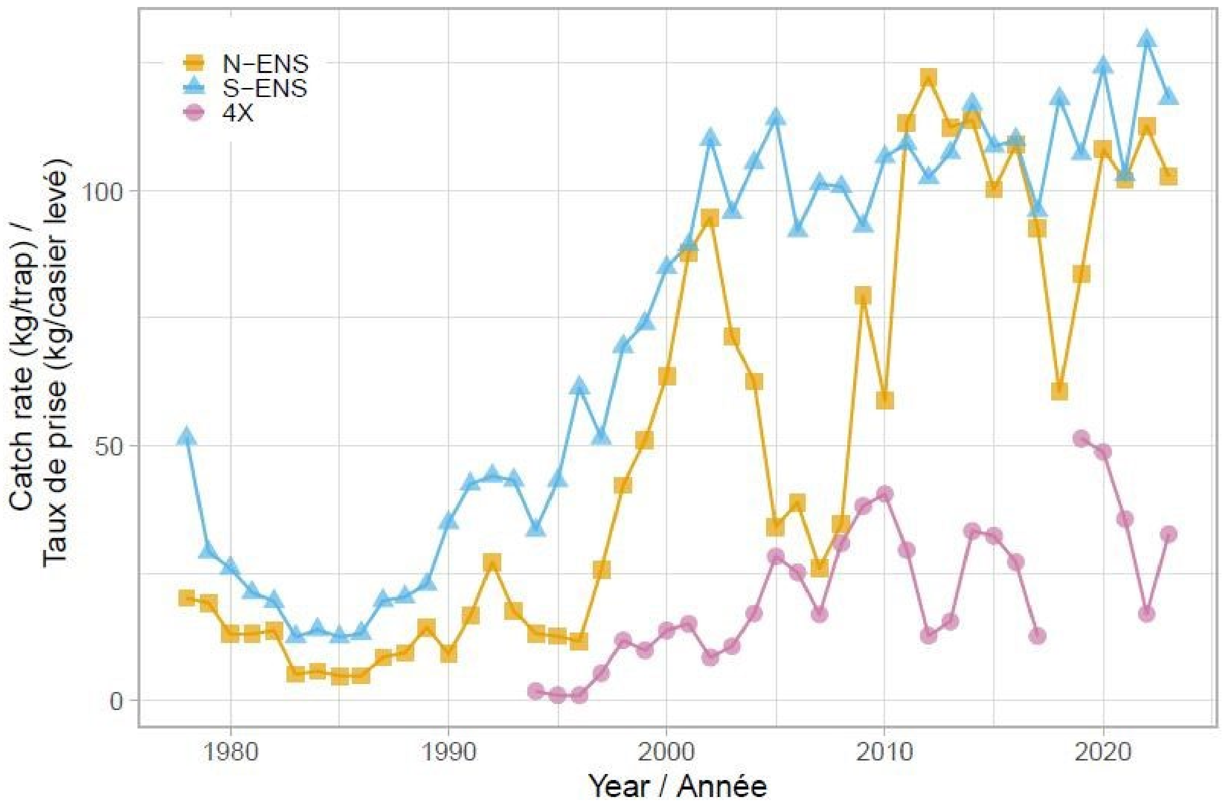

Figure 11. Temporal variations in crude catch rates of Snow Crab in the three fishing areas (kg/trap haul). Note in 4X there was 0 TAC in 2018.

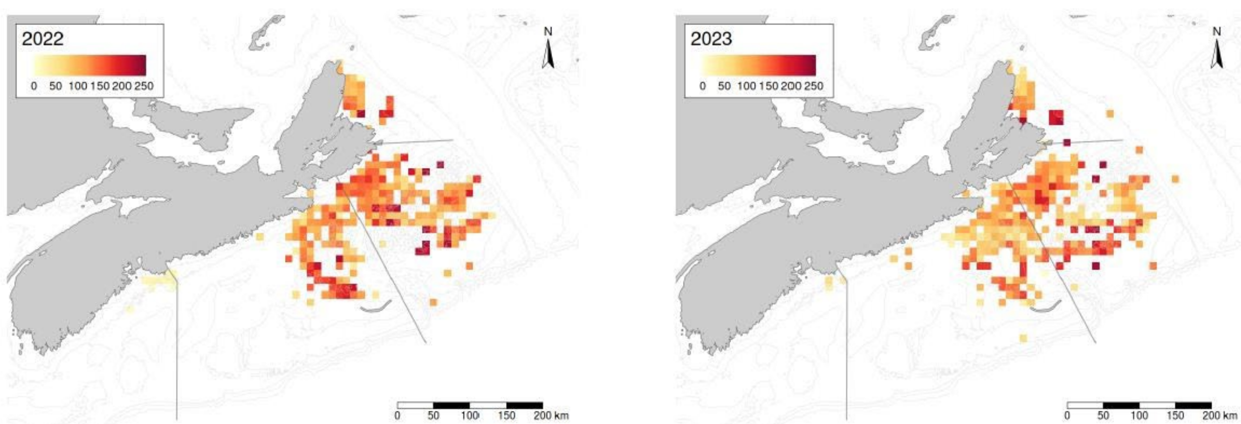

Figure 12. Snow Crab unstandardized catch rates on the Scotian Shelf for 2022 and 2023. Units are in kg/trap haul per 10 km x 10 km grid.

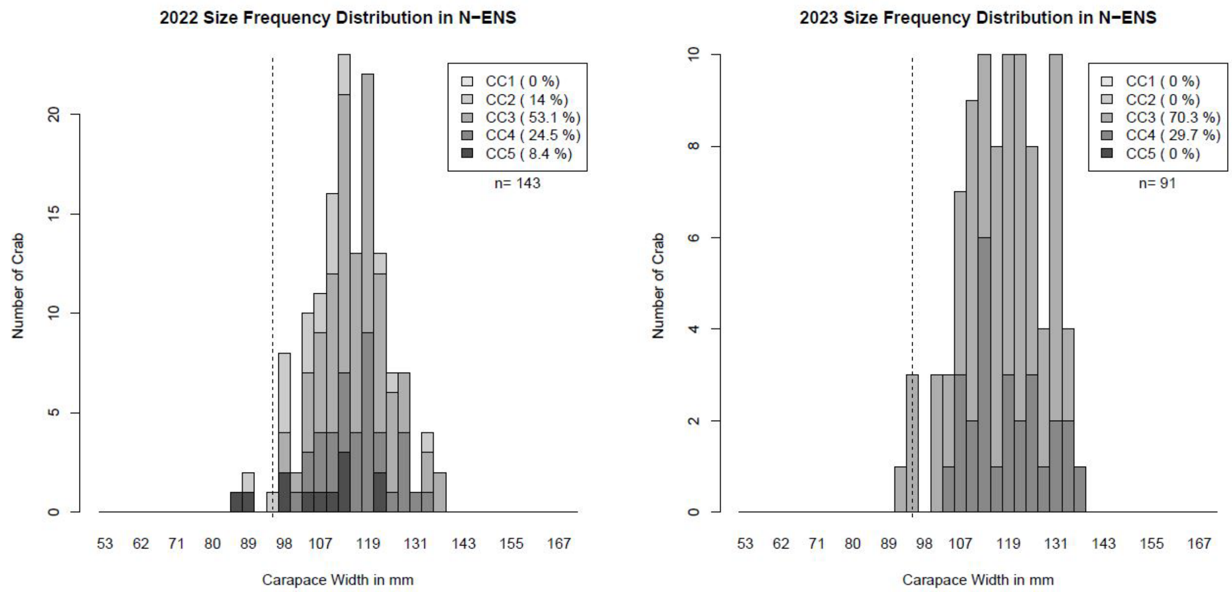

Figure 13. At-sea-observed size frequency distributions in 2022 and 2023 in N-ENS for carapace conditions (CC) 1-5. n represents the number of Snow Crab measured by their carapace width in mm.

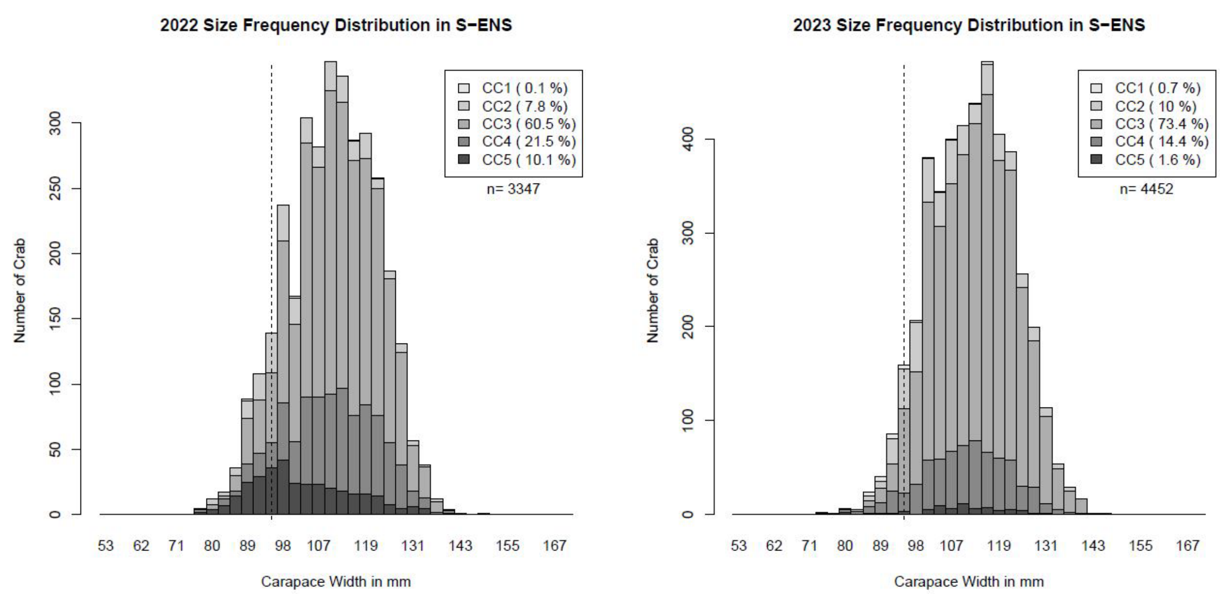

Figure 14. At-sea-observed size frequency distributions in 2022 and 2023 in S-ENS for carapace conditions (CC) 1-5. n represents the number of Snow Crab measured by their carapace width in mm.

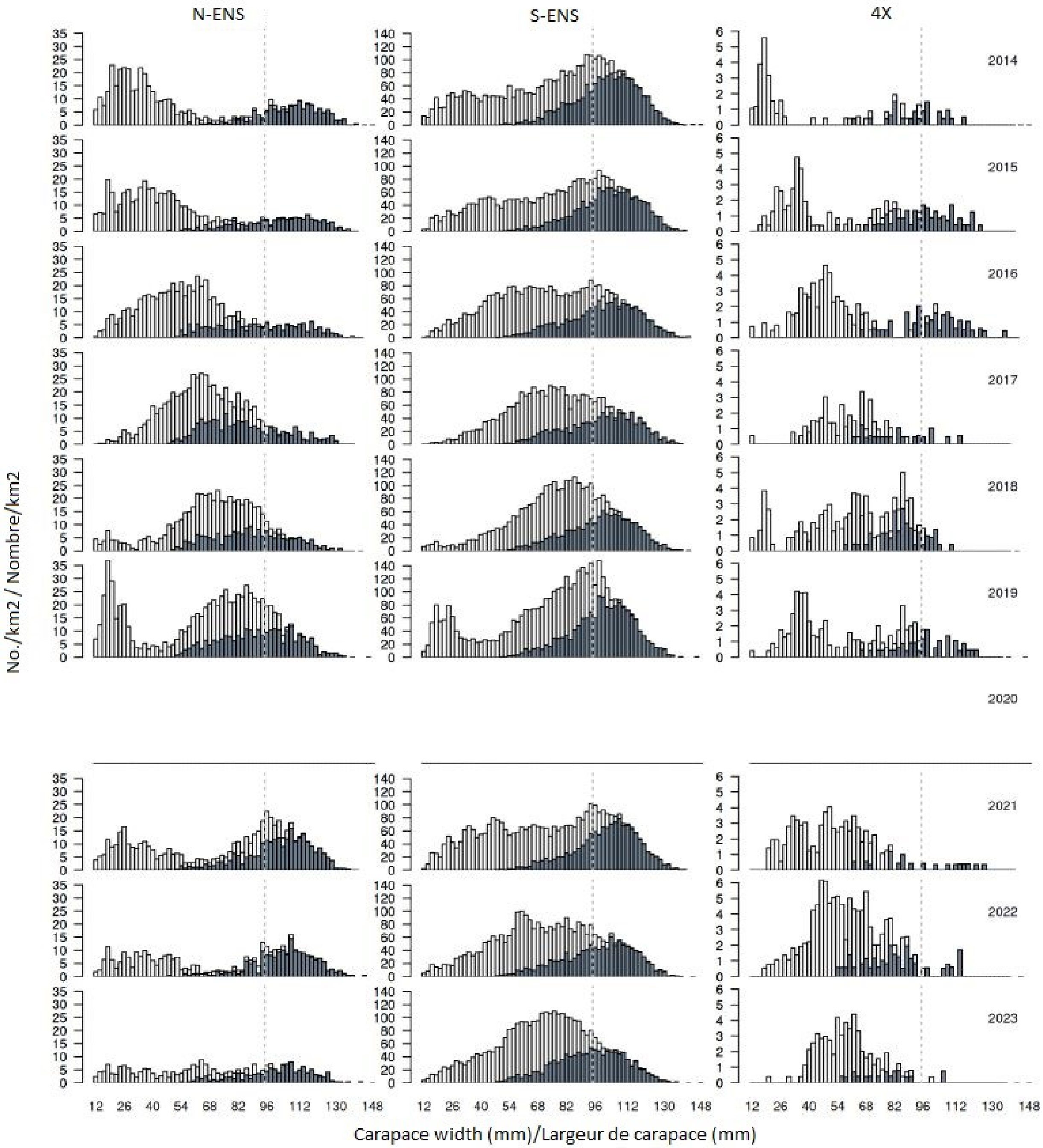

Figure 15. Size-frequency (areal density, No./km²) histograms of carapace width of male Snow Crab from the snow crab survey. This figure provides information about the relative densities within a given year. The vertical line represents the legal size (95 mm). Immature animals are shown with the lighter bars and mature with darker. The year 2020 is left blank as there was no survey.

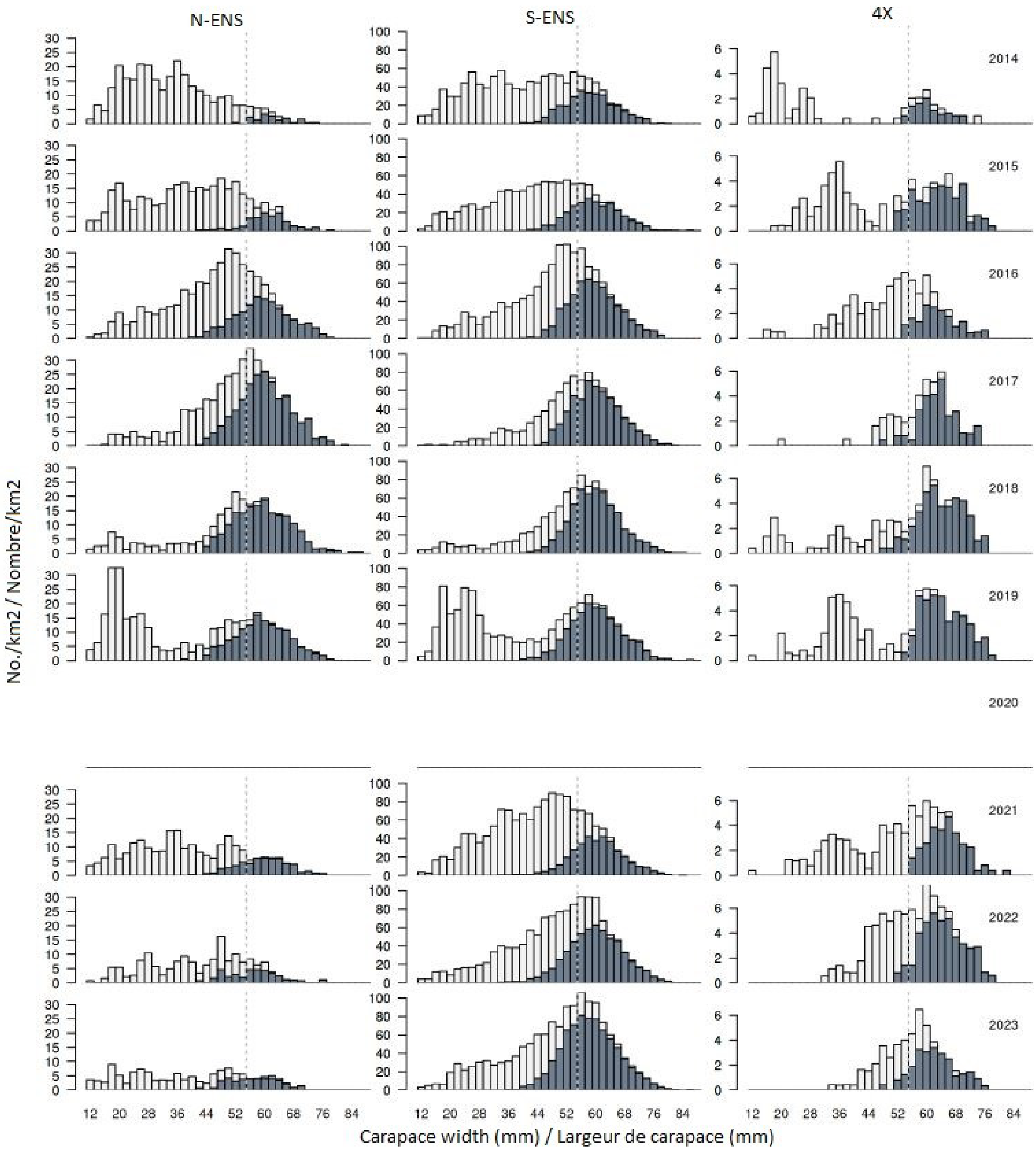

Figure 16. Size-frequency histograms of carapace width of female Snow Crab from the Snow Crab survey. This figure provides information about the relative densities within a given year. Immature animals are shown with the lighter bars and mature with darker. The year 2020 is left blank as there was no survey.

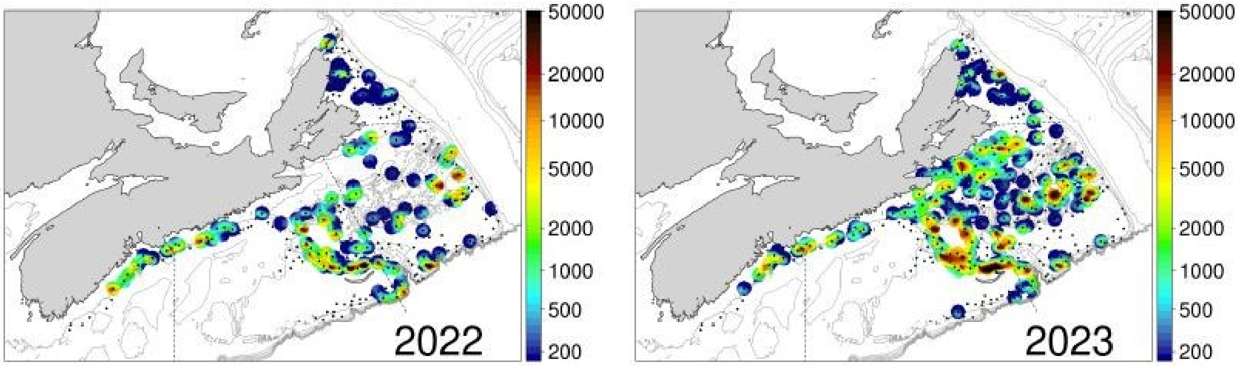

Figure 17. Mature female density log_{10} (no/km^2) from the Snow Crab survey. The black dots represent the survey station locations where females were caught in 2022 and 2023.

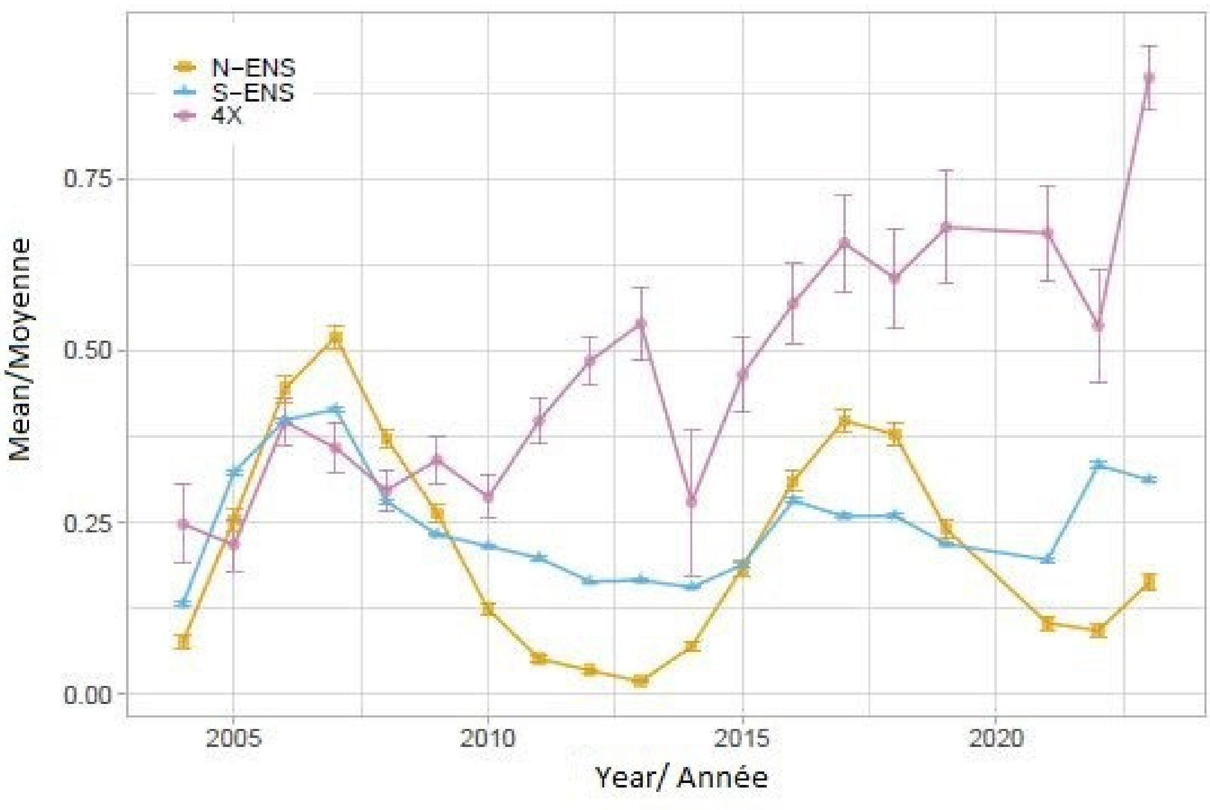

Figure 18. Time series of sex ratios (proportion female) of mature Snow Crab by area. No survey was conducted in 2020.

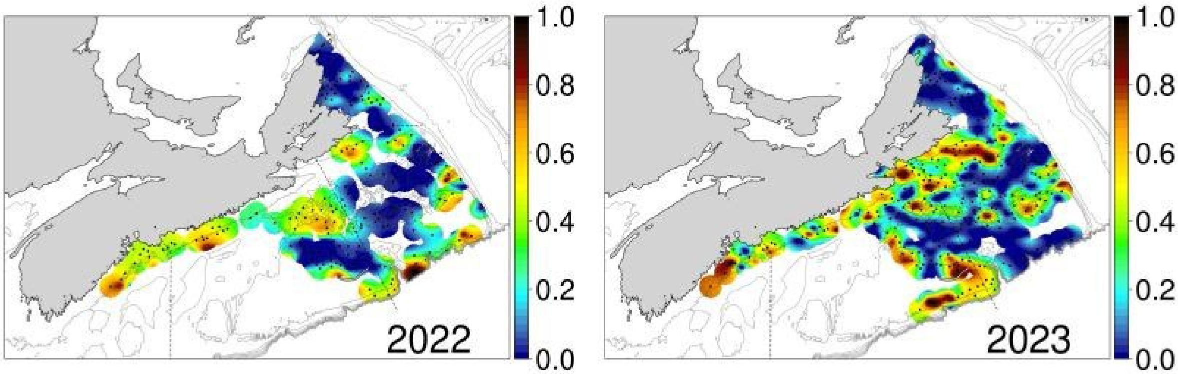

Figure 19. Map of sex ratios (proportion female to male) of mature Snow Crab. Black dots represent Snow Crab survey station locations in 2022 and 2023.

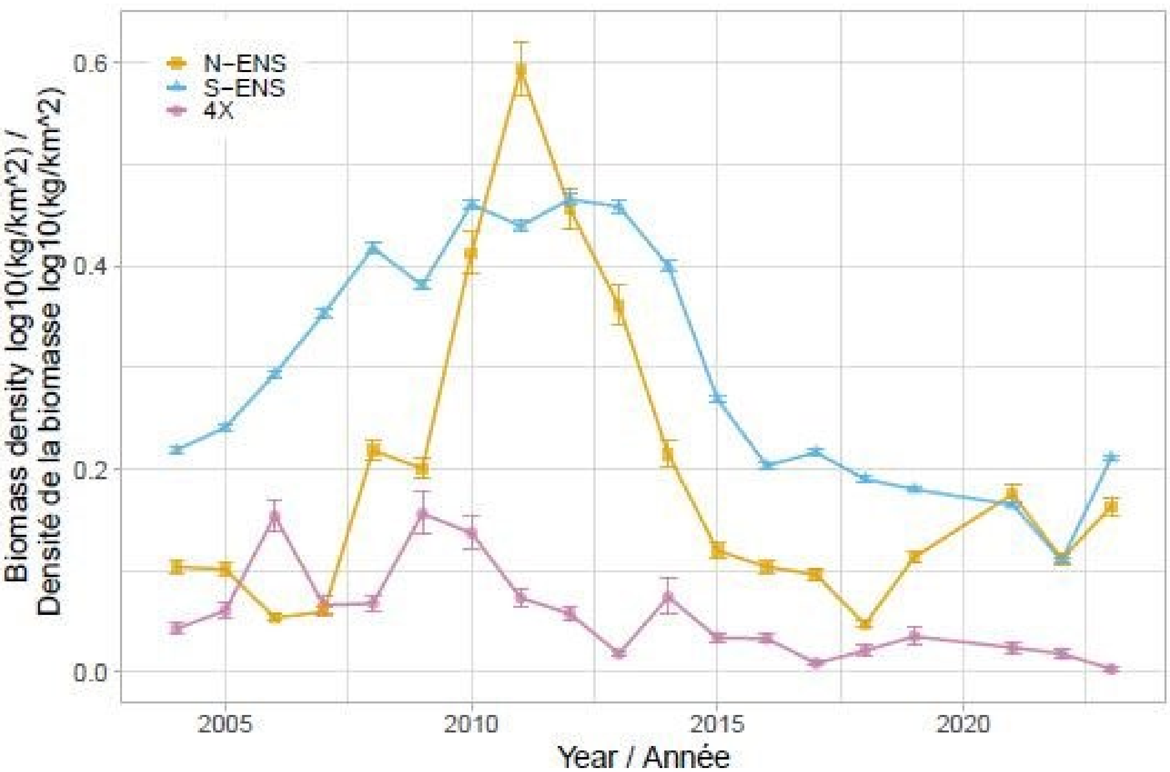

Figure 20. The unstandardized, unadjusted geometric mean fishable biomass density log10(kg/km²) of Snow Crab from the snow crab survey. Error bars represent 95% confidence intervals. Note the absence of data in 2020 due to no survey being conducted. Prior to 2004, surveys were conducted in the spring.

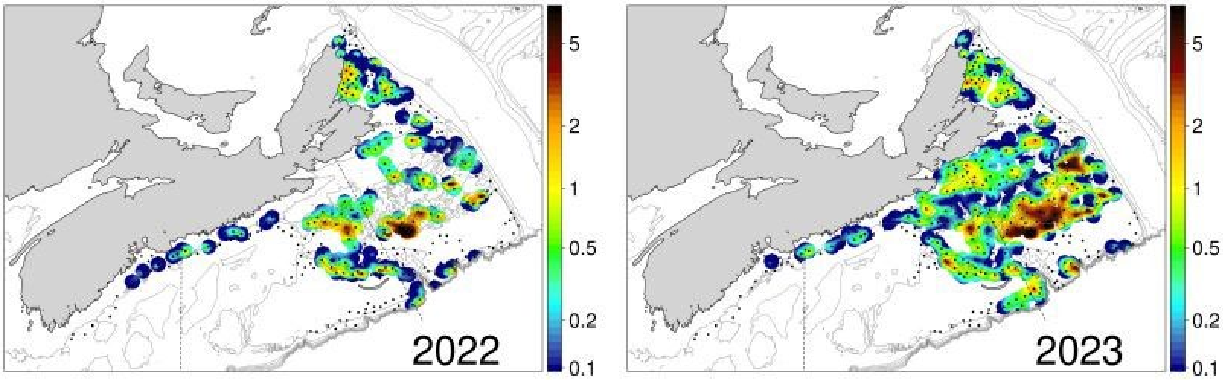

Figure 21. Snow crab survey fishable component biomass density (t/km²) of Snow Crab in 2022 and 2023. The black dots represent the snow crab survey station locations.

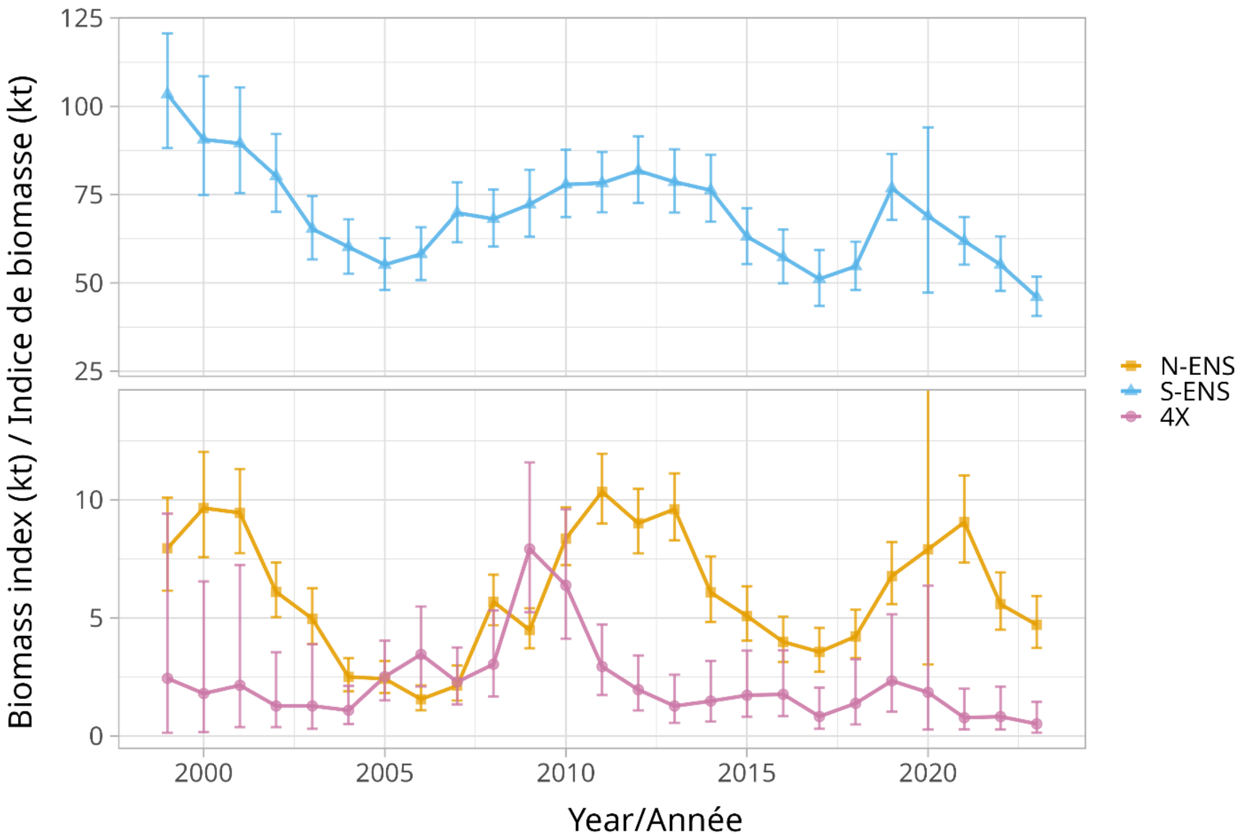

Figure 22. The fishable biomass index (kt) predicted from the snow crab survey. Error bars represent bayesian 95% credible intervals. Note large errors in 2020 when there was no survey completed.

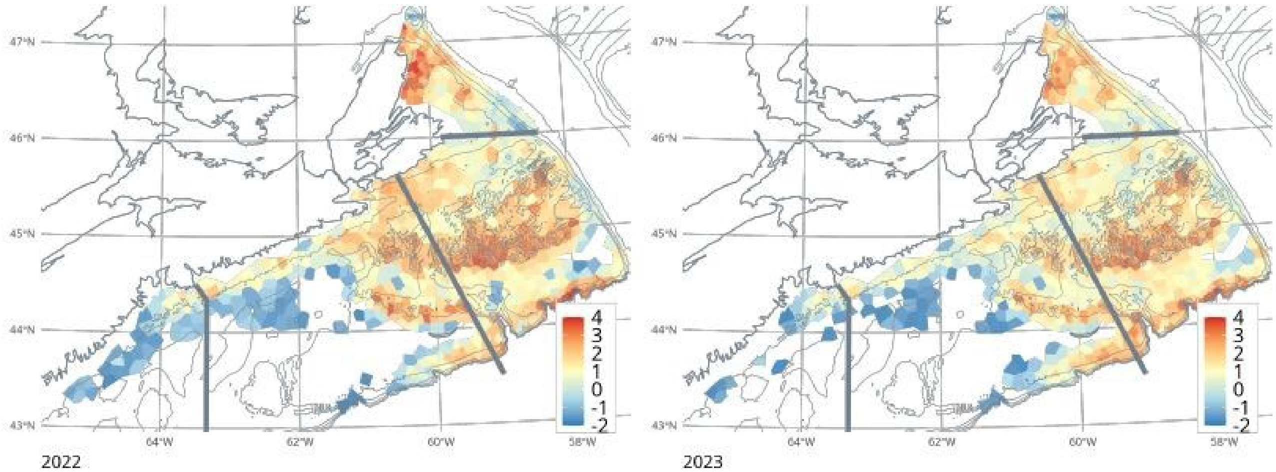

Figure 23. Snow Crab biomass index log10 (kt/km²) predicted from the Snow Crab survey in 2022 and 2023.

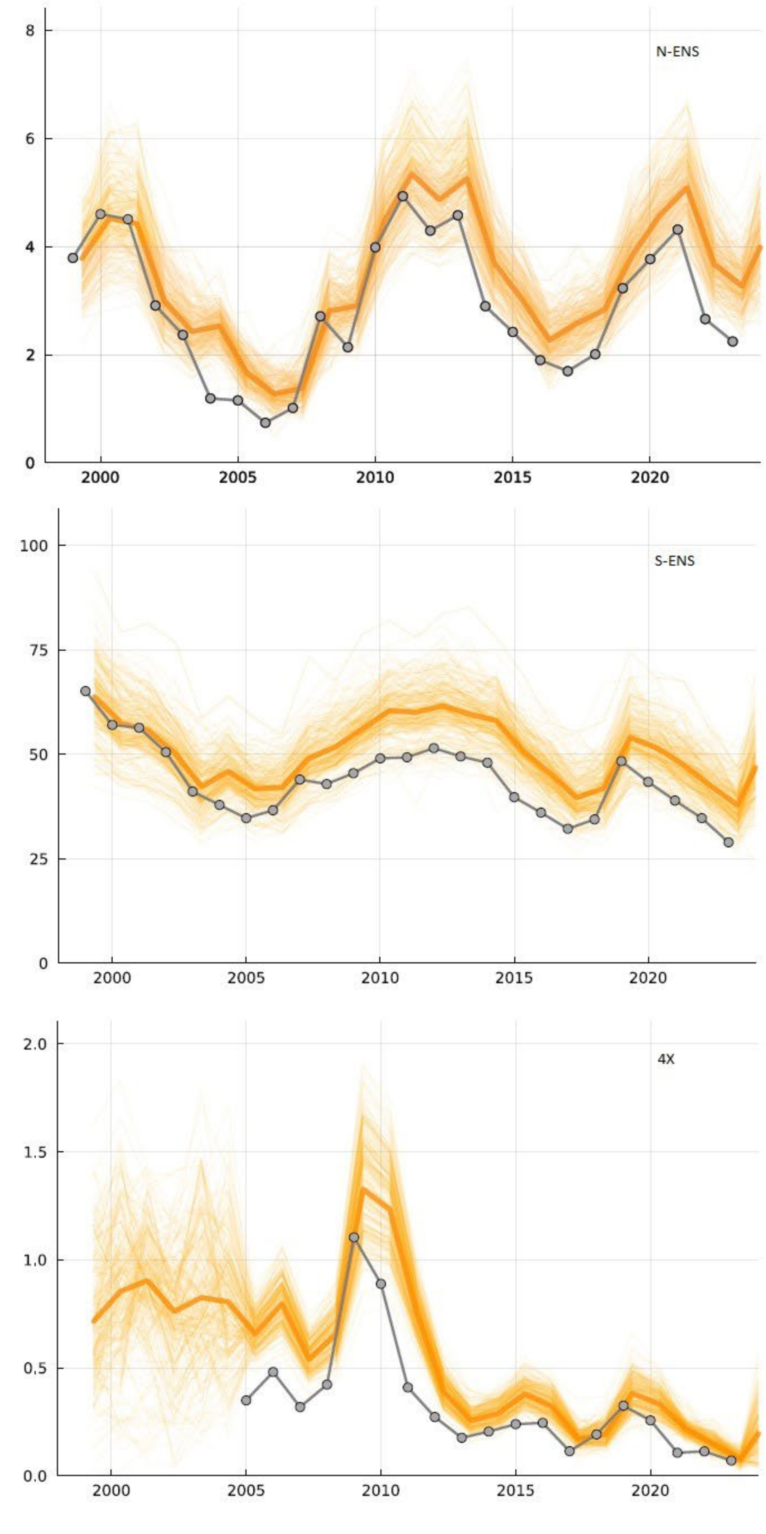

Figure 24. Fishable posterior mean modelled biomass (pre-fishery; kt) are shown in dark orange for N-ENS, S-ENS and 4X. Light orange are posterior samples of modelled biomass (pre-fishery; kt) to illustrate the variability of the predictions. The biomass index (post-fishery; kt) after model adjustment by the model catchability coefficient is in grey.

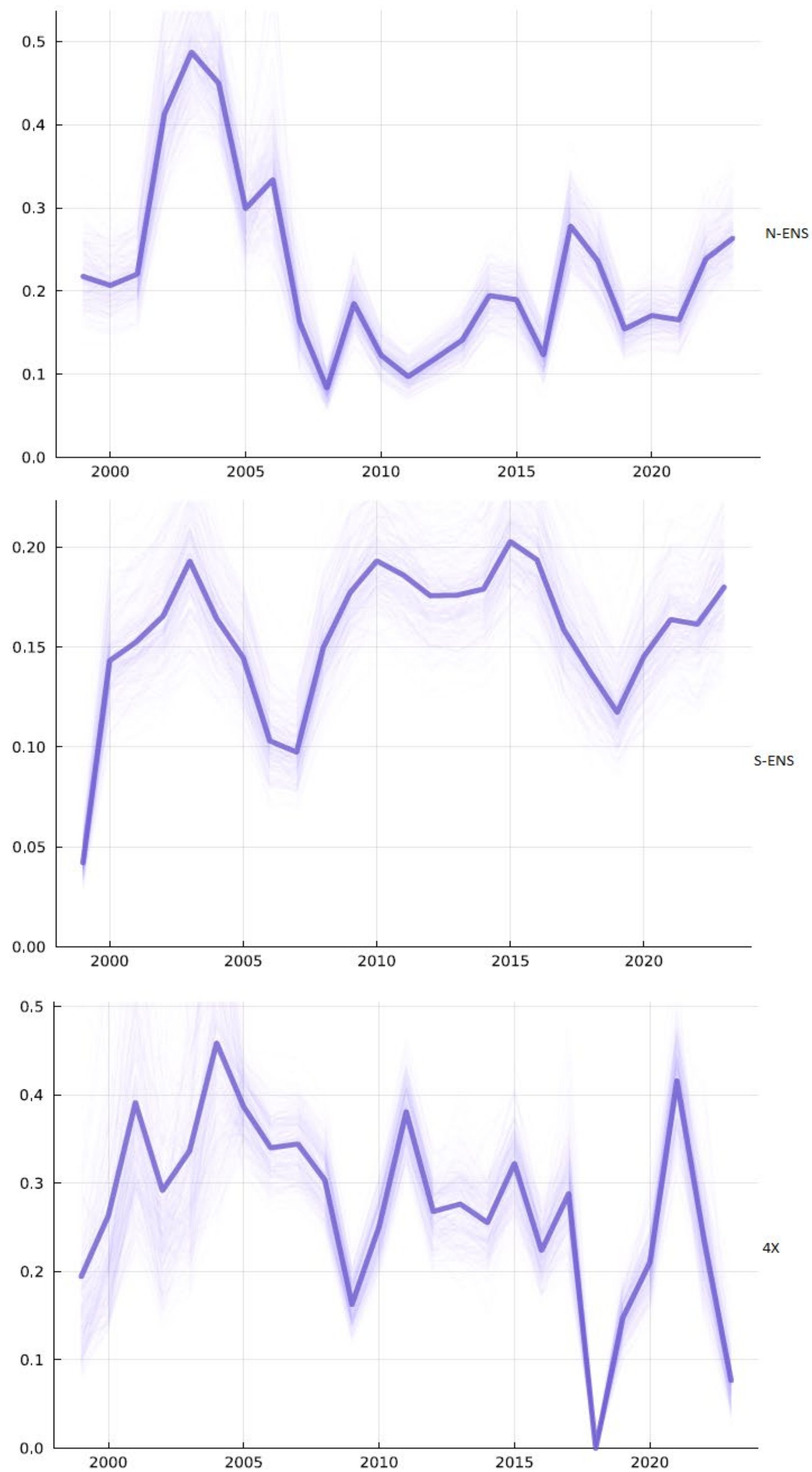

Figure 25. Time-series of modelled instantaneous fishing mortality for N-ENS, S-ENS and 4X. Samples of the posterior densities are presented, with the darkest line being the mean.

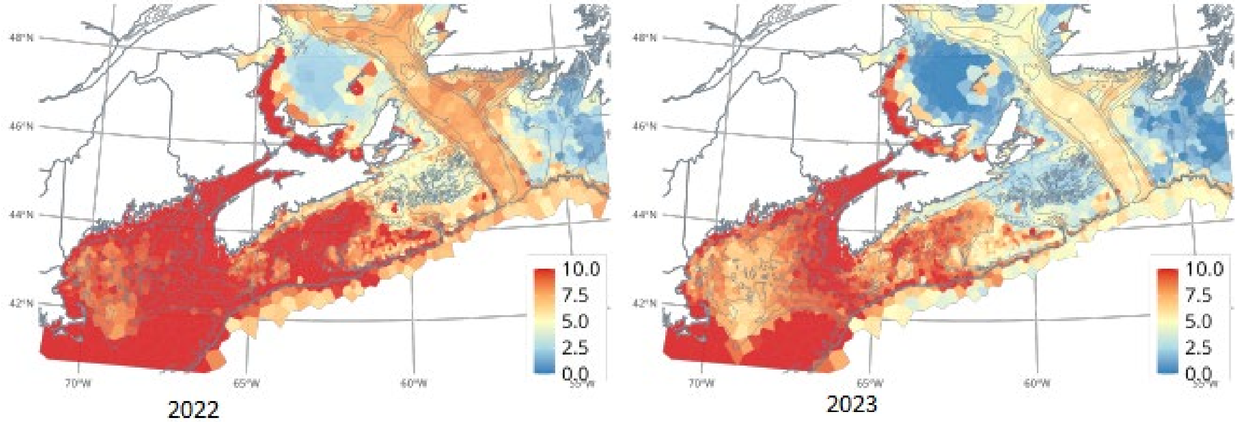

Figure 26. Spatial variations in bottom temperature estimated from a historical analysis of temperature data for September 1st in 2022 and 2023.

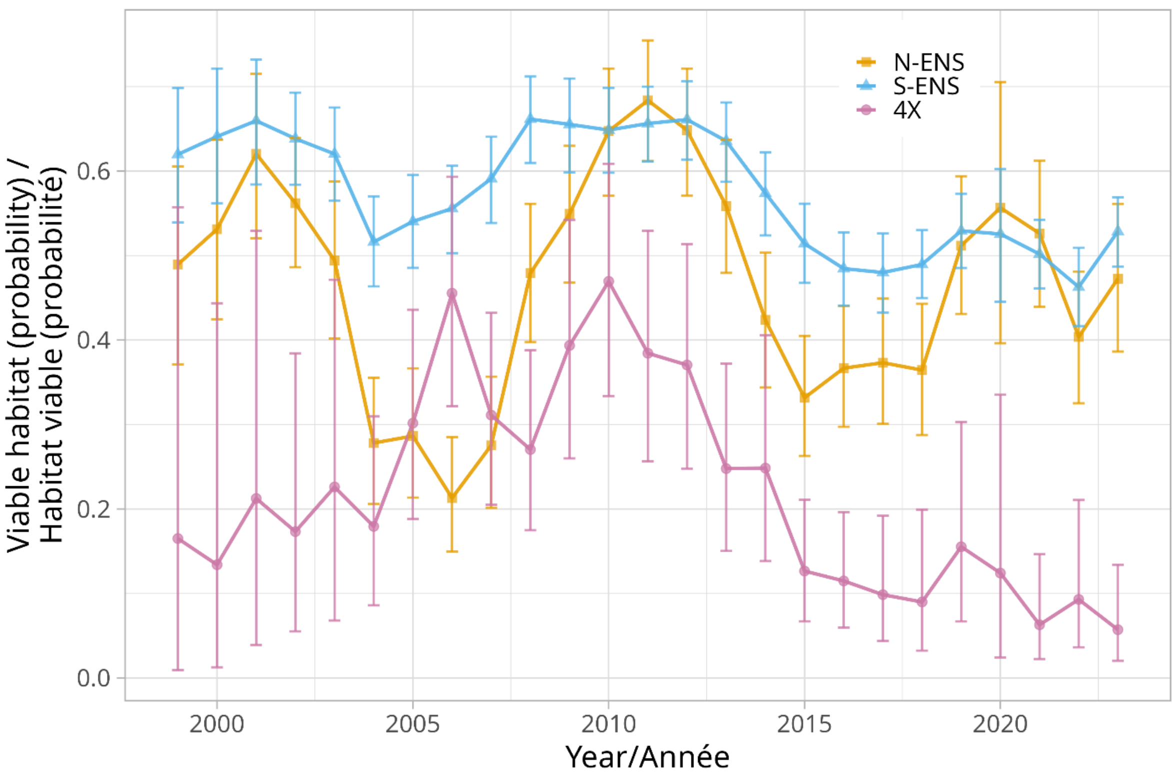

Figure 27. Habitat viability (probability; fishable Snow Crab). Annual means and 95% credible intervals are presented.

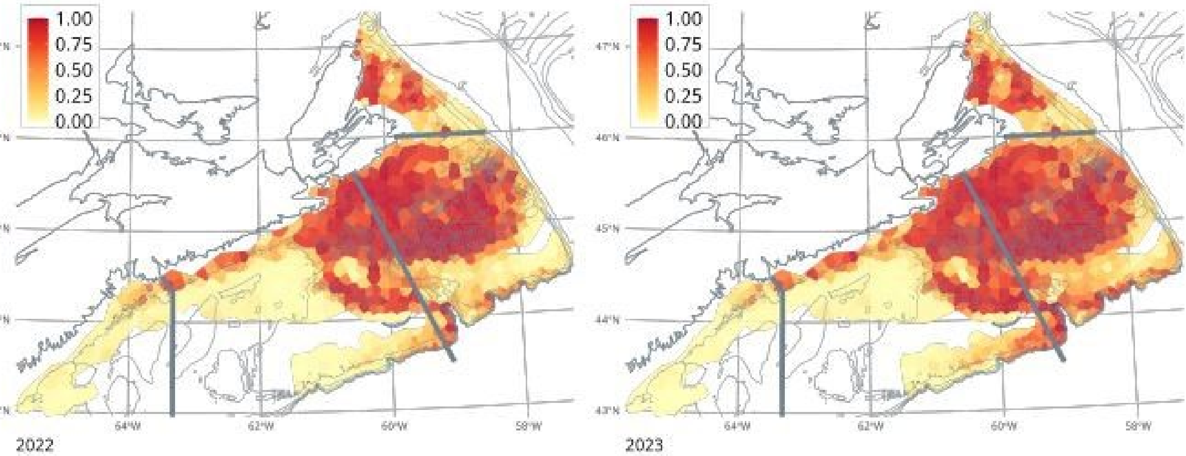

Figure 28. Habitat viability (probability; fishable Snow Crab) for 2022 and 2023.

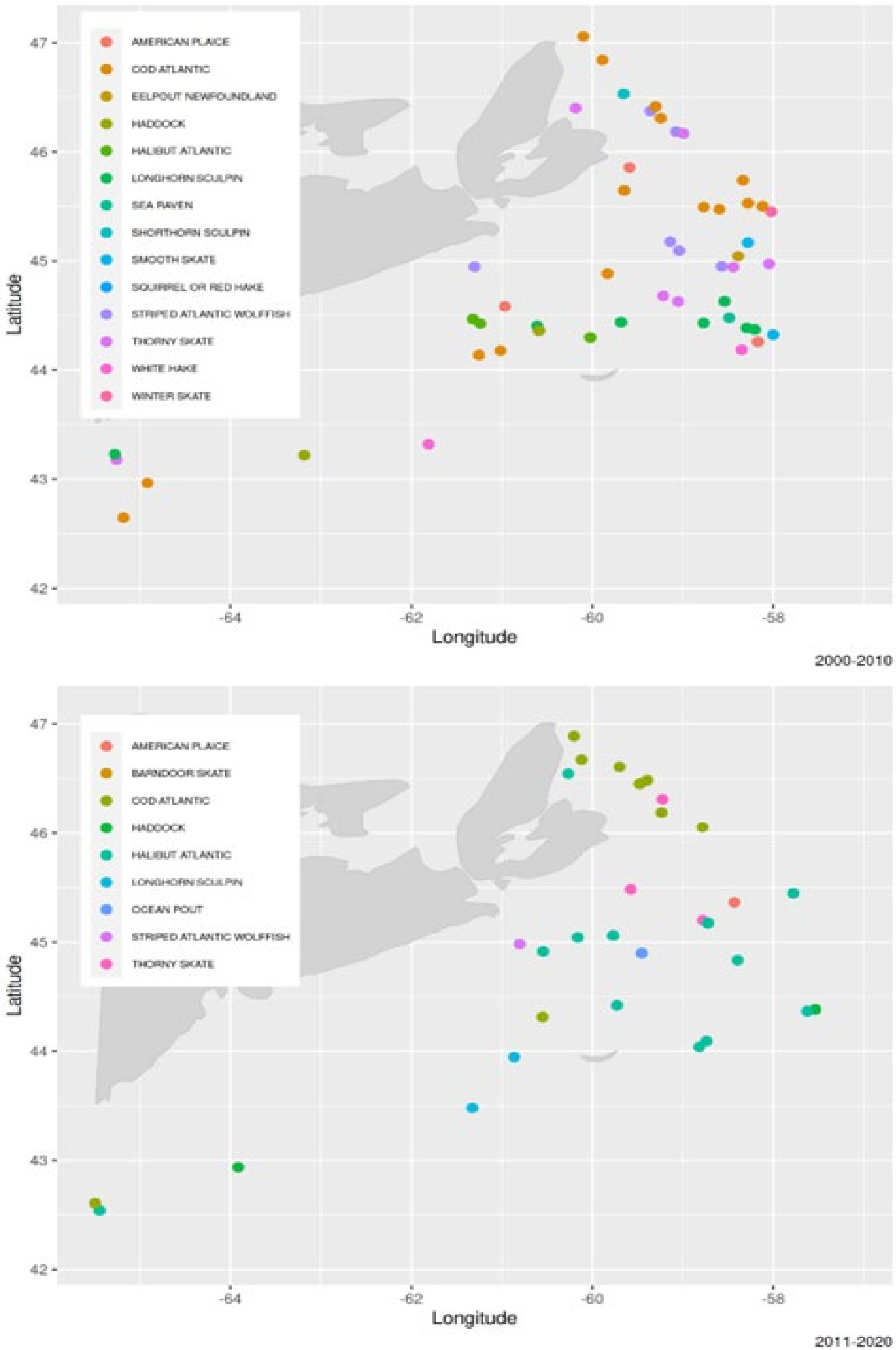

Figure 29. Locations of known predators of Snow Crab as encountered on the snow crab trawl surveys for 2000-2010 (top) and 2011-2020 (bottom).

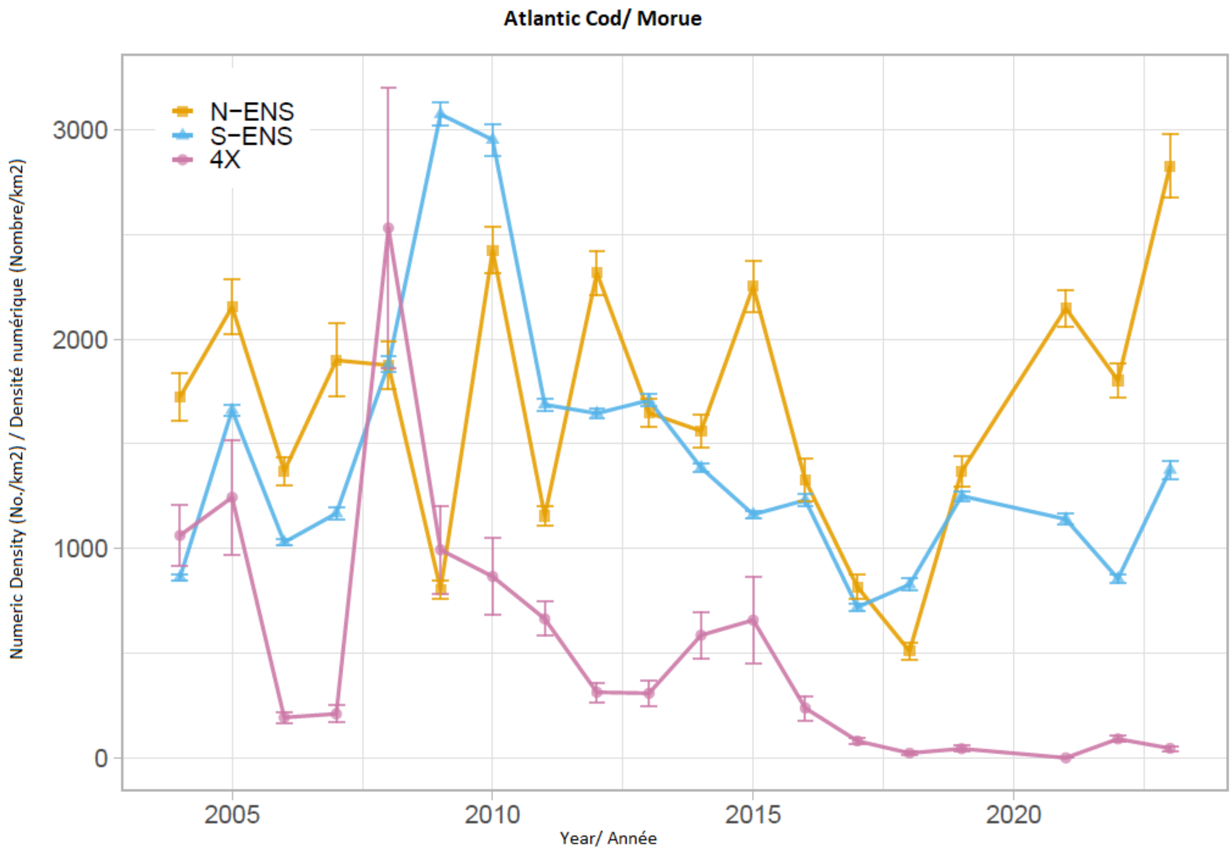

Figure 30. Atlantic Cod unstandardized, unadjusted geometric mean numerical density (no/km²) from the annual snow crab surveys. Error bars are 95% confidence intervals. There was no survey in 2020.

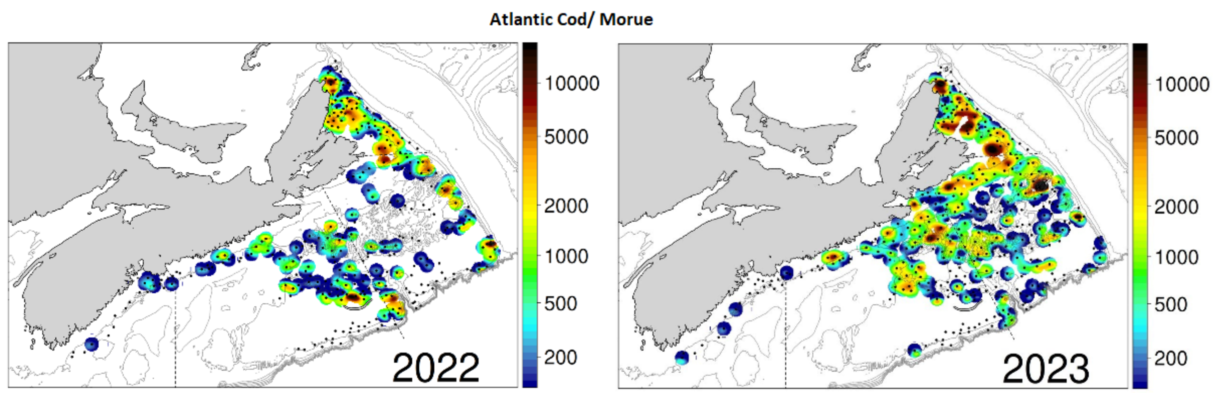

Figure 31. Atlantic Halibut density log¹⁰ (no/km²) from snow crab surveys. Black dots represent the survey station locations.

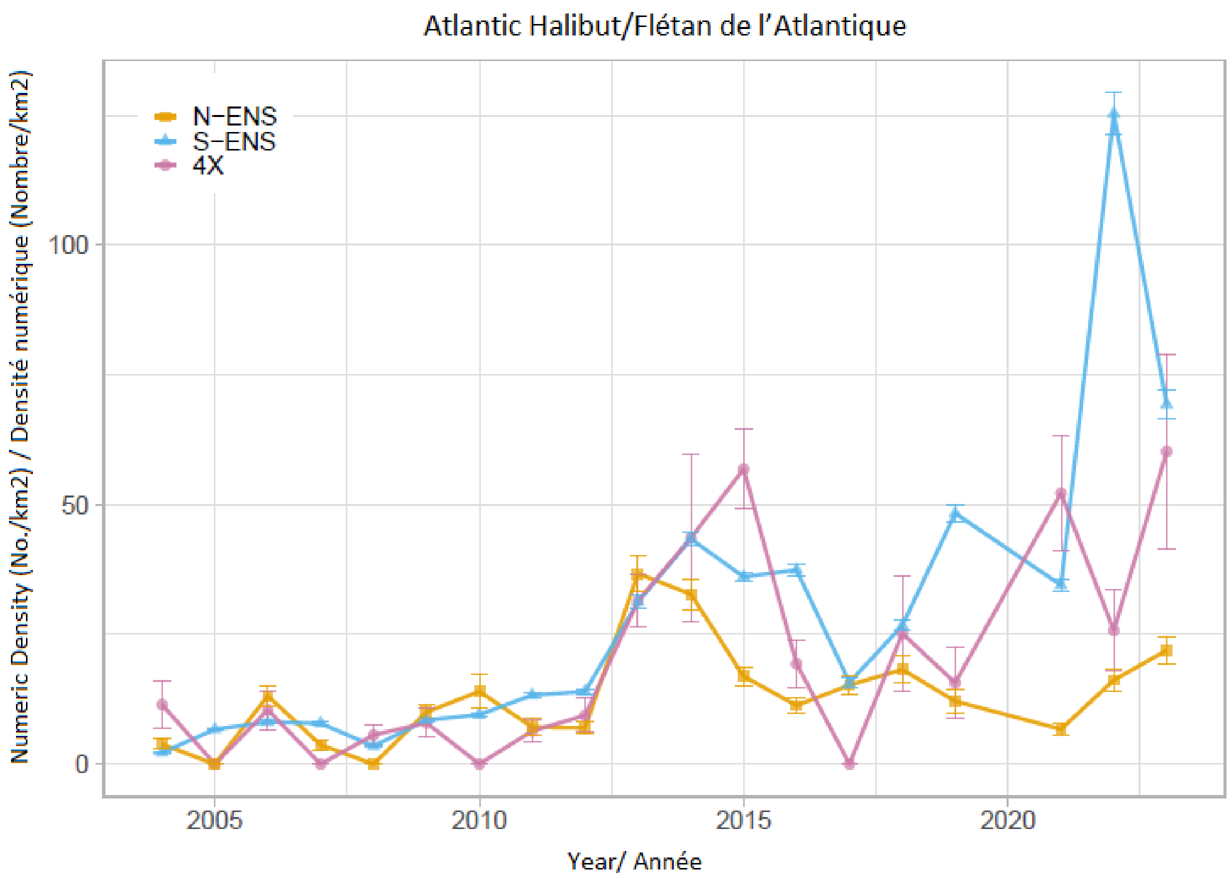

Figure 32. Atlantic Halibut unstandardized, unadjusted geometric mean numerical density (no/km²) from the annual snow crab surveys. Error bars are 95% confidence intervals. There was no survey in 2020.

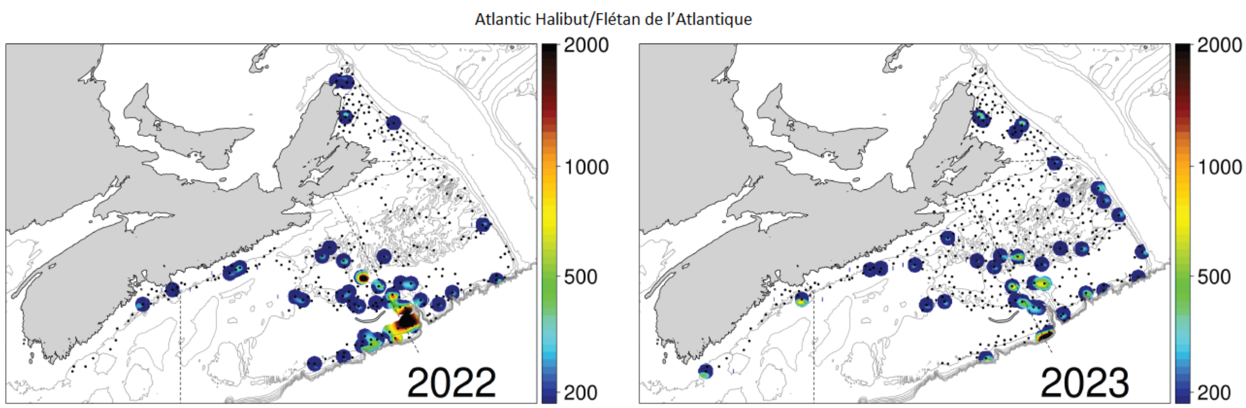

Figure 33. Atlantic Halibut density log^{10} (no/km²) from snow crab surveys. Black dots represent the survey station locations.

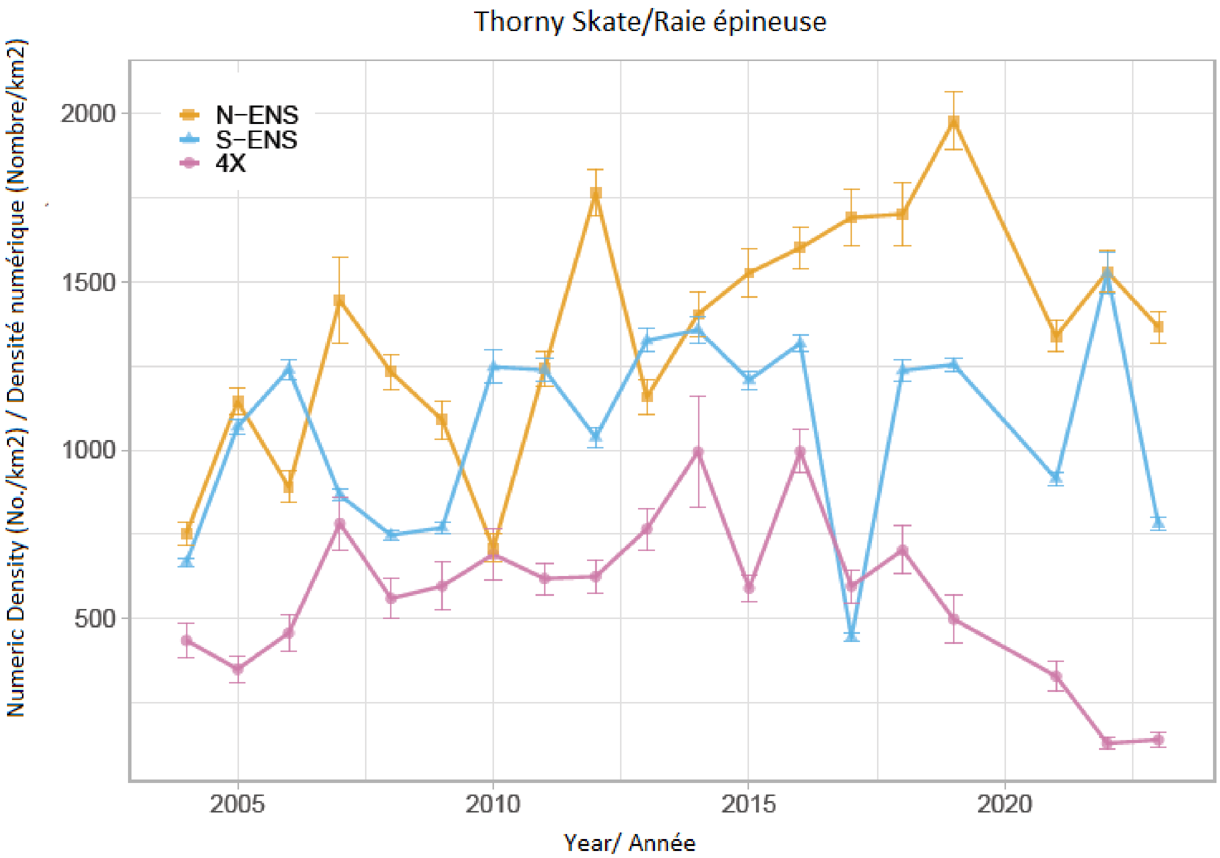

Figure 34. Thorny Skate unstandardized, unadjusted geometric mean numerical density (no/km²) from annual snow crab surveys. Error bars represent 95% confidence intervals. There was no survey in 2020.

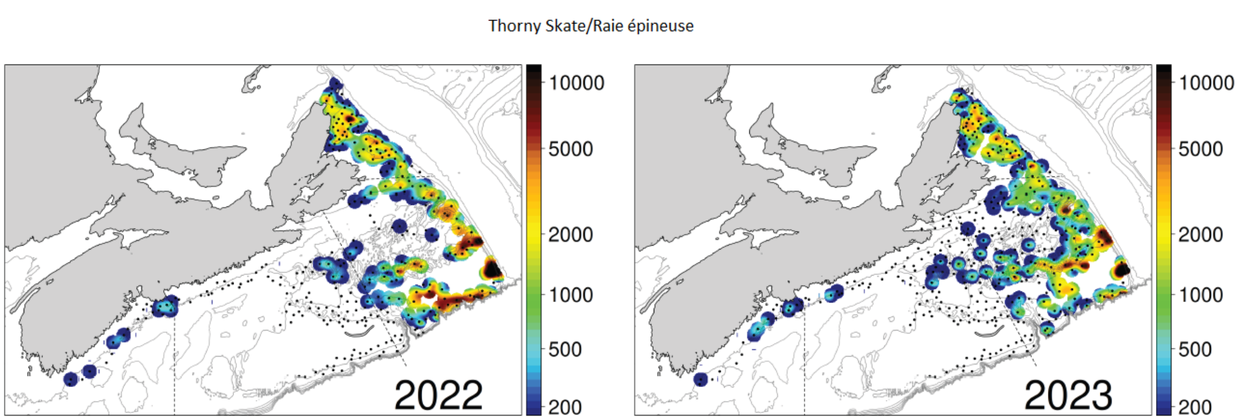

Figure 35. Thorny Skate density log¹⁰ (no/km²) from the snow crab surveys. The black dots represent the snow crab survey station locations.

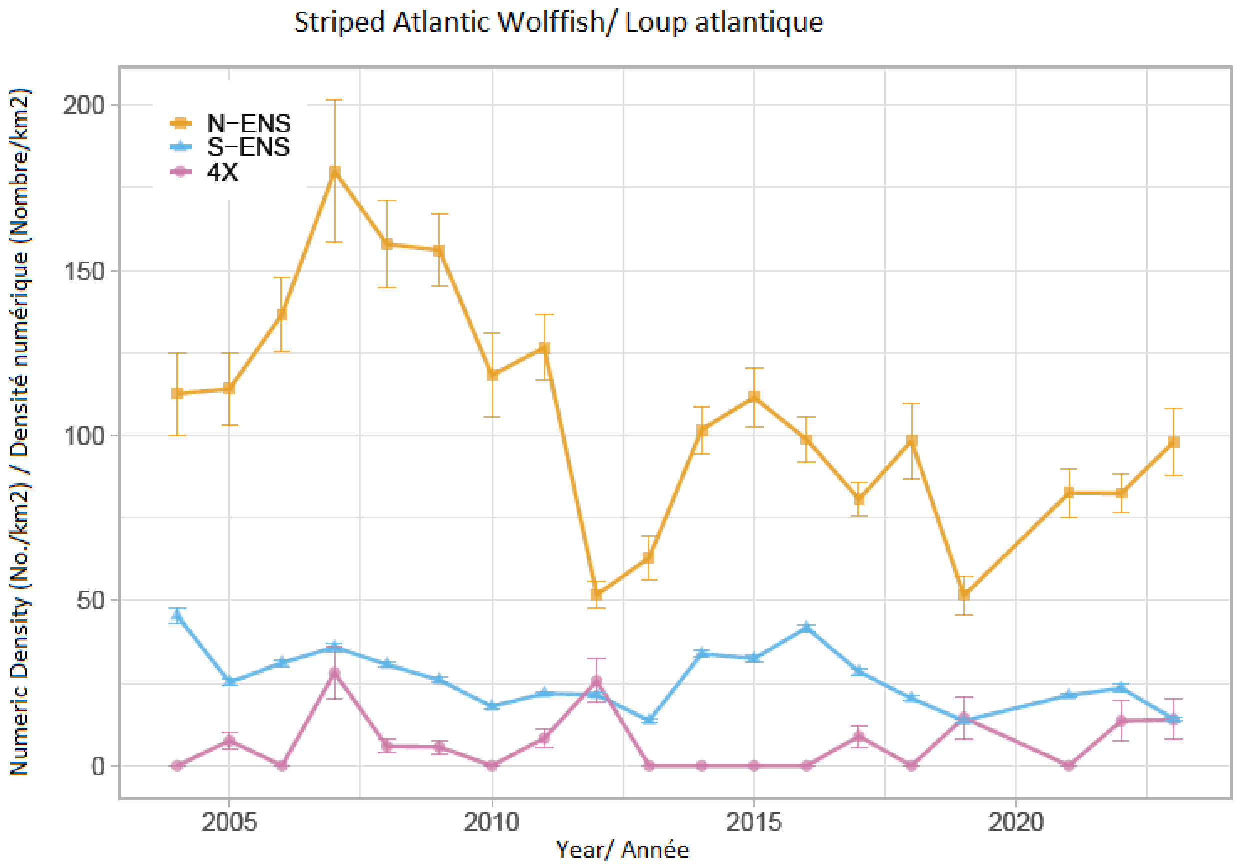

Figure 36. Striped Atlantic Wolffish unstandardized, unadjusted geometric mean numerical density (no/km²) from the snow crab surveys. There was no survey in 2020.

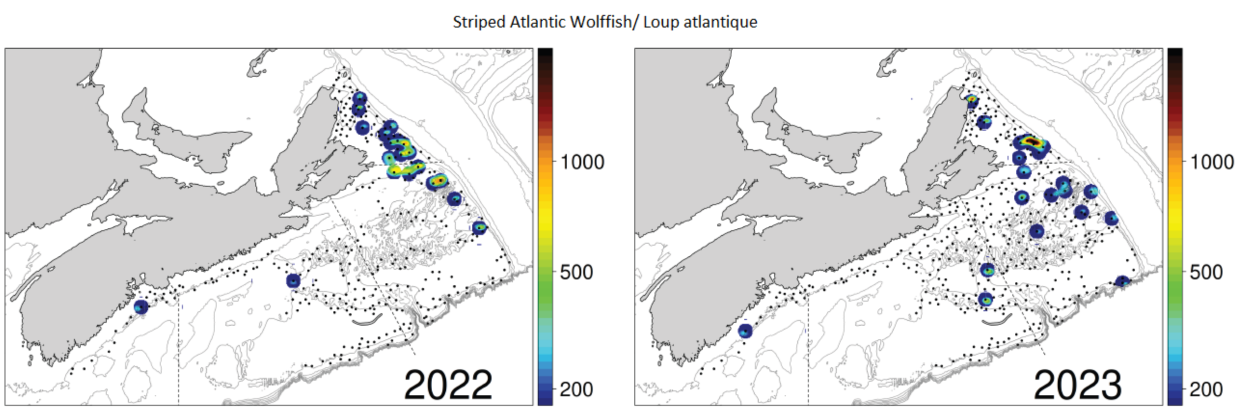

Figure 37. Striped Atlantic Wolffish density log¹⁰ (no/km²) from snow crab surveys. The black dots represent the snow crab survey station locations.

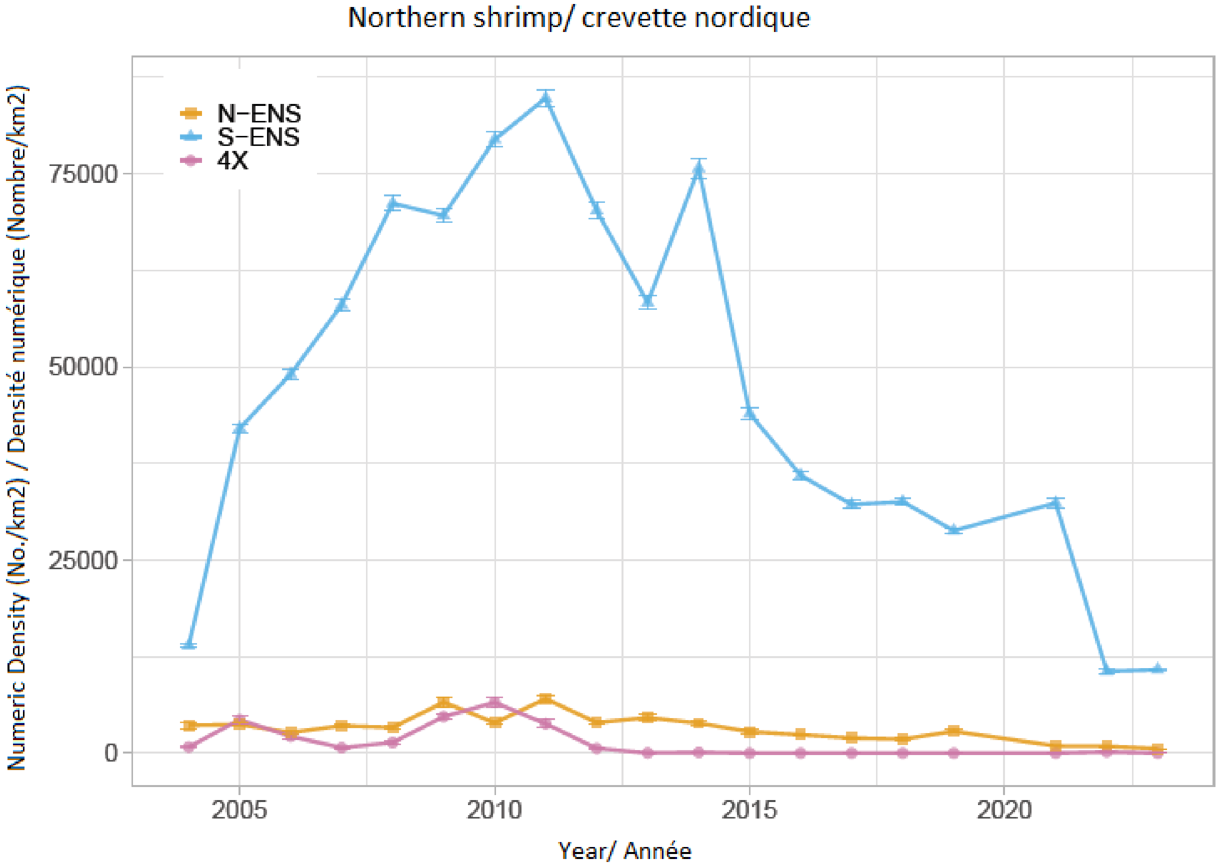

Figure 38. Northern Shrimp unstandardized, unadjusted geometric mean numerical density (n/km²) from annual snow crab surveys. Error bars represent 95% confidence intervals. No survey was done in 2020.

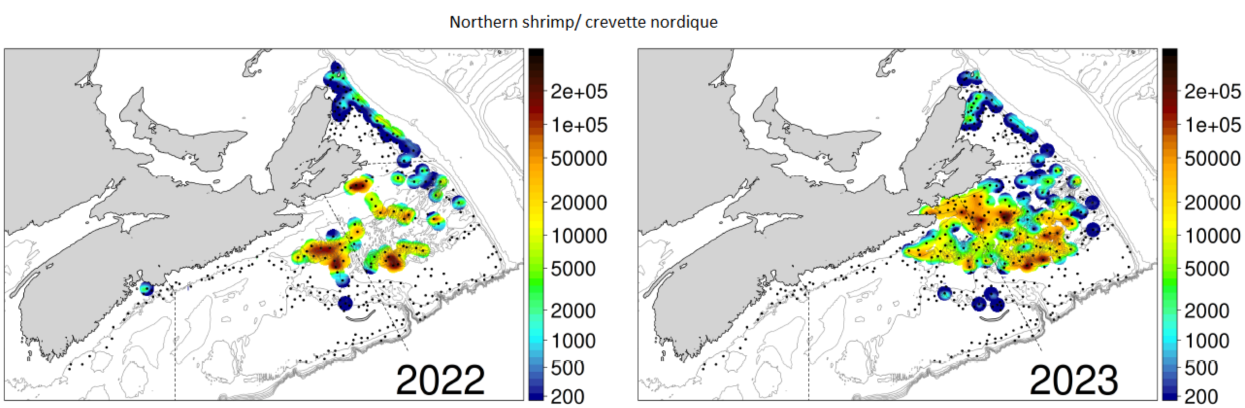

Figure 39. Northern Shrimp density log[10] (no/km²) from the Snow Crab survey. Black dots represent the snow crab survey station locations.

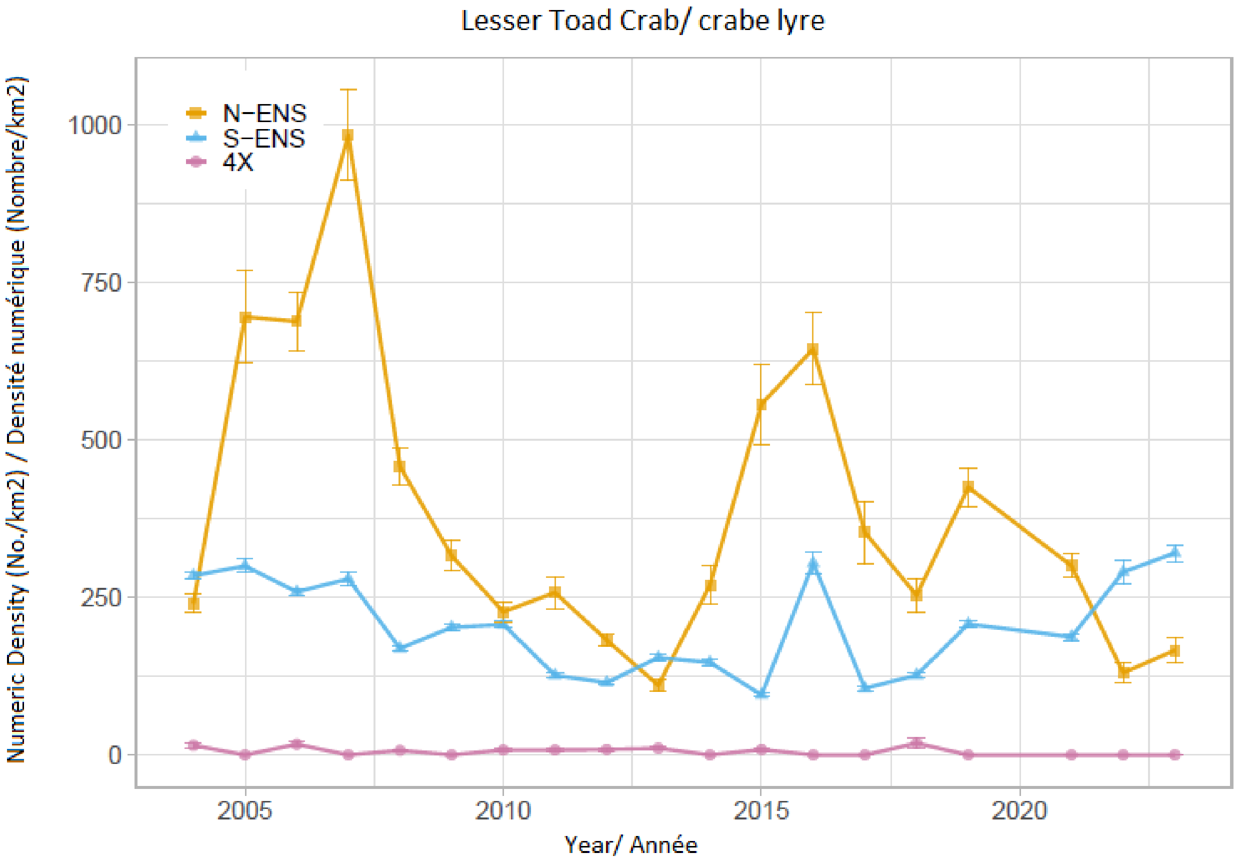

Figure 40. Lesser Toad Crab unstandardized, unadjusted geometric mean numerical density (no/km²) from annual snow crab surveys. Error bars represent 95% confidence intervals. No survey was done in 2020.

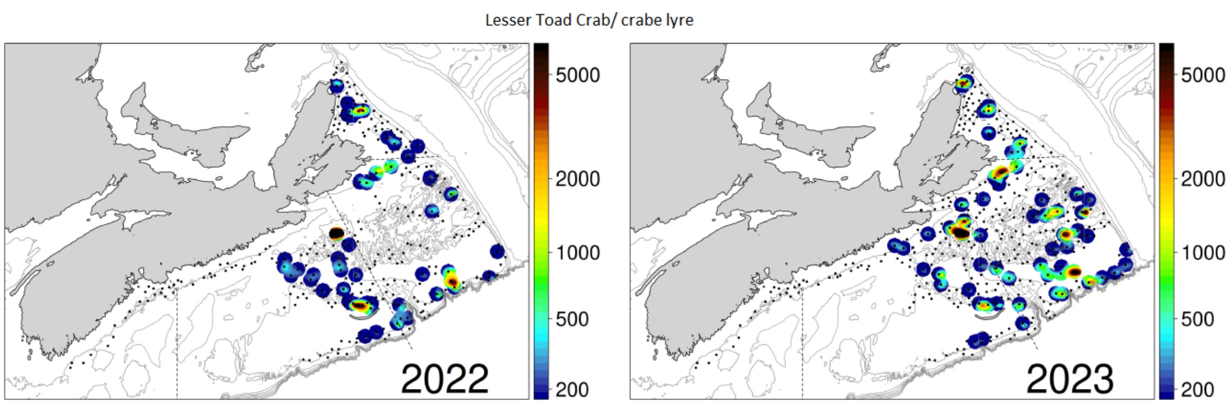

Figure 41. Lesser Toad Crab density log¹⁰ (no/km²) from the snow crab surveys. The black dots represent the snow crab survey station locations for 2022 and 2023.

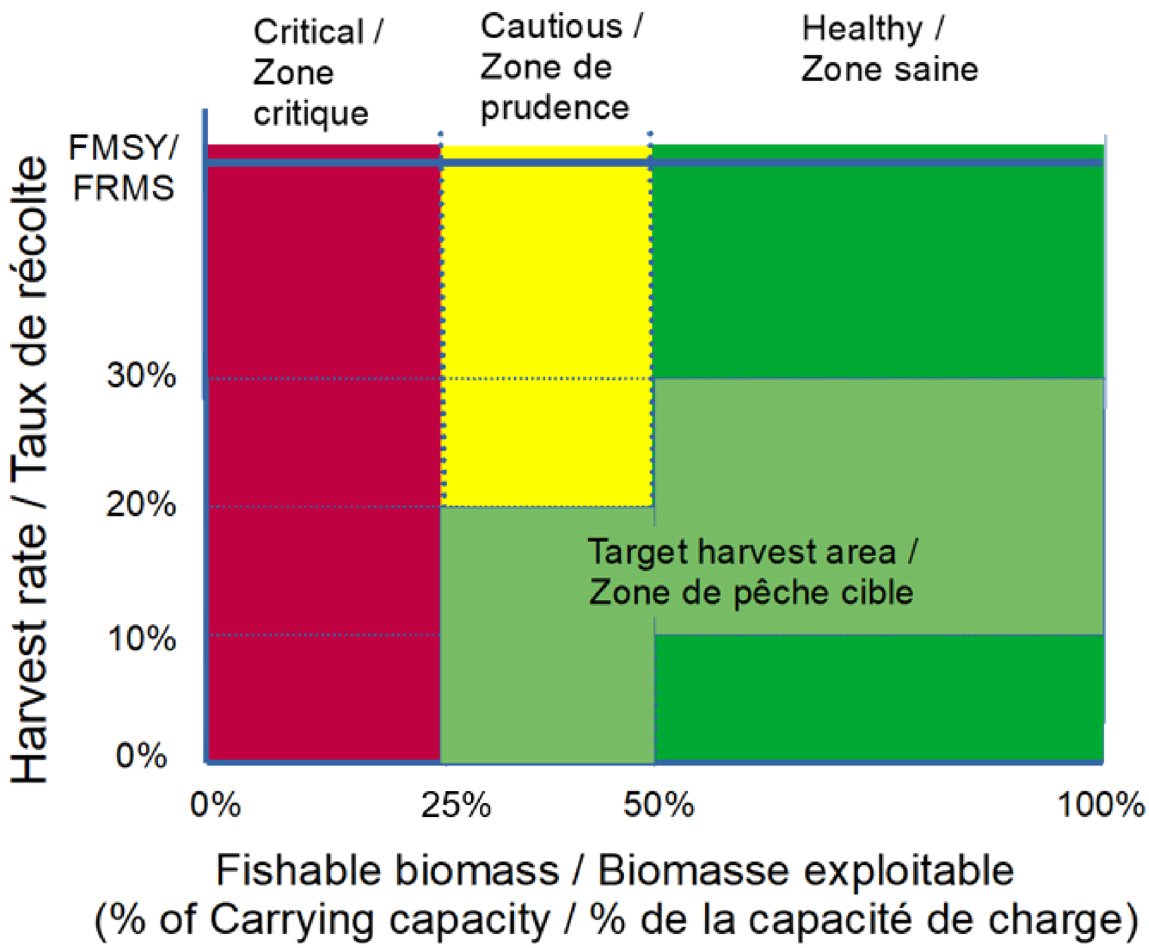

Figure 42. Harvest control rules for the Scotian Shelf Snow Crab fisheries.

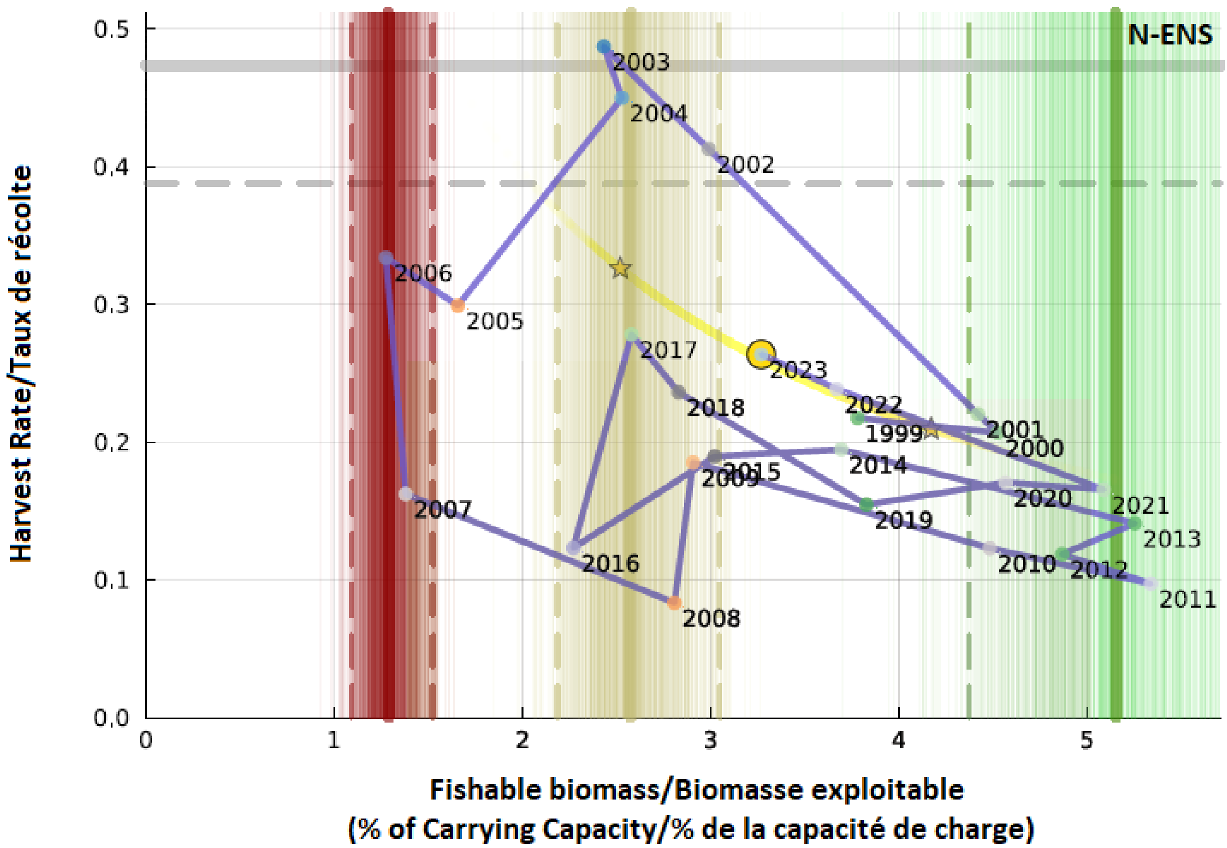

Figure 43. Reference points (fishing mortality and modelled biomass (kt)) for N-ENS. The circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large yellow dot and the 95% credible intervals are presented by yellow stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick yellow lines 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% (red), 50% (yellow) and 100% (green) 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.

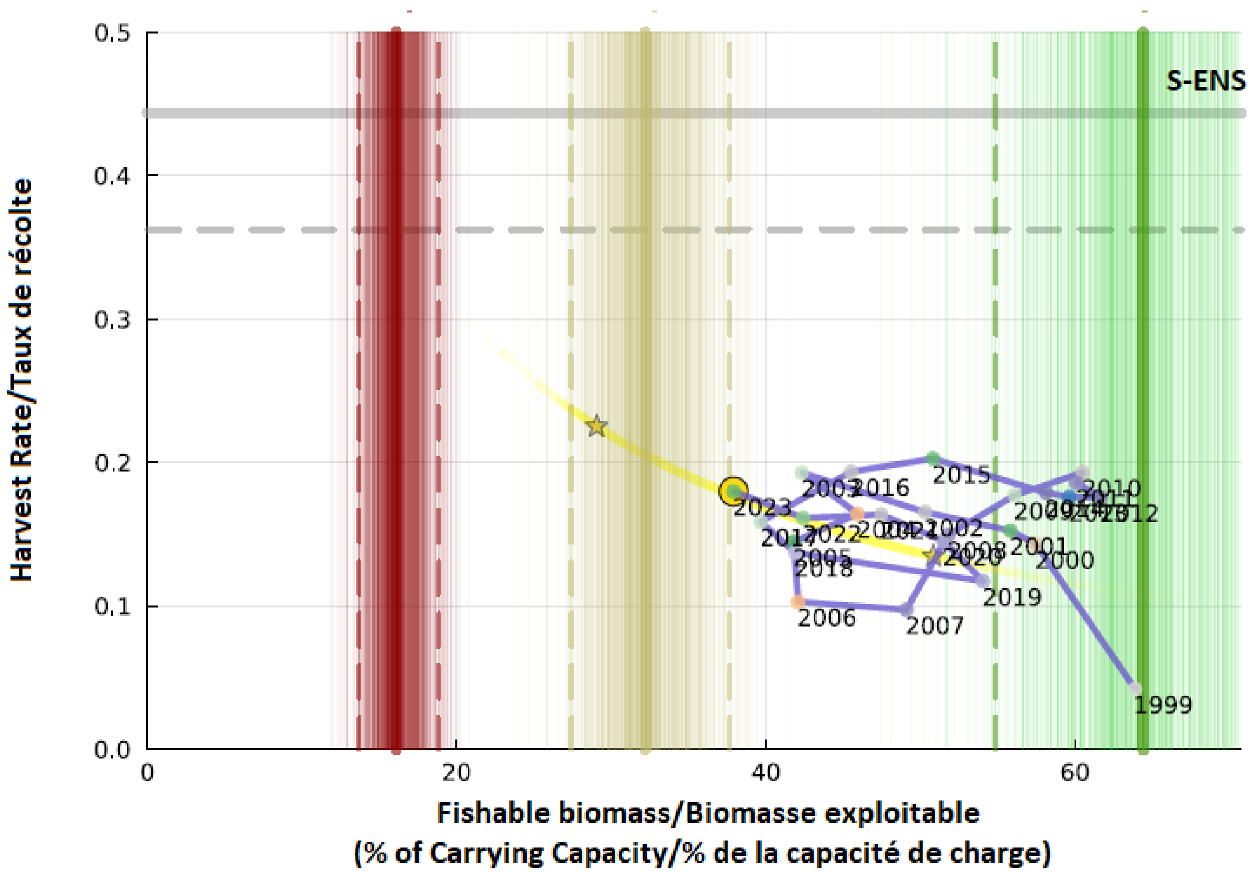

Figure 44. Reference points (fishing mortality and modelled biomass (kt)) for S-ENS. The circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large yellow dot and the 95% credible intervals are presented by yellow stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick yellow lines 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% (red), 50% (yellow) and 100% (green) 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.

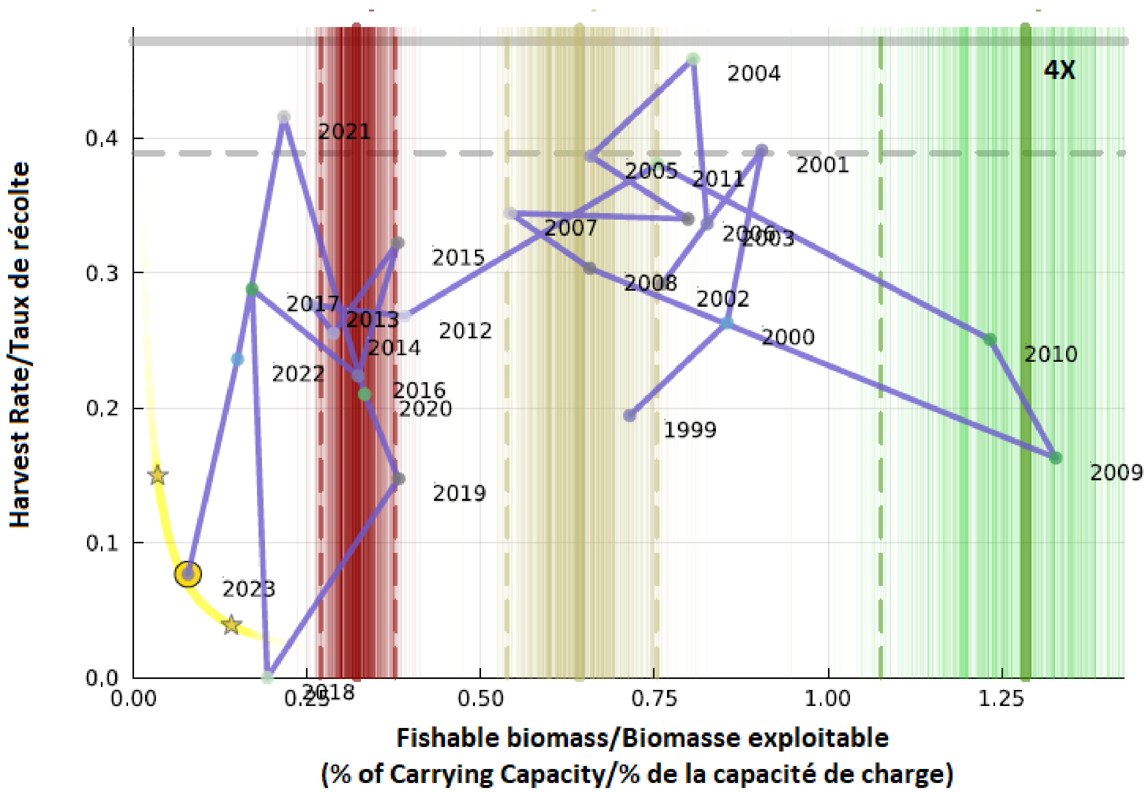

Figure 45. Reference points (fishing mortality and modelled biomass (kt)) for 4X. The circular points represent posterior mean estimates of stock biomass and instantaneous fishing mortality (harvest rate). The most recent year is indicated with a large yellow dot and the 95% credible intervals are presented by yellow stars. The posterior distribution of fishable biomass and fishing mortality is shown as the thick yellow lines 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% (red), 50% (yellow) and 100% (green) 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.