Fisheries and Oceans Canada
Pêches et Océans Canada
Ecosystems and Oceans Science
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2025/027

Gulf Region

Southern Gulf of St. Lawrence (CFAs 12, 12E, 12F and 19) Snow Crab (*Chionoecetes opilio*) Stock Assessment in 2024

Tobie Surette and Joël Chassé

Fisheries and Oceans Canada
Science Branch, Gulf Region
343 Université Avenue
Moncton, NB E1C 5K4

May 2025

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
DFO.CSAS-SCAS.MPO@dfo-mpo.gc.ca

ISSN 1919-5044
ISBN 978-0-660-76879-3 Cat. No. Fs70-5/2025-027E-PDF

Correct citation for this publication:

Surette, T., and Chassé, J. 2025. Southern Gulf of St. Lawrence (CFAs 12, 12E, 12F and 19) Snow Crab (*Chionoecetes opilio*) Stock Assessment in 2024. DFO Can. Sci. Advis. Sec. Res. Doc. 2025/027. v + 44 p.

Aussi disponible en français :

*Surette, T. et Chassé, J. 2025. Évaluation du stock de crabe des neiges (*Chionoecetes opilio*) dans le sud du golfe du Saint-Laurent (ZPC 12, 12E, 12F et 19) en 2024. Secr. can. des avis sci. du MPO. Doc. de rech. 2025/027. v + 46 p.*

TABLE OF CONTENTS

ABSTRACT

Stock status of southern Gulf of St. Lawrence (sGSL) snow crab (*Chionoecetes opilio*) in 2024 is in the healthy zone of the Precautionary Approach (PA). A commercial biomass of 51,786 tonnes (t) is projected for 2025. Fishery recruitment biomass is estimated at 34,946 t, while the residual biomass was estimated at 17,091 t. Based on the harvest decision rule, the commercial biomass estimate corresponds to a target exploitation rate of 35.73% and a catch option of 18,503 t for the 2025 fishery. For this catch option, a risk analysis indicates that there is a very low likelihood that the residual biomass would be below the limit reference point and a moderate likelihood (39.6%) that the 2025 commercial stock biomass will fall below the upper stock reference point of 41,400 t. Female spawning stock abundance remains high, although primiparous abundance is low. Population recruitment has declined to below average levels. There is continued evidence of warming conditions in the southern Gulf of St. Lawrence that can impact snow crab population dynamics and distribution.

1. INTRODUCTION

The snow crab, *Chionoecetes opilio*, is a common cold-water species found in many northern regions from Greenland, northern Europe, Japan, the Bering Sea, and eastern Canada. Canadian snow crab populations are found off the coasts of Nova Scotia and Newfoundland and Labrador, as well as the northern and southern portions of the Gulf of St. Lawrence.

The southern Gulf of St. Lawrence (sGSL) snow crab population is naturally bounded by warm coastal temperatures to the south and west, and by warm deep waters of the Laurentian channel to the northeast (Figure 1), residing within an area of cold intermediate water layer (CIL). The snow crab population in the sGSL is considered as a single stock unit, with limited exchanges with northern and southern snow crab populations (Biron et al. 2008) and some free-floating larval inputs from the Quebec population to the north (Puebla et al. 2008).

1.1. BIOLOGY

The snow crab is a crustacean with a flat, almost circular body and five pairs of legs. The hard outer shell is periodically shed in a process called moulting, after which crabs have a relatively soft shell for a period of 8 to 10 months. Snow crab do not moult throughout their lifespan, but rather undergo a final, terminal moult after which they attain full sexual maturity (Conan and Comeau 1986; Comeau and Conan 1992). Sexually mature males have larger claws and span a wide range of sizes from 40 to 150 mm carapace width (CW). Sexually mature females develop a wider abdomen for carrying eggs and range in size from 40 mm to 95 mm CW. Females produce eggs that are carried beneath the abdomen for approximately two years in the sGSL (Moriyasu and Lanteigne 1998). Eggs hatch in late spring or early summer and the newly-hatched larvae spend 12-15 weeks in the water column, then settle on the bottom. It takes at least 8-9 years (post-settlement) for males to grow to the commercial size (> 95 mm CW).

1.2. FISHERY AND MANAGEMENT

Since its beginnings in the mid-1960s, the sGSL snow crab fishery has grown to be a commercially important fishery with landings generally in excess of 20,000 tonnes (t) annually (Figure 2). Management of the fishery is based on annual quotas (attributed by crab fishing area (CFA) and distributed among license holders) and effort controls (number of licenses, trap allocations, trap dimensions, and seasons). Landing of females is prohibited. The commercial stock is defined as hard-shelled mature males with a minimum size of 95 mm CW.

There are currently four CFAs in the sGSL: 12, 12E, 12F and 19 (Figure 1), with CFA 12 being the largest by area, number of participants, and landings. Area bounds are not based on biological considerations, but solely for management purposes (DFO 2009). The fishing season in CFAs 12, 12E and 12F generally starts as soon as the sGSL is clear of ice in early April to early May and lasts until the end of June or when the area quota is caught. In CFA 19, the fishing season starts in July, after the lobster season, and ends in mid-September or when the quota is caught. The number of traps per license varies by harvester group and CFA.

There are two buffer zones within the sGSL where fishing is prohibited: one is along the northern edge of CFA 19 and the other is located along the south edge of CFA 19. During the season, the fishery is subject to local area closures, usually in the form of 10’ x 10’ grids, to limit fishery impacts on soft-shelled and white-shelled crabs. Local area closures are also used to minimize the risks of entanglement of critically endangered North Atlantic Right Whales (NARW) with fishing gear, which has been an ongoing concern since 2017.

1.3 ASSESSMENT CONTEXT AND OBJECTIVES

Snow crab stocks are known to go through cycles of abundance. The recent period from 2016 to 2022 was characterized by high levels of commercial recruits that were above 50,000 t annually. However, the snow crab stock is currently experiencing a downturn, characterized by below average levels of not only commercial recruits, but also population and reproductive stock recruits.

This research document contains advice to support two management objectives. The first is to ensure that a viable reproductive stock of commercial males remains after the fishery. The second aims to maintain a minimum quantity of commercial stock to sustain a commercial fishery. The advice is supported by survey-derived estimates of stock trends of different life stages, including the commercial biomass. We determined the 2024 stock status in relation to the Precautionary Approach (PA) framework and performed a risk analysis for specific catch options along with their likely stock status for 2025.

2. METHODS

Stock status of snow crab is mainly assessed through trends in abundance and biomass indices calculated using data from a dedicated post fishery annual trawl survey, conducted between July and September. These data provide indices of recruitment, spawning stock, and other crab categories of biological or commercial interest.

2.1. FISHERY PERFORMANCE

Data on reported landings and fishing effort (number of trap haul) were obtained from fishery logbooks and dockside monitoring data, compiled by the DFO statistics branches from the Quebec and Gulf Regions. Post-processing of these data by science staff involved verification, correction or deletion of erroneous data. This included corrections for fishing dates, fishing coordinates, landings and effort data.

Only effort data meeting certain data quality standards were used for calculating catch-per-unit-of-effort (CPUE). Two types of CPUEs were calculated: a seasonal CPUE representing an index of overall fishery performance, and a standardized CPUE. Total effort was estimated from the landings divided by the CPUE estimate, to account for missing effort in the data.

Standardized CPUEs were calculated using fishery landings data from 2017 to 2024 due to some data quality issues in earlier data. We defined standardized CPUEs as the average model-predicted catches per trap 7 days after the opening of the fishery, after a 36-hour soak time for an average vessel within each CFA. Day 7 was chosen as a reference to eliminate some of the issues surrounding trap setting while being close to the start of the fishery when CPUEs are generally at their highest. A 36-hour soak time was chosen because it is an intermediate value between the shorter soak times in CFA 19 (1-2 days) and those of CFAs 12, 12E and 12F (3 days). Nonlinear relationships were assumed between the log-scale landings and the day since the start of the fishery, as well as trap soak time. Log-scale landings were also assumed to vary by fishing vessels and number of traps. Formally the statistical model is:

$$\ln L_{ijz} = \alpha_z + s_f\left(d_{ij}\right) + s_f\left(t_{ij}\right) + v_j + \ln n_{ij} + \varepsilon_{ijz}$$

Where L_{ijz} is the recorded landings for fishing vessel i, and logbook entry j in CFA z. The model components are: the intercept parameters by CFA α_z for fishing fleet *f*, $s_f\left(d_{ij}\right)$ is a smoothing spline over fishing day d_{ij} for fishing fleet *f*, $s_f\left(t_{ij}\right)$ is a smoothing spline over trap soak time t_{ij}, v_j is a vessel a random effect for each fishing vessel $v_j \sim N(0, \sigma_v^2)$, $\ln n_{ij}$ is an offset term for the number of traps fished and $\varepsilon_{ij} \sim N(0, \sigma^2)$ is an error term. Two fishing fleet groups were assumed: one for CFAs 12, 12E and 12F and another for CFA 19. Data analysis was performed using the Generalized Additive Mixed Models (GAMM) function from the R package mgcv package, version 1.8 (Wood 2017). This model was fit separately for each year.

2.2. SURVEY METHODS

2.2.1. Spatial Design

The sGSL snow crab trawl survey has undergone changes in sampling design, survey area and sampling protocol since its inception in 1988. Originally, the extent of the survey area was smaller and concentrated over fishing grounds. The survey area was sub-divided using a lattice of 10’ x 10’ latitude-longitude grids and a small number of randomly selected sampling locations were then selected and held as fixed stations in subsequent surveys, though stations were often discarded and relocated over subsequent years due to trawl damage. Major methodological reviews occurred in 2005 (DFO 2006) and 2011 (DFO 2012a; Wade et al. 2014), which resulted in major design changes in the 2006 and 2012 surveys, respectively. In 2006, a large portion of survey stations was redistributed with the 10’x10’ lattice-grid design so that sampling stations would be more uniformly distributed within the survey area. In 2012, the 10’x10’ lattice-grid layout was discarded in favor of square grids, as defined using a Universal Transverse Mercator (UTM) (NAD 83) projection. This change was also accompanied by an expansion of the survey area boundaries to the 20 and 200 fathom isobaths. We consider that the survey area encompasses the vast majority of snow crab habitat in the sGSL.

As part of the implementation of the 2011 review, a new set of 325 sampling stations was generated for the 2012 survey and 355 new stations were generated for the 2013 survey. As was the common practice in previous surveys, it was decided that sampling locations generated for 2013 were to be retained as fixed stations in subsequent surveys.

However, not all regions within the survey area are amenable to trawling. About 20% of first tows in 2012 and 2013 failed due to damage to the trawl. The survey vessel does not sound the sea bottom prior to trawling. The survey vessel was directed to a new, randomly-generated alternate sampling station within its assigned survey grid when significant trawl damage was incurred. The alternate location station would then be used as the reference fixed station for the following year’s survey. At the time, it was felt that the fact that these alternate sampling locations were randomly generated would ensure that survey catches would remain as representative samples of their assigned grids, as was the intent of the original sampling design. However, this had the overall effect of a portion of stations being displaced to more trawlable areas within their respective sampling grids over time.

Since 2021, survey stations have been held at fixed locations from the 2020 survey, with the exception of an ongoing experiment involving a random subset of 100 of the survey sampling stations temporarily reverting to their original locations, as per the 2013 survey design (Hébert et al. 2021). This experiment is being performed in an effort to monitor and assess possible bias due to stations being relocated to more trawlable areas over time with possibly higher catches of snow crab.

2.2.2. Trawling

Sampling stations are trawled during civil twilight hours using a Bigouden Nephrops bottom trawl net, originally developed for Norway lobster fisheries in France. The trawl has a 20 m opening and a 28.2 m footrope (Moriyasu et al. 2008). The vessel fishes at a target speed of 2 knots for 5 minutes. A 3:1 warp-to-depth ratio is used, up to a maximum warp length of

575 fathoms. Monitoring probes were attached to the trawl at various positions. eSonar ® acoustic probes (eSonar, St. John's, NL, Canada) relayed real-time measurements of trawl depth, headline height and wing spread. Star-Oddi ® DST centi-TD et DST tilt probes (Star-Oddi, Gardabaer, Iceland) recorded water pressure and temperature, along with tilt angle measurements from a tilt probe attached to the center of the footrope.

2.2.3. Sampling Protocols

Survey catches were sorted by species or taxonomic group and measured directly aboard the vessel. For every crab, carapace width and carapace condition were recorded. Chela height (CH) was also measured for males while gonad color and egg clutch fullness were recorded for females (Hébert et al. 1997). Other species or taxonomic groups in the catch were identified, weighed and counted.

2.2.4. 2024 Survey

The *Avalon Voyager II*, a 65-foot stern-trawling (850 HP) fiberglass boat performed the survey from July 10th to September 15th, 2024. A total of 344 sampling stations (Figure 3) were successfully trawled out of a target number of 355, with a total of 393 trawling attempts. A maximum of two to three trawling attempts were performed at each sampling station. Eleven sampling stations were abandoned this year due to significant trawl damage. The 100 sampling stations which were reverted to their original random locations from 2013 are shown in Figure 4.

The average trawling speed in 2024 has been increasing over the years, at 2.28 knots in 2024, 2.25 knots in 2023, 2.22 knots in 2022 and 2.17 knots in 2021. The target trawling speed for the survey is 2.0 knots. Average trawl wing spread measurements were comparable to those of past years, at an average 7.6 meters.

Reliability of the eSonar trawl acoustic monitoring system improved relative to 2023, with 87% of tows (297 of 344 tows) in 2024 having sufficient wingspread observations to estimate the swept areas, up from 75% in 2023. The tow duration was a median of 306 seconds (s) in 2024, compared to 302 s in 2023, 298 s in 2022 and 309 s in 2021. Trawl swept areas slightly decreased to an average 2,691 m^2, from 2,782 m^2 in 2023.

Following a change in end-of-trawling protocol in 2021, the duration of the passive trawling phase, the period during which the trawl remains on the bottom during the winching of the trawl, has been greatly reduced, passing from ~90 s in 2019 and 2020, to 18 s in 2021, 13 s in 2022, 8 s in 2023, and 7 s in 2024 (Surette and Chassé 2022).

2.2.5. Biological Categories

The following definitions were used to specify the various snow crab categories used in this assessment. Crab maturity is assessed morphometrically using a chela height versus carapace width classifier in males (Conan and Comeau 1986), while female maturity was based on visual inspection of the abdomen. Commercial crab are defined as mature male crab ≥ 95 mm CW. Immature males may be landed though they represent only a small percentage of overall landings. Commercial crab are divided into two groups: new recruits to the fishery (also called R-1 crab), identified as new-shelled crab (carapace conditions 1 and 2); and remaining or residual crab, which represents the portion of the commercial crab that is left over after the fishing season, identified as old-shelled crab (carapace conditions 3, 4 and 5). Skip moulting crab were identified as immatures with an old shell.

Adolescent male crab were grouped into size categories according to the time they are expected to recruit to the fishery. These categories are R-2 (83 to 98 mm CW), R-3 (69 to

83 mm CW), and R-4 (56 to 68 mm CW), which are expected to recruit to the fishery in two, three or four years' time, respectively. Female snow crab were separated into primiparous (defined in this report as mature and new-shelled) and multiparous (mature and old-shelled) categories.

2.2.6. Catch Standardization

Survey catches were standardized by trawl swept area, calculated using wing spread measurements and vessel speed, integrated over the time interval defined by the trawl touchdown, calculated using tilt probe angle data, and the stop time, which signals the start of trawl winching.

2.2.7. Stock Composition

Annual size-frequency distributions were determined from standardized survey catches, separated by sexual maturity. For surveys prior to 2012, size-frequencies within each 10'x10' grid (generally less than three stations), the survey design used at the time, were averaged prior to calculating the annual average. This step was performed to spatially disaggregate survey catches for these older surveys. Means and interquartile ranges of crab sizes were calculated for fishery recruits (legal-sized, new-shelled mature males) and mature females from their corresponding spatially disaggregated size-frequency distributions for each year.

2.2.8. Abundance and Biomass

The survey bounds are defined by a polygon with a surface area of 57,842.8 km^2. The survey area was partitioned using CFA and buffer zone spatial bounds (Figure 5). Kriging with external drift was used to estimate all abundance and biomass indices (DFO 2012a). For biomass estimates, crab counts at each tow were first converted to weights using the size-weight equation $w = (2.665 \times 10^{-4})\ CW^{3.098}$, where w is the weight in grams and CW is the carapace width in mm (Hébert et al. 1992).

2.2.9. Pre-Recruit Survival Indices

To further investigate recent downward trends observed in the size-frequencies and fishery pre-recruits, we compared the abundances of different recruit and pre-recruit categories to the abundances of their corresponding successors the following year. Four recruit categories were considered: pubescent females and three fishery pre-recruit categories, i.e., R-4, R-3 and R-2. The abundance of pubescent females, easily identified as being immature with developing (orange colored) gonads was compared to the abundance of primiparous females from the following year. This category represents a relatively simple case for snow crab: females only remain in the pubescent stage for one year before they almost all become primiparous females the following year. Skip-molting rates among pubescents were considered negligible. For males, we considered fishery pre-recruit categories and their successors the following year. Because of skip-molting and variable maturation rates, these successors were defined as the sum of three categories: skip-moulters, new-shelled immatures and new-shelled matures from the following year.

2.3. SURVIVAL AND EXPLOITATION RATES INDICES

An index for annual exploitation rates (F_t) was defined as a proportion of fishery landings (L_t) for fishing year t over the commercial biomass B_{t-1} estimate from the previous year:

$$F_t = L_t / B_{t-1}$$

An index of the survival rate of commercial crab from post-fishery survey in year *t-1* to the post-fishery survey in the following year was calculated as the ratio of the landings (L_t) plus the residual biomass (R_t) in year *t* after the fishery over the commercial crab estimate (B_{t-1}) from year *t-1*:

$$S_t = (L_t + R_t) / B_{t-1}$$

Annual survival rates projection are subject to estimation error, changes in survey catchability and misidentification of carapace conditions. Also note that this estimate assumes that discard mortality from the fishery is negligible.

2.4. RISK ANALYSIS AND CATCH OPTIONS

The risk analysis calculated the probabilities that the biomass estimates from the 2025 survey would fall below their target reference points, considering a range of catch options. Specifically, that the residual biomass would fall below the Limit Reference Point (LRP) of 10,000 t, and that the total commercial biomass from the post-fishery survey would be below the Upper Stock Reference (USR) of 41,400 t. Inputs to the risk analysis were the projected recruitment biomass to the fishery (R-1) for next year's survey, using a Bayesian model (Surette and Wade 2006; Wade et al. 2014). Risk probabilities were then calculated for each catch option, with an assumed natural mortality equal to the observed rate from the survey for the past 5 years.

2.5. SNOW CRAB HABITAT INDICES

Snow crab habitat was defined as the area in the sGSL with bottom temperatures less than 3 °C. Habitat indices for snow crab, which included the size of the area and their average bottom temperature, were calculated using CTD profile data from the sGSL September multispecies survey (Galbraith et al. 2022). This temperature time series is the longest available and most reliable for the sGSL.

Temperature distributions for each crab category was obtained by first calculating average densities by 0.1 degree temperature bins, then scaling by the September temperature distribution within the survey area for the corresponding year. Quantiles of the resulting temperature distribution were then calculated and displayed as a whisker plots by crab categories and survey years. To account for the different survey design prior to 2012, standardized catches and temperature data were averaged by 10'x10' grid prior to analysis. The temperature distribution of three crab categories of interest were examined:

1. mature females, an index of reproductive stock,
2. instar VIII crab, an index of population recruitment, and
3. commercial crab.

2.6. HISTORICAL CHANGES IN SPATIAL DISTRIBUTION

To explore spatial changes in distribution which have occurred in the sGSL over the years, kriged maps were created for total crab densities from the survey for each year between 1997 and 2024. From these maps, a single map was created by taking the maximum density of crab over the time series at each location. Another map was then generated showing the time elapsed since the maximum densities were reached over the history of the survey. A final map was generated by calculating the ratio between densities from the 2024 survey and the maximum density map.

2.7. ERRATA

A minor error was found in the data for the 2023 survey. Crab measurement data from July 27th, 2023, tow number 10, had a misidentified tow identification number ("GP154F2" rather than "GP154FR2"). This had the effect that crab from this tow did not appear in the abundance and biomass estimates for 2023. The abundance and biomass data values were updated in this report and the changes were minor. For example, the commercial biomass estimate changed from 67,703 t to 67,731 t.

3. RESULTS

3.1. FISHERY PERFORMANCE

The seasonal average of CPUEs, an index of overall fishery performance, was calculated directly from landings and effort data, compiled from crab harvesters' logbook data. These CPUE values were not standardized (Surette and Chassé 2023). In CFA 12, the seasonal average CPUEs decreased by 16.4% to 60.3 kilograms per trap haul (kg/th) in 2024, above the long-term mean of 54.9 kg/th (average from 1998 to 2022). CFA 12E remained unchanged at 78.2 kg/th while CFA 12F decreased slightly by 7.1% to 90.0 kg/th. In CFA 19, the CPUE remained at high levels, only decreasing by 2.9% to 136.5 kg/th, which was above the long-term mean of 108.0 kg/th. CPUEs by CFAs are shown in Figure 6.

Standardized CPUEs, which represent predicted values at day 7 of the fishery, for a 36-hour soak time for an average vessel of the fleet, were generally very similar to seasonal average CPUEs. This picture remains true for CFA 12 in 2024 (Table 1). There were some pronounced differences between the two values for CFAs 12F and especially CFA 19. For CFA 19, the seasonal CPUEs was 136.5 kg/th while the standardized value was only 81.6 kg/th. This large difference was due to a much more severe decline in CPUEs by day 7 of the fishery than in previous years (Figure 7). This was likely driven by many harvesters reaching their quotas as early as the fifth day of the fishery.

3.2. STOCK COMPOSITION

3.2.1. Size Distributions

Size-frequency distributions for immature, new-shelled matures and old-shelled matures are shown for male crab in Figure 8 and female crab in Figure 9. The abundance of immature males across all sizes has significantly decreased from record-high levels in 2019 to 2021, down to moderate levels in 2024. New-shelled mature males have also visibly declined in 2024, relative to the period from 2019 to 2023. In contrast, the level of old-shelled mature males, in particular at sub-legal sizes, has remained relatively constant over the same years.

Size frequency distributions among female snow crab (Figure 9) show that immature females and new-shelled mature females have declined to below average levels in 2024, relative to the period from 2019 to 2023. Old-shelled mature females have declined somewhat in 2024, but remain at relatively high levels in 2024. The size distribution of old-shelled females shows a shift from an instar X (see mode at about 58 mm CW) dominated distribution from 2019 to 2023, to a size distribution which contains roughly equal parts instar IX (mode at about 48 mm CW) and X in 2024. This is likely the result of new-shelled female distributions which were dominated by instar IX females in 2022 and 2023. We note that record-high abundances of instar VII crab (~28 mm CW) 2020 and instar VIII crab (mode at 38 mm CW) in 2021 and 2022 only yielded modest amounts of new shell mature females in 2022 and 2023.

Annual variation in mean crab sizes was examined for legal-sized new-shelled mature males (i.e., fishery recruits). Mean size among these recruits have varied from a low of 107.6 mm CW in 1999 to high of 115.1 mm in 2008. The mean size then decreased to 109 mm in 2011-2012, increased to 113.0 mm in 2015, then decreased to 108.8 mm in 2018 and has since slightly increased to 110.9 mm in 2024 (Figure 10), which is very near the series average.

Mean sizes among mature females have varied from 56.8 mm CW in 1999, to a high of 60.7 mm in 2005. Since 2005, mean size has gradually decreased to 56.7 mm in 2019, to 55.5 mm in 2022 and 2023, to 55.1 mm CW in 2024, the lowest in the series (Figure 10). The size range among mature females has also been steadily decreasing over the period from 1997 to 2021, with the interquartile range (IQR) decreasing from 13.0 mm CW to 10.0 mm from 1997 to 2005, and decreased to record lows of 9.4 mm in 2020 and 2021, but has since increased slightly to 10.6 mm in 2022, 11.2 mm in 2023 and 10.6 mm in 2024. This decline in mean size reflects a greater tendency of females to mature at instar IX rather than instar X in recent years. The 6 mm CW decrease in mature females size (Figure 10) from 2005 to 2024 translates to a potential 28% decrease in individual fecundity.

3.2.2. Population Recruitment

The population recruitment index is defined as the abundance of small male crabs (34-44 mm CW), which roughly corresponds to instar VIII. Population recruitment has seen precipitous declines from a record high of 329 million crab in 2021, to 202 million in 2022, 120 million in 2023, down to 66 million crab in 2024 (Figure 11), which is about half of the series average of 121.6 million crab, and the fourth lowest in the series. We note that the error associated with this index is higher than for larger crab, in part due to the lower catchability of the trawl at these sizes, as well as the occasional very large catches of such crab. Male instar VIII is expected to reach commercial size in 5-6 years, though some portion may skip a moult and/or mature at sizes smaller than the commercial size.

3.2.3. Spawning Stock

Total mature male abundance from the survey had a period of high abundance from 1999 to 2004 with a high of 401 million animals in 1999, then declined to 160 million in 2009 (Figure 12). Abundance then increased to 299 million in 2012, decreasing to lower levels of about 235 million from 2013 to 2015. Since 2016, total abundance of mature males has increased to highs of 420 million in 2021 and 425 million in 2022, 376 million in 2023 and 284 million in 2024, which is slightly below the series average of 303 million crab. From 2018 to 2022, the quantity of legal-sized mature males was between 144 and 154 million crab and decreased to 93 million crab in 2024, which is below the time-series average of 119 million. The abundance of sub-legal sized mature crab, passing from 173 million in 2018 to 271 million in 2021 and 2022, then decreased to 191 million in 2024, which is very near the time-series average of 184 million.

Mature female abundance from the survey was over 600 million crab from 1999 to 2002, then declined to 237 million in 2006 (Figure 12). Since then, female abundance has gradually increased to a high of 777 million in 2020, then declined by 25% to 582 million crab in 2021, then remained relatively constant until 2023, then declined to 502 million in 2024, which is near the time-series average of 507 million.

Primiparous abundance from the survey was high from 1997 to 2001, with a sudden drop from 233 million in 2001 to 51 million in 2002, which gradually increased to 152 million in 2010, followed by a decrease to 79 million in 2011, which grew to 201 million in 2018 and 197 million in 2019, but decreased in subsequent years down to 56 million crab in 2024, which is below the series average of 127 million, and the 6th lowest in the time-series. Primiparous females generally represent an average of 25% of the spawning stock. In 2024, primiparous females only made up 11% of the spawning stock in 2024.

3.2.4. Fishery Recruitment

Fishery recruit estimates from the 2024 survey showed that R-4 abundances decreased by 12.0% to 122.8 million, which is slightly below the time-series average of 128.1 million (Table 2). R-3 abundances decreased by 7.9% to 71.8 million, which is below the time-series average of 118.2 million. R-2 abundances decreased by 24.6% to 54.8 million, which is almost half the series average of 104.7 million. R-1 abundances also decreased by 23.8% to 59.7 million, which is below the time-series average of 80.8 million.

In terms of biomass, fishery recruitment (R-1) was relatively stable over the period from 2018 to 2021, with a low of 58,438 t in 2020 to a high of 62,473 t in 2021, and increased by 9.5% in 2022 to 68,348 t (Table 3). From this high level, there was a 34.9% decrease to 44,512 t in 2023, plus another 21.4% decrease to 34,496 t (30,191 t to 40,235 t) in 2024.

Skip-moulting proportions among R-2 crab remained high in 2024 at 45% (Figure 13). This value is the fourth highest in the series, with the highest value being 56% in 2003, 52% in 2015, and 56% in 2023. The average skip-moulting proportion for R-2s over the series is 31%. Previously skip-moulting events in 2003 and 2015 had generated sizeable increases in fishery recruitment in the 2004 and 2016 surveys. However, the corresponding abundances of R-2s at that time were much higher than current levels: 179 million in 2003 and 128 million in 2015, compared to 72.7 million in 2023 and 54.8 million in 2024.

One-year predictions from the Bayesian recruitment model had over-estimated recruitment by 21.3% in 2020 and 15.6% in 2021, but the 2022, 2023 and 2024 predictions were similar to the survey estimates (Figure 14). Fishery recruitment is predicted to further decrease to 29,570 t (20,590 t to 41,170 t) in 2025, which would represent a 15.4% decrease from the observed recruitment in 2024 and lies below the series average of 47,287 t.

3.2.5. Commercial Biomass

Commercial biomass for 2024 is estimated at 51,786 t, with a 95% confidence interval of (45,558 – 58,621 t) (Table 3, Figure 15). This represents a 23.5% decline from 2023, and a 39.4% decline from 2022. Recruitment represents 67% of the commercial biomass in 2024. The spherical variogram model used for interpolating the commercial biomass had a nugget value of 0, a sill at 1.5×10^6 and a range of 12.5 km.

Residual biomass (i.e., commercial crab with carapace conditions 3, 4 and 5) was estimated at 17,091 t (14,373 to 20,172 t), representing a decrease of 29.9% from 2023, but comparable to the residual biomass from 2022 (Table 3, Figure 15). Residual biomass was dominated by carapace condition 3, representing 71% of survey catches, with 24% made up of carapace condition 4 crab and 5% carapace condition 5 crab (Table 2). The large proportion of carapace condition 3 in the residual biomass suggests that the post-fishery population is young and does not show signs of an ageing population, presumably because of high mortality due to fishing pressure.

A breakdown of the 2024 commercial biomass by CFA and buffer zone is shown in Table 4. The commercial biomass for CFA 12 was 42,090 t (36,714 – 48,028 t) representing 81.7% of the total estimated biomass located within the four fishing areas. In CFA 12E, the commercial biomass was estimated at 717 t (178 – 1,980 t), representing 1.4% of the biomass located within the four CFAs. In CFA 12F, the commercial biomass was estimated at 3,395 t (2,561 – 4,415 t), representing 6.6% of the total estimated biomass located within the four fishing areas.

The commercial biomass for CFA 19 was estimated at 5,271 t (4,201 – 6,529 t), representing 10.2% of the total estimated biomass located within the four CFAs. An estimated 386 t of commercial crab lie within the unassigned zone above CFA 12E/12F and the two buffer zones (Table 4, Figure 5).

3.3. SPATIAL DISTRIBUTION OF COMMERCIAL CRAB

The spatial distribution of commercial crab in 2024, though similar to that of recent years, saw notable declines in the Baie des Chaleurs, Shediac Valley, with more modest declines to the west of the Magdalen Islands, and north of PEI. Densities were similar in CFA 12F and increased in CFA 19 (Figure 16).

The spatial distribution of the residual portion of commercial crab is shown in Figure 17. The residual stock was generally low in 2024, with local pockets in 12F, north of PEI and CFA 19. Concentration of residuals closely mirror that of the commercial biomass from the previous year (Figure 16).

Fishery pre-recruits in 2024 continue to show a gradual shift in spatial distribution from the eastern part of the sGSL in 2020, towards the western in 2024 (Figure 18). There are notable declines and low levels in CFA 12F, CFA 19 and the western Magdalen Islands. The area of high crab concentration to the south of the Magdalens, which has been a hotspot of commercial crab in recent years, continues to decline.

3.4. PRE-RECRUIT SURVIVAL INDICES

Figure 19 showed the relationship between the abundances of four recruit categories and their respective successors the following year. Differences between recruits and successors are driven mainly by annual variations in: natural mortality, survey catchability, new/old-shell condition identification and size-selectivity differences due to growth.

Interannual comparison of primiparous and pubescent females shows that in general, the abundance of pubescent females is a strong predictor of primiparous females the following year, with most years showing that primiparous abundance is nearly equal to pubescent females from the year before.

However, there are important departures from this pattern. Primiparous abundance significantly exceeded pubescent abundance in 2015 (+47%), 2018 (+31%) and 2019 (+68%). While the source of the 2015 deviation is not known, 2018 was likely driven by shell condition identification issues, and 2019 was associated with a survey catchability due to a vessel change. The recent years 2022, 2023 and 2024 all show record-low deviations of -57%, -46%, and -57%, respectively. This strongly suggests high levels of mortality for the past three years and explains much of the disappearance of the record-level population recruitment of 2020 and 2021 in subsequent years.

When we compare the relationship between the abundance of R-4 and its successors, we see some of the same patterns observed among pubescent and primiparous. Years 2018 and 2019 still significantly exceed R-4 abundance from the previous year (+41%), as well as 1999 and 2010. The latter was also associated with shell condition identification issues. The years 2022 to 2024 had similarly lower deviations of -26%, -14% and -28%, which also suggest significant increases in natural mortality for these years.

The relationship between the abundance of R-3 and its successors does not show the same negative deviation for 2022 to 2024, suggesting that natural mortality for this group has not greatly increased in recent years. There are still more cases where the abundance of successors of R-3 exceed that of their progenitors, indicating that there may have been survey catchability increases or shell condition identification issues for 1999, 2014 and 2015, in addition to the known issues for 2018 and 2019.

The relationship between the abundance of R-2 and its successors was somewhat more consistent than for smaller-sized crab. A particularity of this group was that the successors exceeded their R-2 progenitors by +41%, largely due to the fact that large crab in the R-1 category are generated by smaller R-1s from the previous year, not only R-2s. As was the case for R-3s, recent years were not associated with seemingly higher levels of mortality.

3.5. COMMERCIAL EXPLOITATION AND SURVIVAL RATES

The exploitation rate for the 2024 fishery was estimated at 37.4%, based on the 2023 survey commercial biomass estimate (Table 3). Exploitation rates have varied between 21.0% and 44.7% from 1998 to 2024, with an average of 35.5% over the period from 1998 to 2024.

Estimated survival rates had been declining ~ 5% annually, from 69.5% in 2018 to a low of 56.1% in 2021, but increased to 60.6% in 2022, 69.9% in 2023, and has now decreased to 62.6% in 2024 (Table 3). The average survival rate was 66.6% over the period from 1998 to 2024.

3.6. ENVIRONMENTAL CONDITIONS

3.6.1. Water Temperatures

Environmental factors, such as water temperature, can affect the timing and frequency of moulting and reproduction, as well as the movement of snow crab. Bottom temperatures over most of the sGSL are typically below 3 °C: temperatures that are suitable for snow crab habitat. Bottom temperatures in deeper waters of CFAs 12E and 12F are higher (1 to 7 °C) than in snow crab grounds in CFA 12 while bottom temperatures in CFA 19 are usually 1 to 2 °C warmer than on the traditional crab grounds in CFA 12 (Chassé and Pettipas 2010).

Bottom temperatures in September 2024 were compared to the average temperatures over the period from 1991 to 2020 using data from surveys (Figure 20). Overall, bottom temperatures for the sGSL during 2024 remained much warmer than average except for the coastal area near PEI and St. George's Bay. Temperatures for CFA 12 in 2024 were 0.5 to 1 °C (or more) above average in the Baie des Chaleurs and over a large area between the Acadian Peninsula, the Magdalen Islands and the Gaspe Peninsula. This area includes the Orphan and Bradelle Banks. Bottom temperatures in CFAs 12E, 12F and 19 were 1 to 2 °C above average.

Although they slightly decreased since 2022, temperatures in the deep waters of the Laurentian channel remained high and were much warmer than average. The temperature at 300 m near Cabot Strait reached 6.7 °C in 2024, which is 0.8 °C warmer than the long term average of 5.94 °C at that depth.

Figure 21 shows the average temperature stratification in September within the snow crab survey area by year. It shows that the depth range at which the deeper waters fall below the 3 °C threshold has been decreasing over the period as these waters warm, reaching record lows in 2021 and 2022, at around 115 m. This depth threshold increased slightly in 2023 and 2024 at just over 125 m.

3.6.2. Habitat Indices

The surface area of the sGSL with bottom temperatures below 3 °C in September, an index of snow crab habitat, rose significantly in 2024 from 2023 and was above the long-term average. This increase is mostly due to the presence of colder waters near PEI during September 2024.

The temperature within the surface area, at an average 1.31 °C, is still well above the long-term average (1991-2020) and is similar to the temperature observed in 2023 (1.3 °C) and a 0.8 °C increase from the latest significant minimum observed in 2014 (0.5 °C). The 2024 average temperature within the snow crab habitat is the fifth highest of the 1971-2024 time series (Figure 22). The highest value was observed in 2021.

Although it slightly rose from 2023, the water volume of the Cold Intermediate Layer (CIL), defined as waters < 1 °C, in 2024 was still one of the lowest on record for September with minimums in 1980, 2012, 2021 and 2022 (Figure 22). The CIL water volume for 2024 was ~1,192 km^3, which was lower than the average of 2,386 km^3. The lowest CIL volumes were observed in 1980 and 2022.

3.6.3. Temperatures Occupied by Snow Crab

Figure 23 shows the September temperature distribution occupied by mature females, male instar VIII and commercial snow crab from 1997 to 2024 in the sGSL. September temperatures occupied by mature females have oscillated over the time series, with warm temperature periods in 2000, 2006, 2010, and 2012. The most recent warming trend began in 2014 with a low temperature of 0.20 °C which rose to the highest value in the series at 1.21 °C in 2021 and decreased slightly to 1.07 °C, 1.02 °C, and 1.05 °C in 2022, 2023 and 2024, respectively (Figure 23). The median temperature for instar VIII crab was very high in 2021 at 1.76 °C, the highest in the series, and remained high at 1.23 °C in 2022, 1.17 °C in 2023 and 1.23 °C in 2024. Commercial crab occupation temperatures in September were relatively warm in 2000 and 2009-2014, and has since warmed from a median 0.17 °C in 2014 to 1.23 °C in 2021, the warmest in the series. Occupation temperatures remained high at 1.18 °C in 2022, 1.12 °C in 2023 and 1.14 °C in 2024. The occupation temperatures from 2020 to 2024 were the highest of the series.

3.6.4. Historical Changes in Snow Crab Spatial Distribution

Figure 24 shows a summary of changes in spatial distribution that have occurred in the sGSL, using the total snow crab caught in the survey from 1997 to 2024. The maximum density map shows that there were three main areas where high densities have occurred: Off the coast of Gaspe, to the east of the Baie des Chaleurs, and north of PEI. Smaller high-density areas were to the north of the American Bank, to the south of Area 19, and south of Area 18. Maximum densities in the series were reached in the northern part of the sGSL in the first half of the time series (14-27 years ago), while maxima were reached much more recently in the Baie des Chaleurs, Shediac Valley, north of PEI and the area surrounding the Magdalen Islands, as well as the western part of Area 19. Comparing densities from the 2024 survey to their respective maxima over the series showed that the northern area east of Gaspe, including the American Bank, are a fraction of their maximum values, at less than 25% of the maximum, and less than 10% of the maximum along the Laurentian Channel. Similarly, the north part of Area 19 and the Cape Breton Trough regions also had low densities at less than 25% of their historical maxima. Areas that stood above 25% of their historical maxima were concentrated around the Magdalen Islands and north of PEI, the Shediac Valley, and the Baie des Chaleurs.

4. PRECAUTIONARY APPROACH

4.1. REFERENCE POINTS

Reference points conforming to the Precautionary Approach (PA) (DFO 2009) were developed for sGSL snow crab in 2010 (DFO 2010). These reference points, in conjunction with appropriate stock parameters, are used to classify stock status as being in the critical, cautious or healthy zones, with each zone being assigned its particular management / harvest decision rules.

The sGSL snow crab stock has three defined reference points (Figure 25). A limit reference point (LRP) = 10,000 t, was defined according to the lowest survey residual biomass observed from 1997 to 2008. An upper stock reference (USR) point = 41,400 t, was defined as 40% of the maximum commercial biomass (i.e., recruitment plus residuals) from the 1997 to 2008 surveys. A removal rate reference F_{lim} = 34.6% (DFO 2012b; Figure 26), was set corresponding to the average annual exploitation rate for fishery years 1998 to 2009. See DFO (2010) for further details on the specification of these reference points.

Note that while the USR was based on the total commercial biomass (which includes both the residual and recruitment), the LRP was calculated using only the residual portion of the commercial biomass (DFO 2010). In practice, the total commercial biomass is used to determine if the stock is in the cautious or healthy zone while the residual commercial biomass is used to determine if the stock is in the critical zone. However, it is possible to have contradictory stock statuses. For example, where the total commercial biomass places the stock in the healthy zone while the residual commercial biomass places the stock in the critical zone.

The commercial biomass estimate for the 2025 sGSL fishery is 51,786 t (Tables 3 and 4), which is within the healthy zone of the PA framework (Figures 25 and 26). The residual biomass after the 2024 fishery was at 17,091 t (Table 3), which was above its limit reference point of 10,000 t.

F_{lim} is not currently used as a limit reference point in the management of sGSL snow crab, in that the target exploitation rate given by the harvest decision rule generally exceeds F_{lim}, up to a maximum of 45%. Under the current harvest decision rule, the exploitation rate will only fall below F_{lim} when the commercial biomass falls below 45,500 t.

4.2. RISK ANALYSIS

Inputs to the risk analysis were the commercial biomass from the 2024 survey (51,786 t), the projected fishery recruitment from the Bayesian model (29,570 t), and the 5-year average annual survival rate of 62.3%. A provisional catch option of 18,503 t, corresponding to an exploitation rate of 35.73%, as per the harvest decision rule, was used for the 2025 fishery (Figure 27).

The risk analysis indicates that the 18,503 t catch option would result in a moderate probability (39.6%) that the commercial biomass would fall below the USR in 2025, largely due to the low level of the predicted fishery recruitment of 29,570 t. In contrast, the residual biomass has a low probability of 3.3% that it would fall below LRP after the 2025 fishery.

Thus, for the first time since the PA reference points for this stock were updated in 2012, there is a moderate likelihood that the stock will be in the cautious zone in 2025 (Table 5). Previously, only the commercial biomass estimates in 2009 and 2010 would have placed the stock in the cautious zone, but these predated the implementation of the PA (Figure 26). Other than the scaling back of the exploitation through the harvest decision rule, there are no additional management measures that would be triggered by this change in stock status. The 2025 commercial biomass is projected to further decrease a 16.3% from 2024, in addition to the 21.4% decrease in 2023, and the 20.8% decrease in 2022.

5. DISCUSSION

5.1. STANDARDIZED CPUE

Standardized and seasonal average CPUEs for 2024 were similar for CFA 12. In contrast, standardized estimates in CFAs 12E and 12F were below the seasonal average values. The standardized CPUEs for CFA 19 was much less than the seasonal average. There are two likely causes for this large discrepancy in CFA 19: CPUEs declined at a faster rate than in previous years possibly due to low stock density or, fishers caught most of their quota before the seven-day mark. Although CPUEs should scale to some degree with the underlying commercial crab density, CPUEs are much more subject to variations in scale than surveys, as they are not subject to monitoring or controls to account for many important factors which would be useful for standardizing (Maggs et al. 2016). However, the standardization variables included here do adjust for certain nuisance factors, such as soak time and time of fishing, many others such as changing fishing practices and the areas that fish harvesters targets were not considered when standardizing. Interpreting changes in the underlying commercial biomass through the optic of standardized CPUEs remains a difficult task, and sheds little light on recent changes in survey catchability. Thus, the proper standardization of the survey time series remains an on-going issue.

5.2. STOCK STATUS INDICATOR UNCERTAINTIES

The sGSL snow crab survey was developed to provide quality abundance and biomass indices: it uses a bottom trawl with high catchability for commercial crab, contains a large number stations, and a survey area that covers most of the crabs' habitat.

Changes in sampling design and fishing protocols have led to improvements in the survey over the years. However, these changes may imply that there have been unaccounted changes in the scale of indices. In particular, survey catchability has changed through time due to changes in survey design, expansion of the survey area, relocation of survey stations and variations in the timing of the survey. In addition, trawl catchability is known to vary with bottom type, sea conditions, current, vessel types, and trawl geometry.

5.3. RECENT FISHERY RECRUIT DYNAMICS

Record-high peaks of small crab observed in the size-frequencies in 2020 and 2021 (Figures 8 and 9) have declined to average levels from 2022 to 2024. Specifically, these declines were driven by record-low yield rates from pubescent females and R-4 males in 2022 to 2024 (Figure 19). In contrast, the yield rates of R-3s and R-2s remained at average levels in 2022 to 2024, suggesting the decline was mainly due to mortality increases among smaller-sized crab. Likely contributors to this increase in natural mortality are: warming temperatures, predation, or density-dependent effects such as competition for prey and cannibalism, or increases in disease prevalence.

Shifting our focus from yield rates to the levels of fishery pre-recruits, R-3, and R-2s have both substantially decreased from 2020 to 2024 and are now at below average levels (Table 2). R-4s had decreased from 2020 to 2022, but have since increased to average levels in 2023 and 2024. Fishery recruits (R-1s) are currently experiencing a decline, driven by corresponding declines in R-2s from the previous year (Table 2). They are predicted to further decline in 2025 (Table 3, Figure 14). Skip-moulting proportions among R-2s were high in 2023 and remained high in 2024. This adds to the prediction uncertainty in the fishery recruitment model, which does not account for annual variations in skip-moulting rate. Previous years with high proportions of skip-moulting were associated with higher than normal yields of R-1s. This pattern did not seem to hold for 2024, which had R-1 levels very much in line with the predicted value from the model.

5.4. ENVIRONMENTAL CONDITIONS

Many aspects of snow crab biology, including feeding, metabolism and reproduction, have characteristically narrow temperature ranges. A laboratory study involving male snow crab from the sGSL showed that metabolic costs above 7 °C exceeded caloric intake and that caloric intake decreased when passing the 5 °C threshold (Foyle et al. 1989). In terms of egg development, optimal temperatures range from 0 to 3 °C (Webb et al. 2007). An experimental study from the sGSL showed that incubating females held in warmer temperatures (between 1.8 and 3.2 °C) passed from a 2-year to a 1-year reproductive cycle (Moriyasu and Lanteigne 1998). Similarly, in eastern Nova Scotia, around 80% of mature females were shown to have a 1-year reproductive cycle, with this region having higher temperatures than in the sGSL (Kuhn and Choi 2011). In terms of recruitment, another laboratory study showed that small benthic recruits favoured temperatures of 0 °C to 1.5 °C, which explained some of the depth distribution patterns observed in the northwestern portions of the Gulf of St. Lawrence (Dionne et al. 2003).

The collapse of the Eastern Bering Sea snow crab stock in 2021 provides a cautionary tale on how quickly stock status can change. Prior to the collapse, assessment biologists were reporting record levels of recruits in 2018 which decreased substantially in 2019 and was minimal levels in 2021. These decreases coincided with a marine heat wave resulting in a substantial decrease of the cold pool in 2018 - 2021. Further investigations suggested that starvation due to increase metabolic demands and thermal stress was a likely cause (Szuwalski et al. 2023).

Median temperatures occupied by sGSL snow crab have slowly trended upwards since 2014 to all-time highs in 2021, ranging from 1.2 °C (mature female and commercial crab) to 1.7 °C (instar VIII), closely mirroring increases in bottom temperatures in the sGSL during September. These temperatures decreased slightly in 2022 to 2024 but remain among the highest in the time series. For reference, occupation temperatures in the Eastern Bering Sea were 2.5 °C during their 2018 survey (Fedewa et al. 2020).

Snow crab is known to cycle through periods of low and high abundance. There is a spatial component to this cycle, with different parts of the gulf reaching their maxima at different times. Maps showed that the northern edge of the survey area were at their maximum densities more than 15 years ago. Current densities are especially low in and around the American Bank, along the slope of the Laurentian Channel and the deeper parts of CFA 19, associated with the Cape Breton troughs. The declines in these areas coincide with warming trends in deeper waters of the Laurentian Channel, which have warmed by 4 degrees over the past 15 years or so, likely excluding snow crab from these deeper waters.

6. CONCLUSION

Indicators show that the sGSL snow crab stock is currently in a downward phase of its population cycle. Commercial and population recruitment are considered to be below average levels. Reproductive stocks are considered healthy, although the level of primiparous females is low. Record levels of small recruits in 2019 and 2020 have only led to average yields in 2024, likely the result of high natural mortality rates from 2022 to 2024.

The commercial stock biomass from the post-fishery survey is estimated at 51,786 t, composed of 67% new recruitment and 33% of residual biomass. Commercial biomass indicators placed the stock in the healthy zone of the PA in 2024. Based on the harvest decision rule, this commercial stock biomass estimate corresponds to an exploitation rate of 35.73%, and a catch option of 18,503 t for the 2025 sGSL snow crab fishery. Under this catch option, a risk analysis indicates there is a moderate likelihood that the stock will be in the cautious zone of the PA in 2025.

However, warming temperatures in the sGSL are a cause of concern. The volume of the CIL has been very low in recent years, associated with a decrease in the area of snow crab habitat. Similarly, analysis of survey data has shown concurrent decreases in snow crab density in areas along the margins of the Laurentian Channel, where a mass of warming, deep waters have been observed over the past decade. In light of this, some portions of the stock may be approaching known thermal limits for egg incubation, larval settlement and metabolic tolerances, which may lead to lower recruitment, increased mortality and emigration, should temperatures keep increasing in the future.

7. ACKNOWLEDGMENTS

Authors thank J.-F. Landry, M. McWilliams, Y. Larocque and the crew of the Avalon Voyager II for their survey work. We also wish to thank M. Moriyasu, R. Allain, and É. Aubry for their aid the preparation and reviewing of this document.

8. REFERENCES CITED

Biron, M., Ferron, C., and Moriyasu, M. 2008. Movement of adult male snow crab, *Chionoecetes opilio*, in the southern Gulf of St. Lawrence and eastern Nova Scotia, Canada. Fish. Res. 91: 260-270.

Chassé, J., and R.G. Pettipas. 2010. Temperature conditions in the southern Gulf of St. Lawrence during 2008 relevant to snow crab. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/087. vi + 24 p.

Comeau, M., and Conan, G.Y.1992. Morphometry and gonad maturity of male snow crab, *Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 49: 2406-2468.

Conan, G.Y., and Comeau, M. 1986. Functional maturity of male snow crab, (*Chionoecetes opilio*). Can. J. Fish. Aquat. Sci. 43: 1710-1719.

DFO. 2006. Proceedings of the Assessment Framework Workshop on the Southern Gulf of St. Lawrence Snow Crab (Areas 12, E, F and 19), Gulf Regional Advisory Process; 11-14 October 2005. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2006/042.

DFO. 2009. A Fishery Decision-Making Framework Incorporating the Precautionary Approach.

DFO. 2010. Reference points consistent with the precautionary approach for snow crab in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/014.

DFO. 2012a. Proceedings of the Gulf Region Science Peer Review Framework Meeting of Assessment Methods for the Snow Crab Stock of the southern Gulf of St. Lawrence; November 21 to 25, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/023.

DFO. 2012b. Revised reference points for snow crab to account for the change in estimation area of the southern Gulf of St. Lawrence biological unit. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/002.

DFO. 2014. Assessment of candidate harvest decision rules for compliance to the Precautionary Approach framework for the snow crab fishery in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/007.

Dionne, M., Sainte-Marie, B., Bourget, E., and Gilbert, D. 2003. Distribution and habitat selection of early benthic stages of snow crab, *Chionoecetes opilio.* Mar. Ecol. Prog. Ser. 259: 117-128.

Fedewa, E.J., Jackson, T.M., Richar J.I., Gardner J.L., and Litzow, M.A. 2020. Recent shifts in northern Bering Sea snow crab (*Chionoecetes opilio)* size structure and the potential role of climate-mediated range contraction. Deep. Sea Res. Pt. II Top. Stud. Oceanogr. pp. 181–182.

Foyle, T.P., O'Dor, R.K., and Elner, R.W. 1989. Energetically Defining the Thermal Limits of the Snow Crab. Journal of Experimental Biology. 145(1): 371–393.

Galbraith, P.S., Chassé, J., Dumas, J., Shaw, J.-L., Caverhill, C., Lefaivre, D. and Lafleur, C. 2022. Physical Oceanographic Conditions in the Gulf of St. Lawrence during 2021. DFO Can. Sci. Advis. Sec. Res. Doc. 2022/034. iv + 83 p.

Hébert, M., Surette T., Wade, E., Landry J.-F., and Moriyasu, M. 2021. The 2019 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F). DFO Can. Sci. Advis. Sec. Res. Doc. 2021/010. iv + 56 p.

Hébert, M., Gallant, C., Chiasson, Y., Mallet, P., DeGrâce, P. et Moriyasu, M. 1992. Le suivi du pourcentage de crabes mous dans les prises commerciales de crabe des neiges (*Chionoecetes opilio*) dans le sud-ouest du golfe du Saint-Laurent (zone 12) en 1990 et 1991. Rapp. Tech. Can. Sci. Halieut. Aquat. 1886.

Hébert, M., Wade, E., DeGrâce, P., Biron, M., and Moriyasu, M. 1997. 1996 assessment of Snow Crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 18, 19, 25/26 and Zones E and F). DFO Can. Stock Assess. Sec. Res. Doc. 97/086.

Kuhn, P.S., and Choi, J.S. 2011. Influence of temperature on embryo developmental cycles and mortality of female *Chionoecetes opilio* (snow crab) on the Scotian Shelf, Canada. Fisheries Research. 107: 245-252.

Maggs, J.Q., Potts, W.M., Dunlop, S.W. 2016. Traditional management strategies fail to arrest a decline in the catch-per-unit-effort of an iconic marine recreational fishery species with evidence of hyperstability. Fish. Man. Ecol. 23: 187–199.

Moriyasu, M., Wade, E., Hébert, M., and Biron, M. 2008. Review of the survey and analytical protocols used for estimating abundance indices of southern Gulf of St. Lawrence snow crab from 1988 to 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/069.

Moriyasu, M., and Lanteigne, C. 1998. Embryo development and reproductive cycle in the snow crab, *Chionoecetes opilio* (Crustacea: Majidae), in the southern Gulf of St. Lawrence, Canada. Can. J. Zoology. 76(11): 2040-2048.

Puebla, O., Sévigny, J.-M., Sainte-Marie, B., Brêthes, J.-C., Burmeister, A., Dawe, E.G., and Moriyasu, M. 2008. Population genetic structure of the snow crab (*Chionoecetes opilio*) at the Northwest Atlantic scale. Can. J. Fish. Aquat. Sci. 65: 425-436.

Surette, T., Chassé, J. 2022. The 2021 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 12E, 12F and 19). DFO Can. Sci. Advis. Sec. Res. Doc. 2022/053. iv + 37 p.

Surette, T., and Chassé J. 2023. The 2022 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of Saint Lawrence (Areas 12,12E, 12F and 19). DFO Can. Sci. Advis. Sec. Res. Doc. 2023/059. v + 44 p.

Surette, T., and Wade, E. 2006. Bayesian serial linear regression models for forecasting the short-term abundance of commercial snow crab (*Chionoecetes opilio*). Can. Tech. Rep. Fish. Aquat. Sci. 2672.

Szuwalski, C.S., Aydim, K., Fedewa, E.J., Garber-Yonts, B., Litzow, M.A. 2023. The collapse of the eastern Bering Sea snow crab. Science. 382: 306-310.

Wade, E., Moriyasu, M., and Hébert, M. 2014. Methods and models used in the 2012 assessment of the snow crab (*Chionoecetes opilio*), stock in the southern Gulf of St-Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/113. v + 50 p.

Webb, J.B., Eckert, G.L., Shirley, T.C., and Tamone, S.L. 2007. Changes in Embryonic Development and Hatching in *Chionoecetes opilio* (Snow Crab) With Variation in Incubation Temperature. Biol. Bull. 213: 67–75.

Wood, S.N. 2017. Generalized Additive Models: An Introduction with R, 2nd Edition. Chapman and Hall/CRC.

9. TABLES

Table 1. Seasonal average and standardized catch-per-unit-of-effort (kg / trap haul) by year and crab fishing area (CFA). Standard errors are shown in parentheses.

Year	CFA 12		CFA 12E		CFA 12F		CFA 19	
	Average	Std.	Average	Std.	Average	Std.	Average	Std.
2017	72.0	78.3 (2.0)	60.9	54.7 (8.6)	72.6	51.5 (3.4)	142.8	154.1 (5.8)
2018	44.2	42.0 (1.1)	46.6	46.0 (7.1)	69.1	61.6 (3.8)	156.1	144.2 (5.8)
2019	55.5	58.2 (1.4)	65.7	44.9 (7.3)	64.5	68.2 (4.0)	112.7	124.7 (4.6)
2020	44.1	42.7 (1.2)	45.9	49.5 (9.8)	45.2	47.0 (3.3)	101.7	97.9 (4.4)
2021	57.4	55.7 (1.4)	55.7	49.6 (8.3)	59.1	54.5 (3.5)	121.0	112.9 (4.6)
2022	51.4	56.8 (1.6)	78.5	72.1 (15.4)	76.4	70.2 (5.4)	112.6	117.8 (4.8)
2023	72.2	72.0 (1.9)	79.1	58.0 (10.6)	96.9	69.7 (5.6)	140.6	76.3 (4.4)
2024	60.3	54.2 (1.5)	78.3	66.6 (14.6)	90.0	77.6 (6.2)	136.5	81.6 (4.1)

Table 2. Annual abundance (in millions) of crab categories based on southern Gulf of St. Lawrence trawl survey data. Table entries shaded in red indicate low values in the series, blue entries indicate high values and white entries indicate near average values. Yellow shaded years indicate survey vessel changes.

Year	Pre-recruits			Recruits	Residuals		
	R-4	R-3	R-2	R-1	CC3	CC4	CC5
1997	114.0	98.2	59.7	59.3	28.3	17.7	5.2
1998	135.3	91.3	60.3	50.9	24.9	16.0	8.6
1999	195.6	151.1	112.9	48.1	32.7	16.8	7.8
2000	237.5	159.1	88.4	68.4	10.3	7.4	2.5
2001	310.8	227.3	136.3	76.4	28.1	5.4	1.6
2002	164.3	242.2	202.2	112.3	21.7	4.3	0.9
2003	133.2	202.3	178.5	100.3	38.0	11.7	1.8
2004	85.8	122.9	144.1	143.3	28.2	9.9	1.2
2005	62.2	79.8	117.2	99.1	30.0	10.5	0.6
2006	54.1	49.6	65.7	84.2	29.2	5.8	1.0
2007	56.5	47.6	55.4	62.8	31.5	14.0	1.0
2008	80.6	54.6	45.8	49.1	23.0	11.4	3.0
2009	88.5	69.3	43.8	31.7	12.5	5.3	1.3
2010	140.8	110.3	72.5	32.8	20.6	4.2	1.6
2011	91.4	99.2	88.2	53.0	44.3	9.8	1.8
2012	95.7	86.4	80.5	86.6	37.9	5.7	1.2
2013	103.1	85.1	79.4	63.7	30.1	18.3	0.7
2014	105.1	93.6	117.2	73.3	29.6	13.1	0.6
2015	107.1	124.7	127.5	56.2	27.2	17.3	0.5
2016	113.1	124.8	101.6	125.9	30.6	14.7	0.1
2017	113.0	119.6	103.3	90.0	21.6	6.1	0.4
2018	135.6	116.5	108.3	115.6	34.6	4.5	0.8
2019	190.7	186.0	185.7	105.1	28.8	9.3	0.8
2020	180.9	170.3	174.3	103.5	29.8	7.2	0.6
2021	135.9	154.4	154.0	112.0	29.7	6.4	1.5
2022	94.7	93.1	102.3	119.6	27.6	6.2	0.7
2023	139.6	78.0	72.7	78.4	36.1	10.1	0.6
2024	122.8	71.8	54.8	59.7	24.5	8.2	1.7
Average	128.1	118.2	104.7	80.8	28.3	9.9	1.8

Table 3. Annual recruitment, residual and total commercial biomass (in tonnes) of southern Gulf of St. Lawrence snow crab, based on trawl survey data. Parentheses show 95% confidence intervals. Also shown are annual landings, annual and five year average survival rates of commercial crab and exploitation rate (ER).

Year	Recruitment (t)		Residual (t)	Commercial (t)	Landings (t)	Survival (%)		ER (%)
	Observed (t)	Predicted (t)				Annual	5-year	
1997	37,910 (30,911-46,018)	-	27,688 (21,982-34,422)	64,518 (54,105-76,345)	17,249			
1998	30,603 (22,695-40,384)	-	28,295 (21,497-36,566)	57,813 (45,856-71,931)	13,575	64.9		21.0
1999	26,015 (20,709-32,265)	-	31,177 (25,044-38,356)	56,757 (47,641-67,102)	15,110	80.1		26.1
2000	40,734 (33,592-48,942)	-	9,979 (6,987-13,827)	50,621 (41,843-60,692)	18,712	50.6		33.0
2001	42,358 (33,800-52,422)	-	17,612 (13,853-22,077)	60,328 (49,851-72,351)	18,262	70.9		36.1
2002	66,076 (55,416-78,180)	-	13,060 (10,793-15,662)	79,228 (67,983-91,791)	25,691	64.2	66.1	42.6
2003	58,270 (50,270-67,175)	-	26,993 (22,124-32,613)	84,448 (73,486-96,574)	21,163	60.8	65.3	26.7
2004	83,764 (74,392-93,981)	-	21,259 (17,343-25,794)	103,146 (92,426-114,758)	31,675	62.7	61.8	37.5
2005	59,939 (53,551-66,870)	60,500 (38,800-86,000)	23,496 (18,902-28,868)	82,565 (73,514-92,415)	36,118	57.8	63.3	35.0
2006	54,541 (48,235-61,438)	49,700 (33,200-73,000)	19,621 (16,697-22,907)	73,645 (65,681-82,302)	29,121	59.0	60.9	35.3
2007	40,048 (35,286-45,269)	35,200 (21,300-55,000)	26,829 (23,232-30,821)	66,371 (59,971-73,264)	26,867	72.9	62.6	36.5
2008	32,241 (27,929-37,027)	29,000 (18,500-42,000)	20,981 (17,989-24,327)	52,921 (47,167-59,178)	24,458	68.5	64.2	36.9
2009	20,618 (17,747-23,818)	27,700 (17,800-38,000)	10,454 (8,687-12,474)	31,015 (27,519-34,829)	23,642	64.4	64.5	44.7
2010	20,477 (17,815-23,423)	25,900 (17,100-37,000)	15,490 (13,022-18,289)	35,929 (32,049-40,147)	9,549	80.7	69.1	30.8
2011	29,643 (25,676-34,045)	33,700 (22,900-47,000)	33,679 (28,430-39,613)	62,841 (55,985-70,299)	10,708	-	71.6	29.8
2012	49,010 (40,382-58,931)	40,700 (31,300-52,400)	25,615 (21,607-30,147)	74,778 (64,881-85,748)	21,956	75.7	72.3	34.9
2013	39,988 (31,504-50,055)	40,380 (31,670-50,380)	27,092 (22,041-32,952)	66,709 (54,294-81,108)	26,049	71.1	73.0	34.8
2014	44,285 (37,440-52,014)	37,893 (28,568-49,114)	23,863 (20,356-27,799)	67,990 (59,802-76,978)	24,479	72.5	75.0	36.7
2015	34,982 (29,145-41,643)	42,300 (32,760-51,840)	24,106 (20,290-28,429)	58,927 (51,368-67,278)	25,911	73.6	73.2	38.1
2016	74,124 (64,811-84,392)	50,000 (36,400-66,900)	24,309 (20,876-28,143)	98,394 (87,150-110,677)	21,725	78.1	74.2	36.9
2017	51,127 (43,976-59,103)	46,200 (31,400-64,230)	14,650 (12,134-17,534)	65,738 (57,221-75,157)	43,656	59.3	70.9	44.4
2018	59,609 (51,755-68,310)	47,700 (33,800-64,880)	21,432 (17,271-26,291)	80,746 (70,984-91,467)	24,260	69.5	70.6	36.9
2019	58,995 (50,215-68,863)	49,820 (33,790-70,970)	20,291 (16,940-24,109)	79,066 (69,072-90,091)	31,707	64.4	69.0	39.3
2020	58,438 (49,759-68,189)	74,280 (49,300-107,400)	19,107 (16,235-22,239)	77,748 (67,706-88,852)	28,156	59.8	66.2	35.6
2021	62,473 (53,650-71,590)	72,230 (48,200-104,100)	19,144 (15,997-22,726)	80,950 (70,543-92,451)	24,479	56.1	61.8	31.5
2022	68,348 (58,894-78,880)	65,100 (44,410-92,220)	17,388 (14,040-21,292)	85,532 (74,658-97,535)	31,661	60.6	62.1	39.1
2023	44,512 (37,846-52,010)	49,100 (34,050-68,450)	24,393 (20,500-28,807)	67,731 (59,204-77,135)	35,404	69.9	62.4	41.4
2024	34,946 (30,191-40,235)	37,040 (25,870-51,370)	17,091 (14,373-20,172)	51,786 (45,558-58,621)	25,328	62.6	62.1	37.4
2025	-	29,570 (20,590-41,170)	-	-	-	-	-	-

Table 4. Commercial biomass by crab fishing area (CFA) and buffer zones based for the last three years. Parentheses show 95% confidence intervals. Labels are from Figure 5.

CFA	Area(km^2)	Biomass (t)			
		2022	2023	2024	
Southern Gulf	57,842.8	85,532	67,731	**51,786**	(45,558 - 58,621)
CFA 12	48,074.0	75,742	58,412	**42,090**	(36,714 – 48,028)
CFA 12E	2,436.9	685	509	**717**	(178 – 1,980)
CFA 12F	2,426.8	4,320	4,675	**3,395**	(2,561 – 4,415)
CFA 19	3,813.0	4,094	3,702	**5,271**	(4,201 – 6,529)
Sum of CFA[1]	56,750.7	84,841	67,298	**51,473**	-
Unassigned zone above 12E/F **(A)**	667.9	43	45	**33**	(0.1 - 226)
Buffer zone 19/12F **(B)**	134.2	137	149	**159**	(64 - 333)
Buffer zone 12/19 **(C)**	289.5	552	311	**194**	(38 – 603)
Sum of total areas and zones	57,842.7	85,573	67,803	**51,859**	-

[1] Small difference in the sum of all individual area estimates compared to the southern Gulf estimates is due to rounding of intermediate calculations.

Table 5. Risk analysis for different catch options for the 2025 southern Gulf of St. Lawrence snow crab fishery showing the probability that the residual commercial biomass (B_{res}) would be below limit reference point (LPR), the probability that the total commercial biomass (B) would be below the upper stock reference (USR), and the expected biomass for the 2025 survey. In bold is the catch option corresponding to an exploitation rate of 35.73%, the rate as per the harvest decision rule.

Catch option (t)	Probability		Predicted survey biomass for 2025 (t)
	B_{res} < LRP	B < USR	
10,000	0.0%	1.9%	51,729 (41,877 – 63,842)
11,000	0.0%	3.3%	50,729 (40,877 – 62,842)
12,000	0.0%	5.4%	49,729 (39,877 – 61,842)
13,000	0.0%	8.3%	48,729 (38,877 – 60,842)
14,000	0.0%	12.1%	47,729 (37,877 – 59,842)
15,000	0.0%	16.9%	46,729 (36,877 – 58,842)
16,000	0.1%	22.6%	45,729 (35,877 – 57,842)
17,000	0.4%	29.0%	44,729 (34,877 – 56,842)
18,000	1.7%	35.9%	43,729 (33,877 – 55,842)
18,503	**3.3%**	**39.6%**	**43,226 (33,374 – 55,339)**
19,000	5.8%	43.2%	42,729 (32,877 – 54,842)
20,000	14.7%	50.5%	41,729 (31,877 – 53,842)
21,000	29.5%	57.6%	40,729 (30,877 – 52,842)
22,000	48.2%	64.3%	39,729 (29,877 – 51,842)
23,000	66.7%	70.4%	38,729 (28,877 – 50,842)
24,000	81.5%	75.9%	37,729 (27,877 – 49,842)
25,000	91.1%	80.6%	36,729 (26,877 – 48,842)
30,000	100.0%	94.7%	31,729 (21,877 – 43,842)
35,000	100.0%	98.9%	26,729 (16,877 – 38,842)
40,000	100.0%	99.8%	21,729 (11,877 – 33,842)

10. FIGURES

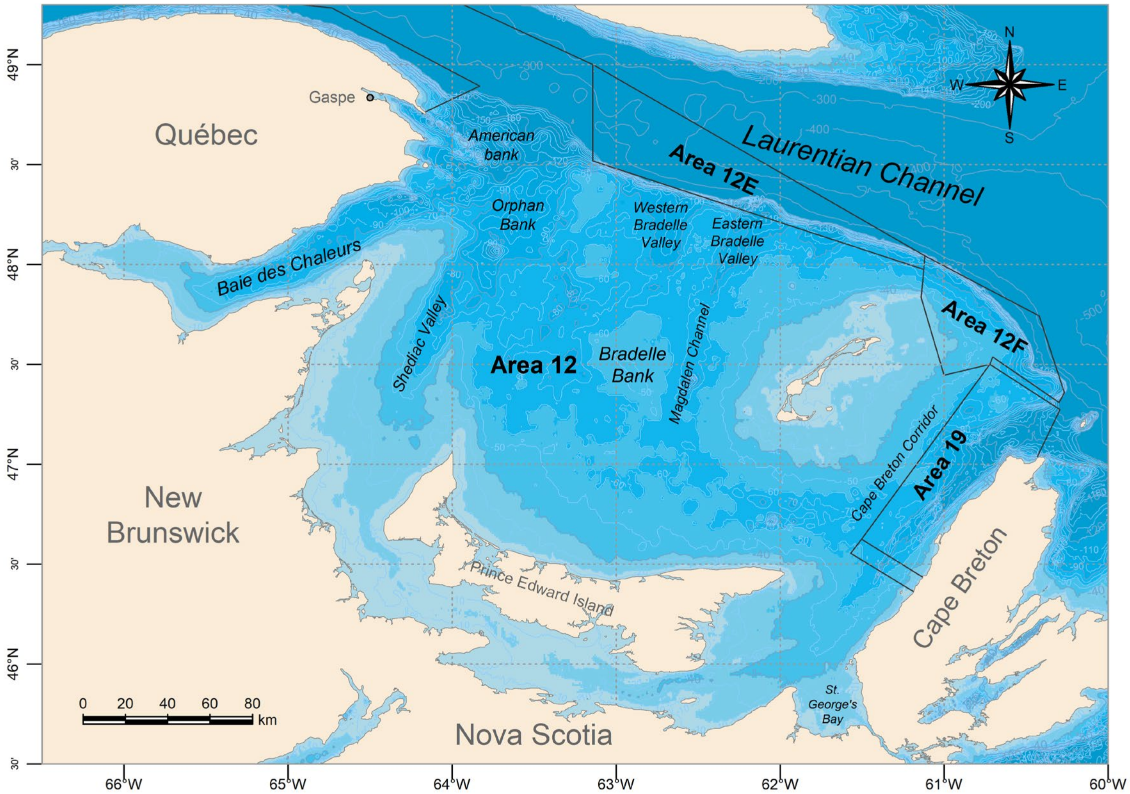

Figure 1. Map of the southern Gulf of St. Lawrence showing snow crab fishery areas (CFAs 12 12E, 12F and 19) and common names for fishing grounds.

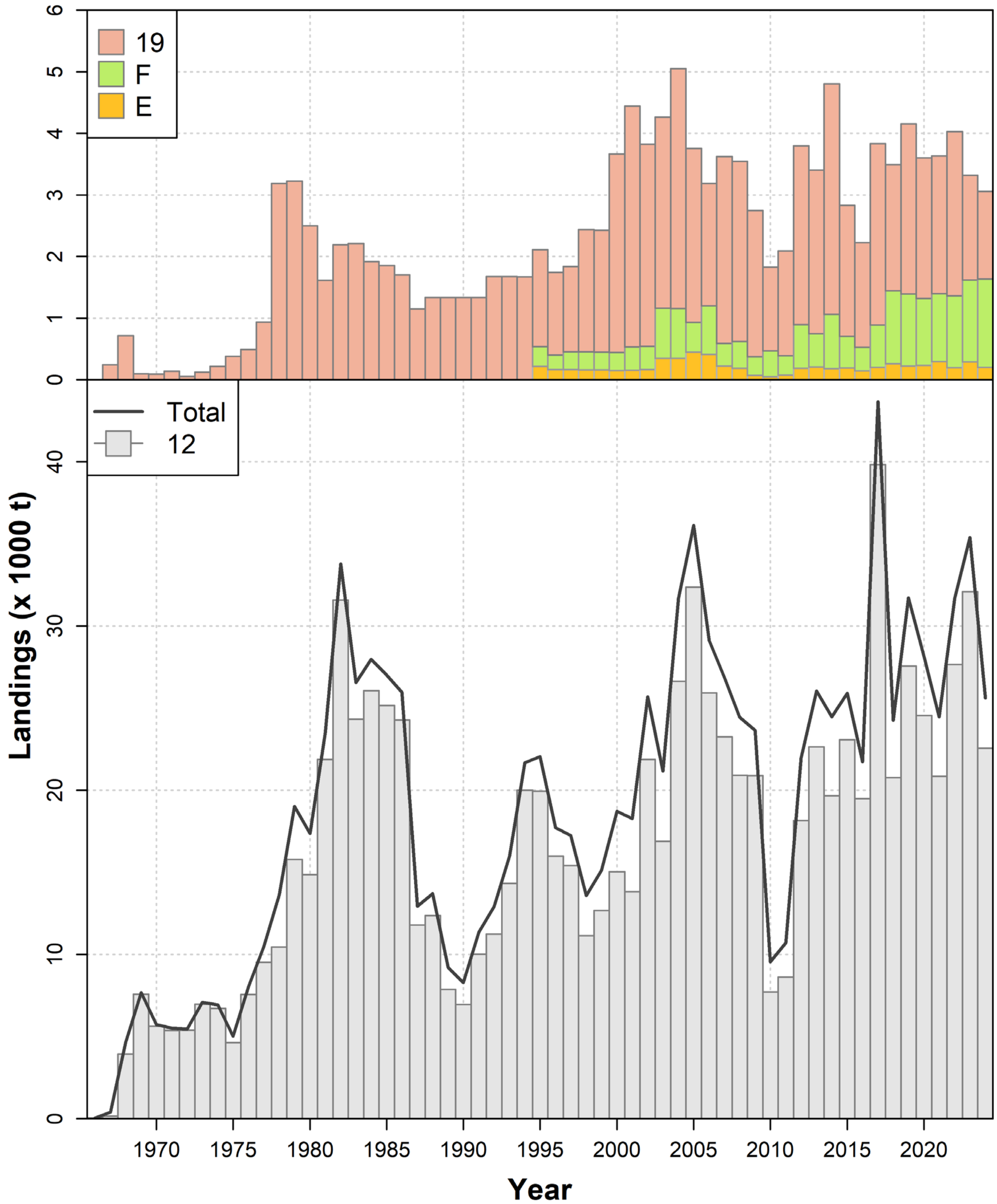

Figure 2. Annual landings (in tonnes) of southern Gulf of St. Lawrence in snow crab fishing areas 12E, 12F, 19 (top panel) and 12 (bottom panel). Solid black line (bottom panel) indicates total landings for the southern Gulf of St. Lawrence (CFAs 12, 12E, 12F and 19).

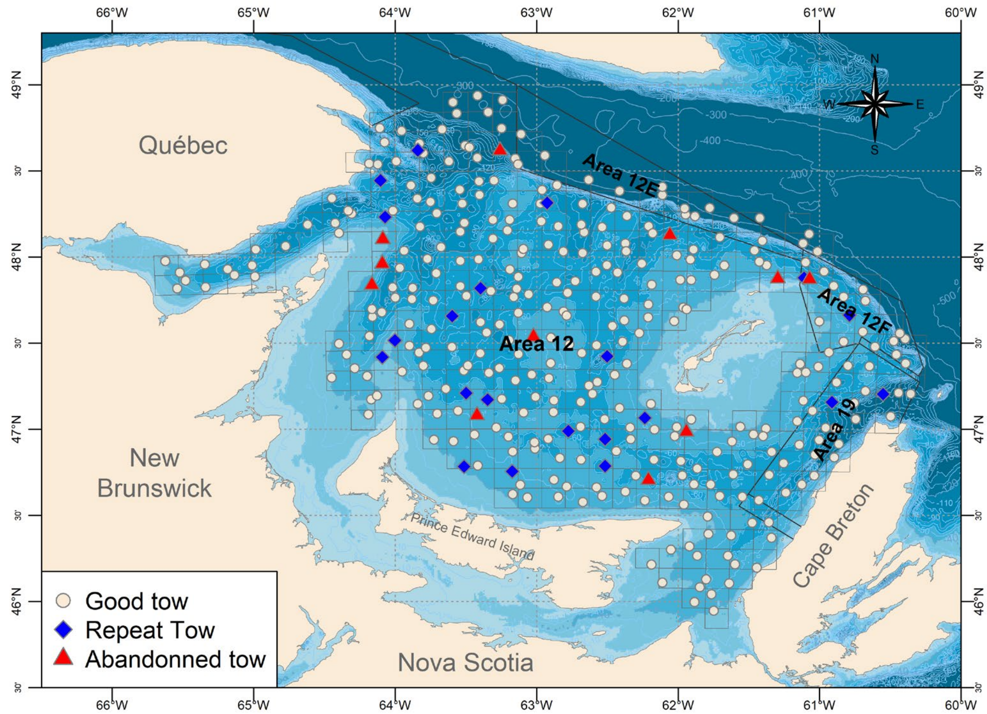

Figure 3. Locations of the 2024 snow crab trawl survey stations. Grey circles points are tows successfully trawled on the first try, blue diamonds show tows repeated and successfully trawl at the same station, and red triangles are abandoned tows. Survey sampling grids are shown in grey.

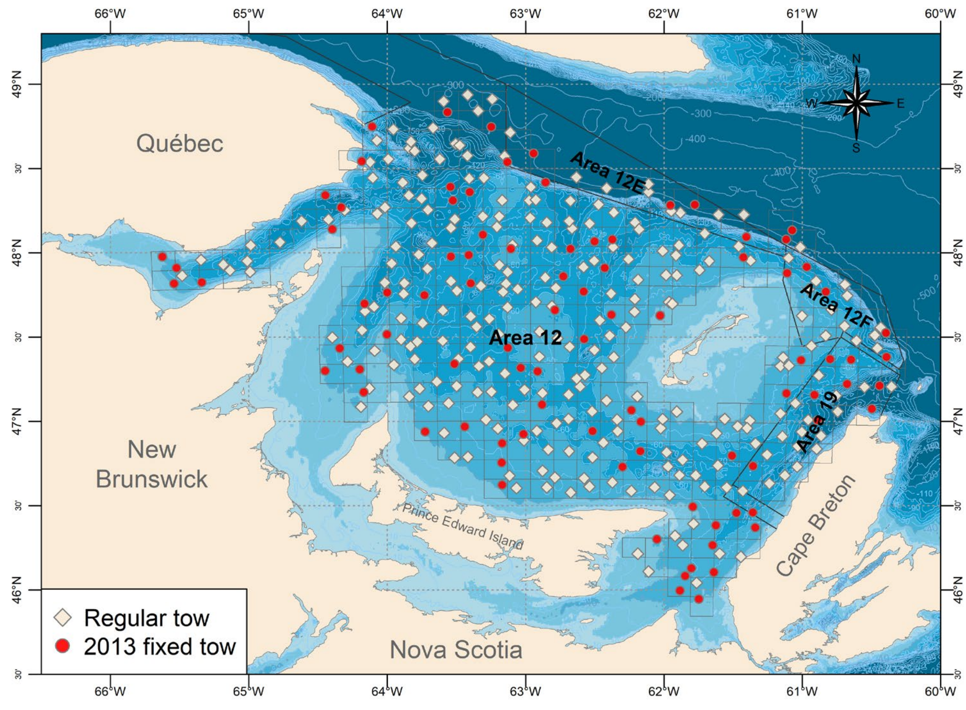

Figure 4. Map showing the 100 stations which were moved to their original 2013 positions (red circles) during the 2024 survey, along with the 255 remaining stations (grey diamonds). Survey sampling grids are shown in grey.

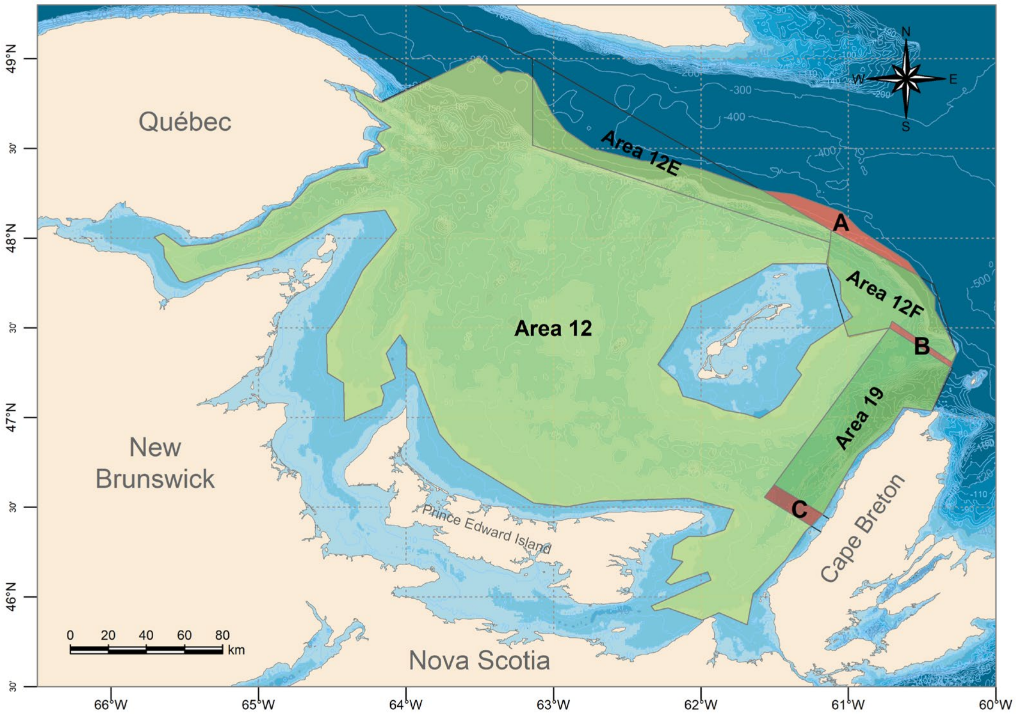

Figure 5. Polygons used for estimating survey stock indices. The unassigned zone north of crab fishing areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

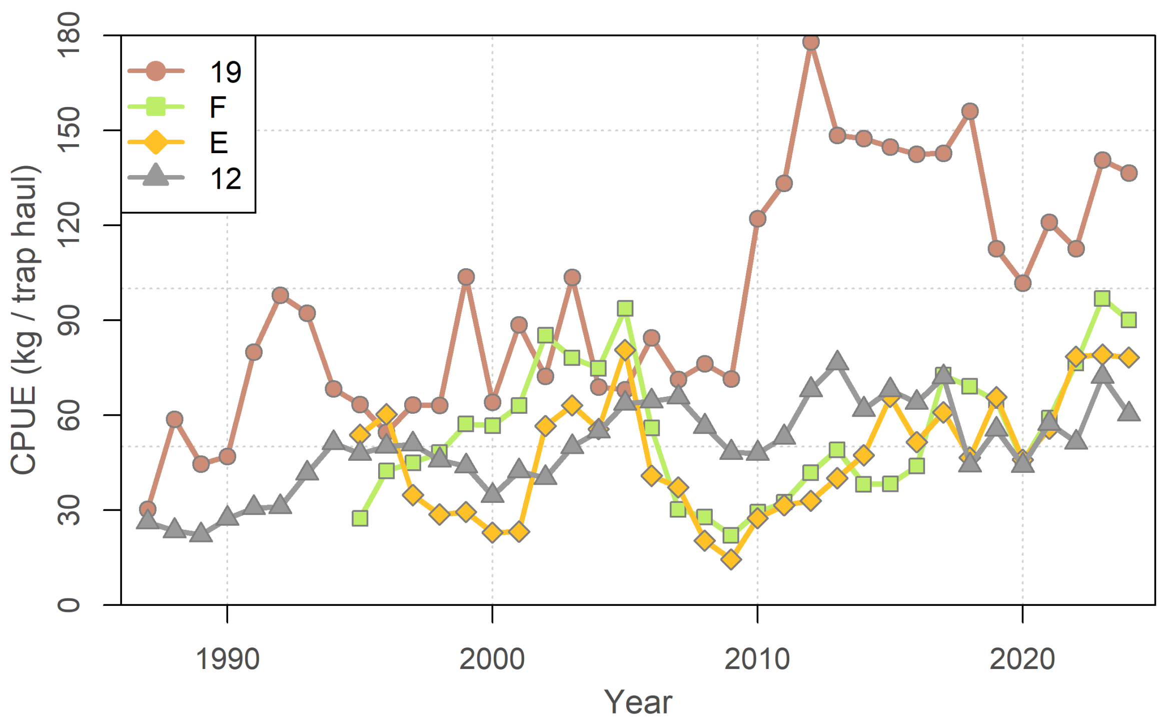

Figure 6. Seasonal average catch-per-unit-of-effort (CPUE; kg / trap haul) by crab fishing area in the southern Gulf of St. Lawrence, based on fishery logbook data.

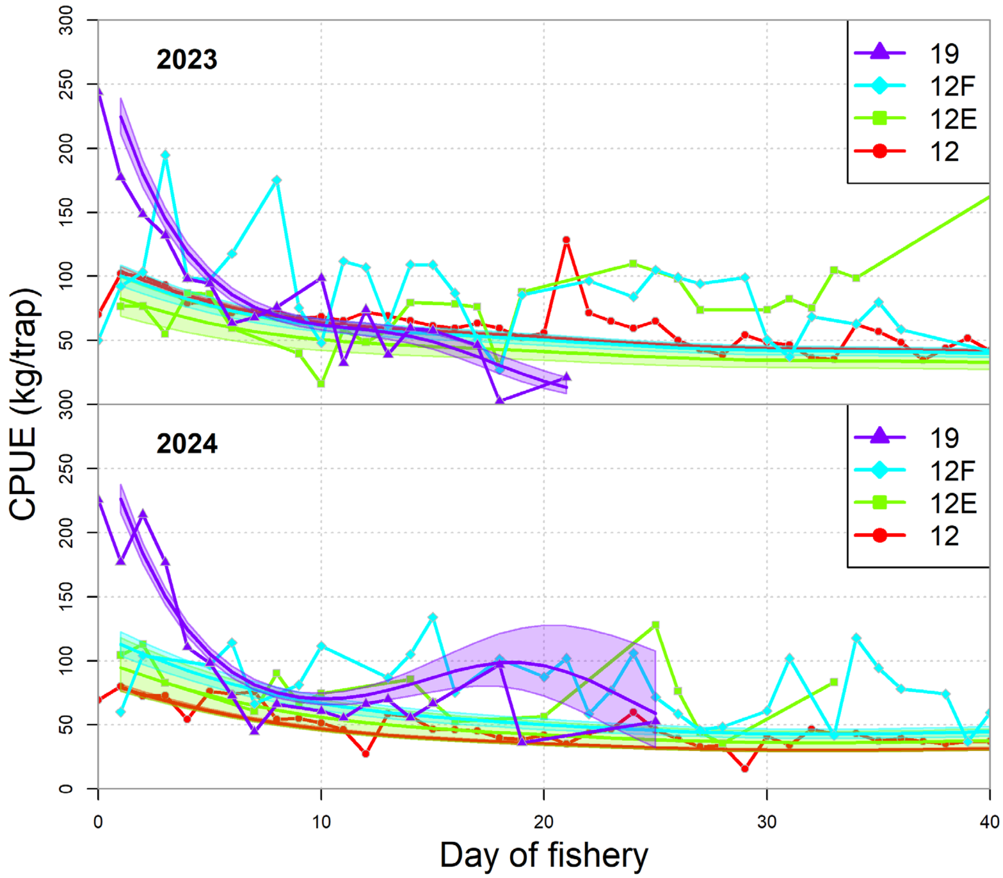

Figure 7. Catch-per-unit-of-effort versus fishing day for the 2023 and 2024 fishery, as estimated from the catch-per-unit-of-effort standardization model, evaluated for 36-hour soak time for an average fishing vessel in each crab fishing area. Shaded areas indicate 95% confidence intervals.

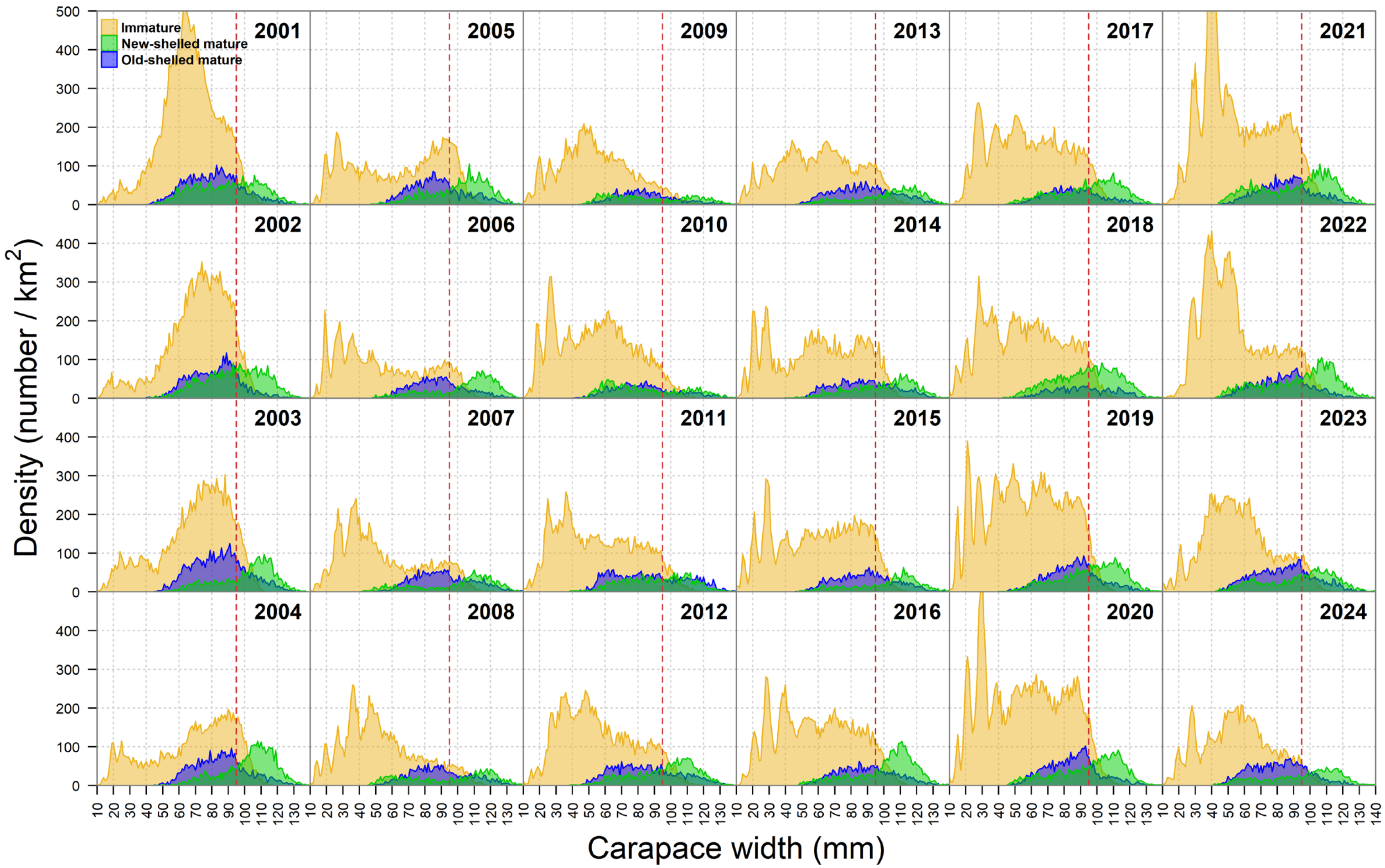

Figure 8. Annual size-frequency distributions of immature and adolescent (yellow), new-shelled mature (green) and old-shelled mature (blue) male snow crab from the trawl surveys. The red dotted line shows the minimum legal size of 95 mm carapace width. Note that abundances for small crab for 2020 and 2021 exceed the scale of the plot.

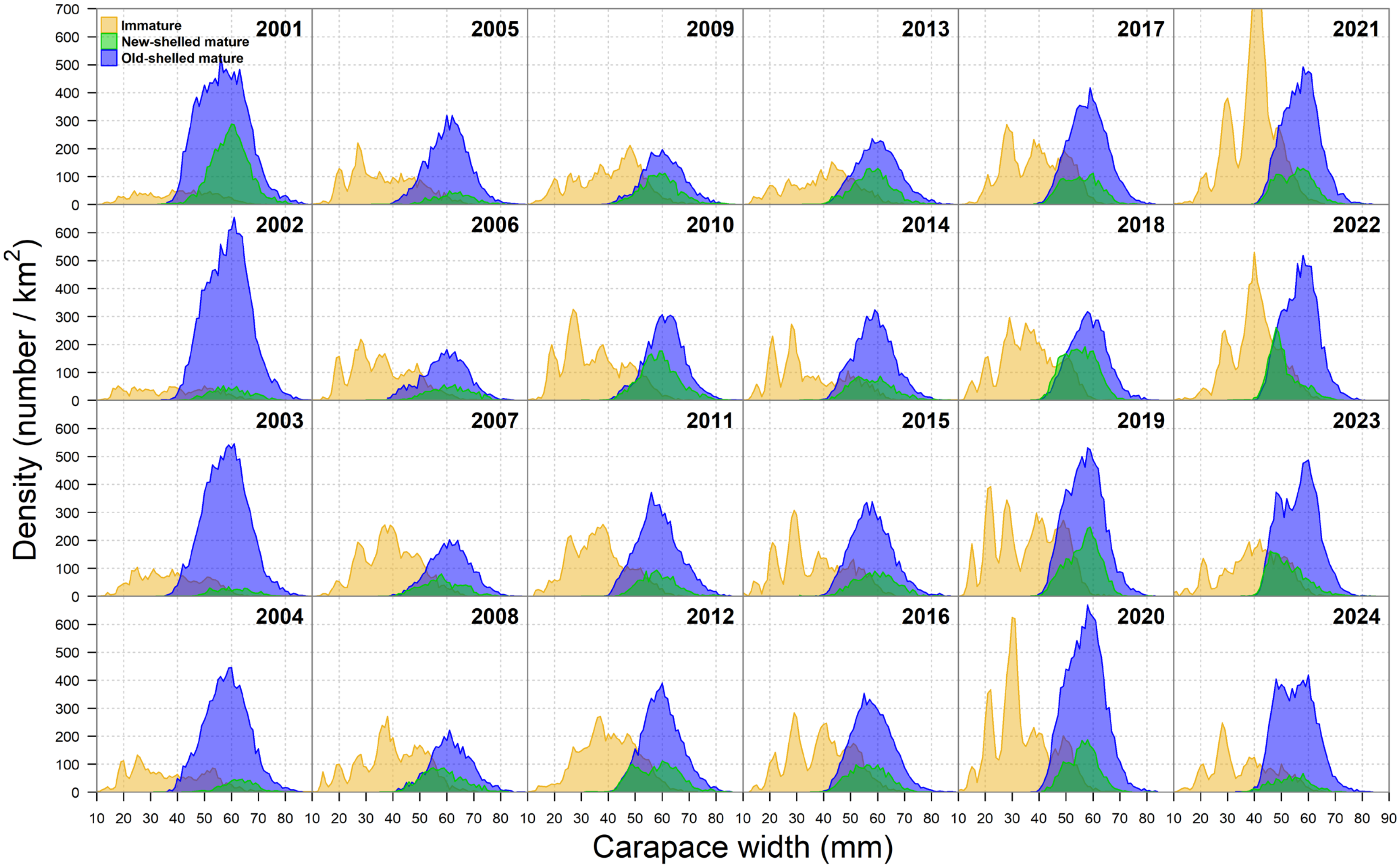

Figure 9. Annual size-frequency distributions of immature and pubescent (yellow), new-shelled matures (green) and old-shelled mature (blue) female snow crab from the trawl surveys. Note that abundances for small crab for 2021 exceed the scale of the plot.

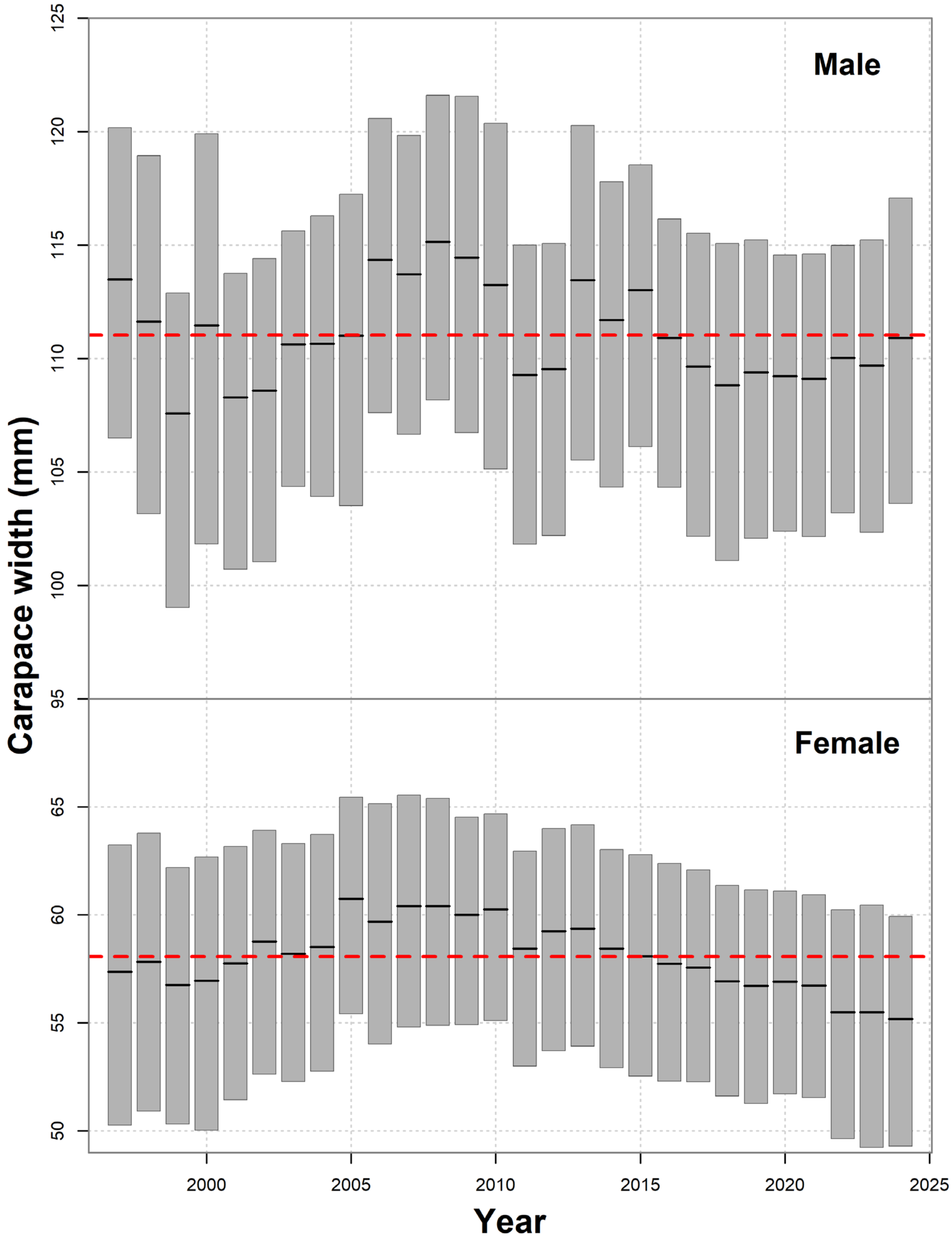

Figure 10. Size variation of mature legal-sized male (top panel) and mature female (bottom panel) snow crab observed in trawl survey data. Middle line shows the mean carapace width and grey bars show interquartile size range. The timeseries mean is shown as red dashed lines for reference.

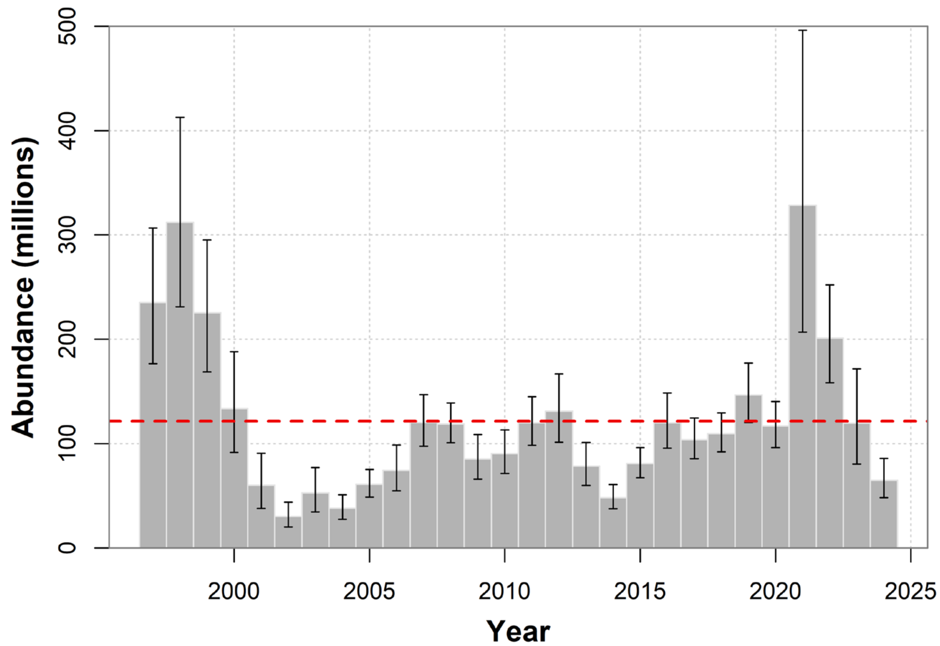

Figure 11. Annual abundance (in millions; means with 95% confidence intervals) of small male crabs of 34 to 44 mm carapace width (Instar VIII), based on the trawl survey data. The red dashed line shows the average for the series.

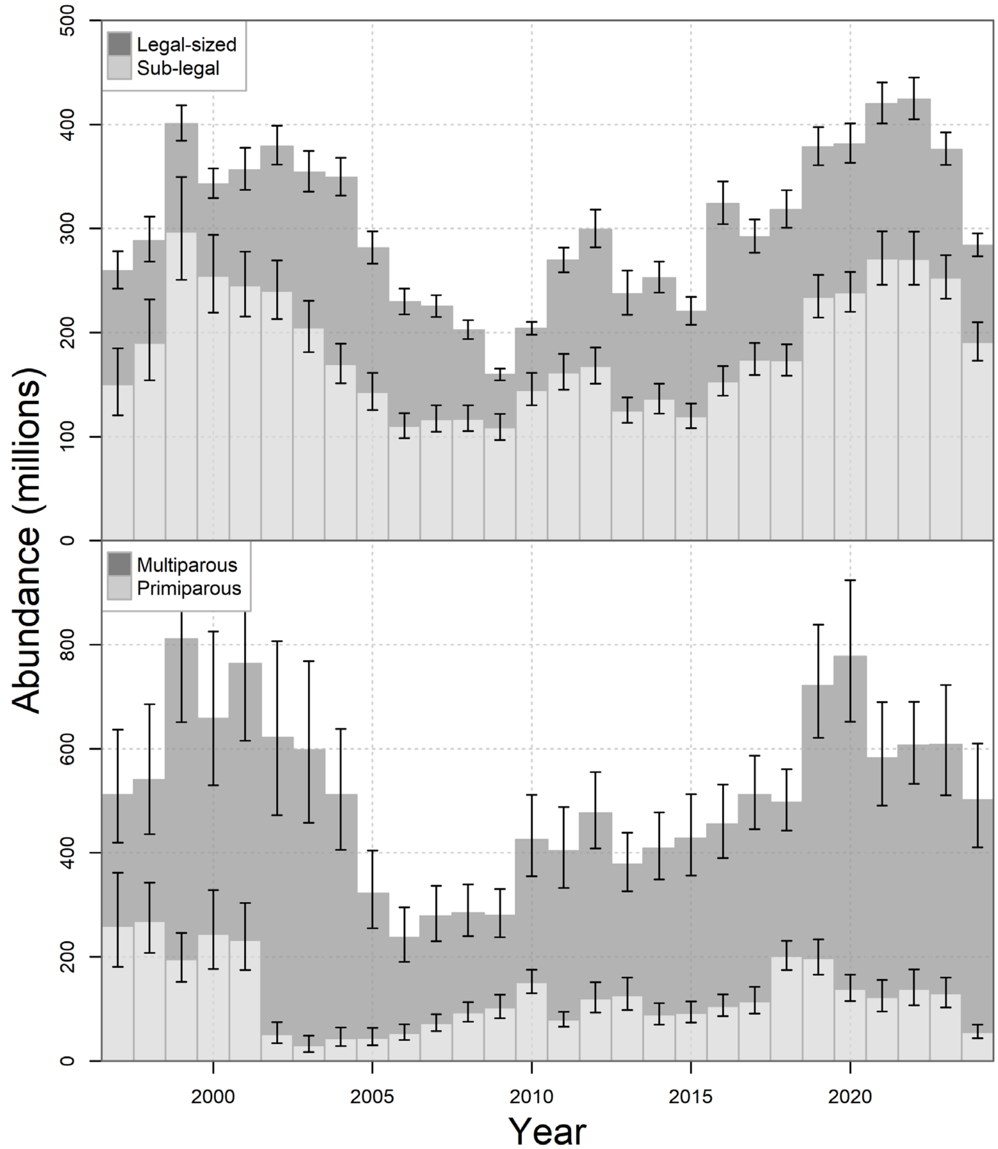

Figure 12. Survey abundance of legal and sub-legal male (top panel) and primiparous and multiparous female snow crab (bottom panel) in the southern Gulf of St. Lawrence. Error bars indicate 95% confidence intervals.

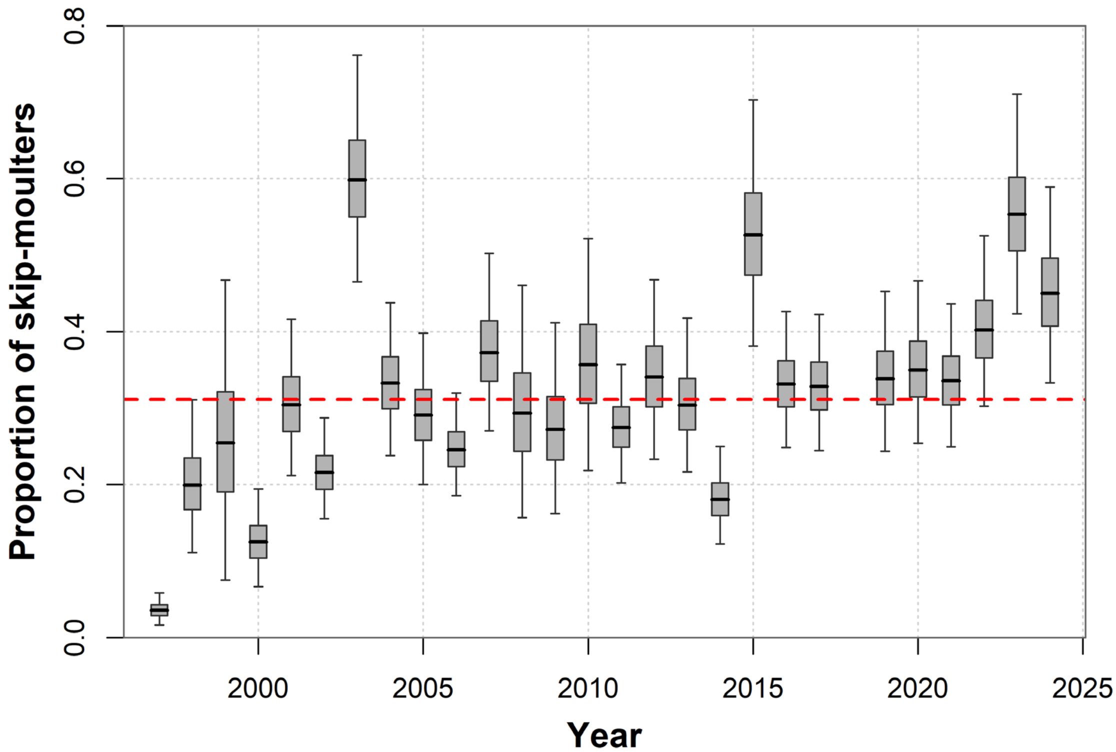

Figure 13. Proportions of R-2 skip moulter crab by survey year. The proportion for 2018 was not included as skip-moulter identification was deemed unreliable. The red dashed line shows the average value of 0.31.

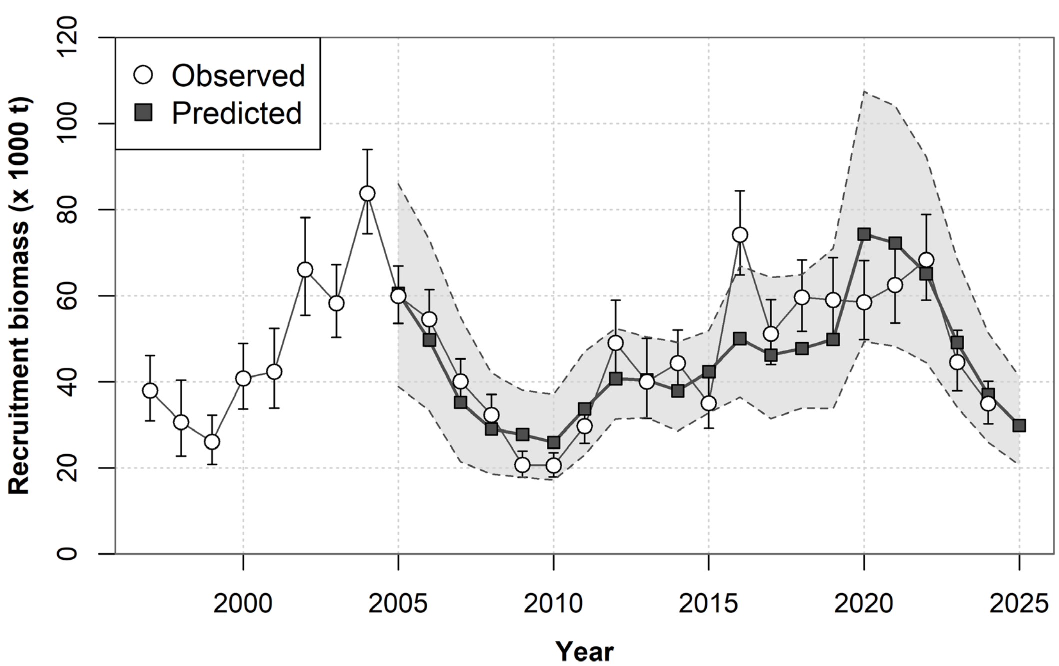

Figure 14. Observed (open circles and 95% confidence interval error bars) and predicted (black squares and shaded 95% confidence intervals) fishery recruitment biomasses of R-1 snow crab in the year of the survey.

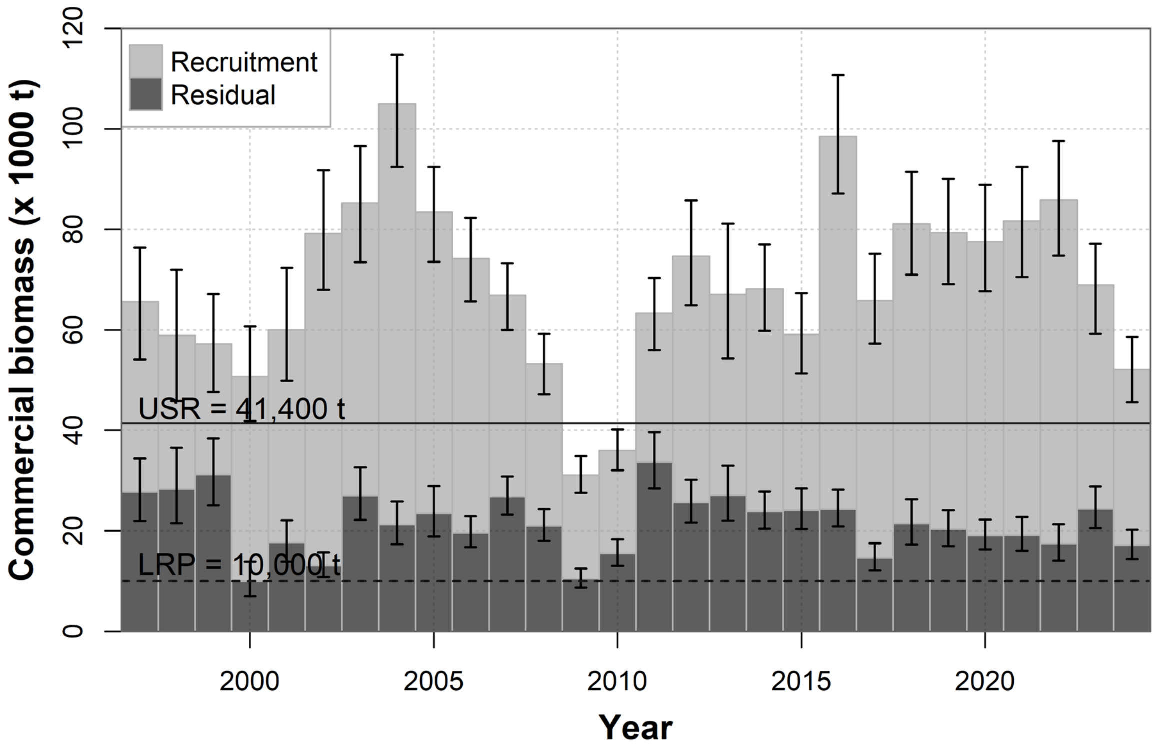

Figure 15. Stacked bar plot of commercial recruitment (light grey bars) and residual (dark grey bars) biomass, as estimated from trawl survey data. Error bars show 95% confidence intervals. Also shown are the corresponding limit reference point (LRP) for the residual biomass (dashed line) and upper stock reference (USR) (solid line).

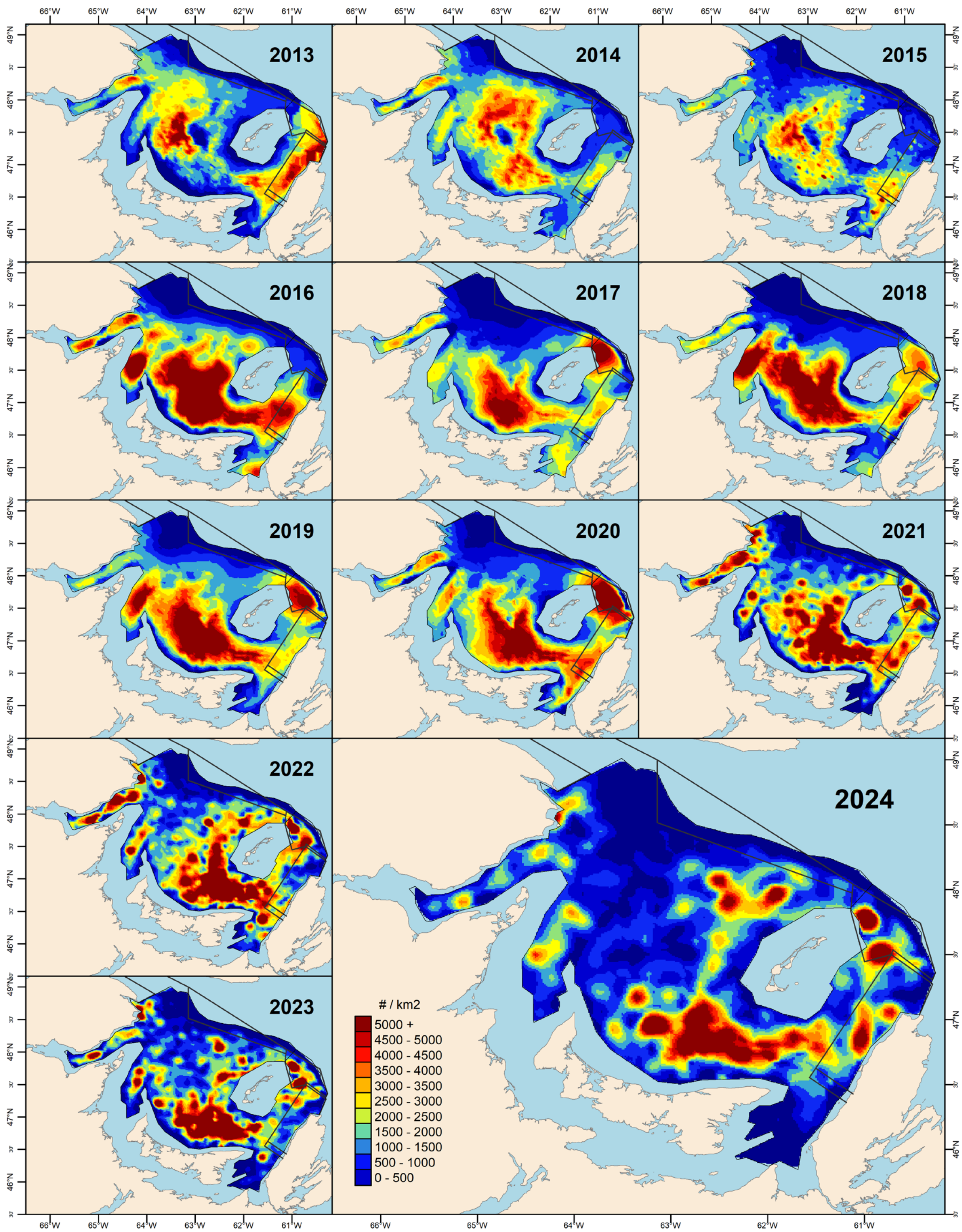

Figure 16. Density (number per km²) contours of commercial crab in the southern Gulf of St. Lawrence from 2013 to 2024, based on the snow crab trawl survey, interpolated using kriging.

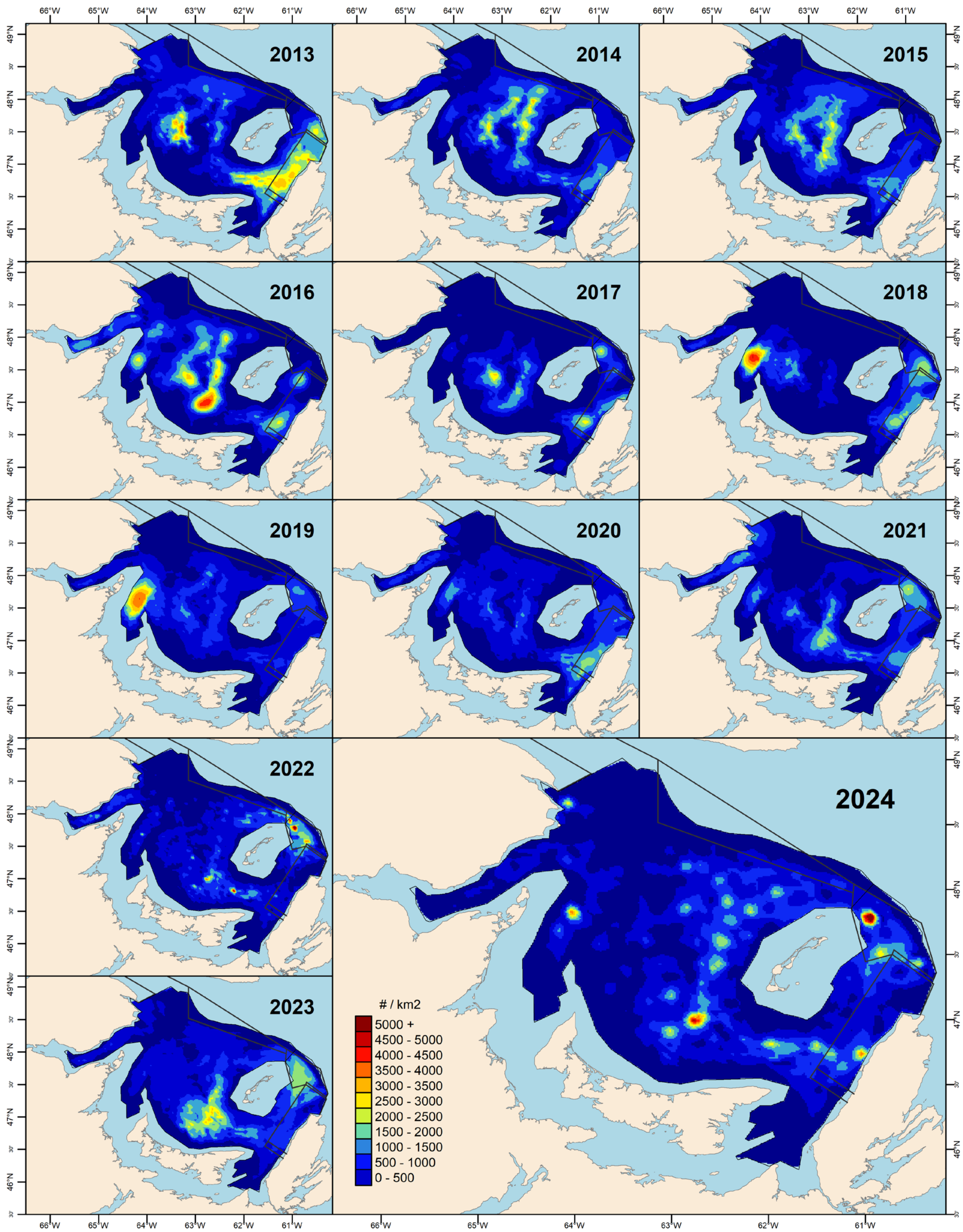

Figure 17. Spatial distribution of the residual component of commercial snow crab (carapace conditions 3,4, and 5) from 2013-2024 based on southern Gulf of St. Lawrence trawl survey data, interpolated using kriging.

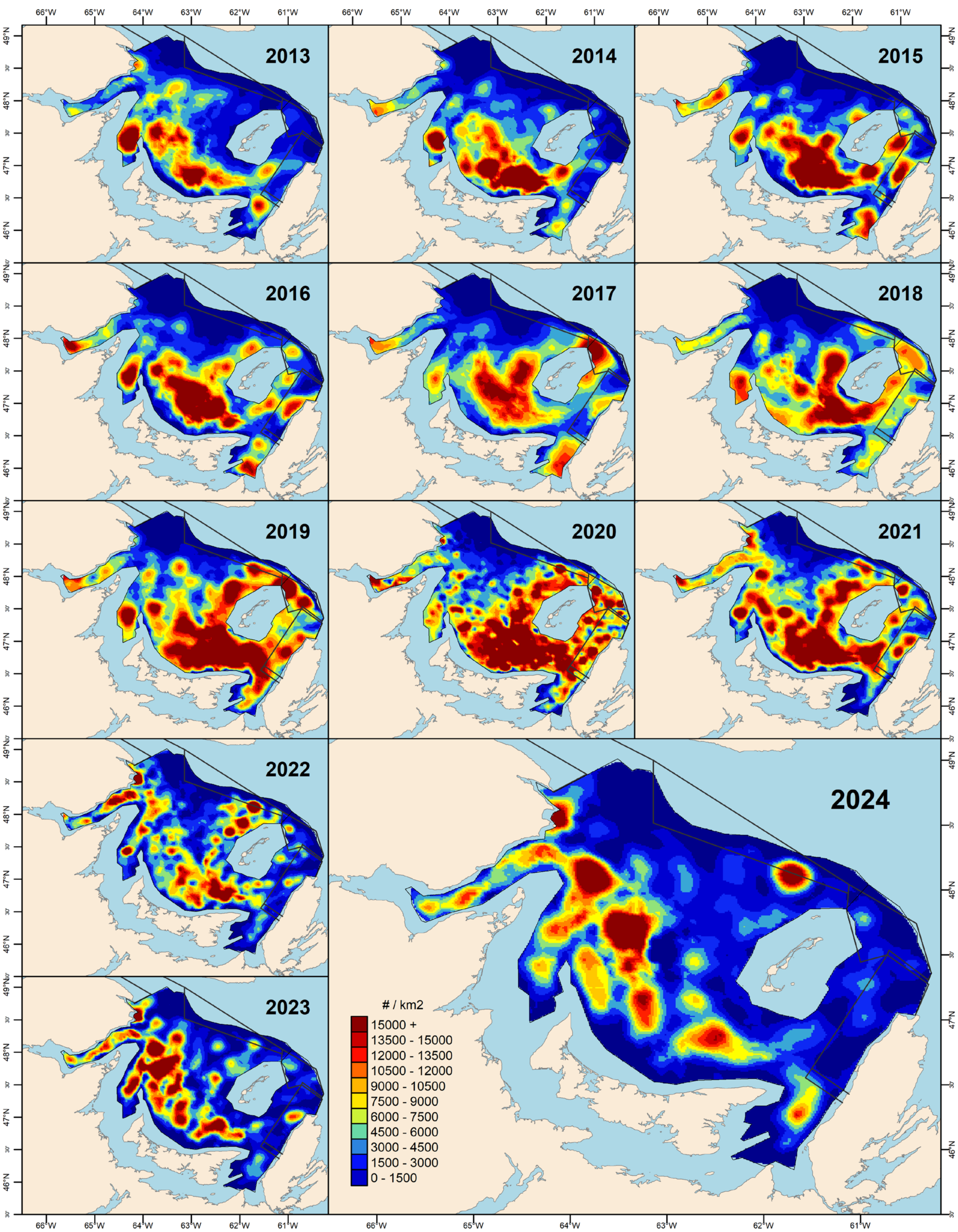

Figure 18. Adolescent male snow crab spatial distribution by year based on southern Gulf of St. Lawrence trawl survey data, interpolated using kriging. Adolescents are future recruits to the fishery (i.e., R-4, R-3 and R-2s).

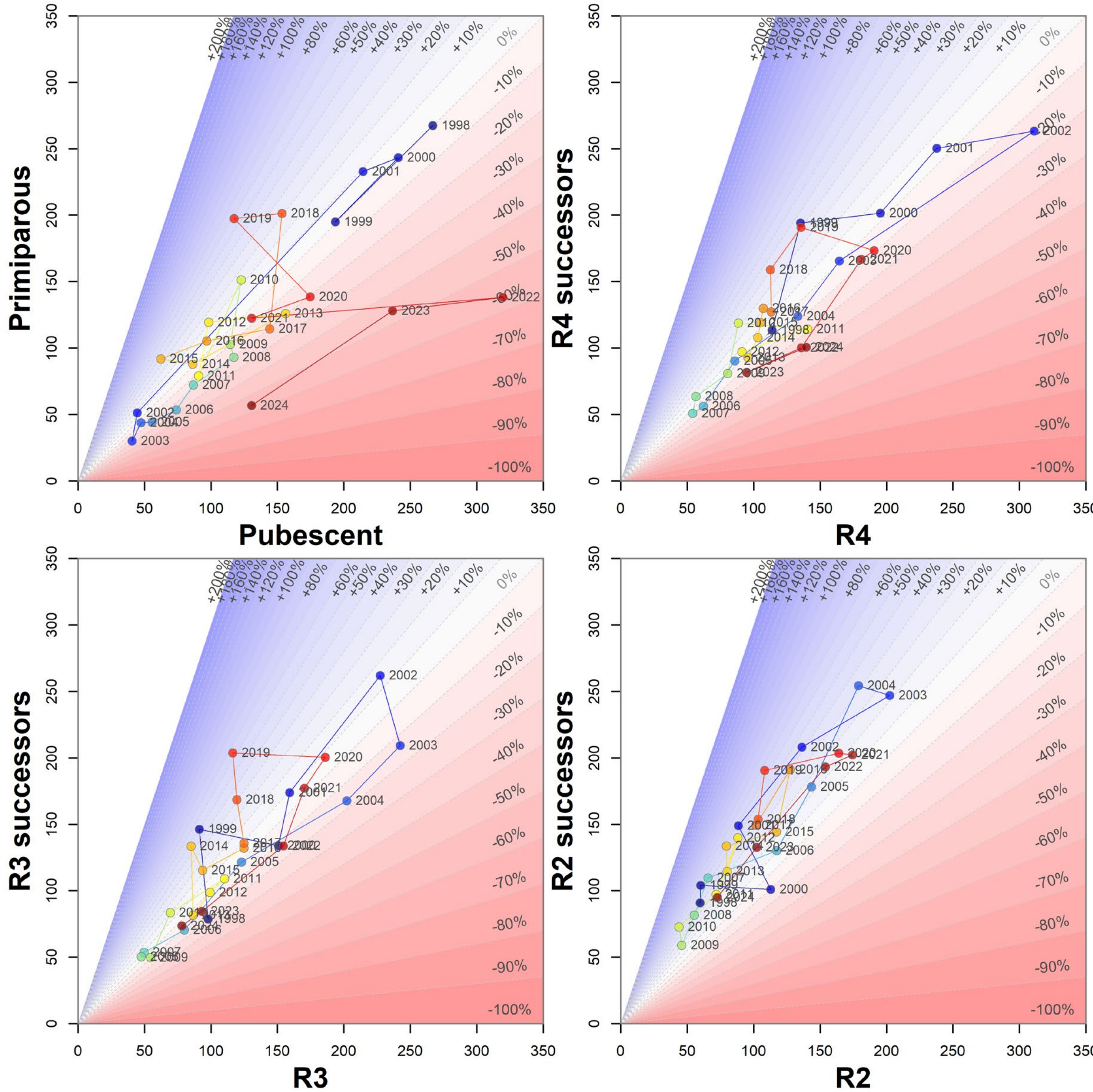

Figure 19. Scatterplot of the abundance of successors versus the abundance of their corresponding recruit/pre-recruit categories from the preceding year. Points are colored and labelled according to the survey year of successor category. The background shows the relative difference between the two, with blue indicating that successors exceed their recruits, white indicating that they are comparable, and red indicating that they are less than their recruits.

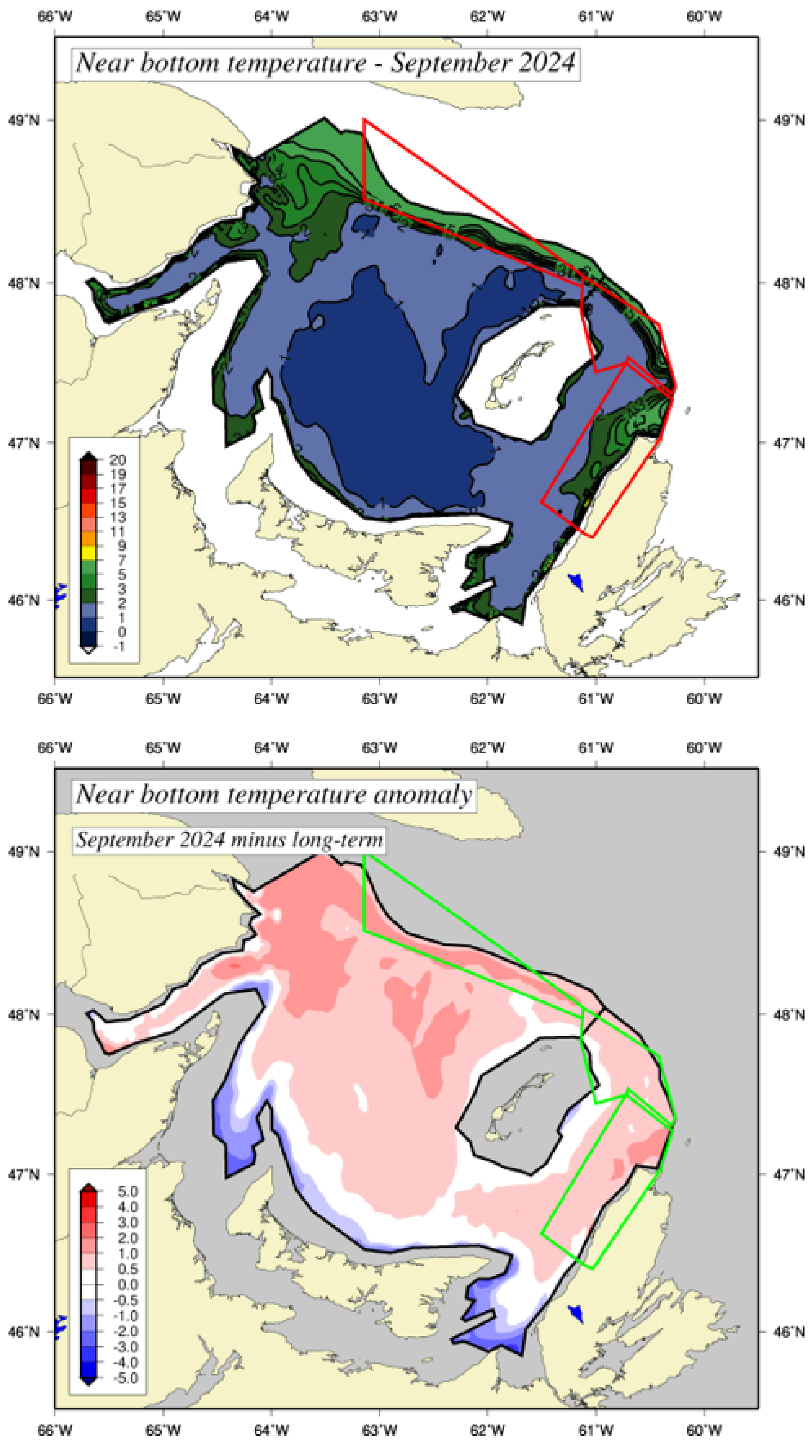

Figure 20. Map of bottom temperatures (top panel) and anomalies (bottom panel) for September 2024. Anomalies were calculated as the difference between September 2024 local bottom temperatures and their long-term means from the period from 1991 to 2020. Blue areas represent colder-than-normal temperatures while red regions represent warmer-than-normal conditions. White areas in bottom panel represent near average conditions.

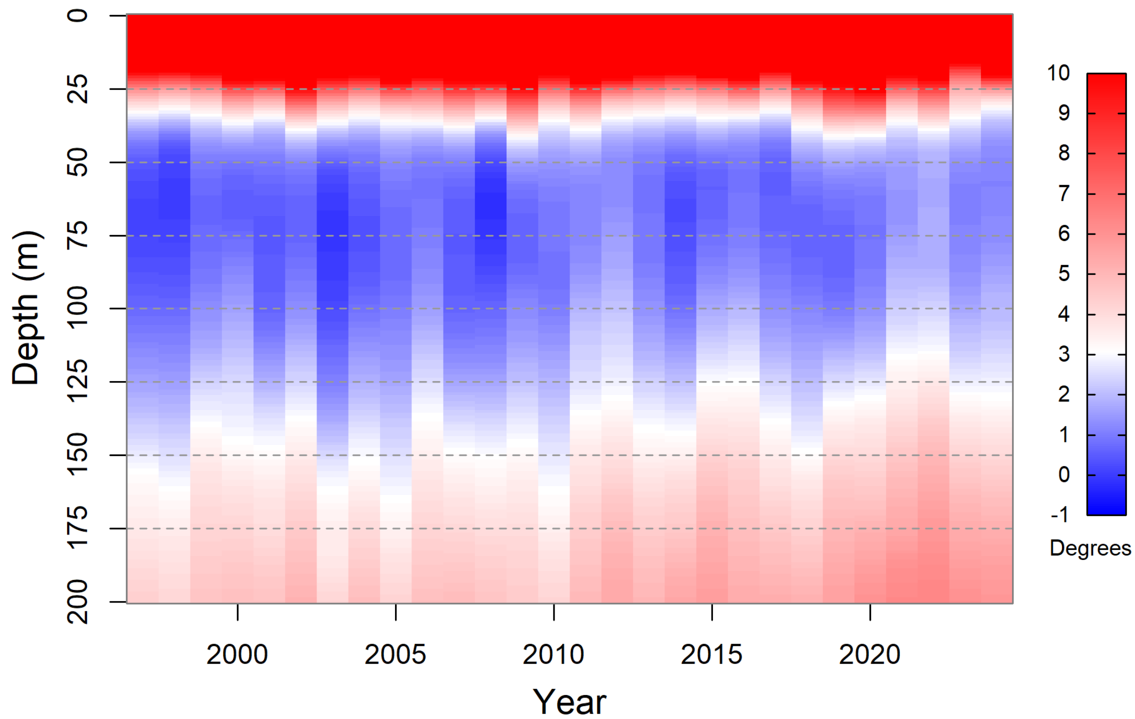

Figure 21. Average temperature stratification in September within the snow crab survey area by year. Blue areas are colder than 3 °C (the Cold Intermediary Layer), white areas are approximately 3 °C, and red areas are warmer than 3 °C. The top red layer corresponds to warm surface waters, while the bottom red layer corresponds to the deep, warm water mass of the Laurentian Channel.

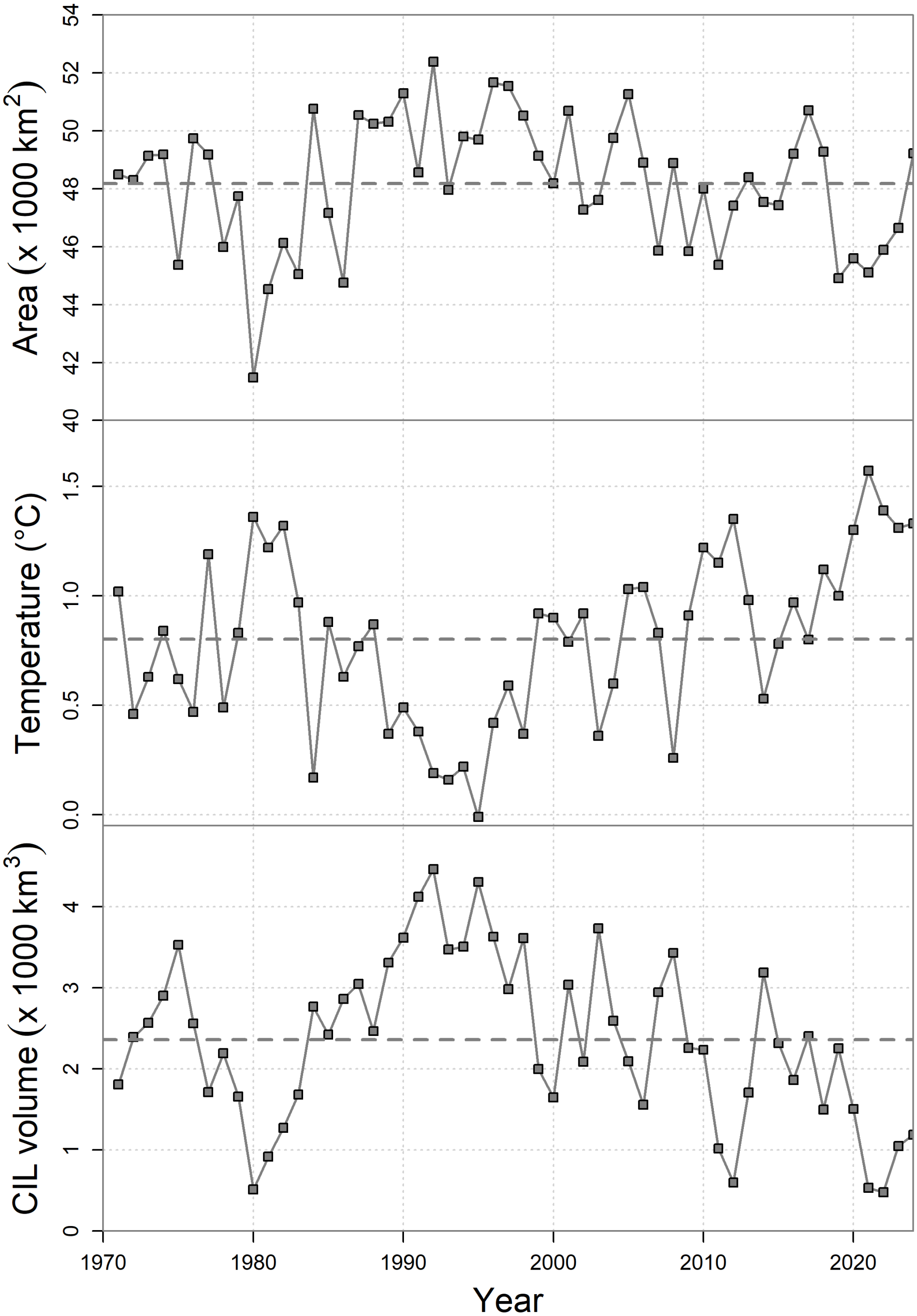

Figure 22. Surface area of the southern Gulf of St. Lawrence with bottom temperatures below 3 °C, an index of snow crab habitat (top panel), mean bottom temperature (middle panel) and cold intermediate layer (CIL) volume (bottom panel) within the area.

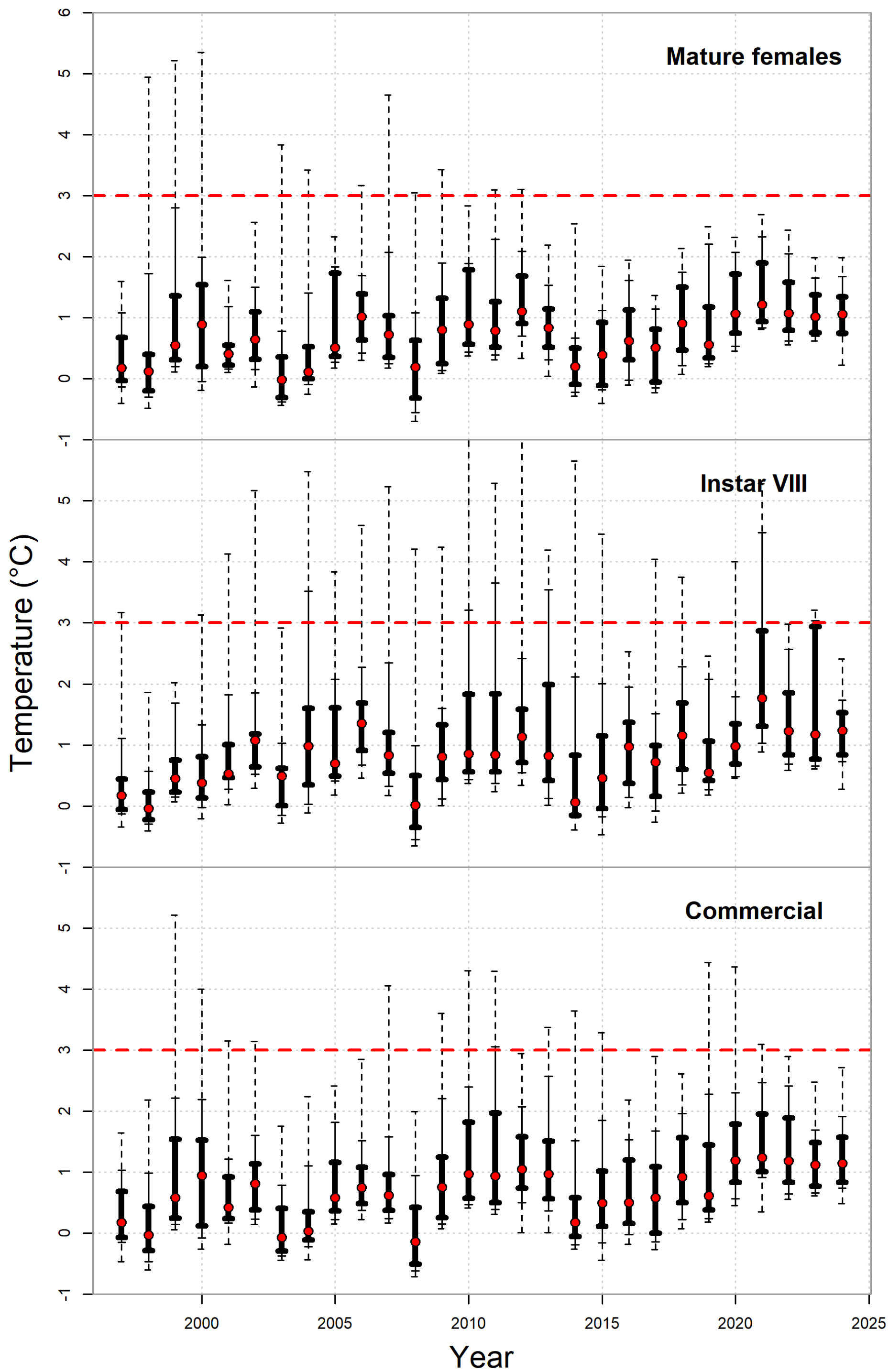

Figure 23. Annual temperature distribution in September for mature female (top panel), instar VIII (middle panel) and commercial (bottom panel) snow crab from the trawl survey. Red dots show the median, the thick black bars show the interquartile range, the thin solid black lines show the range between the 10% and 90% percentiles and the dashed lines show the 2.5% and 97.5% percentiles.

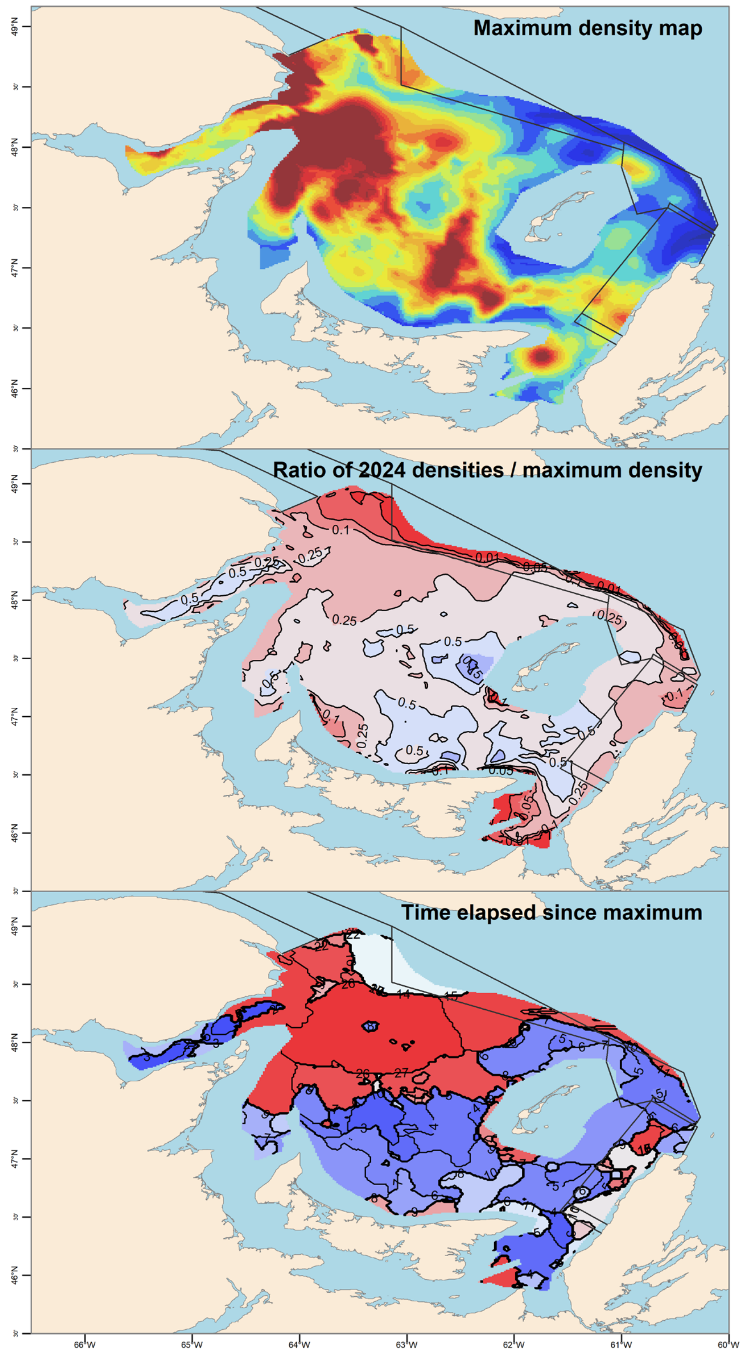

Figure 24. Spatial distribution changes in the southern gulf of St. Lawrence for total crab from the survey. Top panel shows a map of the maximum crab densities from kriging from 1997 to 2024. The middle panel shows the ratio between the kriged densities from the 2024 survey and the maximum densities over the 1997 to 2024 period. Red-shades correspond to areas with densities less than half of the series maximum. Similarly, blue areas correspond to areas with densities above half of the series maximum. The bottom panel shows a map of the time elapsed since maximum densities occurred. Red areas indicate areas where the maximum was reached before 2010, while blue areas indicate areas where the maxima were more recent. White areas indicate maxima occurring near 2010-2011.

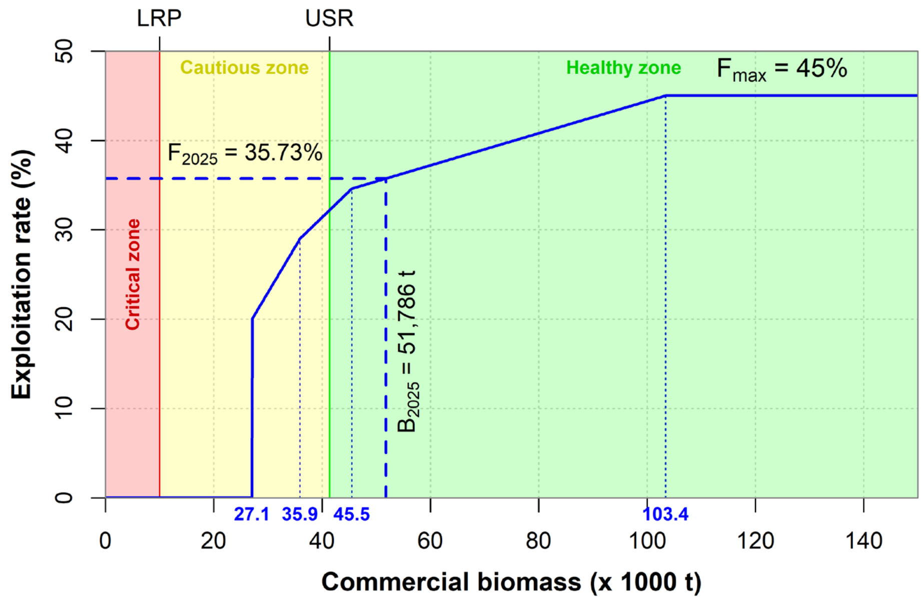

Figure 25. Harvest decision rule used for the southern Gulf of St. Lawrence snow crab fishery (DFO 2014), expressed as exploitation rate versus commercial biomass (solid blue line). The red line shows the limit reference point (LRP) for residual biomass and the green line shows the upper stock reference (USR) point for commercial biomass. F_{max} represents the maximum exploitation rate harvest decision rule. The blue dashed line shows the projected biomass estimate for 2025 along with the corresponding target exploitation rate.

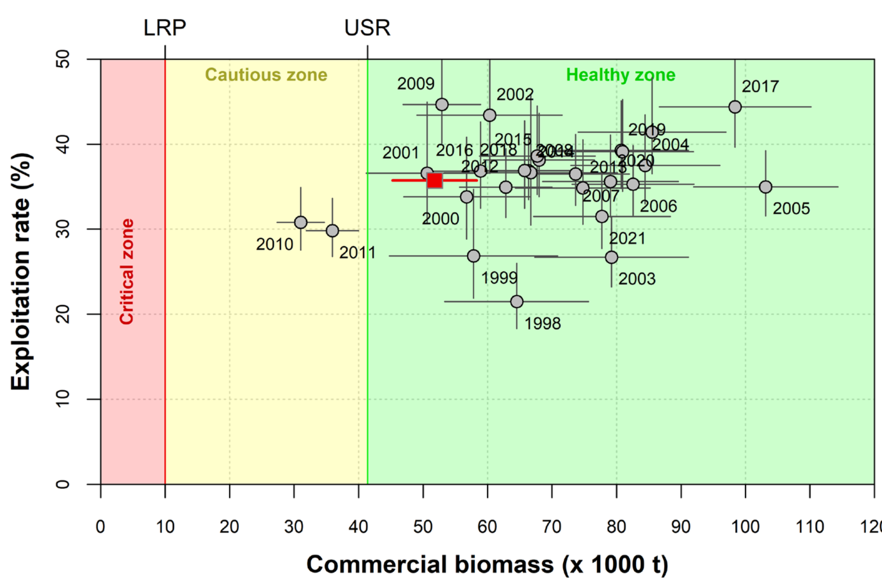

Figure 26. Exploitation rate versus the commercial biomass, with 95% confidence intervals. Year labels represent the fishery year. Coloured lines represent reference points: LRP (red line) is the limit reference point for residual commercial biomass and USR (green line) is the upper stock reference point for commercial biomass. The red square corresponds to the commercial biomass estimate with the target exploitation rate of 35.73% for the 2025 fishery.

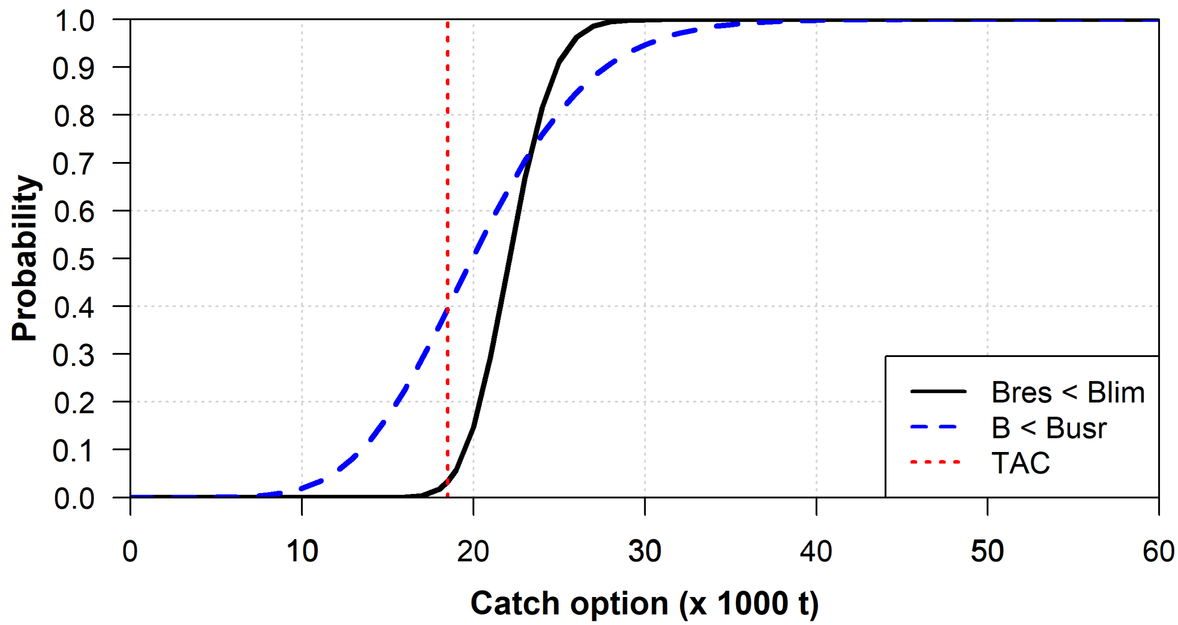

Figure 27. Risk analyses showing the probability that the residual commercial biomass falls below limit reference point (black solid line) or that the total commercial biomass falls below the upper stock reference (blue dashed line) point after the 2025 fishing season. The catch option for the 2025 fishery, 18,503 t, corresponding to the target exploitation rate of 35.73%, is shown by the dashed red line.