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Southern Gulf of St. Lawrence (CFAs 12, 12E, 12F and 19) Snow Crab (*Chionoecetes opilio*) Stock Assessment in 2023

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Canada

Foreword

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

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ABSTRACT

Stock status of southern Gulf of Saint Lawrence (sGSL) snow crab (*Chionoecetes opilio*) in 2023 is in the healthy zone of the Precautionary Approach (PA). A commercial biomass of 67,703 tonnes (t) is projected for 2024. Fishery recruitment biomass is estimated at 44,484 t, while the residual biomass was estimated at 24,393 t. Based on the harvest decision rule the commercial biomass estimate corresponds to a target exploitation rate of 38.59% and a catch option of 26,126 t for the 2024 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 very high likelihood that the 2024 commercial stock biomass will remain above the upper stock reference point. Female spawning stock abundance remains at high levels. Population recruitment has declined to average levels. Warming bottom temperatures remain a cause for concern, with crab densities in areas along the margins of the sGSL showing marked declines in recent years.

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 Saint Lawrence.

The southern Gulf of Saint 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 and 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 and only large, hard-shelled males with a minimum size of 95 mm CW are commercially exploited.

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 late April to early May and lasts until mid-July or when the area quota is caught. In CFA 19, the fishing season starts in July 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

Stock trends have been positive in recent years, with high levels of recruitment and reproductive stock. Commercial biomass remained at high levels of around 80,000 t for the past five years. While the crab stock remains healthy in 2023, it is undergoing an apparent decline in fishery recruitment.

This research document contains advice to support the implementation of two main 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. These objectives are achieved through survey-based estimation of commercial biomass and then evaluating risks associated with various catch options based on this estimate.

2. SURVEY METHODS

Stock status of snow crab is mainly assessed through trends in abundance and biomass indices calculated using data from a dedicated 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. 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 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. TRAWLING AND SAMPLING PROTOCOLS

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.

Survey catches were sorted by species or of taxonomic groups 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.

2.3. 2023 SURVEY

The Avalon Voyager II, a 65-foot stern-trawling (850 HP) fiberglass boat performed the survey from July 10th and September 4th, 2023. A total of 346 sampling stations (Figure 3) were successfully trawled out of a target number of 355, with a total of 396 trawling attempts. A maximum of two to three trawling attempts were performed at each sampling station. Nine 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 2023 was slightly faster than in previous years, at 2.25 knots, compared to 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 7.7 meters.

In 2023, more issues occurred with the eSonar trawl acoustic monitoring system, used to measure the width of the trawl compared to 2022. This led to a reduction of 20% in the number of wing spread measurements from the eSonar acoustic trawl in 2023 versus 2022. This resulted in a much higher number data-based estimates of swept area: 25% of tow swept areas were estimated using the ten nearest neighbouring tows with available data, compared to 13% in 2022. Nonetheless, 261 tows had sufficient wing spread data to calculate trawl swept area, while swept areas for the remaining 85 tows were calculated as described above. The tow duration was a median of 302 seconds (s) in 2023, compared to 298 s in 2022 and 309 s in 2021. Trawl swept areas slightly increased to an average 2,782 m^2 in 2023, compared to 2,614 m^2 in 2022 and 2,670 m^2 in 2021.

Following a change in end-of-trawling protocol in 2021, the duration of the passive trawling phase 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, and 8 s in 2023 (Surette and Chassé 2022).

3. METHODS

3.1. 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 soft-shelled or white 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 previous fishing season, identified as hard-shelled crab (carapace conditions 3, 4 and 5). Skip moulting crab were identified as immatures with a hard 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. Note that the R-2 crab abundances reported in the 2020, 2021 and 2022 assessments were based on a different definition (adolescent crab 83+ mm CW), which led to discrepancies between the predicted and observed R-1 biomasses. R-2 abundances were corrected and predicted R-1 abundances were updated in this report.

Female snow crab were separated into primiparous (defined in this report as mature and new-shelled) and multiparous (mature and old-shelled) categories.

3.2. 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 using only the last seven years of data. 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 2023. 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:

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

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*, $s_f(d_{ij})$ is a smoothing spline over fishing day d_{ij} for fishing fleet *f*, $s_f(t_{ij})$ 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.

3.3. 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.

3.4. 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.

3.5. 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).

3.6. SURVIVAL AND EXPLOITATION RATES FOR COMMERCIAL CRAB

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.

3.7. RISK ANALYSIS AND CATCH OPTIONS

The risk analysis calculated the probabilities of two events following the 2024 fishery: that the residual biomass would be below the Limit Reference Point (LRP) of 10,000 t, and/or that the total commercial biomass from the 2024 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 2024, using a Bayesian model (Surette and Wade 2006; Wade et al. 2014). A range of catch options were considered, including the one prescribed by the Harvest Decision Rule for sGSL snow crab (DFO 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.

3.8. SNOW CRAB HABITAT INDICES

Snow crab habitat was defined as the area 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 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.

4. RESULTS

4.1. 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 increased by 40.5% to 72.2 kilograms per trap haul (kg/th) in 2023, above the long-term mean of 54.9 kg/th (average from 1998 to 2022). CFA 12E remained unchanged at 79.1 kg/th while CFA 12F had a 26.8% increase to 96.9 kg/th. In CFA 19, the seasonal average CPUE increased by 24.9% to 140.6 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 2023 (Table 1). There were strong divergences between the two values for CFAs 12E, 12F and especially CFA 19. For CFA 19, the seasonal CPUEs was 140.6 kg/th while the standardized value was only 73.3 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 driven in part by many harvesters reaching their quotas as early as the fifth day of the fishery.

4.2. STOCK COMPOSITION

4.2.1. Survey size distribution

Crab size distributions were standardized by trawl swept area for each tow, then averaged across all tows from the survey and the resulting densities scaled to the survey area. 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.

Size distributions among sub-legal immature males show an overall decrease in 2023 as was the case for the past three years. This decrease can be seen among fishery pre-recruits with R-2 crab decreasing by 29% and R-3 crab decreasing by 16% (Table 2). In contrast, R-4 crab increased markedly by 47% due to the growth of a strong recruitment pulse which was observed among instar VIII crab in 2021 (Figure 8).

Despite the vessel change in 2019 and the decreases in R-2 over the past three years, R-1 crab (representing recruitment to the fishery) remained relatively constant from 2018 to 2022 (Table 2). However, R-1 crab abundance decreased from 120 million in 2022 to 78 million in 2023.

Skip moulting proportions among R-2 crab were exceptionally high in 2003 (56%), 2015 (52%) and in 2023 (56%) while typical rates are 30% (Figure 10). The skip moulting events in 2003 and 2015 generated significant increases in fishery recruitment in the 2004 and 2016 surveys. While the high skip moulting proportion in 2023 will likely contribute to a stronger than usual fishery recruitment rate, the abundance of R-2 crab in 2023 is substantially lower (73 million) than the corresponding values in 2003 (179 million) and 2015 (128 million) (Table 2).

Size frequency distributions among female snow crab (Figure 9) show that the high abundances seen among instar VII crab (~28 mm CW) 2020 and instar VIII crab (~38 mm CW) in 2021 only yielded limited amounts of new shell mature females in 2022 and 2023. However, levels of mature females remain consistent.

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 remained at this level (Figure 11), and stands currently at 109.7 mm in 2023.

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, 56.9 mm in 2020, 56.7 mm in 2021, and 55.5 mm in 2022 and 2023, the lowest in the series (Figure 11). 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 and increasing slightly to 10.6 mm in 2022 and 11.2 mm in 2023.

4.2.2. Commercial biomass

Commercial biomass for the sGSL is estimated at 67,703 t, with a 95% confidence interval of (59,174 – 77,109) (Table 3, Figure 12). Commercial biomass estimates were relatively stable (within 8,000 t range) from 2018 to 2022, with 77,748 t in 2020 being the lowest and the 2022 estimate (85,532 t) being the highest. The spherical variogram model used for interpolating the commercial biomass had a nugget value of 0, a sill at 2.9×10^6 and a range of 12.5 km.

Fishery recruitment in 2023 decreased by 34.5% to 44,484 t (37,816 t to 51,983 t) from 68,348 t in 2022, representing 65% of the commercial biomass (Table 3, Figure 12). Residual biomass (i.e. commercial crab with carapace conditions 3, 4 and 5) increased by 40.3% and was estimated at 24,393 t (20,500 t to 28,807 t) from 17,388 t in 2022 (Table 3, Figure 12). Residual biomass was dominated by carapace condition 3, representing 77% of survey catches, with 22% made up of carapace condition 4 crab and 1% 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 fishing pressure. The increase in residual biomass after the 2023 fishery, which contrasts to the decrease in recruitment, may be explained by an increase in annual survival, shell condition misclassification or commercial biomass underestimation.

A breakdown of the commercial biomass by CFA and buffer zone is shown in Table 4. The 2023 trawl survey estimate of commercial biomass for CFA 12 was 58,385 t (50,988 – 66,546 t) representing 86.8% of the total estimated biomass located within the four fishing areas. In CFA 12E, the commercial biomass from the 2023 trawl survey was estimated at 509 t (42 – 2,210 t), representing 0.8% of the biomass located within the four CFAs. In CFA 12F, the commercial biomass from the 2023 trawl survey was estimated at 4,675 t (3,549 – 6,046 t), representing 6.9% of the total estimated biomass located within the four fishing areas. The 2023 post-fishery trawl survey estimate of the commercial biomass for CFA 19 was 3,702 t (2,353 – 5,551 t), representing 5.5% of the total estimated biomass located within the four CFAs. An estimated 505 t of commercial crab lie within the unassigned zone above CFA 12E/12F and the two buffer zones (Figure 5).

4.2.3. Spatial distribution of commercial crab

The spatial distribution of commercial crab in 2023 was similar to that from 2021 and 2022, with crab concentrations south of Bradelle Bank, to the south of the Magdalen Islands, CFA 12F and Shediac Valley (Figure 13). Densities in the Baie des Chaleurs have decreased relative to 2022. Densities in CFA 19 have remained low which were similar to 2022 with the exception moderate concentrations in the northwestern part (Figure 13).

The spatial distribution of the residual portion of commercial crab is shown in Figure 14. The residual stock is most abundant in CFA 12F and between the Magdalen Islands and PEI. The density of residual crab is low in CFA 19, the Baie des Chaleurs, Shediac Valley and the Bradelle Bank.

4.2.4. 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 15). 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, then slightly decreasing to 376 million in 2023. From 2018 to 2022, the quantity of legal-sized mature males was between 144 and 154 million crab and decreased to 123 million in 2023. The abundance of sub-legal sized mature crab, passing from 173 million in 2018 to 271 million in 2021 and 2022, then decreasing slightly to 253 million in 2023.

Mature female abundance from the survey was over 600 million animals from 1999 to 2002, then declined to 237 million in 2006 (Figure 15). 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 and rose by 3.7% to 602 million in 2022 and 4.3% to 607 million crab in 2023.

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, followed by a decrease to 139 million in 2020, 123 million in 2021, 138 million in 2022, and now stands at 129 million in 2023. Primiparous females represent an average of 25% of the spawning stock.

The 6 mm CW decrease in mature females size (Figure 11) from 2005 to 2023 translates to a potential 28% decrease in individual fecundity. However, this decrease is more than offset by the increase in mature female abundance over the same period. No significant changes in egg clutch fullness have been observed.

4.2.5. 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 decreased from a record high of 329 million crab in 2021, to 202 million in 2022 and 120 million in 2023 (Figure 16), which is close to the average value of the series at 123.7 million crab. 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.

4.2.6. Fishery recruitment

Table 5 compares the old values of R-2 abundances used in the past three years and their corrected values. The corrected values were 14% to 22% lower than their uncorrected values. Using the corrected R-2 values yielded new one-year predictions of R-1 biomass from the Bayesian recruitment model which were from 10% to 14% lower than their previously reported values. This had the consequence of resolving an apparent discrepancy between the predicted and observed R-1, which had been consistently overestimated over the past three years.

Fishery recruit estimates from the 2023 survey showed that R-4 abundances increased by 47.4% to 139.6 million, close to the time series average of 128.3 million, R-3 abundances decreased by 16.2% to 78.0 million, which is below the series average of 119.9 million, R-2 abundances decreased by 28.9% to 72.7 million, which is also below the series average of 106.6 million, R-1 abundances decreased by 34.4% to 78.4 million, which is below the series average of 81.5 million (Table 2).

Fishery recruitment biomass (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, but increased by 9.5% in 2022 to 68,348 t (58,894 t to 78,880 t), followed by a 34.9% decrease to 44,484 t (37,816 t to 51,983 t) in 2023 (Table 3).

One-year predictions from the Bayesian recruitment model over-estimated recruitment by 21.3% in 2020 and 15.6% in 2021, but the 2022 and 2023 predictions were similar to the survey values (Figure 17). Fishery recruitment is predicted to decline to 37,040 t (25,870 to 51,370 t) in 2024, which would represent a 24.6% decrease from the observed recruitment in 2023 and lies below the series average of 47,744 t.

Fishery pre-recruits in 2023 show a gradual shift in spatial distribution since 2020 from the eastern towards the western part of the sGSL (Figure 18). There are notable declines 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, is also showing decline with respect to recent years.

4.3. COMMERCIAL EXPLOITATION AND SURVIVAL RATES

The exploitation rate for the 2023 fishery was estimated at 41.4%, based on the 2022 survey commercial biomass estimate (Table 3). Exploitation rates have varied between 21.0% and 44.7% from 1998 to 2023, with an average of 35.1% over the period from 1998 to 2023.

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 and 69.9% in 2023 (Table 3). The average survival rate was 66.7% over the period from 1998 to 2023.

4.4. ENVIRONMENTAL CONDITIONS

4.4.1. 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 between -1 and 3 °C, a temperature range 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 2009).

Bottom temperatures in September 2023 were compared to the average temperatures over the period from 1991 to 2020 using data from surveys (Figure 19). Overall, bottom temperatures for the sGSL during 2023 were still much warmer than normal except for the coastal area over the southwest portion of the Cape Breton trough and on the eastern side of Northumberland Strait. Temperatures for CFA 12 in 2023 were 0.5 to 1 °C (or more) above normal in the Baie des Chaleurs and over a large area between the Acadian Peninsula, the Magdalen Islands and the Gaspé Peninsula. This area includes the Orphan and Bradelle Banks. Bottom temperatures near the coast of PEI were also warmer than normal. Bottom temperatures in CFAs 12E, 12F and the northeastern portion of CFA 19 were 1 to 2 °C above normal. The southwest portion of CFA 19 showed temperatures in the normal range. Very few areas had below-normal temperatures in 2023.

Temperatures in the deep waters of the Laurentian channel remained high and were much warmer than normal. The temperature at 300 m near Cabot Strait reached 7.04 °C, which is 1.1 °C warmer than the long-term average of 5.94 °C at that depth.

Figure 20 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 within 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 at just under 125 m.

4.4.2. Habitat Indices

The surface area of the sGSL with bottom temperatures between -1 and 3 °C in September, an index of snow crab habitat, rose slightly in 2023 from 2022 but remained low. The temperature within this area, at an average 1.3 °C, is still well above the long-term average (1991-2020) representing a decrease of 0.1 °C from 2022 (1.4 °C) and a 0.8 °C increase from the latest significant minimum observed in 2014 (0.5 °C). The 2023 average temperature within the snow crab habitat is the sixth highest of the 1971-2022 time series (Figure 21). The highest value was observed in 2021.

Although it rose from 2022, the water volume of the Cold Intermediate Layer (CIL), defined as waters < 1 °C, in 2023 was still one of the lowest on record for September with minimums in 1980, 2012, 2021 and 2022 (Figure 21). The CIL water volume for 2023 was ~1049 km^3, which was lower than the average of 2386 km^3. The lowest CIL volumes were observed in 1980 and 2022.

4.4.3. Temperatures occupied by snow crab

Figure 22 shows the September temperature distribution occupied by mature females, male instar VIII and commercial snow crab from 1997 to 2023 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 of 0.20 °C and rose to the highest value in the series at 1.21 °C in 2021 and remained high in 2022 and 2023 at temperatures of 1.07 °C and 1.02 °C respectively. Similarly, minimum temperatures that mature females occupy, using the 2.5^{th} percentile values, are also currently at their highest values at 0.81 °C for 2021, and remained high at 0.56 °C in 2022 and 0.62 °C in 2023 (Figure 22).

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 and 1.17 °C in 2023. The minimum temperatures for instar VIII were similar to those of mature females.

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 and at 1.12 °C in 2023. The occupation temperatures from 2020 to 2023 were the four highest of the series.

5. PRECAUTIONARY APPROACH

5.1. 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 23). 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 24), 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.

The commercial biomass estimate for the 2024 sGSL fishery is 67,703 t (Tables 3 and 4), which is well within the healthy zone of the PA framework (Figures 23 and 24). The residual biomass after the 2023 fishery was at 24,393 t (Table 3), which was above its limit reference point of 10,000 t, and is thus also considered to be in the healthy zone.

F_{lim} is not currently treated 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%. The limit removal rate prescribed by the harvest decision rule is only applied when commercial biomass falls below 45,500 t, a situation which has not occurred since 2010.

5.2. RISK ANALYSIS

Inputs to the risk analysis were the commercial biomass from the 2023 survey (67,703 t), the projected fishery recruitment from the Bayesian model (37,040 t), and the 5-year average annual survival rate of 62.4%. A provisional catch option of 26,126 t, corresponding to an exploitation rate of 38.59%, as per the harvest decision rule, was used for the 2024 fishery (Figure 25).

The risk analysis indicates that the 26,126 t catch option results in a very low probability (3.4%) of the commercial biomass would be below USR despite the decrease in fisheries recruitment, which remains at a relatively high level. Similarly, the residual biomass has a low probability of 1.1% that it would fall below LRP after the 2024 fishery. Thus, the snow crab stock is projected to remain in the healthy zone of the PA in 2024 using that catch option (Table 6, Figure 25). The 2024 commercial biomass is projected to decrease a further 21.4% relative to 2023 which had itself decreased by 20.8% from 2022.

Due to the miscalculation of the R-2 abundances during the 2020, 2021 and 2022 assessments, the projected R-1 values used in their respective risk analyses were not accurate, with the projections being on the order of 8000 t less than what was assumed. However, we note that at the current projected R-1 of 37,040 t, the lowest since 2014, still does not lead to high-risk projections after the 2024 fishery. We therefore assume that, at the corrected recruitment levels, which were much higher than 37,040 t, would also not have led to high risks of exceeding biomass reference points at the stated target exploitation rates.

6. DISCUSSION

6.1. STANDARDIZED CPUES

Standardized and seasonal average CPUEs for 2023 were almost identical for CFA 12. In contrast, standardized estimates in CFAs 12E and 12F were below the seasonal average values, while the standardized CPUEs for CFA 19 was only half of the seasonal average. There are two likely causes: 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.

6.2. 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, trawling speed and trawl symmetry.

6.3. RECENT FISHERY RECRUIT DYNAMICS

Fishery pre-recruits (R-4, R-3, R-2) have decreased substantially from 2020 to 2022. R-3s and R-2s continued their downward trend in 2023 and are now below average levels. R-4s increased in 2023 due to the influx of a large wave of population recruitment. However, this increase was less than expected based on the scale of population recruits from previous years. This echoes the rather modest increase seen among mature females from high levels of female pre-recruits seen in 2021 and 2022. These trends are indicators of increasing mortality.

Despite the decrease in R-2s from 2020 to 2023, R-1s remained relatively stable, with the first significant decrease only appearing in 2023. Thus there is a disconnect between R-1s and R-2s in recent years. Furthermore, skip-moulting proportions among R-2s are high in 2023. This adds to the prediction uncertainty in the fishery recruitment model, which neither accounts for annual variations in mortality, nor accounts for variations in skip-moulting rates.

6.4. 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 Saint 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 and 2023 but are still 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).

7. CONCLUSION

Current indicators for the sGSL snow crab stock continue to be positive, positioning the stock within the healthy zone of the PA, with relatively high commercial biomass, female spawning stock, population recruitment and projected fishery recruitment. The commercial stock biomass from the post-fishery survey is estimated at 67,703 t, composed of 65% new recruitment and 35% of residual biomass. Based on the harvest decision rule, this commercial stock biomass estimate corresponds to an exploitation rate of 38.59%, and a catch option of 26,126 t for the 2024 sGSL snow crab fishery. A risk analysis indicates that such catch option in 2024 would result in a very low likelihood that the residual stock biomass would fall below the LRP and a very high likelihood that the 2024 commercial stock biomass would remain above the USR, as defined by the PA.

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.

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10. 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 (1.0)	60.9	54.0 (1.2)	72.6	51.4 (1.1)	142.8	154.0 (1.0)
2018	44.2	42.0 (1.0)	46.6	45.5 (1.2)	69.1	61.5 (1.1)	156.1	144.0 (1.0)
2019	55.5	58.2 (1.0)	65.7	44.3 (1.2)	64.5	68.0 (1.1)	112.7	124.6 (1.0)
2020	44.1	42.7 (1.0)	45.9	48.6 (1.2)	45.2	46.9 (1.1)	101.7	97.8 (1.1)
2021	57.4	55.7 (1.0)	55.7	48.9 (1.2)	59.1	54.4 (1.1)	121.0	112.9 (1.0)
2022	51.4	56.6 (1.0)	78.5	77.8 (1.4)	76.4	69.8 (1.1)	112.6	115.9 (1.0)
2023	72.2	72.0 (1.9)	79.1	58.0 (10.6)	96.9	69.7 (5.6)	140.6	73.3 (4.4)

Table 2. Annual abundance (in millions) of crab categories based on southern Gulf of Saint 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	Residual		
	R-4	R-3	R-2(83-98)	R2 (83+)	CC 1&2 (R-1)	CC 3	CC 4	CC 5
1997	114.0	98.2	59.7	75.9	59.3	28.3	17.7	5.2
1998	135.3	91.3	60.3	80.0	50.9	24.9	16.0	8.6
1999	195.6	151.1	112.9	143.1	48.1	32.7	16.8	7.8
2000	237.5	159.1	88.4	102.8	68.4	10.3	7.4	2.5
2001	310.8	227.3	136.3	159.7	76.4	28.1	5.4	1.6
2002	164.3	242.2	202.2	241.4	112.3	21.7	4.3	0.9
2003	133.2	202.3	178.5	220.6	100.3	38.0	11.7	1.8
2004	85.8	122.9	144.1	194.3	143.3	28.2	9.9	1.2
2005	62.2	79.8	117.2	162.4	99.1	30.0	10.5	0.6
2006	54.1	49.6	65.7	95.4	84.2	29.2	5.8	1.0
2007	56.5	47.6	55.4	85.3	62.8	31.5	14.0	1.0
2008	80.6	54.6	45.8	69.6	49.1	23.0	11.4	3.0
2009	88.5	69.3	43.8	58.0	31.7	12.5	5.3	1.3
2010	140.8	110.3	72.5	90.6	32.8	20.6	4.2	1.6
2011	91.4	99.2	88.2	114.5	53.0	44.3	9.8	1.8
2012	95.7	86.4	80.5	105.1	86.6	37.9	5.7	1.2
2013	103.1	85.1	79.4	102.6	63.7	30.1	18.3	0.7
2014	105.1	93.6	117.2	147.3	73.3	29.6	13.1	0.6
2015	107.1	124.7	127.5	155.5	56.2	27.2	17.3	0.5
2016	113.1	124.8	101.6	130.9	125.9	30.6	14.7	0.1
2017	113.0	119.6	103.3	127.3	90.0	21.6	6.1	0.4
2018	135.6	116.5	108.3	126.6	115.6	34.6	4.5	0.8
2019	190.7	186.0	185.7	186.2	105.1	28.8	9.3	0.8
2020	180.9	170.3	174.3	203.0	103.5	29.8	7.2	0.6
2021	135.9	154.4	154.0	188.9	112.0	29.7	6.4	1.5
2022	94.7	93.1	102.3	131.9	119.6	27.6	6.2	0.7
2023	139.6	78.0	72.7	93.3	78.4	36.1	10.1	0.6
Average	128.3	119.9	106.6	133.0	81.5	28.4	10.0	1.8

Table 3. Annual recruitment, residual and total commercial biomass (in tonnes) of southern Gulf of Saint 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.

Year	Recruitment (t)		Residual (t)	Commercial (t)	Landings (t)	Survival (%)		ER (%)
	Observed	Predicted				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	44,484 (37,816-51,983)	49,100 (34,050-68,450)	24,393 (20,500-28,807)	67,703 (59,174-77,109)	35,404	69.9	62.4	41.4
2024	-	37,040 (25,870-51,370)	-	-	-	-	-	-

Table 4. Commercial biomass by crab fishing area (CFA) and buffer zones based on 2023 southern Gulf of Saint Lawrence survey data. Parentheses show 95% confidence intervals. Labels are from Figure 5.

CFA	Area (km^2)	Biomass (t)	
Southern Gulf	57,842.8	**67,703**	(59,174-77,110)
CFA 12	48,074.0	**58,385**	(50,988 – 66,546)
CFA 12E	2,436.9	**509**	(42 - 2,210)
CFA 12F	2,426.8	**4,675**	(3,549 - 6,046)
CFA 19	3,813.0	**3,702**	(2,353 – 5,551)
Sum of CFA[1]	56,750.7	**67,271**	
Unassigned zone above 12E/F **(A)**	667.9	**45**	(0.1 - 306)
Buffer zone 19/12F **(B)**	134.2	**149**	(44 - 373)
Buffer zone 12/19 **(C)**	289.5	**311**	(75 – 872)
Sum of total areas and zones	57,842.7	**67,776**	

[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. Table showing corrected R-2 abundances and the resulting changes in the predicted R-1 recruitment biomass from the Bayesian recruitment model.

Year	Variable	Old value	Corrected value	Difference
2020	R-2	203.0 million	174.3 million	-28.7 million
2021	R-2	188.9 million	154.0 million	-34.9 million
2022	R-2	131.8 million	102.3 million	-29.5 million
2021	Predicted R-1	79,870 t	72,230 t	-7640 t
2022	Predicted R-1	73,120 t	65,100 t	-8020 t
2023	Predicted R-1	57,280 t	49,100 t	-8180 t

Table 6. Risk analysis for different catch options for the 2024 southern Gulf of Saint 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 2024 survey. In bold is the catch option corresponding to an exploitation rate of 38.59%, the rate as per the harvest decision rule.

Catch option (t)	Probability		Predicted survey biomass for 2024 (t)
	B_{res} < LRP	B < USR	
20,000	0.0%	0.1%	59,333 (46,811 – 74,558)
21,000	0.0%	0.2%	58,333 (45,811 – 73,558)
22,000	0.0%	0.4%	57,333 (44,811 – 72,558)
23,000	0.0%	0.8%	56,333 (43,811 – 71,558)
24,000	0.1%	1.3%	55,333 (42,811 – 70,558)
25,000	0.3%	2.1%	54,333 (41,811 – 69,558)
26,000	0.9%	3.2%	53,333 (40,811 – 68,558)
26,126	**1.1%**	**3.4%**	**53,207 (40,685 – 68,432)**
27,000	2.6%	4.7%	52,333 (39,811 – 67,558)
28,000	6.1%	6.7%	51,333 (38,811 – 66,558)
29,000	12.2%	9.2%	50,333 (37,811 – 65,558)
30,000	21.5%	12.4%	49,333 (36,811 – 64,558)
31,000	33.6%	16.1%	48,333 (35,811 – 63,558)
32,000	47.4%	20.4%	47,333 (34,811 – 62,558)
33,000	61.1%	25.2%	46,333 (33,811 – 61,558)
34,000	73.3%	30.4%	45,333 (32,811 – 60,558)
35,000	83.0%	35.9%	44,333 (31,811 – 59,558)
40,000	99.4%	63.9%	39,333 (26,811 – 54,558)
45,000	100.0%	84.4%	34,333 (21,811 – 49,558)
50,000	100.0%	94.6%	29,333 (16,811 – 44,558)
60,000	100.0%	99.6%	19,333 (6,811 – 34,558)

11. FIGURES

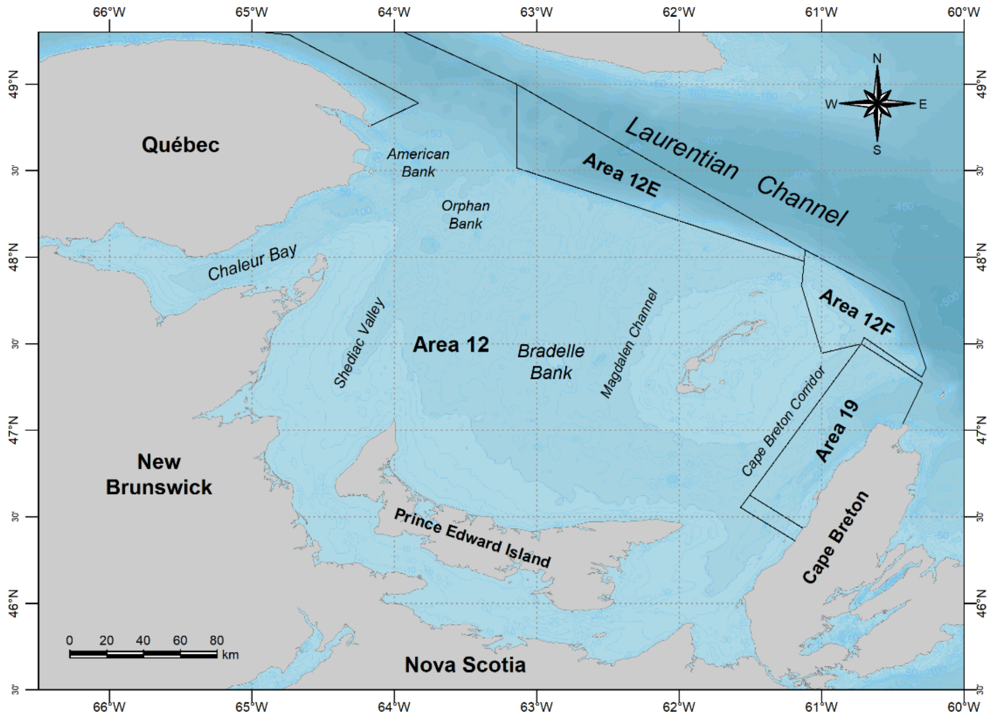

Figure 1. Map of the southern Gulf of Saint Lawrence showing snow crab fishery areas (CFAs 12 12E, 12F and 19) and common names for fishing grounds.

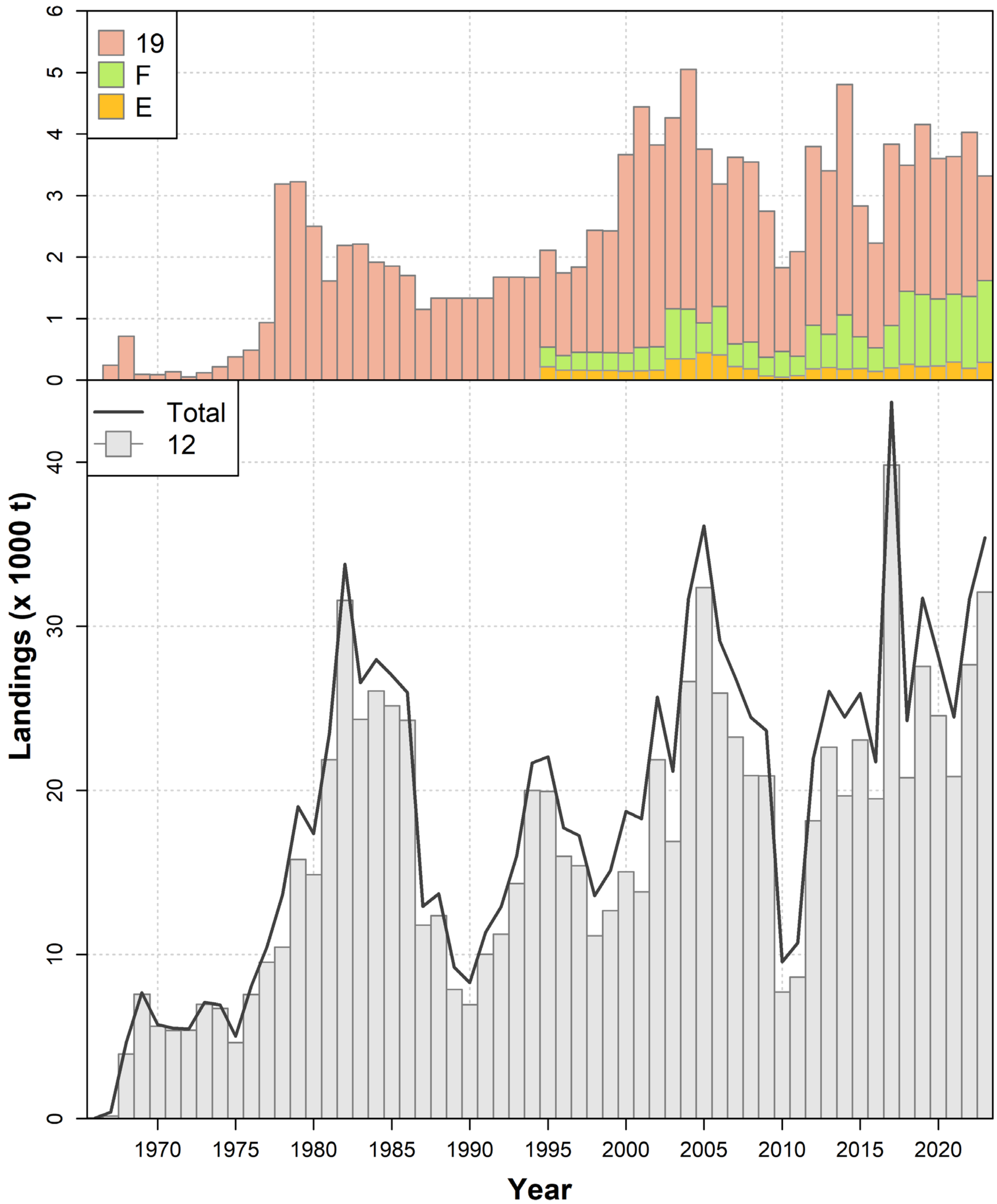

Figure 2. Annual landings (in tonnes) of southern Gulf of Saint Lawrence in snow crab fishing areas 12E, 12F, 19 (top panel) and 12 (bottom panel). Solid black lie (bottom panel) indicates total landings for the southern Gulf of Saint Lawrence (CFAs 12, 12E, 12F and 19).

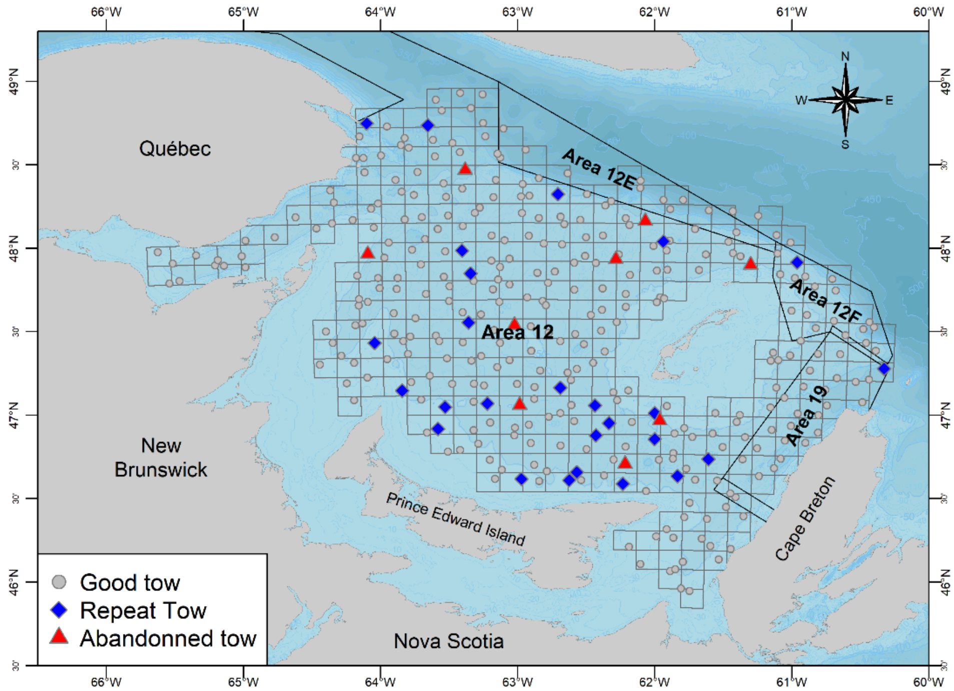

Figure 3. Locations of the 2023 snow crab trawl survey stations. Grey circles points are tows successfully trawled on the first try, blue diamonds show tows repeated and successfully trawl at the same station, and red triangles are abandoned tows. Survey sampling grids are shown in grey.

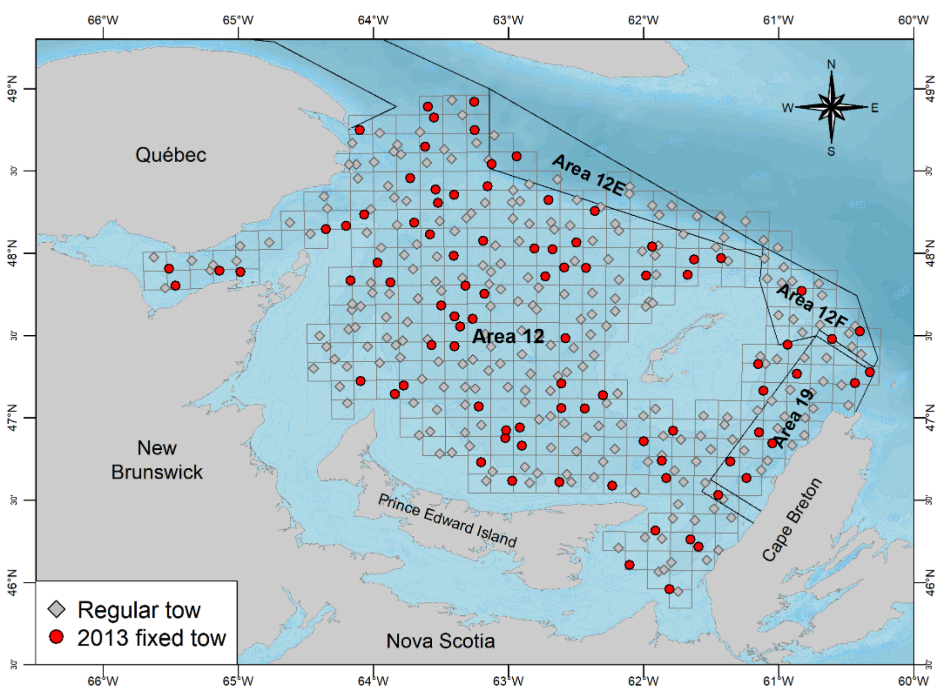

Figure 4. Map showing the 100 stations which were moved to their original 2013 positions (red circles) during the 2023 survey, along with the 255 remaining stations (grey diamonds). Survey sampling grids are shown in grey.

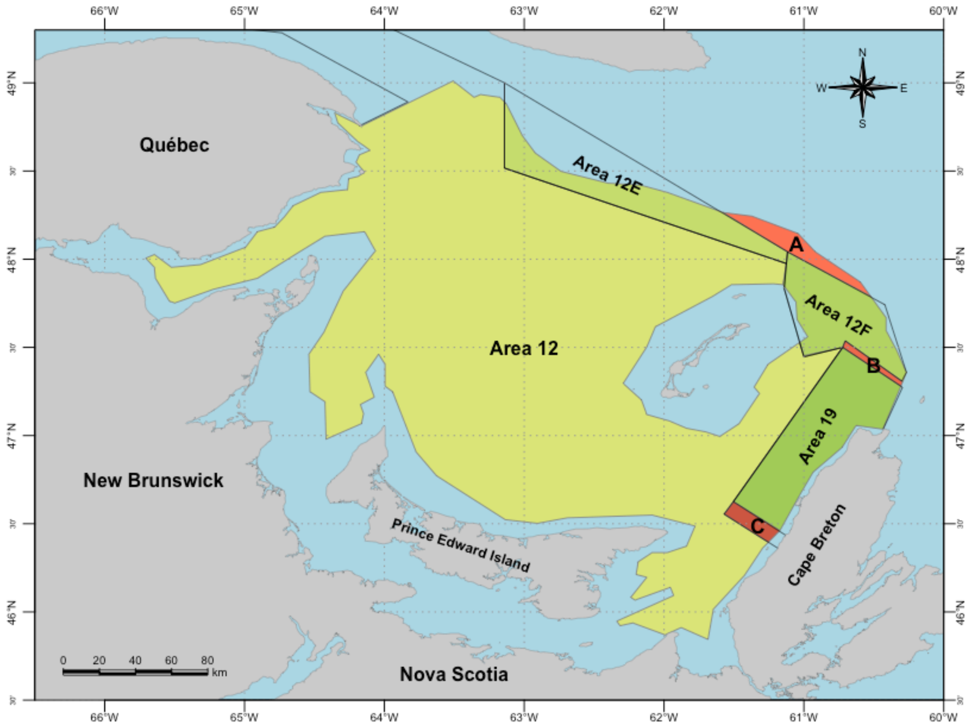

Figure 5. Polygons used for estimating survey stock indices. The unassigned zone north of crab fishing areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

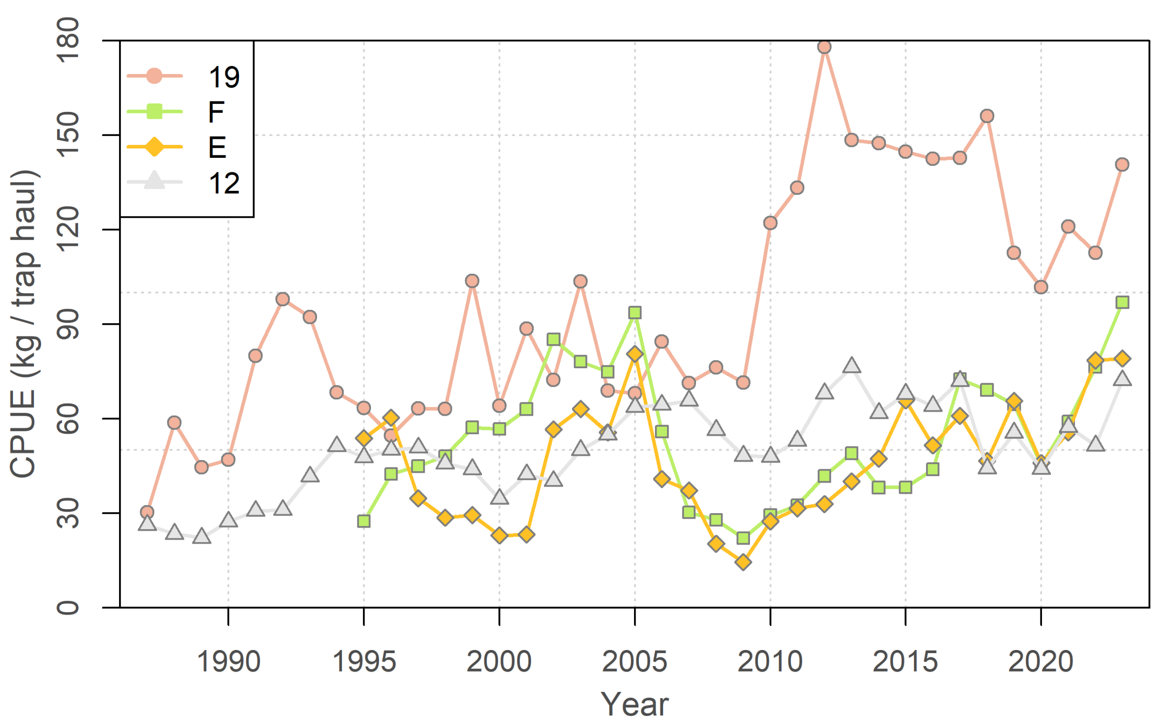

Figure 6. Seasonal average catch-per-unit-of-effort (CPUE; kg / trap haul) by crab fishing area in the southern Gulf of Saint Lawrence, based on fishery logbook data.

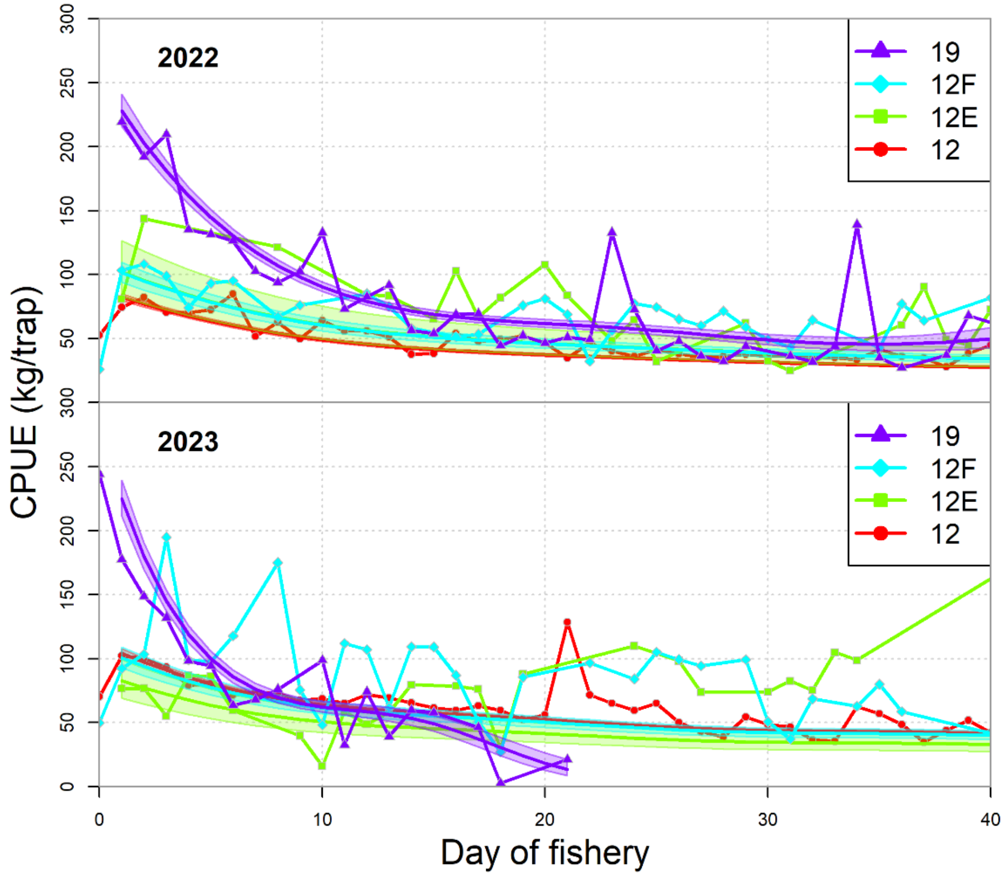

Figure 7. Catch-per-unit-of-effort versus fishing day for the 2023 fishery, as estimated from the catch-per-unit-of-effort standardization model, evaluated for 36-hour soak time for an average fishing vessel in each crab fishing area.

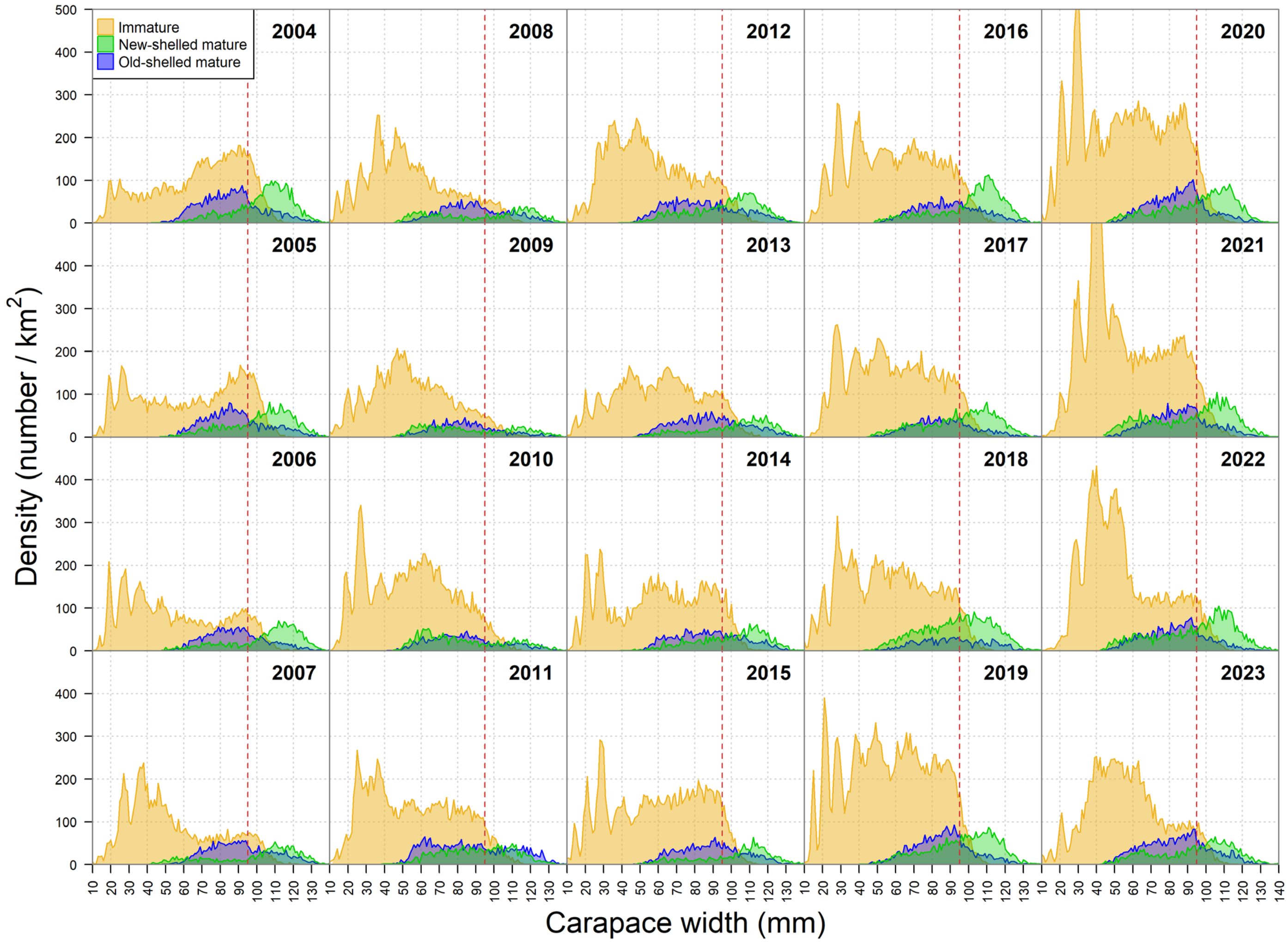

Figure 8. Annual size-frequency distributions of immature and adolescent (yellow), new-shelled mature (green) and old-shelled mature (blue) male snow crab from the trawl surveys. The red dotted line shows the minimum legal size of 95 mm carapace width. Note that abundances for small crab for 2020 and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

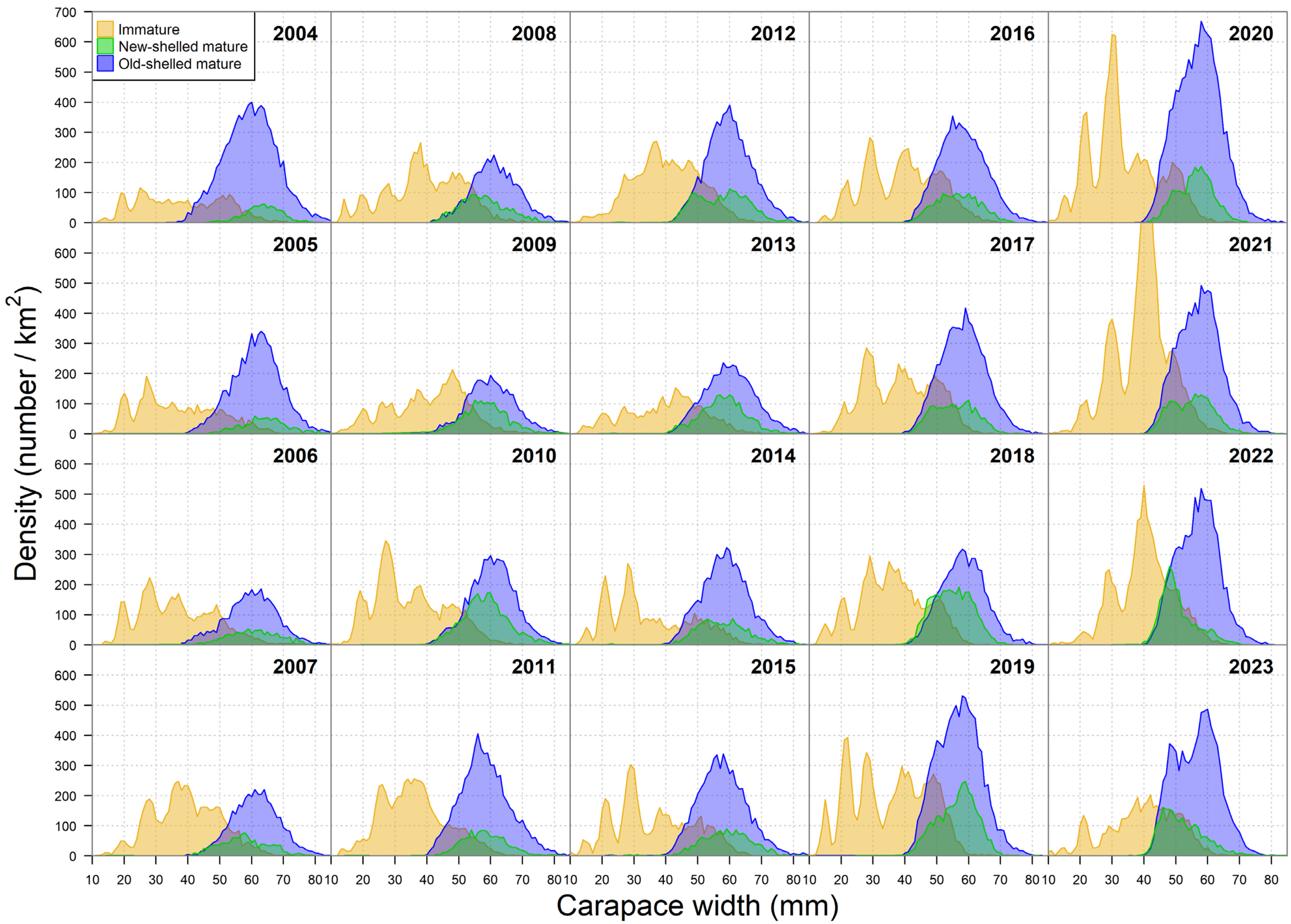

Figure 9. Annual size-frequency distributions of immature and pubescent (yellow), new-shelled matures (green) and old-shelled mature (blue) female snow crab from the trawl surveys. Note that abundances for small crab for 2021 exceed the scale of the plot.

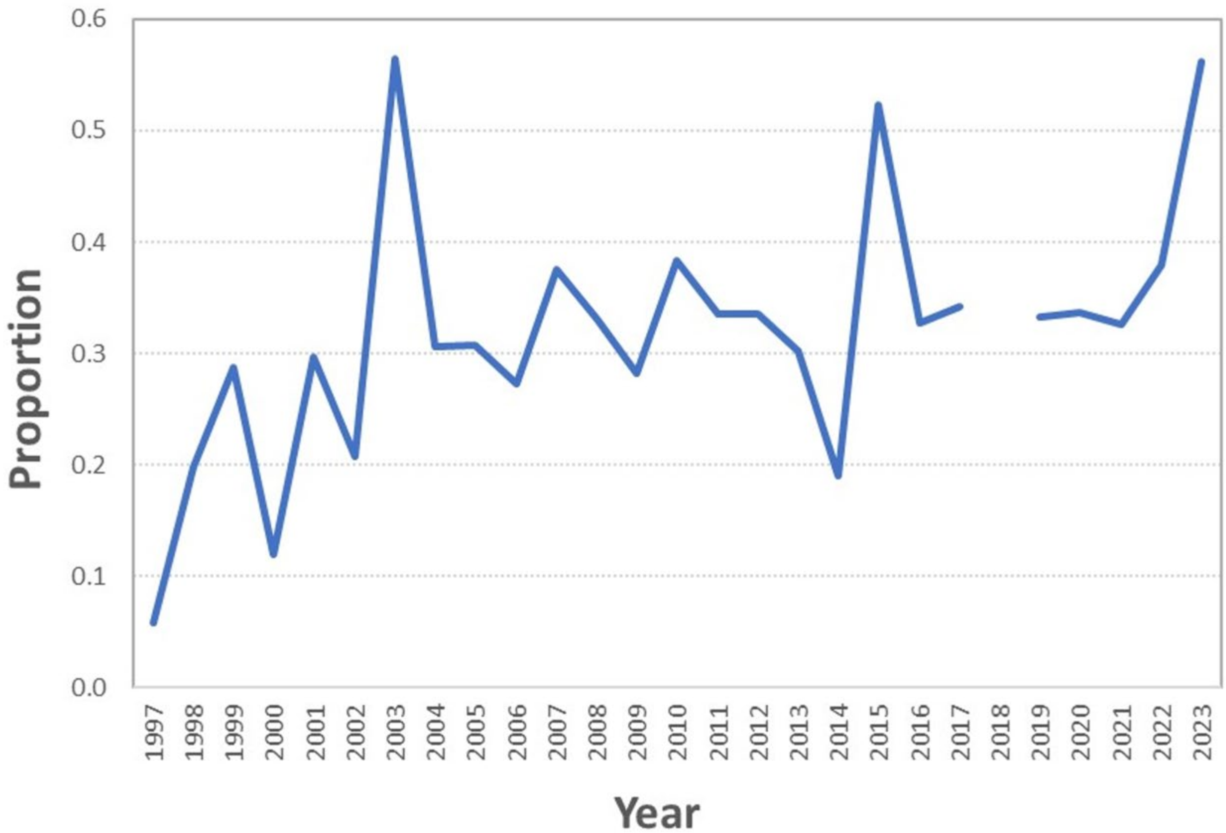

Figure 10. Proportions of R-2 skip moulter crab by survey year. In 2018, classification of skip moulters were not reliable thus not included.

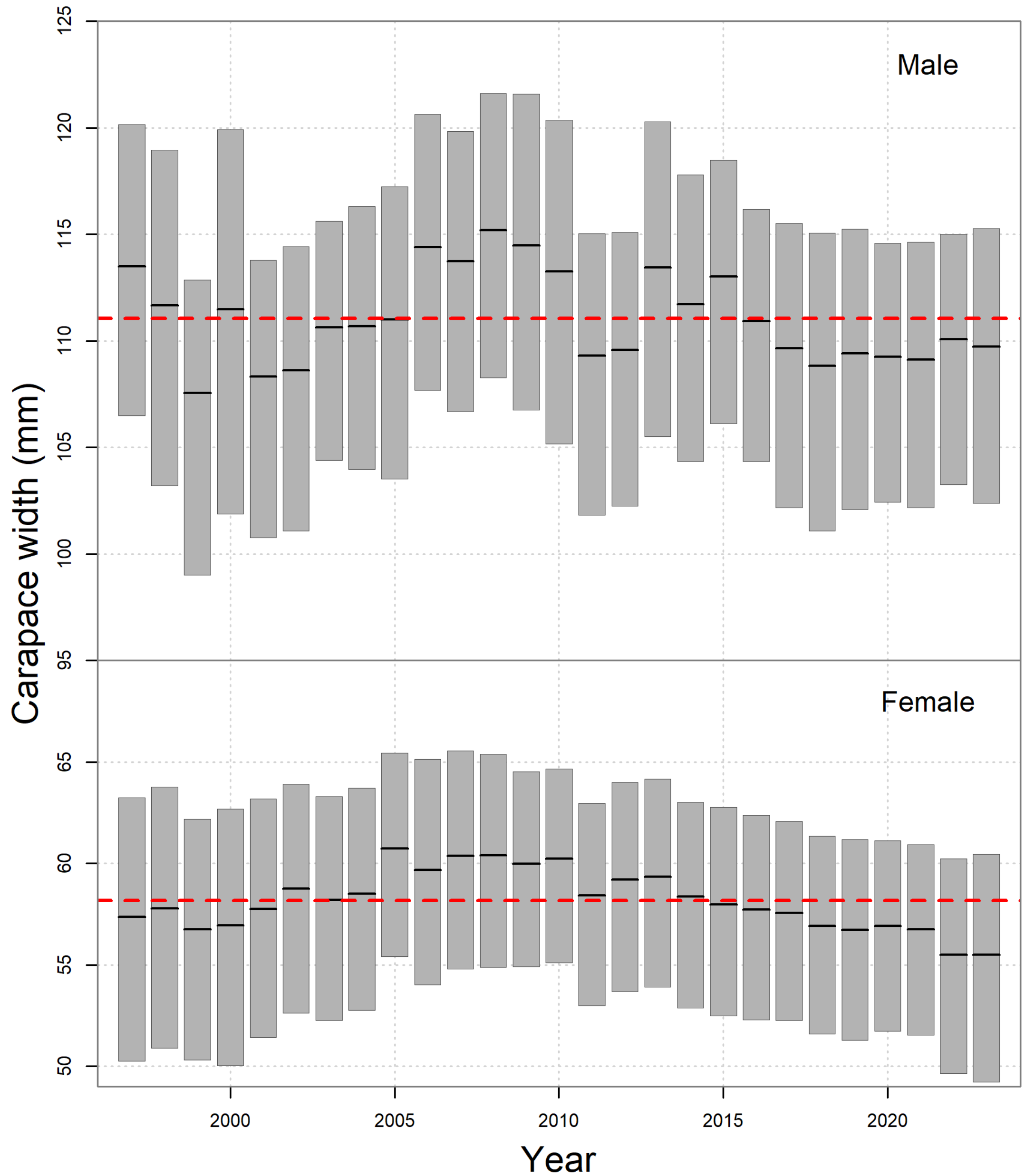

Figure 11. Size variation of mature legal-sized male (top panel) and mature female (bottom panel) snow crab observed in trawl survey data. Middle line shows the mean carapace width and grey bars show interquartile size range. The timeseries mean is shown as red dashed lines for reference.

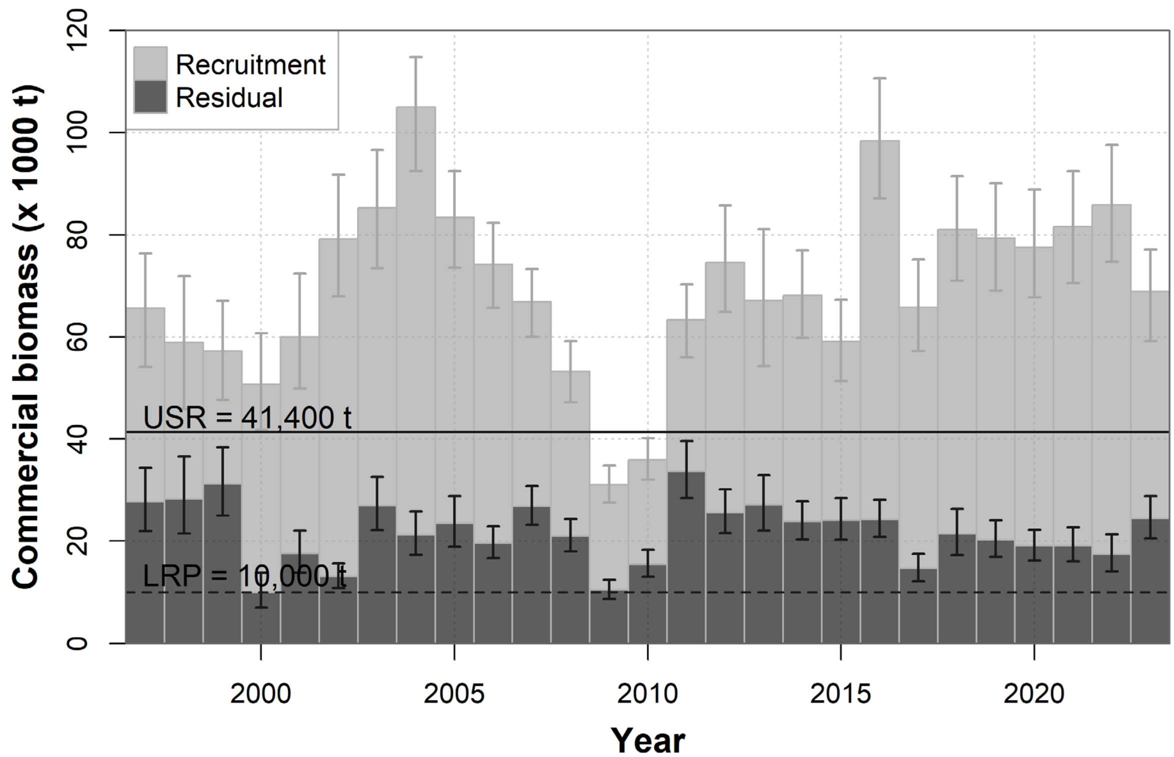

Figure 12. Stacked bar plot of commercial recruitment (light grey bars) and residual (dark grey bars) biomass, as estimated from trawl survey data. Error bars show 95% confidence intervals. Also shown are the corresponding limit reference point (LRP) for the residual biomass (dashed line) and upper stock reference (USR) (solid line).

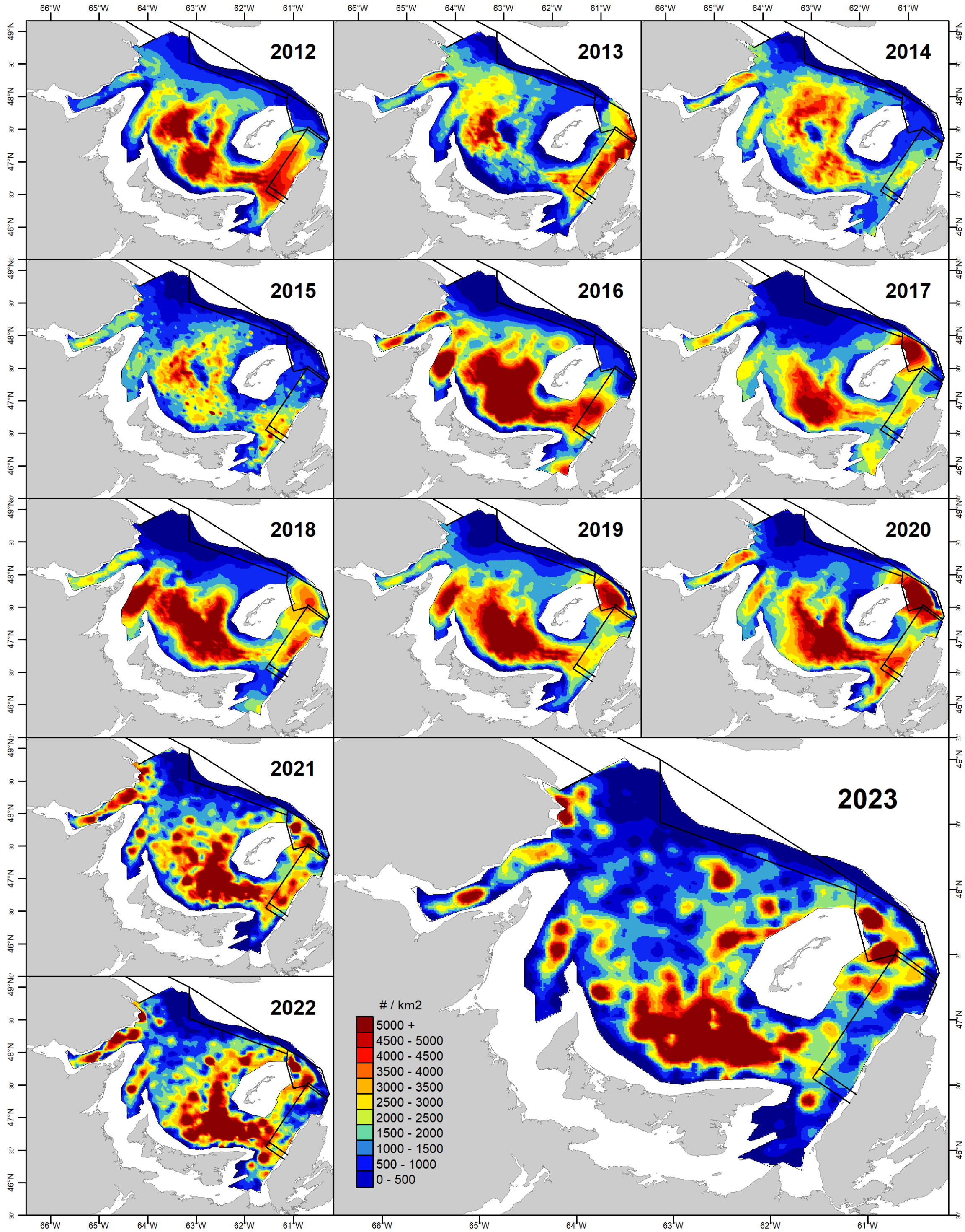

Figure 13. Density (number per km^2) contours of commercial crab in the southern Gulf of Saint Lawrence from 2012 to 2023, based on the snow crab trawl survey, interpolated using kriging.

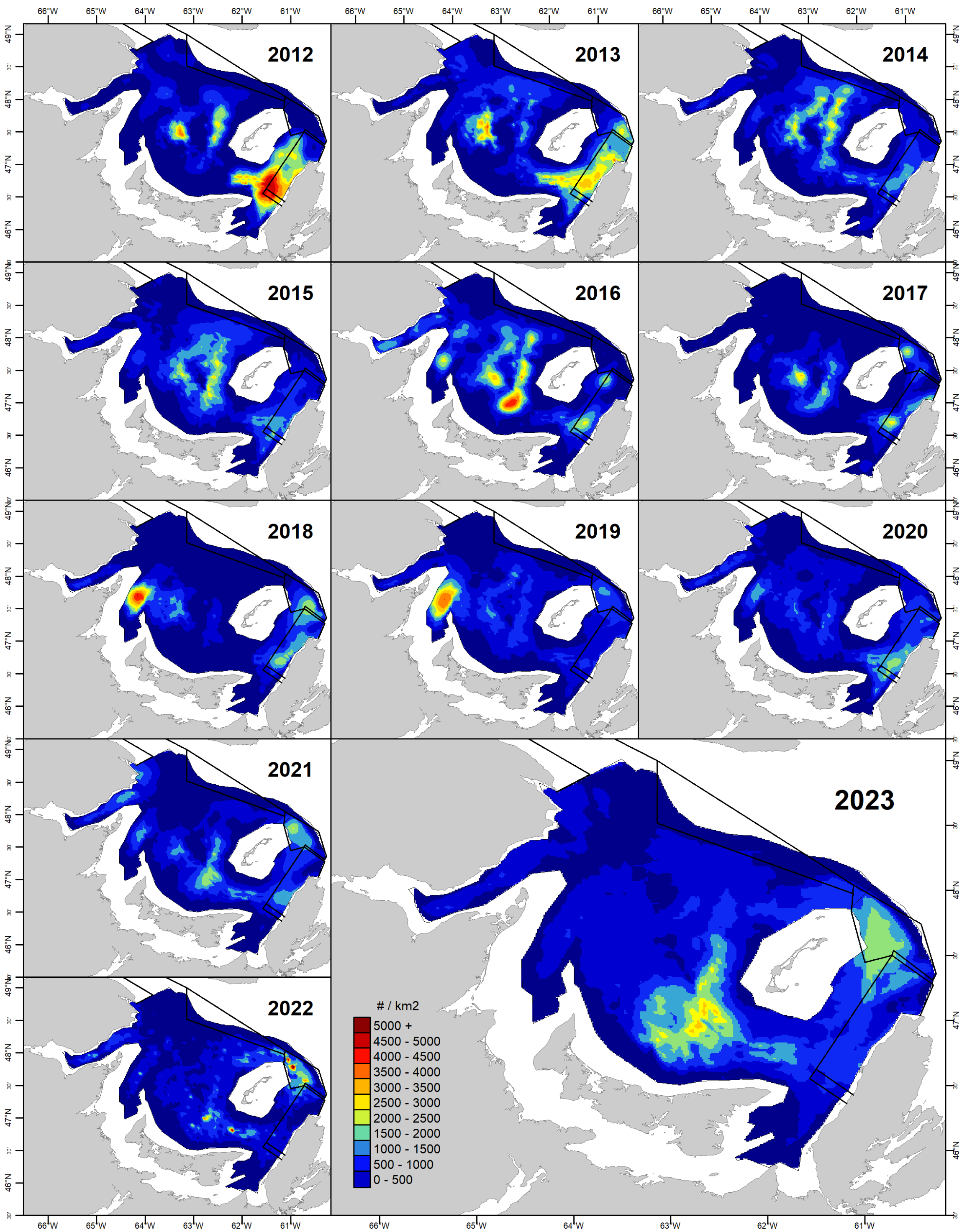

Figure 14. Spatial distribution of the residual component of commercial snow crab (carapace conditions 3,4, and 5) from 2012-2023 based on southern Gulf of Saint Lawrence trawl survey data, interpolated using kriging.

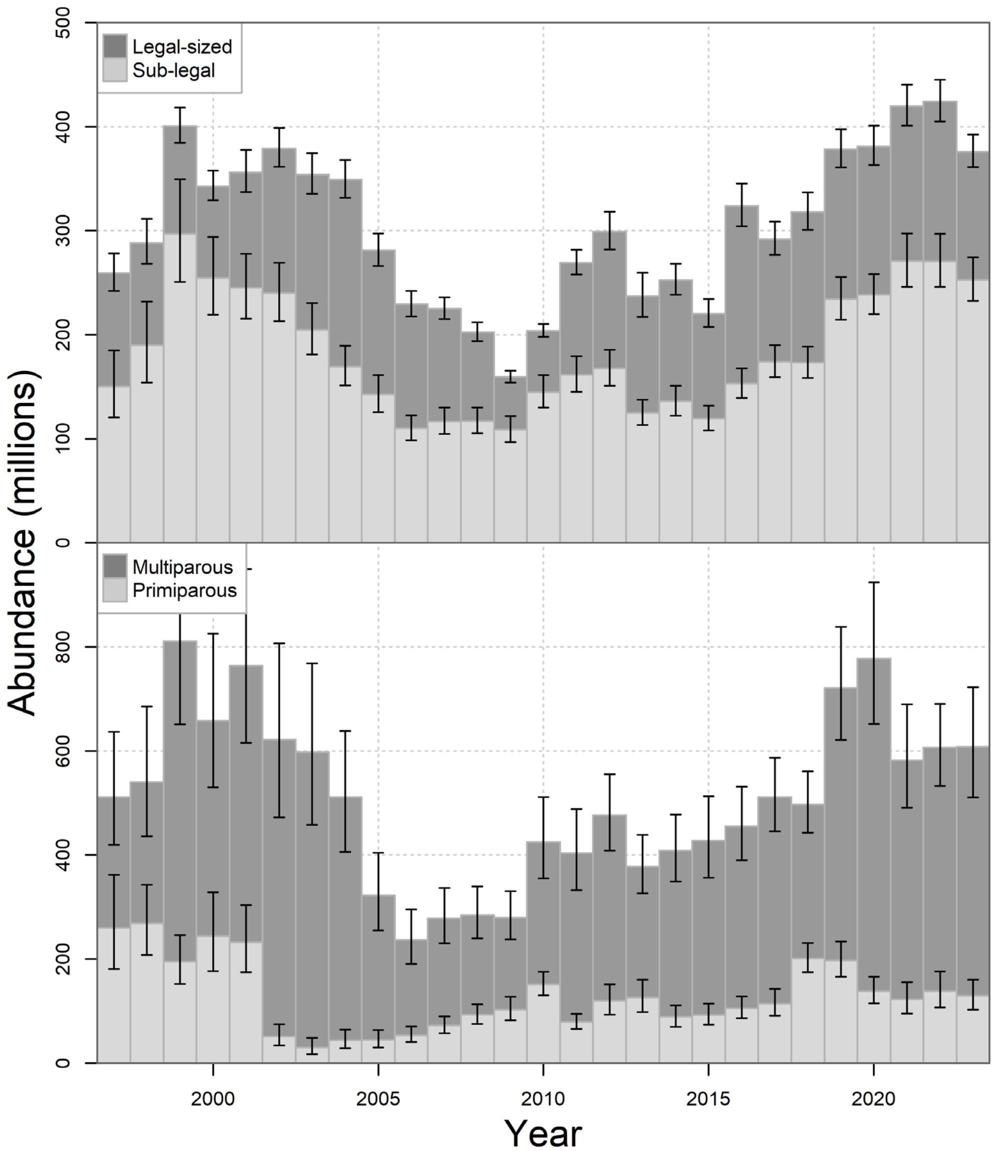

Figure 15. Survey abundance legal and sub-legal male (top panel) and primiparous and multiparous female snow crab (bottom panel) in the southern Gulf of Saint Lawrence.

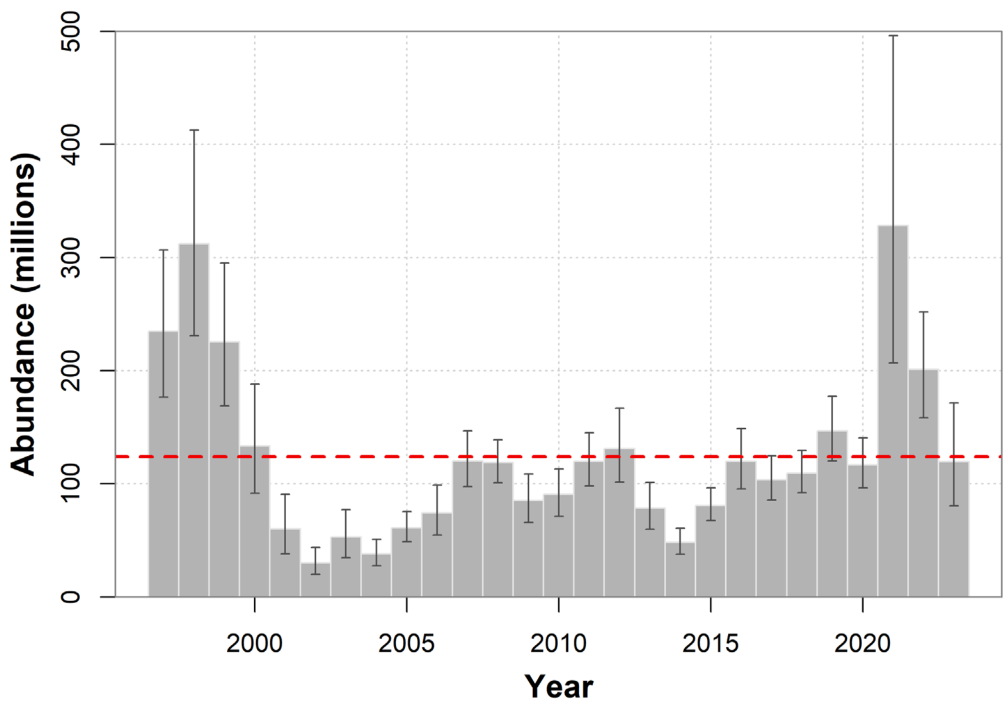

Figure 16. Annual abundance (in millions; means with 95% confidence intervals) of small male crabs of 34 to 44 mm carapace width (Instar VIII), based on the trawl survey data. The red dashed line shows the average for the series.

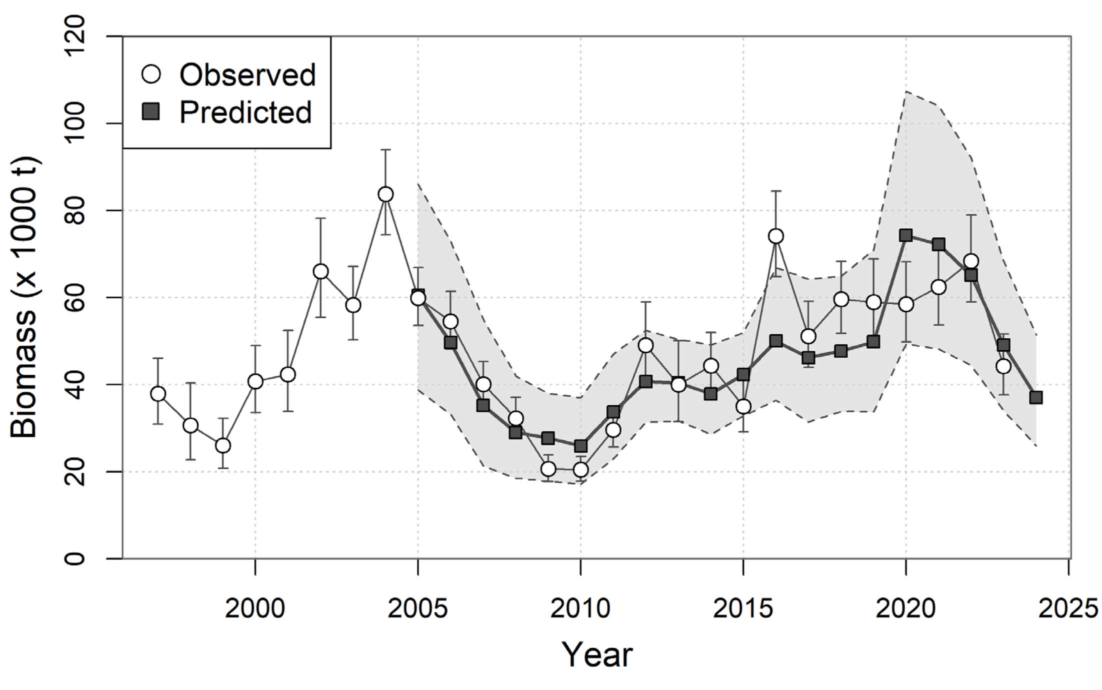

Figure 17. Observed (open circles and 95% confidence interval error bars) and predicted (black squares and shaded 95% confidence intervals) fishery recruitment biomasses of R-1 snow crab in the year of the survey.

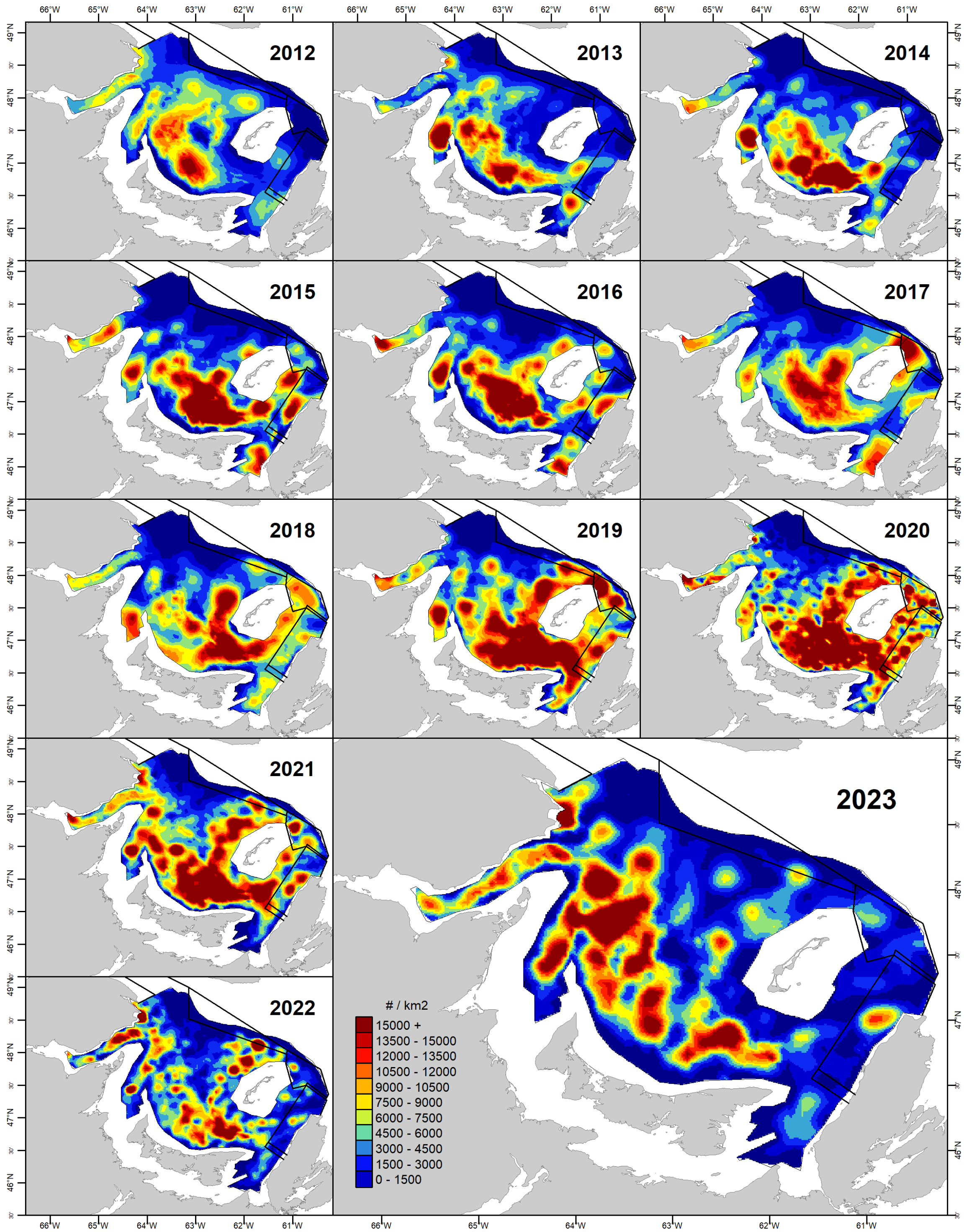

Figure 18. Adolescent male snow crab spatial distribution by year based on southern Gulf of Saint Lawrence trawl survey data, interpolated using kriging. Adolescents are made up of future recruits to the fishery (i.e. R-4, R-3 and R-2s).

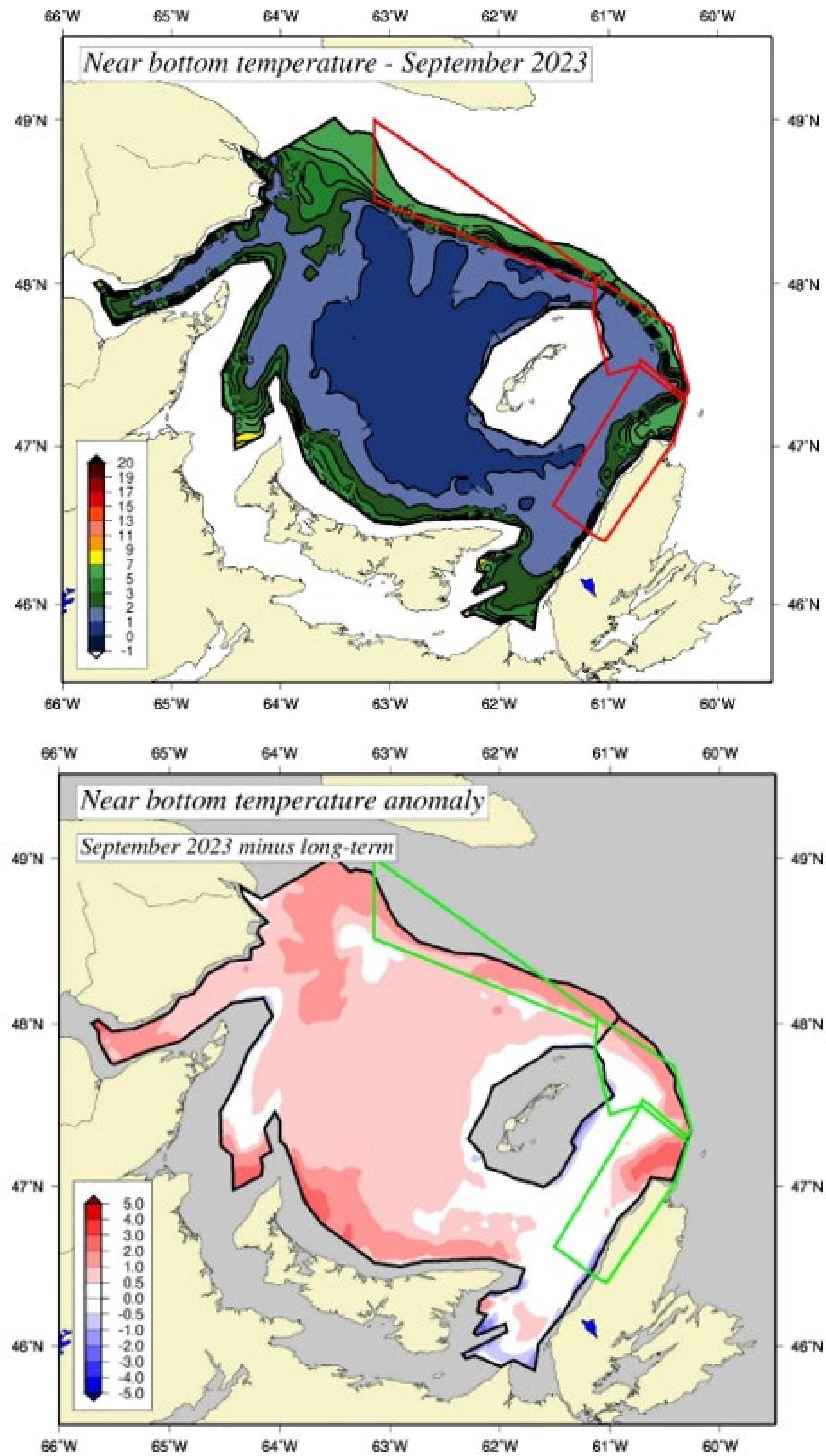

Figure 19. Map of bottom temperatures (top panel) and anomalies (bottom panel) for September 2023. Anomalies were calculated as the difference between September 2023 local bottom temperatures and their long-term means from the period from 1991 to 2020. Blue areas represent colder-than-normal temperatures while red regions represent warmer-than-normal conditions. White areas in bottom panel represent near normal conditions.

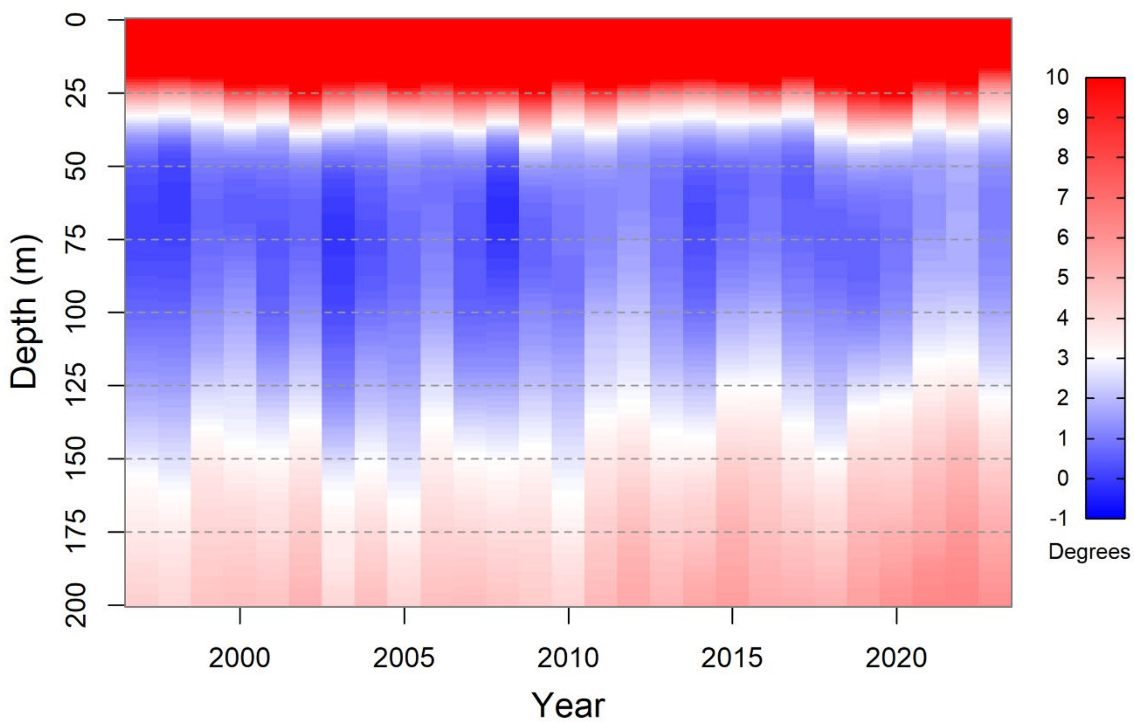

Figure 20. Average temperature stratification in September within the snow crab survey area by year. Blue areas are colder than 3 °C (the Cold Intermediary Layer), white areas are approximately 3 °C, and red areas are warmer than 3 °C. The top red layer corresponds to warm surface waters, while the bottom red layer corresponds to the deep, warm water mass of the Laurentian Channel.

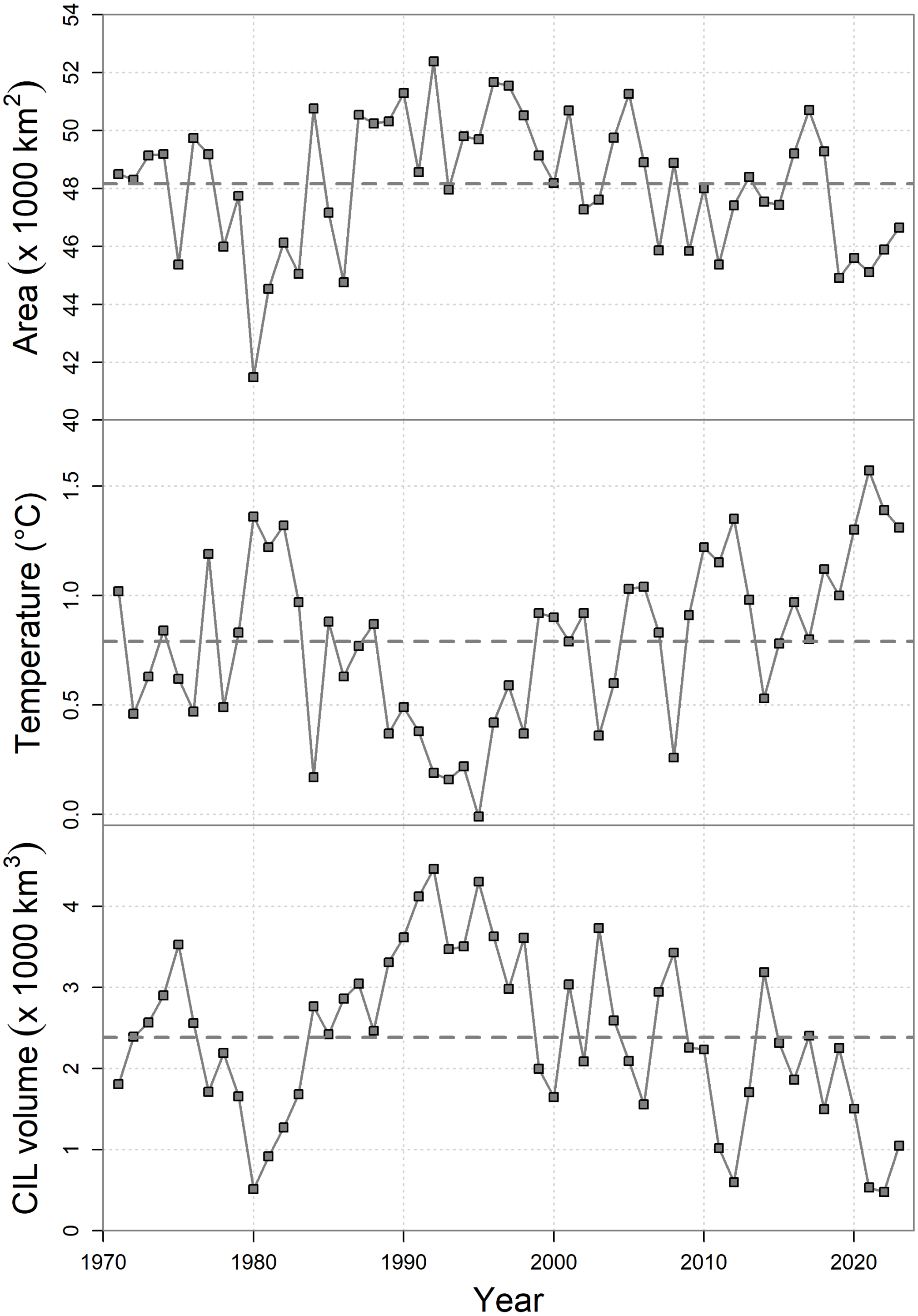

Figure 21. Surface area of the southern Gulf of Saint Lawrence with bottom temperatures between -1 °C to 3 °C, an index of snow crab habitat (top panel), mean bottom temperature (middle panel) and cold intermediate layer (CIL) volume (bottom panel) within the area.

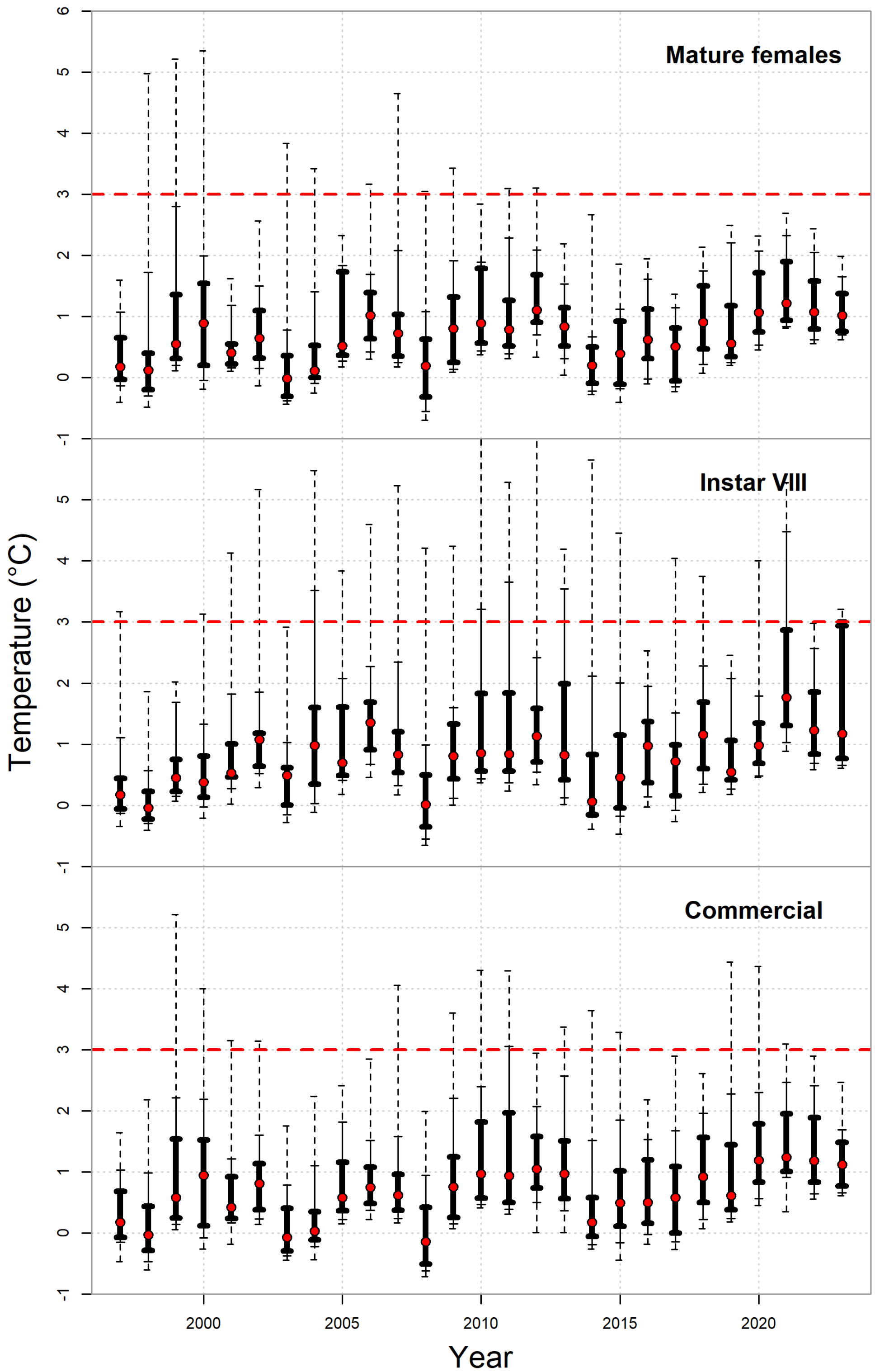

Figure 22. Annual temperature distribution in September for mature female (top panel), instar VIII (middle panel) and commercial (bottom panel) snow crab from the trawl survey. Red dots show the median, the thick black bars show the interquartile range, the thin solid black lines show the range between the 10% and 90% percentiles and the dashed lines show the 2.5% and 97.5% percentiles.

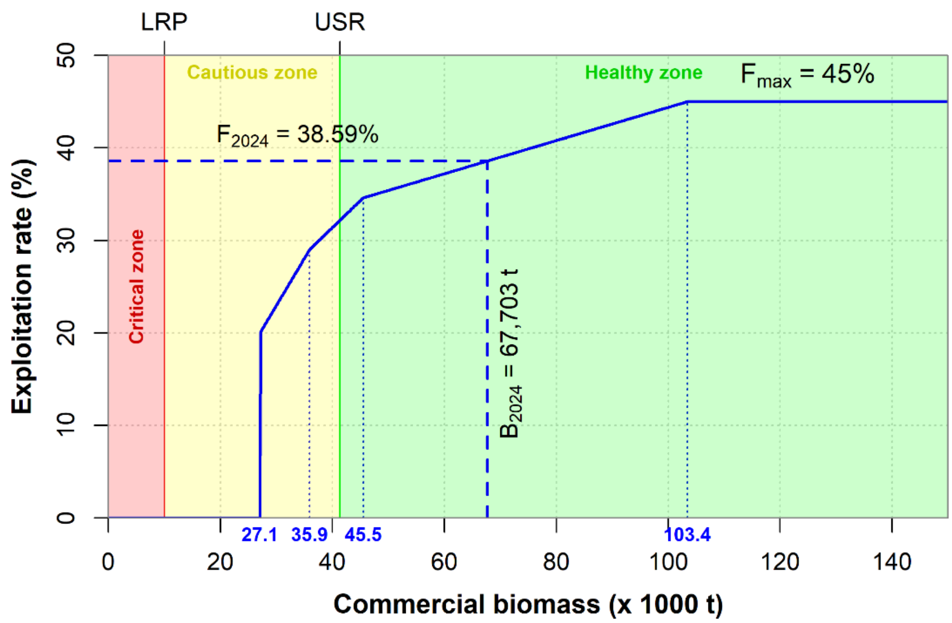

Figure 23. Harvest decision rule used for the southern Gulf of Saint Lawrence snow crab fishery (DFO 2014), expressed as exploitation rate versus commercial biomass (solid blue line). The red line shows the limit reference point (LRP) for residual biomass and the green line shows the upper stock reference (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 2024 along with the corresponding target exploitation rate.

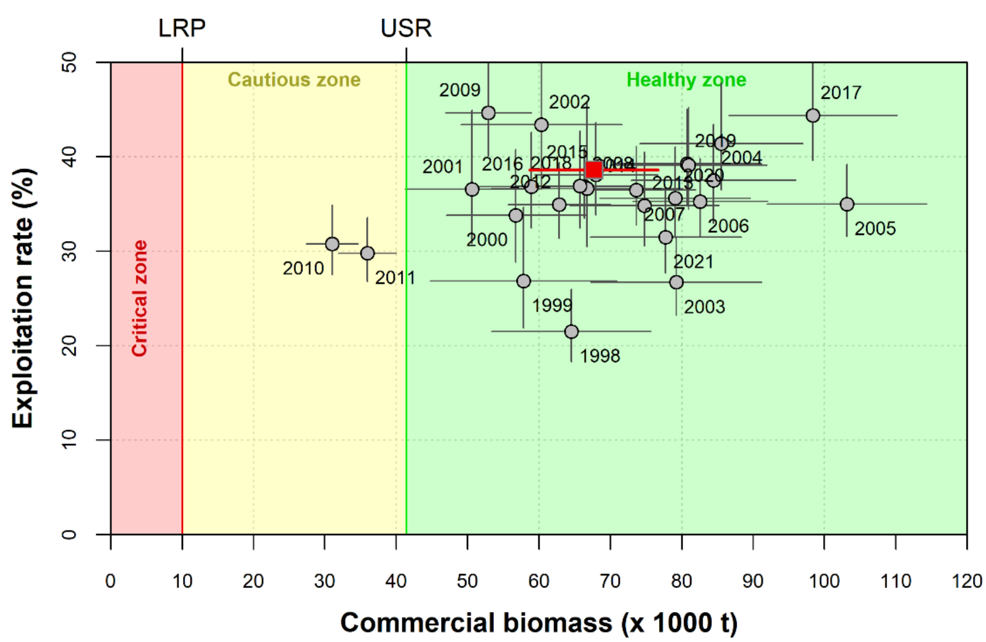

Figure 24. Exploitation rate versus the commercial biomass, with 95% confidence intervals. Year labels represent the fishery year. Coloured lines represent reference points: LRP (red line) is the limit reference point for residual commercial biomass, USR (green line) is the upper stock reference point for commercial biomass and F_{lim} (blue line) is the limit reference point for fishing removal rate. The red square corresponds to the commercial biomass estimate with the target exploitation rate of 38.59% for the 2024 fishery.

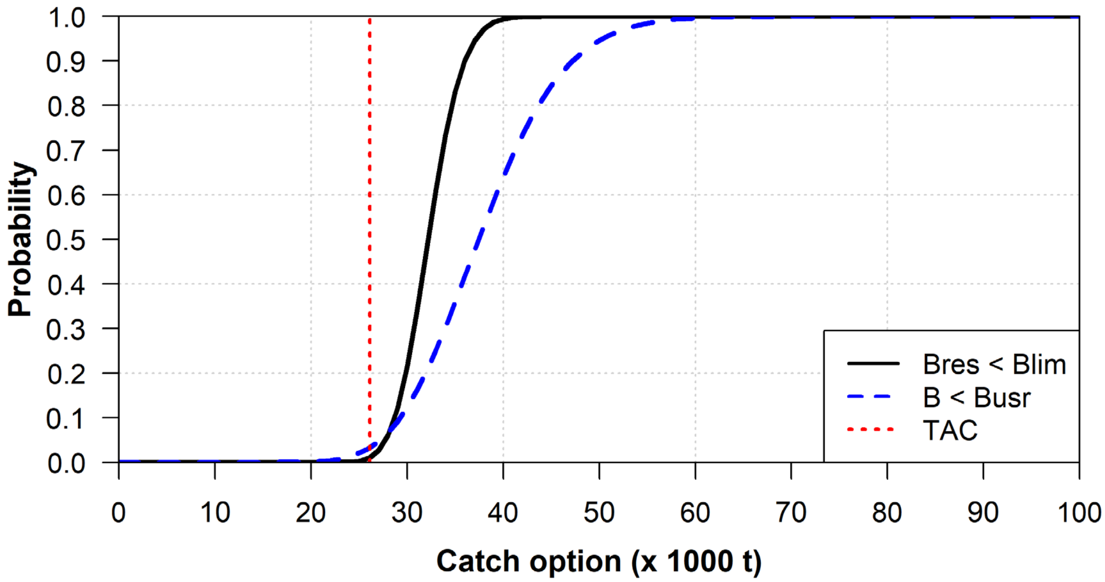

Figure 25. Risk analyses showing the probability that the residual commercial biomass falls below limit reference point (black solid line) or that the total commercial biomass falls below the upper stock reference (blue dashed line) point after the 2024 fishing season. The catch option for the 2024 fishery, corresponding to the target exploitation rate of 38.59%, is shown by the dashed red line.