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The 2021 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 12E, 12F and 19)

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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 St. Lawrence (sGSL) snow crab, *Chionoecetes opilio*, in 2021 is in the healthy zone based on the defined reference points for this stock, with an a commercially exploitable biomass of 80,950 t projected for 2022. The exploitation rate of the 2021 fishery was estimated at 31.5%, a relatively low value stemming from a 15% reduction in commercial biomass estimates made in response to concerns of over-estimation of stock indices during the 2019 and 2020 surveys. Fishery recruitment biomass is estimated at 62,473 t, while residual biomass was estimated at 19,144 t. Based on the harvest control rule, the commercial stock biomass index corresponds to a target exploitation rate of 40.96% resulting in a Total Allowable Catch (TAC) of 33,163 t for the 2022 fishery. Based on this catch option, a risk analysis indicates that there is a very low likelihood that the residual stock biomass would be below the limit reference point and a very high likelihood that the 2022 commercial stock biomass would be above the upper stock reference point. Mature female abundance remains high, though at lower levels than those observed in 2019 and 2020 and the population recruitment index is very high.

1. INTRODUCTION

The snow crab, *Chionoecetes opilio*, is a common cold-water species found in many northern regions from Greenland, northern Europe, the Sea of Japan, the Bering Sea, and eastern Canada. In Eastern Canadian snow crab populations are found off the coast of Nova Scotia, around the coasts of Newfoundland, as well as the northern and southern portions of the of the Gulf of Saint-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, residing within an area of cold intermediate water layer during the summer and fall seasons (Fig. 1). The snow crab population in the sGSL can be considered as a single stock unit, though there are limited exchanges with northern and southern snow crab populations (Biron et al. 2008) through some free-floating larval inputs may arise from the Quebec population to the north (Puebla et al. 2008).

1.1. BIOLOGY

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 moulting, crabs have a soft shell for a period of 8 to 10 months. Soft-shelled crab is defined by shell hardness (< 68 durometer units) and includes both new-soft (condition 1) and clean hard-shelled crab (condition 2). The term white-crab is used in the summer fishery of Area 19 because the newly-moulted crabs have reached a relatively harder carapace than those observed during the spring fishery (Areas 12, 12E and 12F). White crab is defined by shell hardness < 78 durometer units and includes both new soft (condition 1) and clean hard-shelled crab (condition 2).

Snow crab do not continue to moult throughout their lifespan. Females stop growing when they acquire a wide abdomen for carrying eggs, occurring at carapace widths (CWs) less than 95 mm. Males stop growing when they acquire large claws on the first pair of legs, which can occur at CWs between 40 and 150 mm. Females produce eggs that are carried beneath the abdomen for approximately two years in the sGSL. The eggs hatch in late spring or early summer and the newly-hatched crab 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 commercial size.

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 t annually (Fig. 2). Management of the fishery is based on annual quotas (attributed by management Area 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 management Areas in the sGSL, 12, 12E, 12F and 19 (Fig. 1), with Area 12 being the largest by area, number of participants, and landings. Area bounds are not based on biological considerations, but solely for management reasons (DFO 2009). The fishing season in Areas 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 Area 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 management Area.

There are two buffer zones within the sGSL where fishing is prohibited: one is a two nautical mile strip located along the northern edge of Area 19 (label B in Fig. 1) and the other is located along the south edge of Area 19 (label C, Fig. 1). During the season, the fishery is subject to local area closures, usually in the form of 10' x 10' latitude-longitude grids, to protect against high occurrence of soft-shelled crab in catches, as well as closures due to occurrence of north Atlantic right whales (NARW) over fishing grounds.

This report contains advice required for the implementation of two management objectives. The first is to maintain a sufficient quantity of commercial stock such that a viable reproductive stock of large males remains after the fishery. The second, is to maintain a minimum quantity of commercial stock to be available for exploitation in the following year's fishery. These objectives are largely achieved through a specific total allowable catch (TAC) recommendation, along with a risk assessment using appropriate stock indicators in relation to reference points, as prescribed by the Precautionary Approach Framework (DFO 2009; DFO 2010).

1.3. RECENT ISSUES

The change in survey vessel in 2019 was accompanied by an apparent increase in survey catchability, raising concerns of overestimation in survey indices. Although a small-scale experiment was performed in the western portion of the sGSL, no significant differences were found between catches from the old and new survey vessel. These results were at odds with the significant year-over-year increases observed in the rest of the survey, which defied biological explanation.

Latent trawling during winching of the trawl was put forward as a possible cause of the catch increases. However, measures put in place during the 2020 survey to decrease the extent of latent trawling by reversing vessel speed when winching were not successful. Survey catches increased by 30-40% among sub-legal sized crab in 2019 and 2020, relative to 2018. In contrast, stock indices for legal-sized crab remained remarkably stable in 2018, 2019 and 2020 despite the vessel change, raising doubts as to whether the commercial stock index was affected by catchability increases to the same degree as their sub-legal counterparts. As a precaution, the estimate for the commercial biomass was reduced by 15% before establishing the catch option for 2021.

A parallel concern, unrelated to the survey catch increases in 2019, relates to the practice of relocating survey sampling stations when trawl damage occurs at a during the survey. Over time, this practice tended to concentrate stations over areas which are more trawlable. If abundance or catchability differences exist between areas of differing trawlability, this would result in biases in the resulting stock indices.

Issues such as these have undermined the reliability of the survey indices used to assess stock status. In this report, we present results from two new experiments. The first was performed prior to the 2021 survey to identify the best method to control latent trawling during hauling of the of the trawl net. The second experiment was performed during the survey to measure the impact that survey station relocations have had on survey catches. Results from these experiments have yielded a higher degree of confidence in the reported indices for 2021.

2. SURVEY METHODS

Stock status of snow crab is mainly assessed through trends in abundance and biomass indices calculated using data from a dedicated trawl survey. These data provide indices of recruitment, spawning stock, and other crab categories of biological or commercial interest. Fishery landings are used as inputs in stock projections and fishery catch-effort data is used to produce auxiliary indices of commercial abundance.

2.1. SPATIAL DESIGN

The sGSL snow crab trawl survey has undergone changes in sampling design, survey area and sampling protocols 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'x10' latitude-longitude grids and a small number of randomly selected sampling locations were then selected and held as fixed stations in subsequent survey, though stations were often discarded or relocated over subsequent years.

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 were 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 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, with about 20% of tows in 2012 and 2013 failing on their first attempt due to damage to the trawl. This failure rate was higher than in previous years, leading to increases in lost sea time and expenses. To mitigate this, the survey vessel was allowed to move 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 insure that survey catches would remain as representative samples of their assigned grids, as was the intent of the original sampling design.

Tow rejection rates subsequently decreased over time, as more and more sampling stations were moved to alternate sampling stations. By 2020, more than half of survey stations had been moved this way, with a majority of these having been moved multiple times (Table 1). An example of station movement within a grid is shown in Figure 3.

The accompanying decrease in tow rejection rates has rightly been highlighted as an indicator of preferential sampling of more trawlable areas over less trawlable areas.

2.2. FISHING 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 Europe. 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 550 to 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 group and measured directly on the vessel. Snow crab were measured for size using carapace width (CW), the chela height (CH) for males, carapace condition (Hébert et al. 1997), and gonad and egg clutch characteristics for females. Other species or taxonomic groups in the catch were weighed and counted. Since 2010, fish species for a random subset of 100 survey sampling stations were measured for length using an electronic measuring board.

2.3. 2021 SURVEY

The survey was performed by a chartered fishing vessel, the Avalon Voyager II, a 65-foot stern-trawling (850 HP) fiberglass boat, from July 17th and September 22nd, 2021. A total of 350 sampling stations (Fig. 4) were successfully trawled, requiring 417 trawling attempts in total. Five sampling stations could not be successfully trawled sampled and were abandoned. Data quality from the eSonar ® was high, with 310 tows having wing spread data of sufficient quality to estimate the trawl swept areas. For the remaining 40 tows, swept areas were set to the averages of the nearest 10 tows.

2.3.1. Trawling Experiment

Before the survey began, a short experiment was performed to identify the best method to control latent trawling during the winching of the trawl net. Two methods are considered. The first, called the slow method, was characterized by a slower winching and slow reversing of the survey vessel towards the resting position of the trawl after active trawling has stopped. The second method, called the fast method, was characterized by higher winch speed operation along with an increase in vessel speed after active trawling stops, with the aim of increasing cable tension so as to raise the trawl from the sea bottom as rapidly as possible.

On July 12th and July 13th, a total of 20 tows were performed at a site 30 kilometers southwest of Cheticamp, Cape Breton (Fig. 5). Ten tows using the slow method and ten tows using the fast method, generally alternating between the two methods. Probes were attached to various parts of the trawl to monitor the configuration of the trawl during the experiment: depth/pressure probes at the center and lateral positions on the trawl headline, depth/pressure probes on either trawl door, tilt probes attached to the center and lateral positions on the trawl footrope, as well as a device for measuring the cable hauling speed during winching.

2.3.2. Station Relocation Experiment

Another experiment was conducted during the survey to test whether the practice of relocating tows since 2013 had resulted in biases among survey catches in 2021. Thus, 100 of the 2021 survey's complement of 355 stations were randomly selected and moved to their original locations from 2013 (Fig. 6). The survey vessel was required to sample at these 100 locations, with a limit of three fishing attempts before stations were abandoned. The remaining 255 tows were fished as per the usual protocol, allowing movement to new alternate stations if required. As is the current practice, no acoustic scanning of the sea bottom for more amenable trawling bottom was permitted.

3. ANALYTICAL 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 chela height in males, and the abdomen width in females (Conan and Comeau 1986). Commercial crab are defined as mature male crab ≥ 95 mm CW. Commercial crab are divided into two component groups: new recruits to the fishery (also called R-1 crab), identified as soft-shelled crab (carapace conditions 1 & 2); and remaining or residual crab, which represents the portion of the commercial crab that is left over after the fishery, identified as hard-shelled crab (carapace conditions 3, 4 and 5). 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 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.

3.2. 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 and end-of-tow procedures.

3.3. STATION RELOCATION EXPERIMENT

Catch levels between the 100 fixed-station subset and the remaining 255 tows were compared for differences via a generalized mixed linear model (GMLM). Formally,

$$ln\mu_{ijk} = \beta_i + \lambda_j + ln a_k$$

$$z_{ijk} \sim NB(\mu_{ijk}, r)$$

$$\lambda_j \sim N(0, \sigma_\lambda^2)$$

where μ_{ijk} is the predicted mean for sex *i,* length category *j* and tow *k*, β_i is the log-linear intercept parameter, λ_j is a normally-distributed random effect for crab size *j* with variance parameter σ_λ^2 (divided by millimetre size categories), and a_k is the swept area. Observed counts z_{ijk} are assumed to follow a negative binomial distribution, with mean μ_{ijk} and dispersion parameter *r.* The analysis was performed using the Generalized Linear Mixed Models (GLMM) using the Template Model Builder package (glmmTMB version 1.0.2), compiled under R version 4.0.

3.4. ABUNDANCE AND BIOMASS

The survey bounds are defined by a polygon with a surface area of 57,842.8 km^2. The portions of the management Areas and buffer zones which overlap with the survey polygon were used to define corresponding sub-polygons which partition the survey area (Fig. 7). A small portion of the survey polygon, called zone A, is not assigned to any snow crab management Area.

Kriging with external drift was used to estimate all abundance and biomass indices (DFO 2012a). Survey catches were standardized by trawl swept area prior to analysis. 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).

3.5. SURVIVAL AND EXPLOITATION RATES FOR COMMERCIAL CRAB

Annual exploitation rate (F_t) is defined as a proportion represented by fishery landings L_t for fishing year *t* over the commercial biomass (B_{t-1}) estimate from the previous year:

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

Annual survival rate of commercial crab (S_t) is calculated as the exploitation rate plus the fraction of commercial crab that remain (R_t) after the fishery:

$$S_t = F_t + R_t / B_{t-1}$$

Annual survival rates projection are variable, being subject to estimation error, changes in survey catchability and carapace condition identification errors.

3.6. RISK ANALYSIS AND CATCH OPTIONS

The risk analysis calculated the probabilities of two events: that the remaining biomass from the 2022 survey would be below the Upper Stock Reference of 10,000 t, or that the total commercial biomass from the 2022 survey would be below the limit reference point of 41,400 t. These probabilities were calculated using projected recruitment biomass to the fishery (R-1) in 2022, application of the average mortality rate in the past 5-years, and application of the proposed TAC level.

The projected R-1 biomass in 2022 was estimated using a Bayesian model (Surette and Wade 2006; Wade et al. 2014), based on survey abundances of pre-recruits R-4, R-3 and R-2. The model incorporated estimation errors in the abundances, which are carried over in the projection. TAC recommendations are set as a function of an estimate of total commercial biomass according to the prescribed Harvest Control Rule for snow crab (DFO 2014). The impact of varying levels of bias on these risk probabilities was considered, along with the bias associated with the R-1 projection.

4. RESULTS

4.1. FISHERY PERFORMANCE

Unstandardized CPUEs in all four management Areas increased in 2021 relative to 2020 (Fig. 8), on the order of 20-30%. The quota decrease, as well as an early start to the fishing season in management Areas 12, 12E and 12F, likely contributed to the rise in CPUEs in 2021. CPUEs have also likely been influenced by extensive local Area closures in recent years, which continue to pose significant challenges to the snow crab fishing fleet. Some Area closures arose due to the occurrence of high proportions soft-shelled crab in fishery catches, but the bulk of closures arose as part of protective measures to minimize the risk of gear entanglement of NARW. Dynamic NARW area closures, in the form of blocks of 10’x10’ grids, have been used since 2018, while static NARW area closures were also used during the 2018 and 2019 fishing seasons. The timing and extent of these closures have varied much in the four years of usage, significantly affecting fleet dynamics as a result.

4.2. TRAWLING EXPERIMENT AND PASSIVE TRAWLING

The duration of the passive trawling phase for the fast method was a short 20.2 seconds (s), with a standard deviation of 8.2 s, while the duration for the slow method was a much longer 169 s with standard deviation of 39 s (Table 2). Moreover, attached pressure probes revealed that the trawl doors lifted off the bottom after only a few seconds upon application of the fast method. For the slow method, the doors lifted after 30-60 seconds.

Based on these results, the fast method was applied to the 2021 survey, resulting in a much shorter passive trawling phase than in previous years, with a median duration of 18 s, compared to ~90 s in 2019 and 2020, and 45 s in 2017 and 40 s in 2018, prior to the vessel change. Passive phase duration for survey years 2014 to 2021 shows much variation, indicating that end-of-tow practices have varied in recent years, despite the fact that there was no change in survey captain (Fig. 9).

4.3. STATION RELOCATION EXPERIMENT

For simplicity, we will refer to the subset of 100 stations fixed to their original 2013 survey locations as the “fixed” set, and the remaining 255 stations as the “free” set for the remainder of the text. Of the 100 fixed stations, 78 stations were successfully trawled during the first attempt, 12 stations in their second attempt, 5 stations in their third attempt, and 5 stations were abandoned after three failed attempts. The remaining 255 free stations had 232 stations which were successfully sampled during the first attempt, 16 in their second attempt, 5 in their third attempt, and 2 after their fourth attempt, and no stations were abandoned (Table 3).

All sizes combined, total catches among male and female crab were 16.2% and 10.1% lower among fixed stations than free stations. Standardized size-frequencies among males shows that fixed stations catches were generally 10-20% lower than those of free stations across the entire size range of crab found in the survey, with the exception of instar VIII crab (35-44 mm CW), which were almost 50% lower (Fig. 10). Catch differences among females were on the order of 10% lower among fixed stations relative to the free stations, with catches of instar VIII crab at comparable levels between the two groups, in contrast to males (Fig. 10).

The formal analysis using a GLMM yielded an effect value for males of -17.8% with 95% confidence interval of (-13.5%, -21.9%) with $p \ll 0.001$. For female crab, the estimated difference was smaller at -10.4% with 95% confidence interval (-3.0%, -18.4%) with $p = 0.008$. For both sexes combined effect is -15.4% with 95% confidence interval of (-11.6% , -19.1%) with $p \ll 0.001$. For commercial crab, average catches were 23.7% less by weight among fixed stations. Kriged biomass estimates for commercial crab were 67,825 t among fixed stations and 85,721 t among free stations, corresponding to a difference of -20.9% (Table 4).

These results seem to indicate that relocating survey stations has led to an overestimation of crab abundance. However, this conclusion relies heavily on the assumption that average densities between the two data sets differ only by reason of the applied treatment. While the random selection of the 100 station ensures that this is true if the experiment was to be repeated a large number of times (i.e. in the expectation), an investigation showed that the particular selection that was used in 2021 already contained catch differences in years prior. In particular, commercial biomass among the 100 selected grids were 17.0% lower in 2019 and 16.5% lower in 2020, relative to survey catches in the 255 other survey grids.

In light of these results, the observed difference of -23.7% observed for commercial catches in 2021 are partially due to differences in local density which were already present in 2019 and 2020. If we assume that the overall abundance and spatial distribution of commercial crab was similar between 2020 and 2021, then there might be an additional 6-7% difference due to survey station relocations, though this difference might as well arise from changes in spatial distribution or catchability changes between the 2020 and 2021 surveys. Thus, results from this analysis remain inconclusive.

4.4. SIZE DISTRIBUTION

Survey size distributions for each tow were standardized by trawl swept area, then averaged across all tows from the survey and the resulting densities scaled to the survey area. Size distributions by maturity are shown for male crab in Figure 11 and female crab in Figure 12.

Instars are size groups of crab, numbered with roman numerals, which correspond to the number of pos-larval moults crab have undergone. Size clusters corresponding to these instars are readily visible in size-distributions, most notably instars V (~13 mm CW), VI (~20 mm CW), VII (~29 mm CW) and VIII (~40 mm CW). Smaller instars are not caught by the survey trawl. Instars IX (~50 mm CW) and larger have more and more size overlap, making them harder to distinguish for most years. A notable feature in 2021 is an exceptionally strong peak in instar VIII juveniles, presaged by a strong peak of instar VII juveniles in 2020. Mature female crab are mainly composed of instars IX and X, while male crab reach maturity at instars IX though XIV.

Because the fishery is a size-selective process, annual variation in crab sizes was examined for legal-sized soft-shelled mature males (i.e. fishery recruits). Size among these recruits varies more than in mature females, from a mean of 108.6 mm CW in 2001 to high of 114.6 in 2008. The mean size then decreased to 109.0 mm CW in 2010-2011, increased to 112.8 mm CW in 2015, then decreased to a low level of 109.0 mm CW in 2018 and has since remained at this level (Fig. 13).

Mature females have undergone changes in size distribution since 1997, with the mean size increasing from 57-58 mm CW in 1997, to a high of 61.6 mm CW in 2005. Since 2005, mean size has decreased to 56.5 mm CW in 2019, 56.8 mm CW in 2020 and 56.6 mm in 2021, the lowest in the series (Fig. 13). The range of sizes among mature females has been steadily decreasing over the period from 1997 to 2021, with the interquartile range (IQR) decreasing from 13 mm CW to 10.5 mm CW from 1997 to 2005, and decreased to record lows of 9.3 mm CW in 2020 and 9.4 mm CW in 2021. This may be an indication that higher proportions of females are maturing at instar X, with fewer maturing at instar XI. These changes are likely driven by density-dependent maturation, environmental or genetic changes.

4.5. STOCK INDICES

The two experiments performed during the 2021 survey have shed new light on the impact of trawling protocol and survey design modifications on survey stock indices.

The 2021 results from the pre-survey trawl experiment and the successful implementation of the fast winching method during the 2021 survey imply that trawl swept area estimates may be regarded as not being significantly under-estimated because of unaccounted trawling during winching of the trawl. This stems from the fact that: 1) the duration of the passive trawling phase is much shorter (~20 s) than the active trawling phase (~330 s) and that 2) the trawl doors lift from the bottom shortly after winching has begun, indicating that trawling efficiency is likely much lower during passive trawling. Therefore, passive phase trawling is not a likely cause of overestimation in observed survey catches in 2021. However, it remains a possibility that the Avalon Voyager II has a higher catchability, at least for intermediate sized crab, than the previous survey vessel the Jean Mathieu. The 2021 survey indices are thus considered more reliable than those of the previous two years, although, results from the survey station relocation experiment were inconclusive.

4.5.1. Commercial Biomass

Commercial biomass for the sGSL is estimated at 80,950 t, with a 95% confidence interval of (70,543, 92,451 t) (Table 5). Commercial biomass estimates have been more or less constant for the past four years, with 77,748 t in 2020 being the lowest and the 2021 estimate being the highest. The spherical variogram model used for interpolating the commercial biomass had a nugget value of 9.3×10^5, a sill at 3.8×10^6 and a range of 11.4 km.

Fishery recruitment in 2021 increased by 6.9% to 62,473 t (53,650 to 71,590 t), representing 77% of the commercial biomass. Residual biomass (i.e. commercial crab with carapace conditions 3, 4 and 5) remained unchanged at 19,144 t (15,997 to 22,726 t). Residual biomass was dominated by carapace condition 3, representing 79% of survey catches, with 17% made up of carapace condition 4 crab and 4% carapace condition 5 crab (Table 6). The large proportion of carapace condition 3 in the residual biomass shows that the post-fishery population is young and does not show signs of an ageing population.

The spatial distribution of commercial crab was similar to 2018 to 2020, with crab concentrations over Bradelle Bank, to the south and west of the Magdalens, moderate concentrations in Shediac Valley and Area 19. Relative to 2020, concentrations decreased in Zone F, and increased in the Baie des Chaleurs and off the coast of Gaspé (Fig. 14). The spatial distribution of the residual component of commercial crab in 2021 increased in three regions: Area 12F, likely a result to NARW closures, the mouth of the Baie des Chaleurs and off the coast of Gaspé, and to the southwest of Bradelle Bank (Fig. 15). The residual component decreased to relatively low levels in Area 19.

A breakdown of the commercial biomass by management Area and buffer zone is shown in Table 7. The 2021 trawl survey estimate of commercial biomass for Area 12 was 69,022 t (60,169 to 78,804 t) representing 86.0% of the biomass located within the four management Areas. The 2021 post-fishery trawl survey estimate of the commercial biomass for Area 19 was 6,550 t (4,806 to 8,722 t), representing 8.2% of the biomass located within the four management Areas. In Area 12F, the commercial biomass from the 2021 trawl survey was estimated at 4,244 t (2,938 to 5,937 t), representing 5.3% of the biomass located within the four management Areas. In Area 12E, the commercial biomass from the 2021 trawl survey was estimated at 453 t (25 to 2,213 t), representing 0.5% of the biomass located within the four management Areas. An estimated 744 t of commercial crab lie within buffer zones or the unassigned zone above Area 12E.

4.5.1.1. Exploitation Rate

The exploitation rate for 2021 was estimated at 31.5% based on the 2020 survey commercial biomass estimate (Table 8; Fig. 16). Exploitation rates have varied between 21.0% and 44.7% from 1998 to 2020, with an average of 35.0% over the period from 1997 to 2021.

4.5.1.2. Survival Rate

Estimates of annual survival rates have declined 5% annually for the past four years to be low in the past three years, declining from 70% in 2018, to 64% in 2019, to 60% in 2020, to 56% in 2021 (Table 5). The average survival rate was 69% over the period from 1998 to 2021, with the 2021 value being the second lowest in the series. These decreasing survival rates are a cause for concern, possibly indicating that mortality processes are on the rise. These may include either natural mortality due to predation or intraspecific competition among mature males, or an increase in fishery discard mortality.

4.5.2. Spawning Stock

Mature male abundance 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 (Fig. 17). 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 a high of 420 million in

2021. In the last four years, the quantity of legal-sized mature males has been fairly constant at 143 to 149 million animals, and the increase has been driven by the abundance of sub-legal sized animals, passing from 173 million in 2018 to 271 million in 2021.

Mature female abundance was over 600 million animals from 1999 to 2004, then declined to 237 million in 2006 (Fig. 18). Since then, female abundance has gradually increased from a to a high of 777 million in 2020. In 2021, abundance decreased by 25% to 585 million crab, relative to 2020. Primiparous abundance was seemingly 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 and 123 million in 2021. Primparous females represent an average of 25% of the spawning stock. The 5 mm CW decrease in mature females size (Fig. 13) from 2005 to 2021 translates to a 20% decrease in individual fecundity, though the increase in abundance over the same period is more than offset by the apparent increase in abundance over the same period.

4.5.3. Recruitment

4.5.3.1. Juveniles

A very strong pulse of juvenile recruitment, in the form of instar VIII crab, was present in 2021 survey catches (Figs. 11 and 19). The abundance of male instar VIII crab, defined as immature crab with 34 to 45 mm CW, stands at 329 million animals, up 125% from 147 million and 144% from 117 million in 2019 and 2020, respectively (Fig. 19). We note that the error associated with this index is higher than for larger crab, partly due to the lower catchability of the trawl at these smaller sizes. Moreover, 20% of catches of instar VIII in the 2021 survey stemmed from a single tow off the coast of Souris, PEI, corresponding to remarkable local densities of 1 crab / m^2 at that location. Male instar VIII crab is expected to reach commercial size in 5-6 years, though some portion may skip a moult and/or mature at sizes smaller than commercial sizes.

4.5.3.2. Fishery

Fishery recruitment biomass (R-1) was relatively stable over the period from 2018 to 2021, with a low of 58,995 t in 2019 to a high of 62,473 t (53,650 t to 71,590 t) for the 2021 survey. However, a different pattern was predicted using the Bayesian model (Surette and Wade 2006; Wade et al. 2014), using R-4, R-3 and R-2 estimates from the previous survey year as inputs. Predictions were underestimated for 2018 at 47,700 t and 2019 at 49,820 t, while predictions were overestimated at 74,280 t for 2020 and 79,870 t for 2021. Although predictions are well within the 95% credibility interval, the associated uncertainty is high (Fig. 20). The discrepancy between the predicted and observed values in recent years are likely driven in part to survey catchability increases in 2019 among sub-legal sized crab, though it is unclear to what extent this remains a factor for the 2021 survey.

Fishery pre-recruit indices declined moderately in 2021 relative to 2020, with R-4s declining by 24.8%, R-3s by 9.3% and R-2s by 6.9%. While these changes may be a reflection of true population decreases, they may be also be the result of the change in end-of-tow procedures or the inclusion of the original 2013 survey stations in the index during the 2021 survey. Even considering the survey catchability increases in 2019, fishery recruitment indices remain high in 2021, with an R-2 estimate of 188.9 million crab just shy of the record of 203 million in 2020.

The spatial distribution of fishery pre-recruits is broadly similar to that of 2020, with decreases discernible in Area 19 and 12F, along the Cape Breton corridor, and south of Area 19. Regional increases are observed in the Baie des Chaleurs, north of the Acadian Peninsula, as well as along the Gaspé coast and the Shediac Valley (Fig. 21). Concentrations remain high to the west of the Magdalens and off the northern shore of PEI.

The predicted fishery recruitment for 2022 is estimated at 73,120 t (48,590 t -105,200 t), using the Bayesian model. This would represents a 17% increase from the observed recruitment in 2021, though it is well to recall that the prediction has been over-estimated by about 22% for the past two years.

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 belonging to critical, cautious or healthy zones, with each zone being assigned its particular management or harvest control rules.

The sGSL snow crab stock has three defined reference points (Figs. 22 and 23). A limit reference point B_{lim} = 10,000 t, was defined according to the lowest survey residual biomass observed from 1997 to 2008. An upper stock reference B_{usr} = 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), 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 2022 sGSL fishery is 80,950 t (70,543, 92,451 t; Table 5), which is well within the healthy zone of the precautionary approach framework (Fig. 22).

5.2. RISK ANALYSIS

Inputs to the risk analysis were the commercial biomass from the 2021 survey (80,950 t), the projected fishery recruitment from the Bayesian model (73,120 t), and the 5-year average annual survival rate of 62%. A provisional TAC of 33,163 t, corresponding to an exploitation rate of 40.96%, as per the harvest control rule, was used for the 2022 fishery (Fig. 23).

The risk analysis indicates that this TAC results in a very low probability of the commercial biomass would be below the upper stock reference point of 41,400 t, and a low 1.4% probability of the residual biomass would be below the limit reference point of 10,000 t after the 2022 fishery. Predicted recruitment has seemingly been overestimated in the past two years, on the order of 16,000-18,000 t (Fig. 21). However, even considering these levels of over-estimation, the likelihood of the commercial biomass would be below B_{usr} in 2022 remains low, given the strong fishery recruitment. Thus, the snow crab stock is projected to remain in the healthy zone of the PA in 2022 (Table 8; Fig. 23).

6. ENVIRONMENTAL CONDITIONS

Environmental factors, such as water temperature, can affect the timing 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 Areas 12E and 12F are higher (1 to 7 °C) than in snow crab grounds in Area 12. Bottom temperatures in Area 19 are usually 1 to 2 °C warmer than on the traditional crab grounds in Area 12 (Chassé and Pettipas 2009).

Overall, bottom temperatures for the sGSL for 2021 were much warmer than normal. Bottom temperatures in September 2021 were compared to the mean temperatures over the period from 1991 to 2021 using data from the September multi-species survey. Temperatures for zone 12 were 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 Gaspe Peninsula. This area includes the Orphan’s and Bradelle Banks. Bottom temperatures near the coasts of New Brunswick and PEI were significantly warmer than normal, up to 5 °C in some areas. Bottom temperatures in Area 12E were 1-2 °C above normal, Area 12F temperatures were normal, and Area 19 temperatures were from 0.5-2 °C above normal. The only areas with below normal temperatures were around the northeastern tip of PEI, the western area of the Magdalen Islands and a small area to the northeast of the Acadian Peninsula (Fig. 24). Bottom temperatures at the Shediac Valley station (Viking buoy) consistently warmed up during the summer of 2021, leading up to a temperature anomaly for September of +1.9 °C.

The surface area of the sGSL with bottom temperatures from -1 to 3 °C in September, an index of snow crab habitat, rose slightly in 2021 from 2020. However the temperature within this area, at an average 1.6 °C, represents an increase of 0.3 °C from 2020 (1.3 °C) and a 0.6 °C increase from 2019 (1.0 °C). This average temperature within snow crab habitat is now at its highest of the 1971-2021 time series (Fig. 25).

Surface waters in 2021 warmed up very quickly during the last three weeks of August, with sea surface temperatures becoming much warmer than normal. Sea surface temperature anomalies decreased somewhat in September, but they rose again in October and November, at an average value of about 2 °C warmer than normal. At the same time, deep waters of the Laurentian channel continued their warming trend and were much warmer than normal. The above conditions led to the volume of water corresponding to the Cold Intermediate Layer (CIL), defined as waters < 1 °C, being one of the three lowest on record for September, from 1971 to 2021, with the first in 1980 and another in 2012. The CIL water volume for 2021, at ~500 km^3, is about 5 times lower than normal, and may be the lowest of the three on record, as the data for 1980 was scarce.

7. UNCERTAINTIES

Meaningful inference of temporal variation and long-term trends of snow crab stocks from survey catches relies on the survey having a robust sampling protocol, sampling design and proper standardization of observed catches. Survey catchability has likely varied in response to historical changes in sampling design, such as multiple areal expansions, survey station redistributions, and survey vessel changes. In particular, gradual relocating survey stations to alternate positions from year to year remains as possible source of bias in survey indices. Consequently, these changes in survey catchability imply that the commercial biomass indices on which the reference points for snow crab were defined may not be on the same scale at those of 2021.

Density and extent of local concentrations of snow crab vary in response to environmental changes, which can result in changes in crab movement, recruitment levels and mortality rates. Such changes, along with the uncertainties from the survey mentioned above, result in annual fluctuations in the observed local crab densities and specifically the proportion of commercial biomass among the different management Areas.

Changes in the environment, such as the general warming trend and the record high bottom temperatures observed in the sGSL in 2021 will likely lead to changes in life history processes including moulting and growth, reproduction, mortality and larval development, though how these processes will be impacted are presently not known.

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9. 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 Pettipas, R.G. 2009. Temperature Conditions in the southern Gulf of St. Lawrence during 2008 relevant to snow crab. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/087.

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. Proc. 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.

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: v + 18 p.

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. Sci. Advis. Sec. Res. Doc. 1997/086.

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.

Puebla, O., Sévigny, J.-M., Sainte-Marie, B., Brêthes, J.-C., Burmeister, A., Dawe, E. G., 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., 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.

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.

TABLES

Table 1. Frequency table showing the number of times survey stations have been relocated by survey year.

Year	0	1	2	3	4+
2013	283	59	12	1	0
2014	250	76	21	6	2
2015	216	88	32	13	6
2016	200	90	33	20	12
2017	187	93	34	21	20
2018	168	99	43	20	25
2019	159	94	42	26	34
2020	149	92	46	32	36
2021	225	44	30	27	29

Table 2. Summary results from the pre-survey experiment showing the duration of the latent passive trawling phase during winching of the trawl.

Date	Longitude	Latitude	Site	Treatment	Depth (fth)	Duration (s)
2021-07-12	6124.457	4630.751	1	slow	33	180
2021-07-12	6125.035	4630.987	1	fast	33	16
2021-07-12	6125.536	4630.315	2	fast	34	11
2021-07-12	6125.631	4630.497	2	slow	34	92
2021-07-12	6127.816	4631.257	3	slow	33	168
2021-07-12	6128.493	4631.097	3	fast	33	16
2021-07-12	6127.262	4631.838	4	fast	33	15
2021-07-12	6126.750	4632.072	4	slow	33	187
2021-07-13	6126.703	4632.287	5	slow	34	154
2021-07-13	6126.922	4632.445	5	fast	34	13
2021-07-13	6124.491	4632.783	6	slow	36	148
2021-07-13	6124.433	4632.700	6	fast	37	28
2021-07-13	6123.415	4632.499	7	fast	37	14
2021-07-13	6122.481	4632.664	7	slow	37	162
2021-07-13	6120.537	4632.246	8	slow	50	250
2021-07-13	6120.574	4632.219	8	fast	51	35
2021-07-13	6122.941	4632.095	9	fast	36	28
2021-07-13	6123.420	4631.923	9	slow	35	172
2021-07-13	6124.930	4632.955	10	slow	34	177
2021-07-13	6124.602	4632.583	10	fast	35	26

Table 3. Number of attempts required for a successful tow for the subset of 100 sampling fixed to their original positions in 2013, and the remaining free 255 sampling stations during the 2021 snow crab survey.

Attempts	Fixed tows	Free tows
1	78	232
2	12	16
3	5	5
4	-	2
Abandoned	5	0
Total	100	255

Table 4. Catch comparison between the subset of 100 sampling fixed to their original positions in 2013, and the remaining free 255 sampling stations during the 2021 snow crab survey.

Catch category	Method	Fixed tows	Free	Difference
Male density (# / km^2)	average	3.50 (2.84, 4.16)	4.18 (3.62, 4.73)	-16.2%
Female density (# / km^2)	average	0.89 (0.63, 1.16)	0.99 (0.77, 1.21)	-10.1%
Commercial density (t / km^2)	average	1.16 (0.89, 1.43)	1.52 (1.24, 1.79)	-23.7%
Commercial biomass (x 1000 t)	kriging	67.8 (54.1, 84.0)	85.7 (72.7, 100.8)	-20.9%

Table 5. Annual recruitment, residual and total commercial biomass (in tonnes) of sGSL 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) Observed	Recruitment (t) Predicted	Residual (t)	Commercial (t)	Landings (t)	Survival (%) Annual*	Survival (%) 5 year	ER (%)**
1997	37,910 (30,911-46,018)	-	27,688 (21,982-34,422)	64,518 (54,105-76,345)	17,249	-	-	26.7
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	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	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	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	39.3

Year	Recruitment (t) Observed		Recruitment (t) Predicted	Residual (t)		Commercial (t)		Landings (t)	Survival (%) Annual*	Survival (%) 5 year	ER (%)**
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)	79,870 (52,760-115,700)	19,144	(15,997-22,726)	80,950	(70,543, 92,451)	24,479	56.1	61.8	31.5
2022	-		73,120 (48,590-105,200)	-		-		-	-	-	-

** Calculated by the sum of the residual biomass and landings divided by the previous year's commercial biomass.*
***Calculated by the landings divided by the previous year's commercial bias.*

Table 6. Annual abundance (in millions) of commercial crab categories based on sGSL trawl survey data. Parentheses show standard errors.

	Pre-recruits			Recruits	Residual		
Year	R-4	R-3	R-2	CC 1&2	CC	CC 4	CC 5
1997	114.0 (12.5)	98.2 (10.5)	59.7 (6.6)	59.3 (6.5)	28.3	17.7	5.2
1998	135.3 (14.9)	91.3 (11.6)	60.3 (7.3)	50.9 (7.6)	24.9	16.0	8.6
1999	195.6 (21.5)	151.1 (16.6)	112.9 (14.6)	48.1 (5.4)	32.7	16.8	7.8
2000	237.5 (26.1)	159.1 (13.8)	88.4 (9.0)	68.4 (5.9)	10.3	7.4	2.5
2001	310.8 (34.2)	227.3 (17.5)	136.3 (12.8)	76.4 (8.4)	28.1	5.4	1.6
2002	164.3 (17.3)	242.2 (20.1)	202.2 (16.9)	112.3 (9.2)	21.7	4.3	0.9
2003	133.2 (15.8)	202.3 (16.2)	178.5 (14.0)	100.3 (7.5)	38.0	11.7	1.8
2004	85.8 (8.2)	122.9 (9.3)	144.1 (10.5)	143.3 (8.4)	28.2	9.9	1.2
2005	62.2 (5.7)	79.8 (6.3)	117.2 (9.7)	99.1 (5.6)	30.0	10.5	0.6
2006	54.1 (5.4)	49.6 (3.2)	65.7 (5.9)	84.2 (4.9)	29.2	5.8	1.0
2007	56.5 (5.0)	47.6 (3.5)	55.4 (4.9)	62.8 (3.8)	31.5	14.0	1.0
2008	80.6 (6.5)	54.6 (4.2)	45.8 (5.2)	49.1 (3.4)	23.0	11.4	3.0
2009	88.5 (5.9)	69.3 (5.5)	43.8 (4.8)	31.7 (2.3)	12.5	5.3	1.3
2010	140.8 (7.7)	110.3 (7.4)	72.5 (7.0)	32.8 (2.2)	20.6	4.2	1.6
2011	91.4 (6.0)	99.2 (6.5)	88.2 (5.9)	53.0 (3.7)	44.3	9.8	1.8
2012	95.7 (8.7)	86.4 (9.9)	80.5 (7.4)	86.6 (8.3)	37.9	5.7	1.2
2013	103.1 (9.3)	85.1 (9.6)	79.4 (8.1)	63.7 (7.3)	30.1	18.3	0.7
2014	105.1 (10.9)	93.6 (9.8)	117.2 (12.1)	73.3 (6.3)	29.6	13.1	0.6
2015	107.1 (7.6)	124.7 (12.3)	127.5 (11.1)	56.2 (5.2)	27.2	17.3	0.5
2016	113.1 (7.1)	124.8 (9.7)	101.6 (6.8)	125.9 (8.6)	30.6	14.7	0.1
2017	113.0 (7.7)	119.6 (9.2)	103.3 (7.2)	90.0 (6.9)	21.6	6.1	0.4
2018	135.6 (7.6)	116.5 (7.2)	108.3 (8.4)	115.6 (7.9)	34.6	4.5	0.8
2019	190.7 (11.8)	186.0 (13.0)	185.7 (16.0)	105.1 (7.8)	28.8	9.3	0.8
2020	180.9 (11.2)	170.3 (12.0)	203.0 (17.2)	103.5 (8.3)	29.8	7.2	0.6
2021	135.9 (7.6)	154.4 (9.5)	188.9 (15.3)	112.0 (8.1)	29.7	6.4	1.5

Table 7. Commercial biomass by management Area and buffer zones based on 2021 sGSL survey data. Parentheses show 95% confidence intervals. Labels are from Figure 7.

Areas	Area (km^2)	Biomass (t)	
Southern Gulf	57,842.8	80,950	(70,543 - 92,451)
Area 12	48,074.0	69,022	(60,169 - 78,804)
Area 19	3,813.0	6,550	(4,806 - 8,722)
Area 12E	2,436.9	453	(25 - 2,213)
Area 12F	2,426.8	4,244	(2,938 - 5,937)
Sum of management Areas[1]	56,750.7	80,269	
Unassigned zone above 12E **(A)**	667.9	61	(0 - 413)
Buffer zone 19/12F **(B)**	134.2	203	(61 - 509)
Buffer zone 12/ 19 **(C)**	289.5	480	(158 - 1,133)
Sum of total areas and zones	57,842.7	81,013	

[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 8. Risk analysis for different catch options for the 2022 sGSL snow crab fishery showing the probability that the residual commercial biomass would be below limit reference point, the probability that the total commercial biomass would be below the upper stock reference, and the expected biomass for the 2022 survey. In bold is the catch option corresponding to an exploitation rate of 40.96%, the rate as per the harvest control rule.

Catch option (t)	Probability		Predicted biomass for 2022 (t)
	$B_{res} < B_{lim}$	$B < B_{usr}$	
28,000	0%	0%	95,378 (70,101-128,140)
29,000	0%	0%	94,378 (69,101-127,140)
30,000	0%	0%	93,378 (68,101-126,140)
31,000	0.2%	0%	92,378 (67,101-125,140)
32,000	0.5%	0%	91,378 (66,101-124,140)
33,000	1.3%	0%	90,378 (65,101-123,140)
33,163	**1.5%**	**0%**	**90,214 (64,938-122,977)**
34,000	2.9%	0%	89,378 (64,101-122,140)
35,000	5.8%	0%	88,378 (63,101-121,140)
36,000	10.6%	0%	87,378 (62,101-120,140)
37,000	17.4%	0%	86,378 (61,101-119,140)
38,000	26.3%	0%	85,378 (60,101-118,140)
39,000	36.9%	0%	84,378 (59,101-117,140)
40,000	48.3%	0%	83,378 (58,101-116,140)
45,000	91.0%	0.1%	78,378 (53,101-111,140)
50,000	99.5%	0.4%	73,378 (48,101-106,140)
80,000	100.0%	48.1%	43,378 (18,101-76,140)
81,000	100.0%	50.9%	42,378 (17,101-75,140)

FIGURES

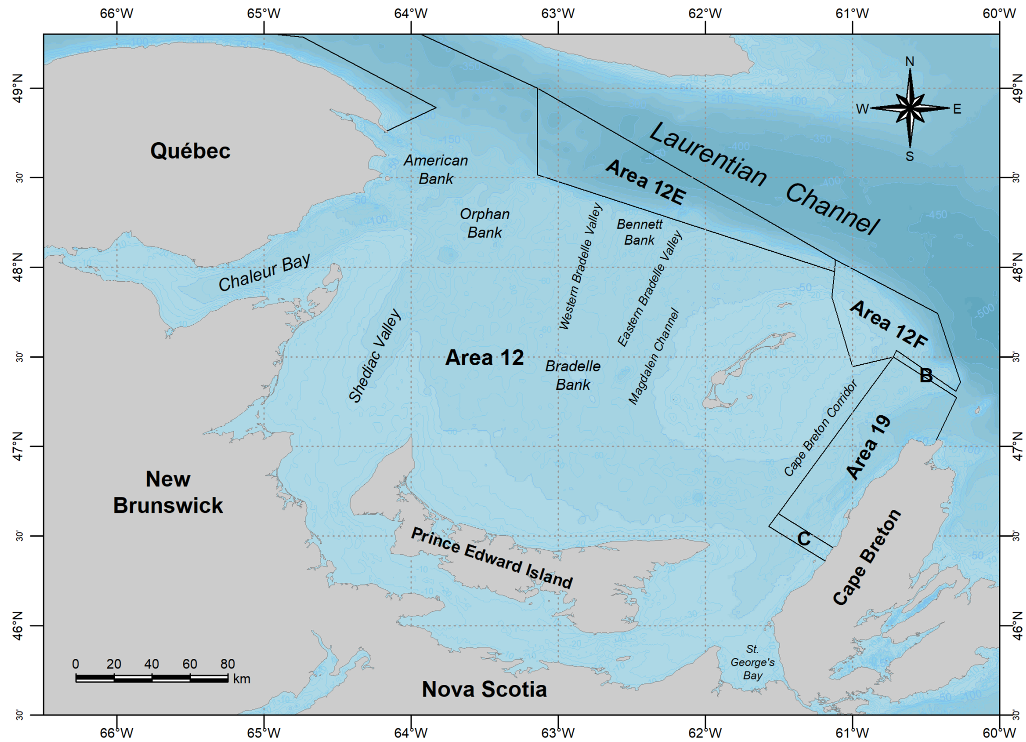

Figure 1. Map of the sGSL showing snow crab fishery management Areas, buffer zones (labels B and C), and common names for fishing grounds.

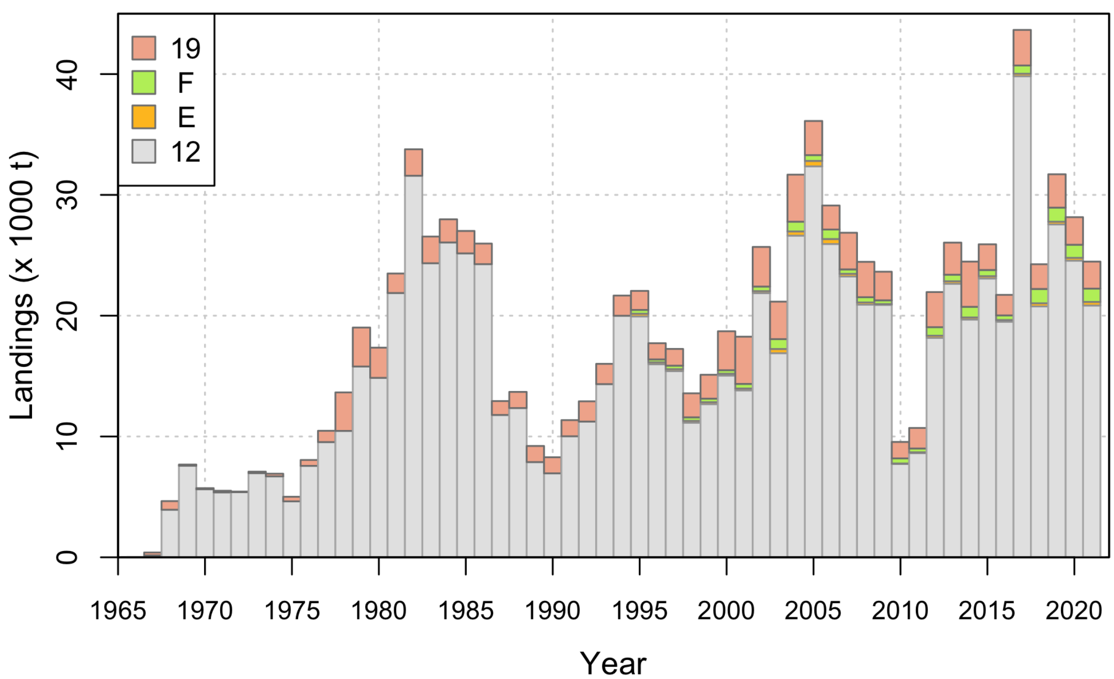

Figure 2. Annual landings (in tonnes) of snow crab by management Area in the sGSL.

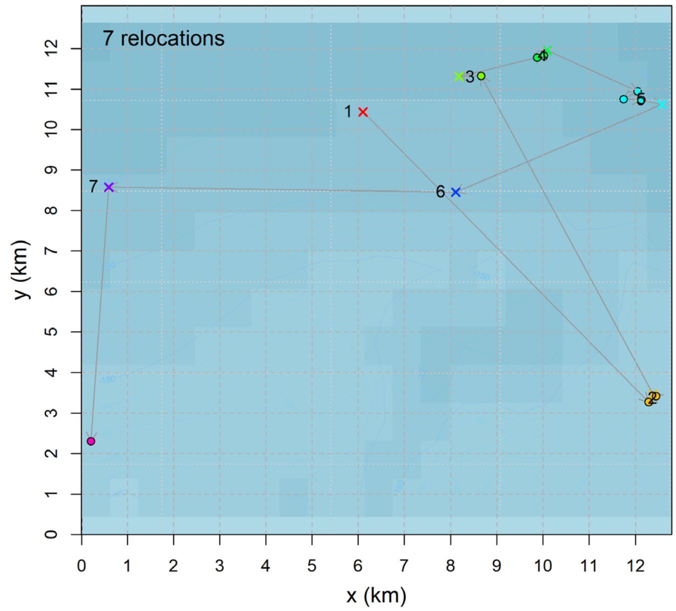

Figure 3. Example of a survey station which was relocated a total of 7 times over the period from 2013 to 2021. Circles indicate a successful tow while an x indicates a rejected tow.

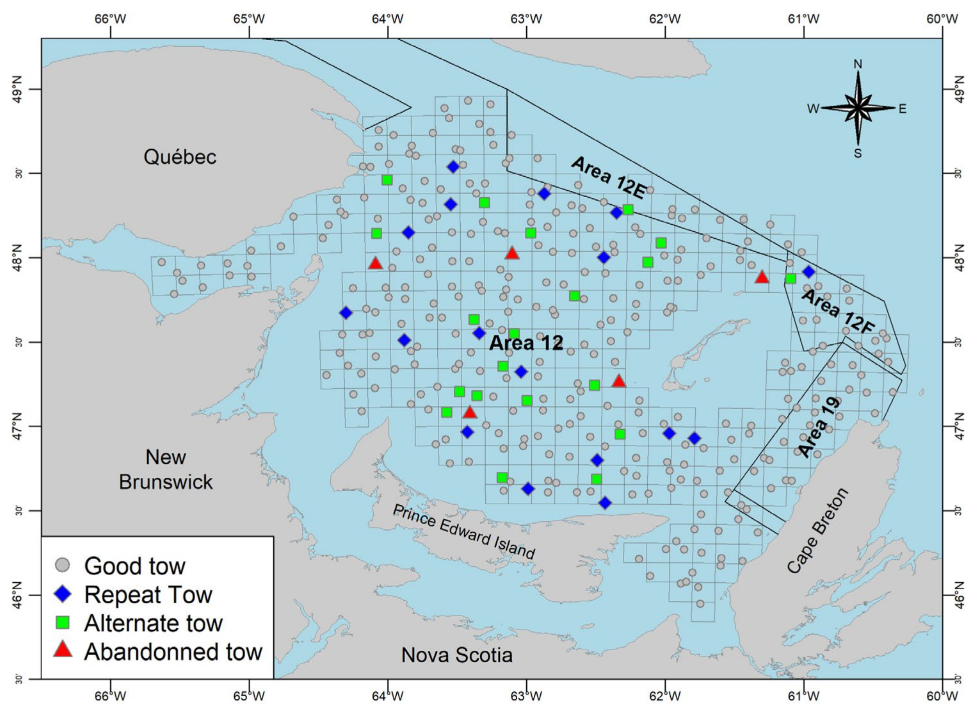

Figure 4. Locations of the 2021 snow crab trawl survey stations. Grey circles points are tows successfully trawled on the first try, blue diamonds show tows repeated at the same station, green squares show tows successfully trawled at an alternate station, and red triangles are abandoned tows. Survey sampling grids are shown in grey.

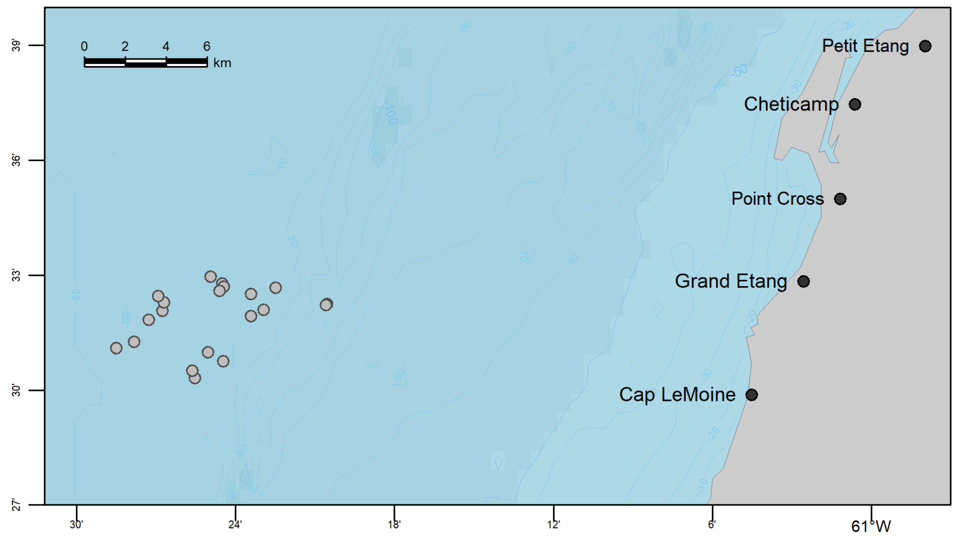

Figure 5. Locations of the 20 sampling stations for the trawling experiment, west of Cape Breton, to test the efficacy of two methods to control latent trawling during winching of the trawl net.

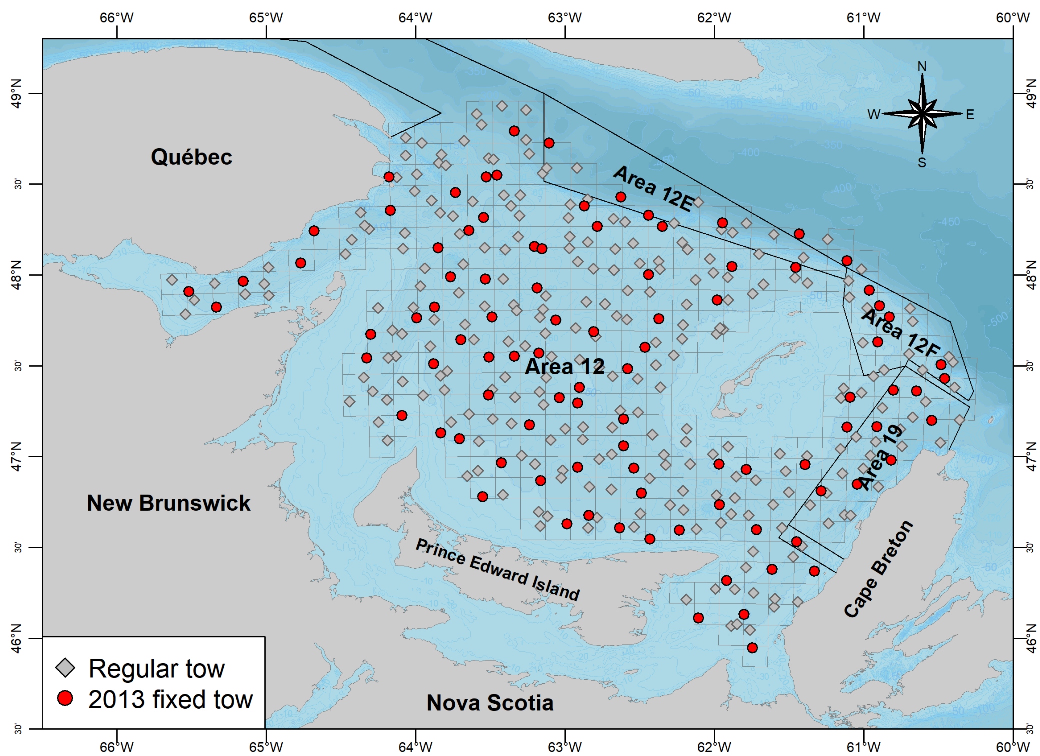

Figure 6. Map showing the 100 stations which were moved to their original 2013 positions (red circles) during the 2021 survey, along with the 255 remaining stations (grey diamonds). Survey sampling grids are shown in grey.

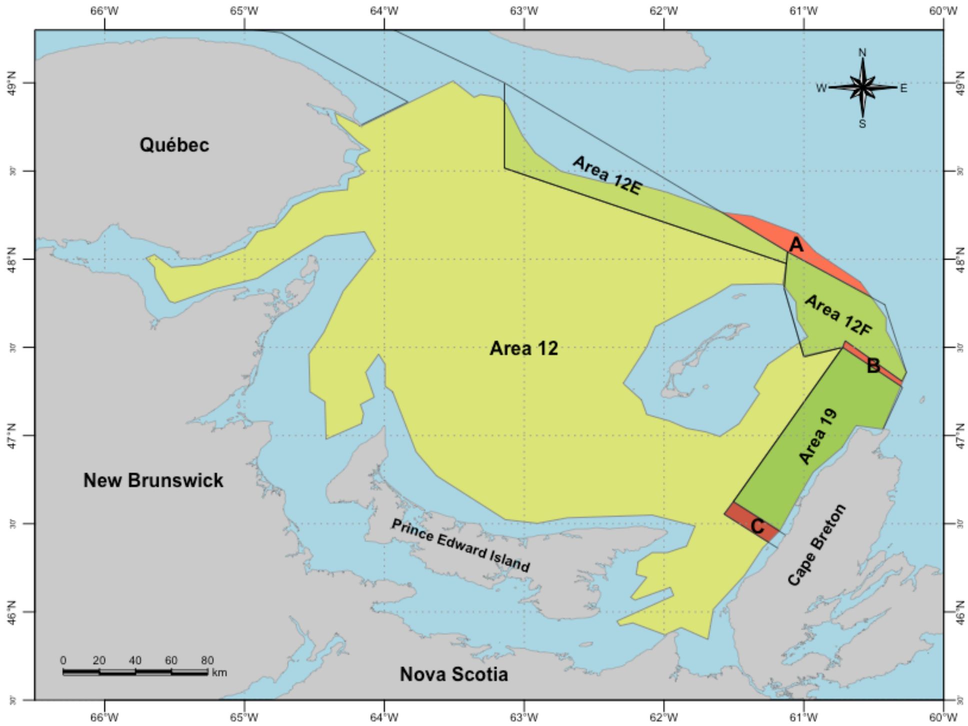

Figure 7. Polygons used for estimating survey stock indices. The unassigned zone north of Areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

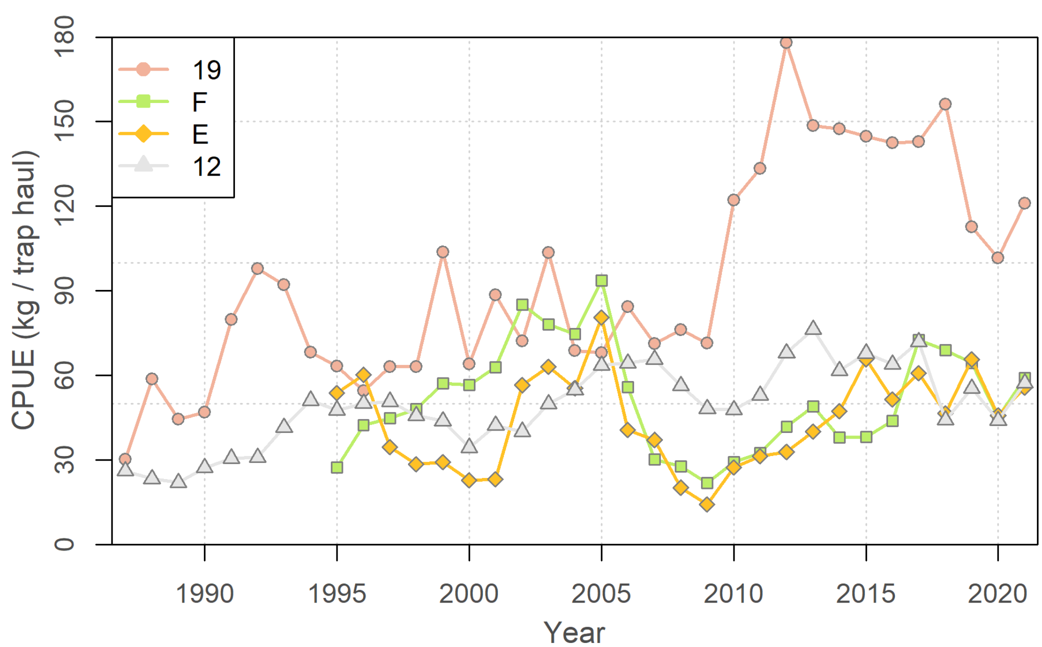

Figure 8. Catch per unit effort (CPUE; kg/th) by management Area in the sGSL, based on fishery logbook data.

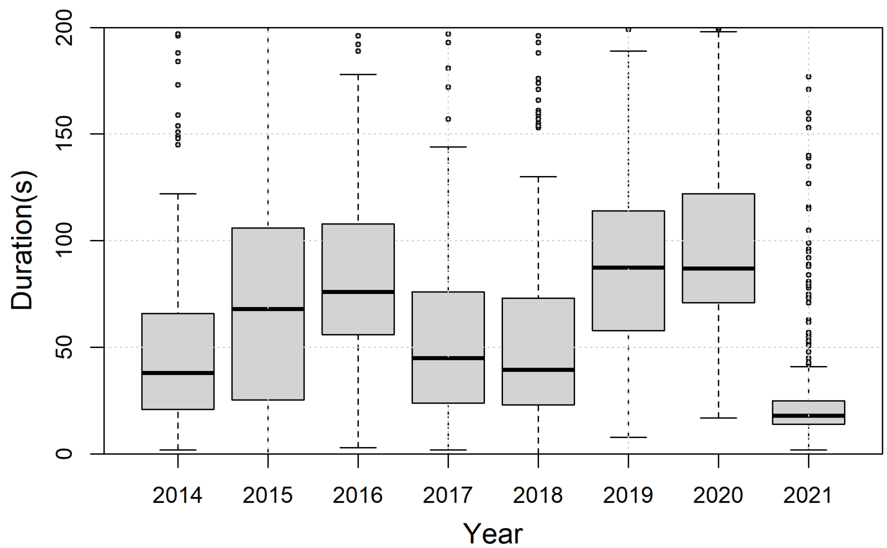

Figure 9. Box plot of annual passive phase duration for recent surveys. The new end-of-tow hauling method introduced in 2021 resulted in much shorter delays before the trawl lifted off the sea bottom during winching.

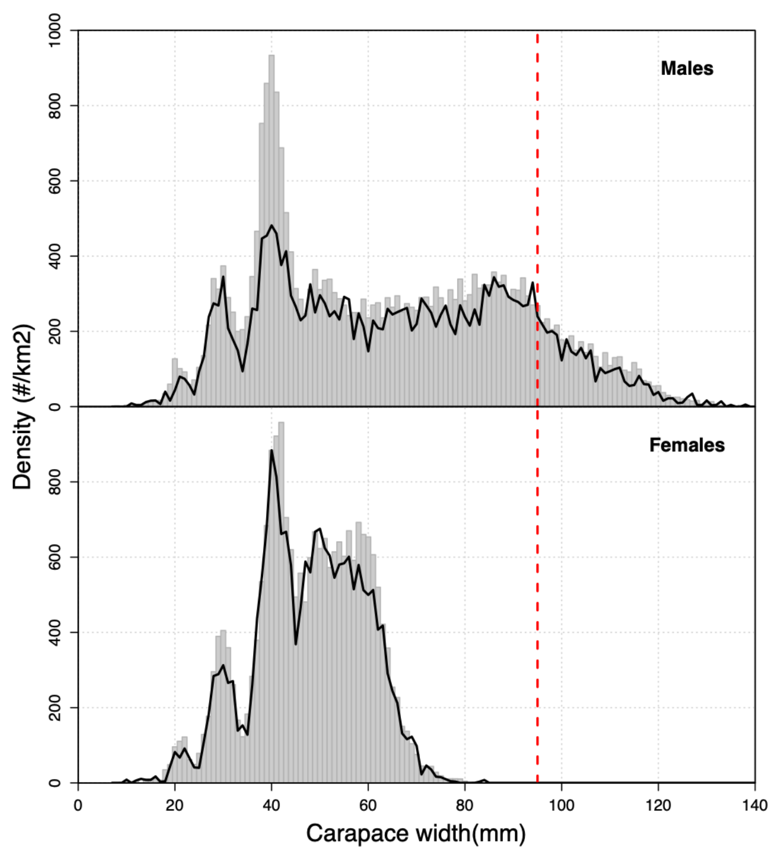

Figure 10. Comparison of size-frequency distributions between the 95 fixed stations (black line) and the 255 free stations (grey bars) from the 2021 snow crab survey. Catches were standardized by trawl swept area.

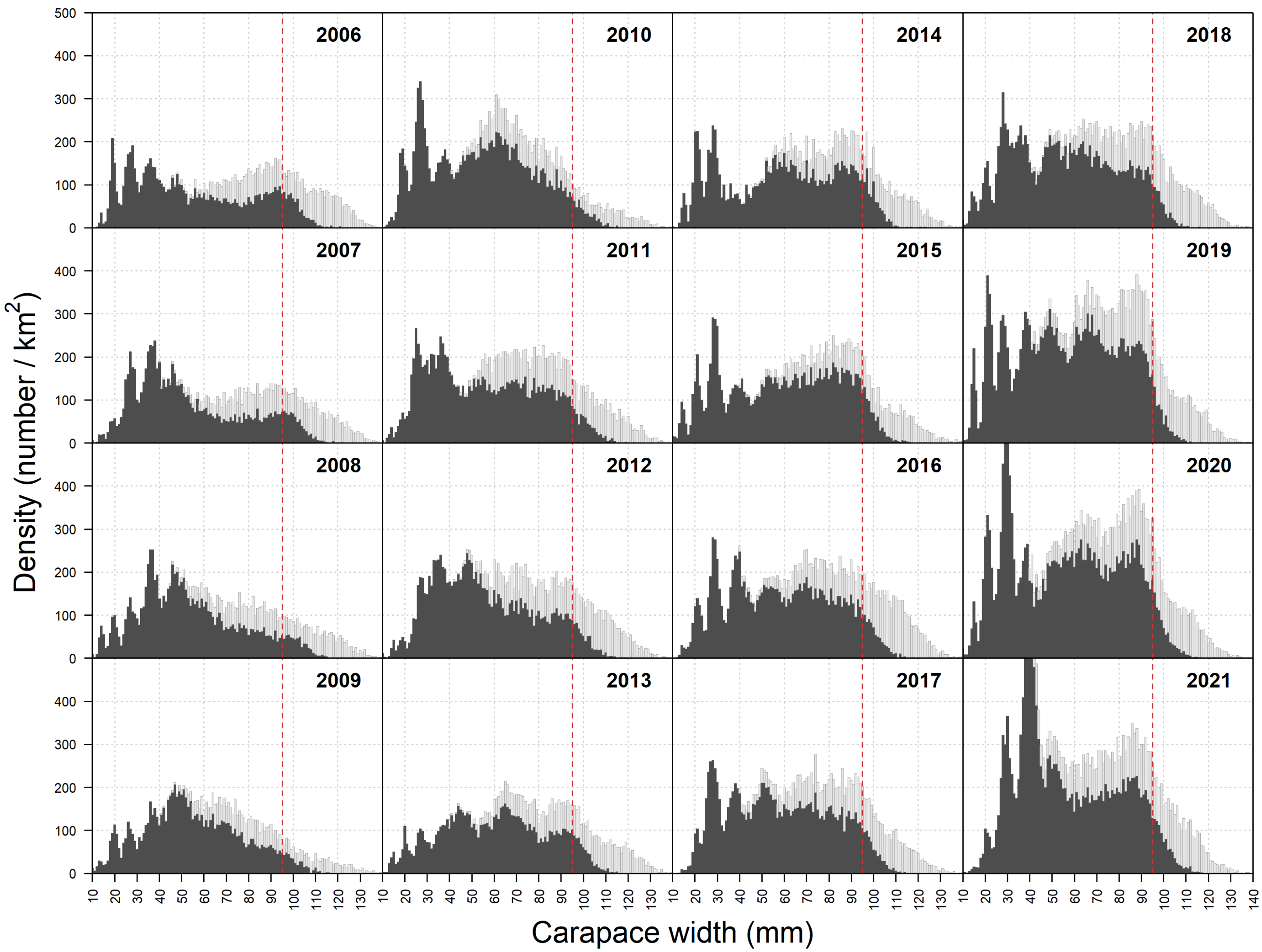

Figure 11. Annual size-frequency distributions of immature and adolescent (dark grey bars) and mature male (light grey bars) snow crab from the trawl surveys. The red dotted line shows the minimum legal size of 95 mm CW. Note that abundances for small crab for 2020 and 2021 exceed the scale of the plot.

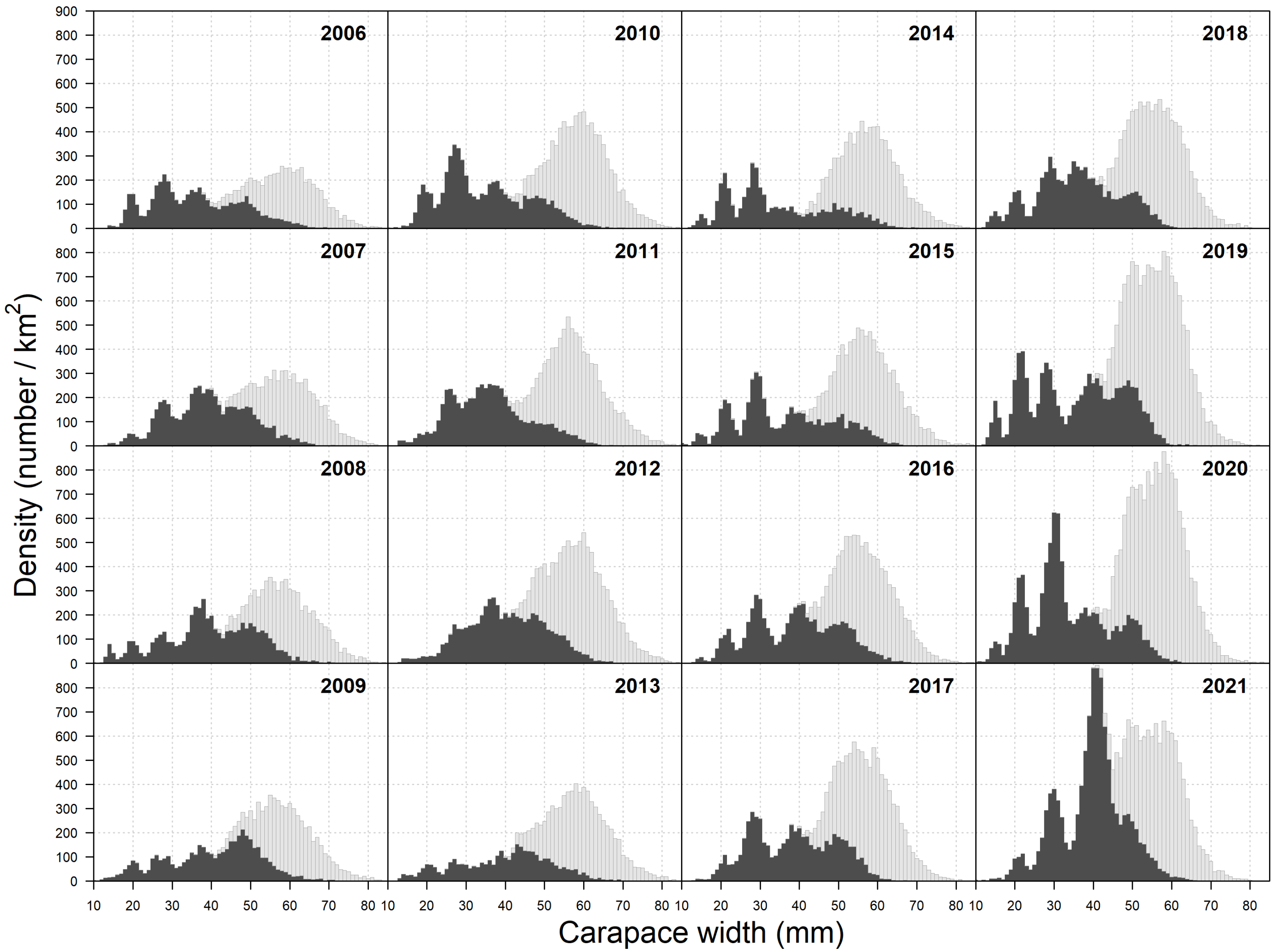

Figure 12. Annual size-frequency distributions of immature and pubescent (black bars) and mature female (grey bars) snow crab from the trawl surveys.

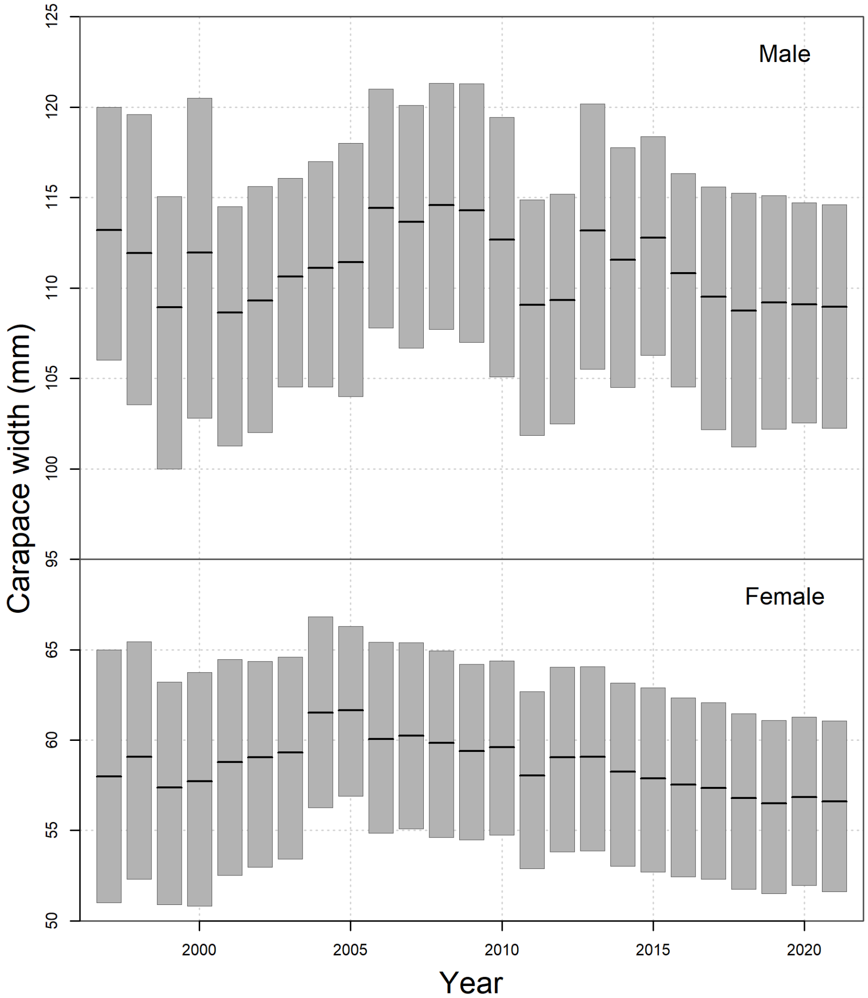

Figure 13. Size variation of mature legal-sized male (top panel) and mature female (bottom panel) snow crab observed in trawl survey data. Middle line shows the mean carapace width and grey bars show interquartile size range.

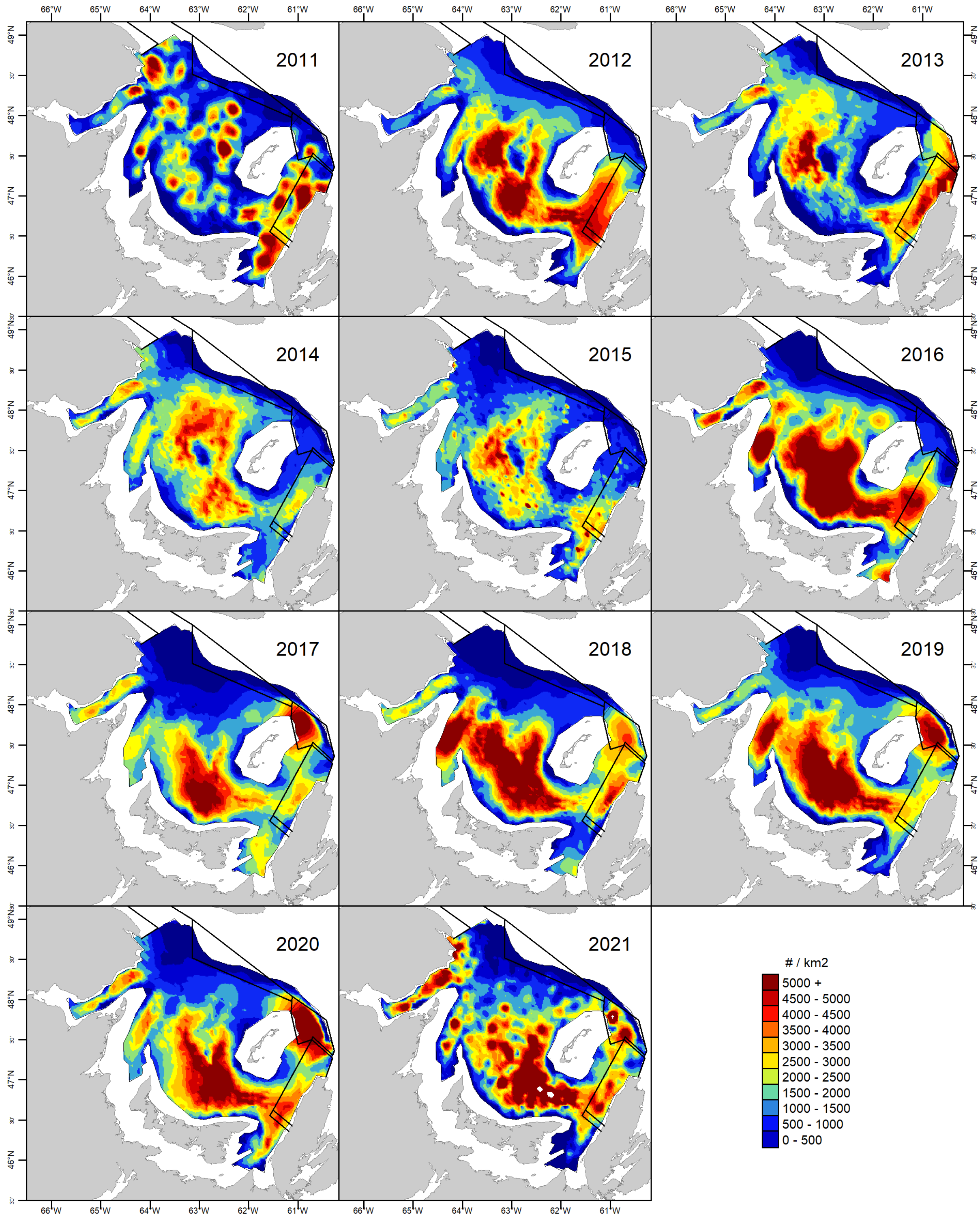

Figure 14. Commercial snow crab spatial distribution from 2011 to 2021 based on sGSL trawl survey data, interpolated using kriging.

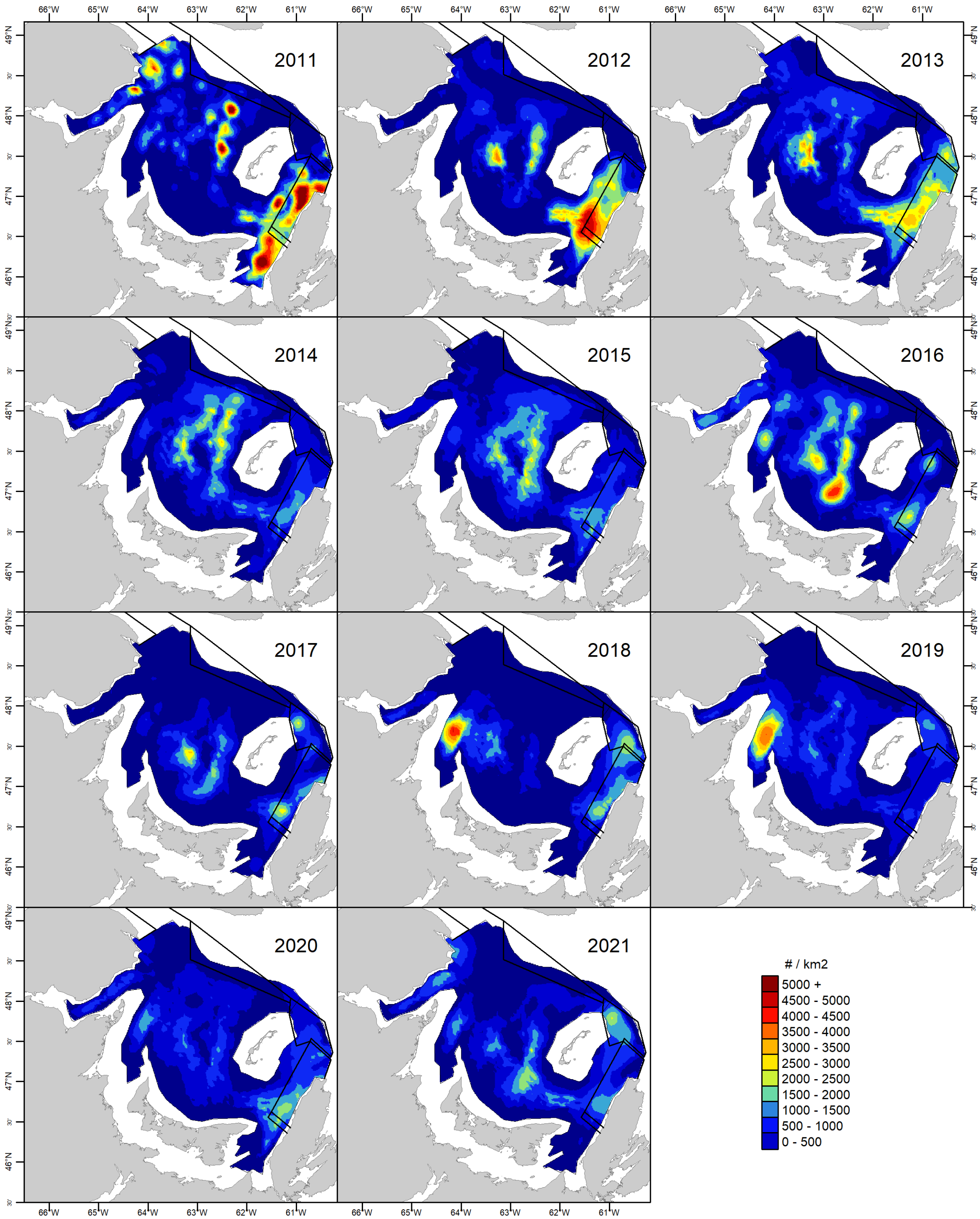

Figure 15. Spatial distribution of the residual component of commercial snow crab (carapace condition 3,4, & 5) from 2011-2021 based on sGSL trawl survey data, interpolated using kriging.

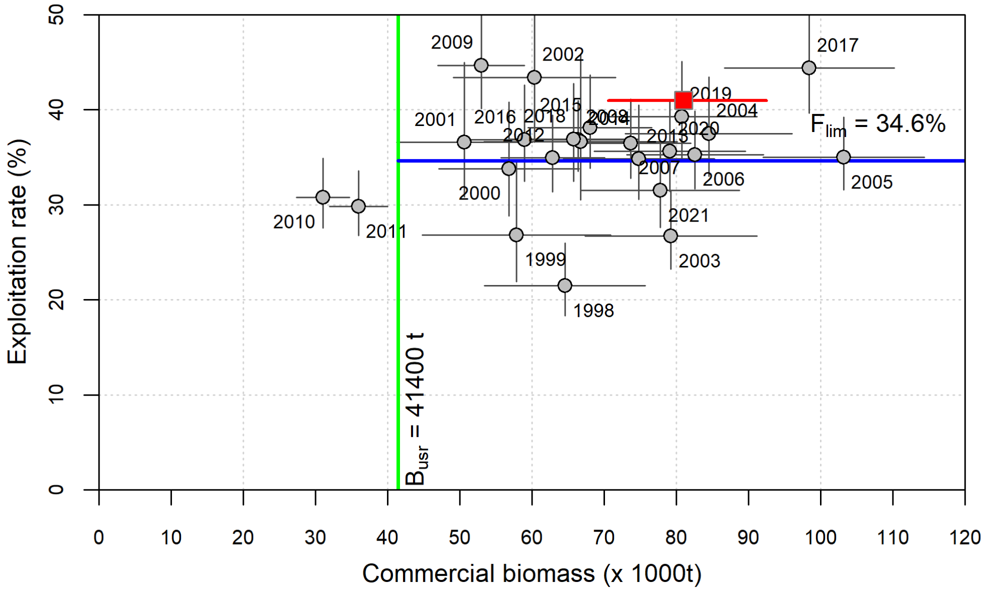

Figure 16. Exploitation rate versus the commercial biomass, with 95% confidence intervals. Year labels represent the fishery year. Coloured lines represent reference points, F_{lim} (blue line) is the limit reference point for fishing removal rate, and B_{usr} (green line) is the upper stock reference point for commercial biomass. Red square corresponds to the commercial biomass estimate with the target exploitation rate for the 2022 fishery.

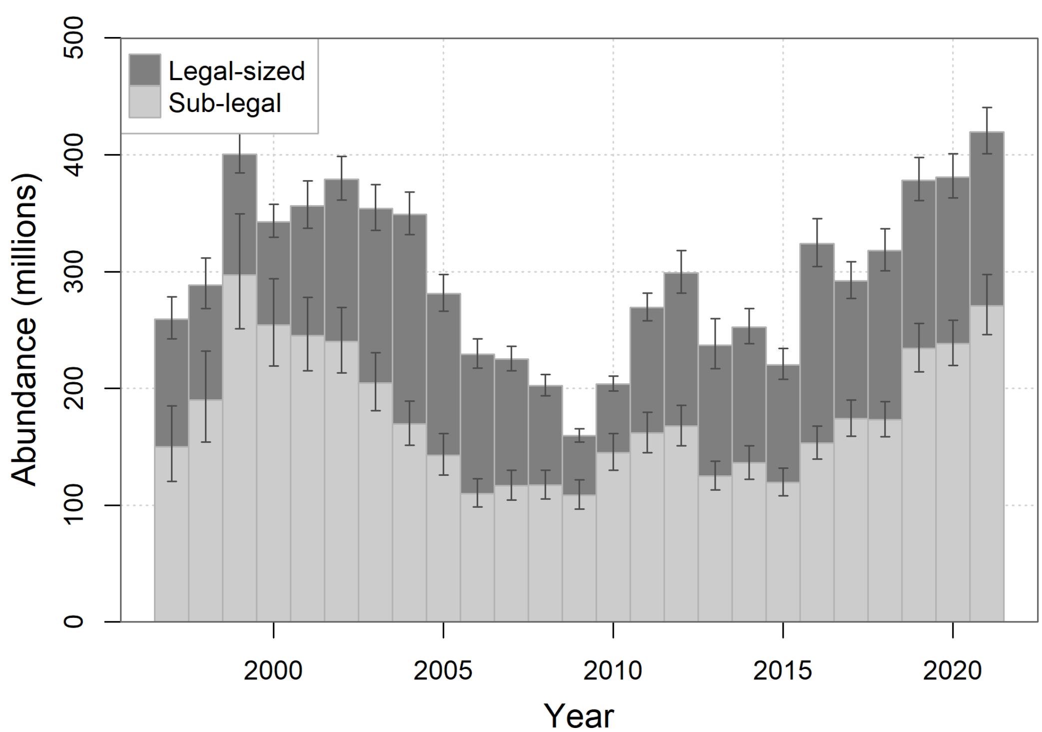

Figure 17. Survey abundance of sub-legal and legal-sized (95 mm CW) mature male snow crab in the sGSL from 1997-2021.

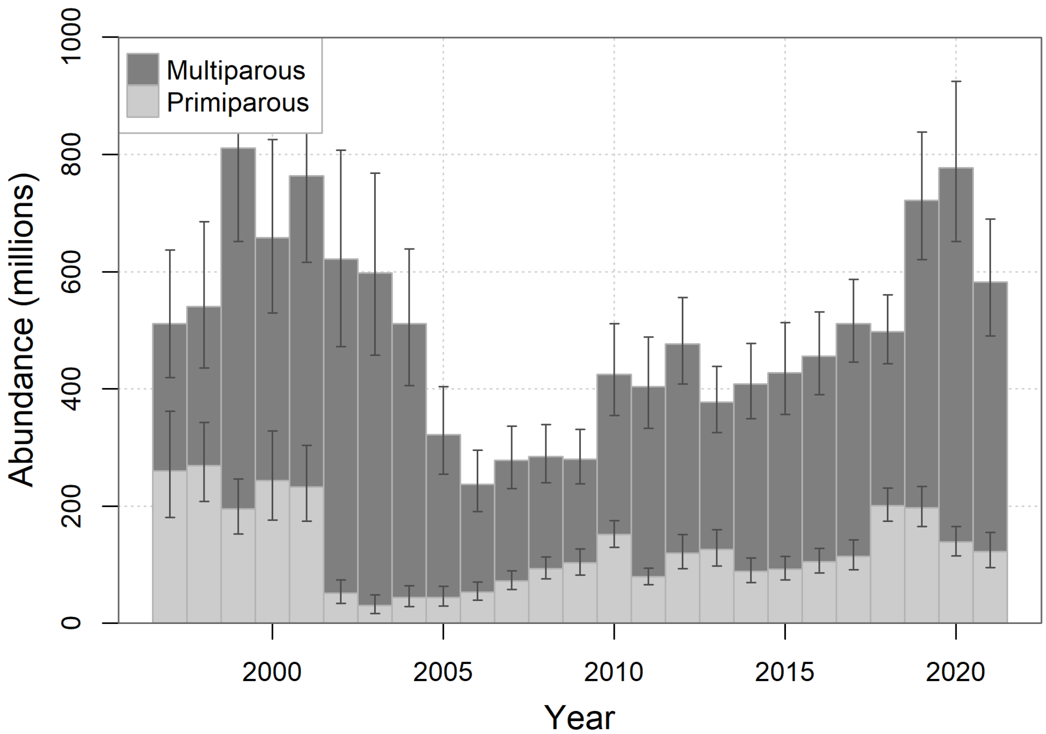

Figure 18. Survey abundance of primiparous and multiparous female snow crab in the sGSL from 1997-2021.

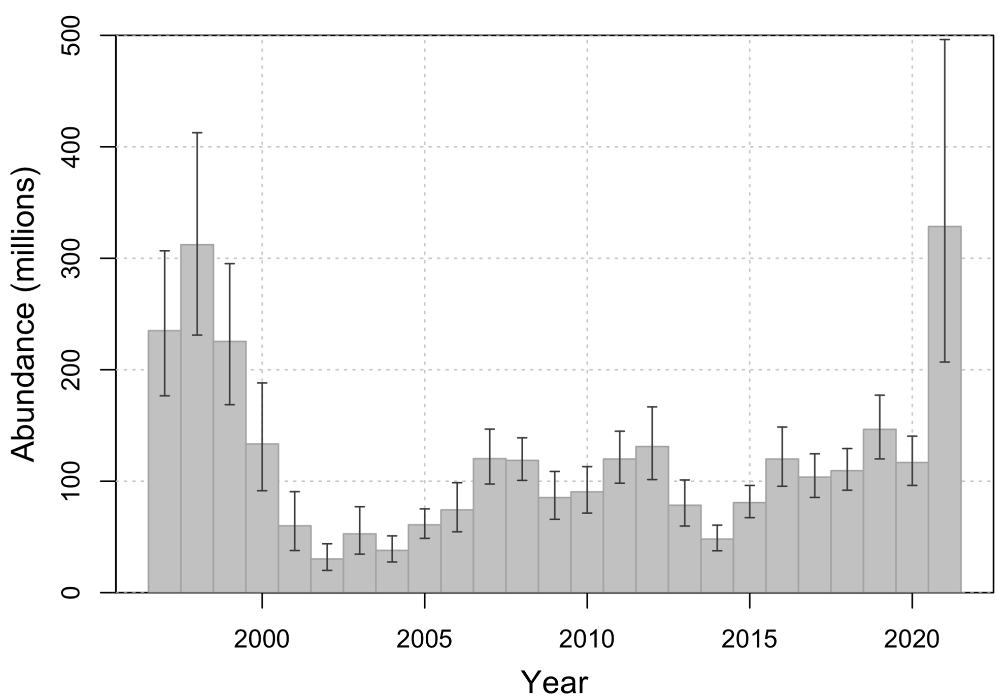

Figure 19. Annual abundance (in millions; means with 95% confidence intervals) of small male crabs of 34 to 44 mm CW, based on the trawl survey data from 1997 to 2021.

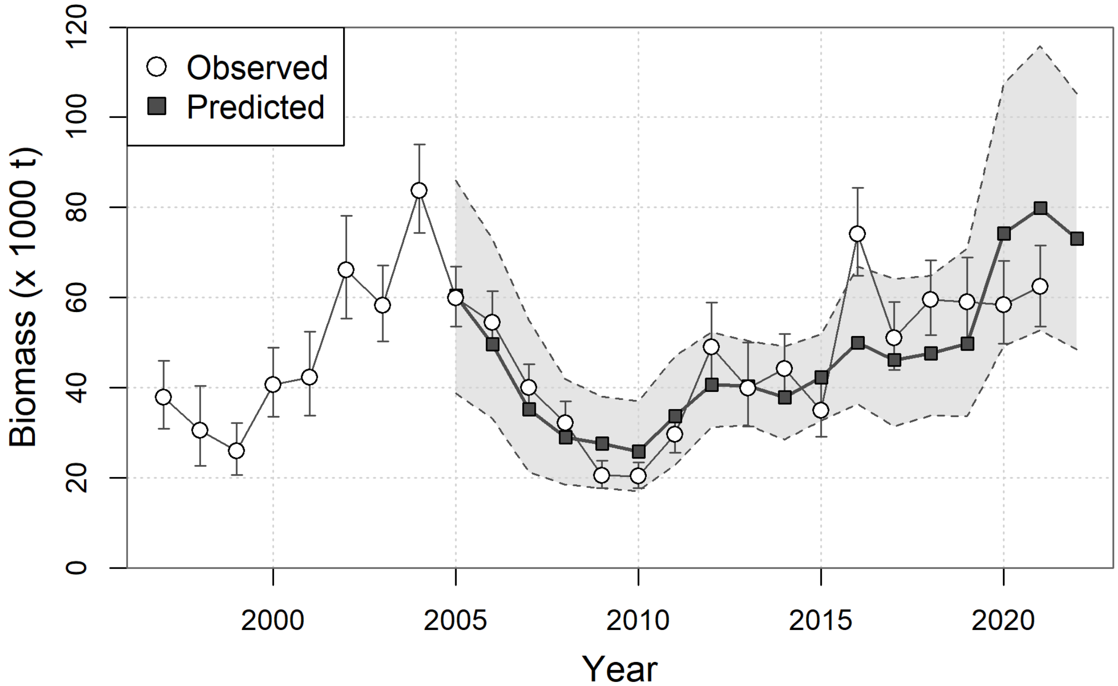

Figure 20. Estimated (open circles are the means with 95% confidence interval vertical bars) and predicted (black squares are the means with the 95% confidence interval bands as dashed lines) biomasses of R-1 (adult male crabs >= 95 mm carapace width of carapace condition 1 and 2) snow crab in the year of the survey, 1997 to 2021. The predicted abundances are based on a relationship to the estimated abundances of R-2 (adolescent male crabs with a carapace width larger than 83 mm) in the previous year.

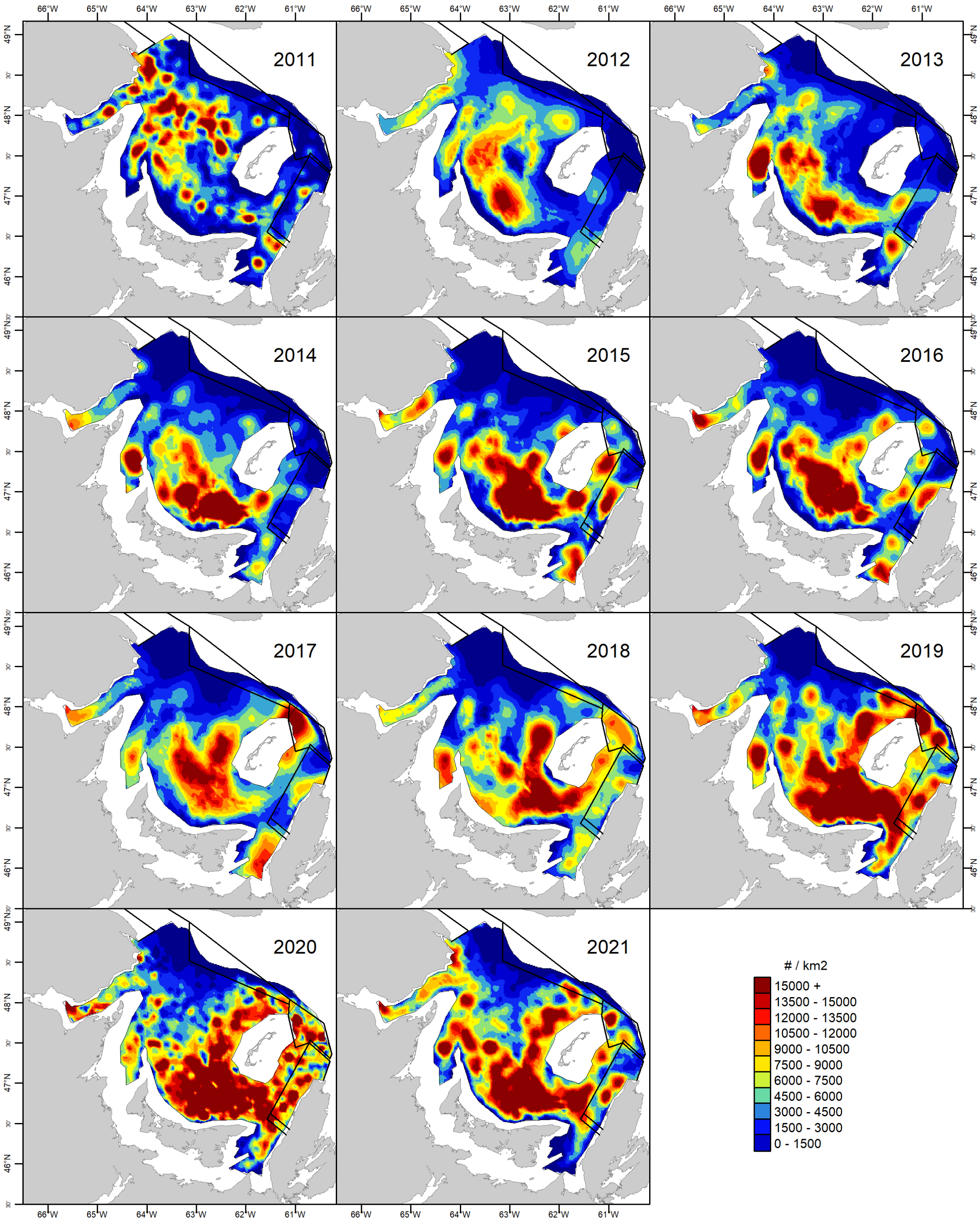

Figure 21. Adolescent male snow crab spatial distribution by year based on sGSL trawl survey data, interpolated using kriging. Adolescents are made up of future recruits to the fishery (i.e. R-4, R-3 and R-2s).

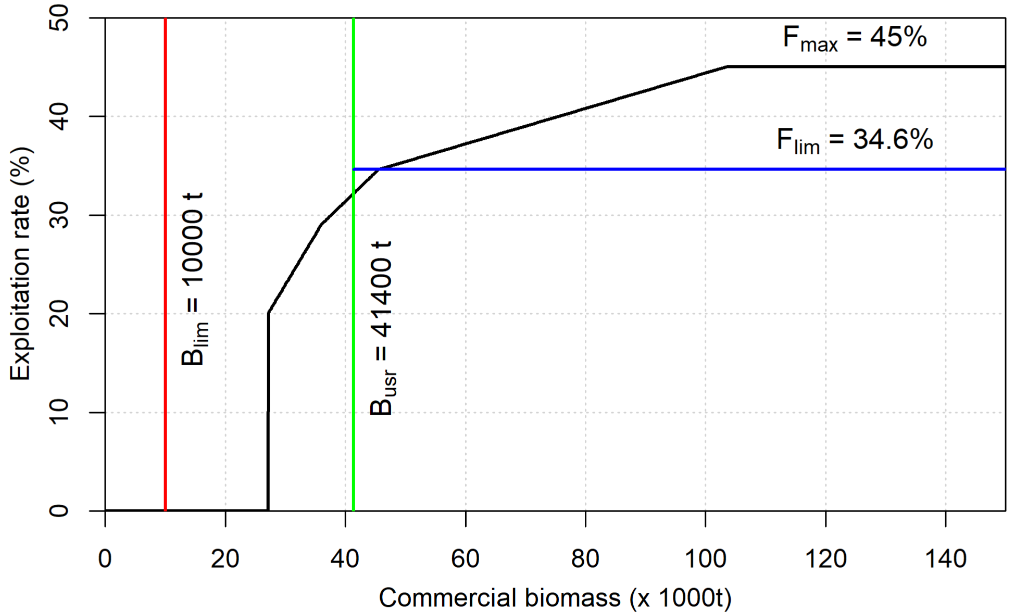

Figure 22. Harvest control rule used for the sGSL snow crab fishery (DFO 2014), expressed as exploitation rate versus commercial biomass (black line). Coloured lines represent reference points: B_{lim} (red line) is the limit reference point for residual biomass, F_{lim} (blue line)is the limit reference point for fishing removal rate, and B_{usr} (green line) is the upper stock reference point for commercial biomass. F_{max} represents the maximum exploitation rate harvest control rule.

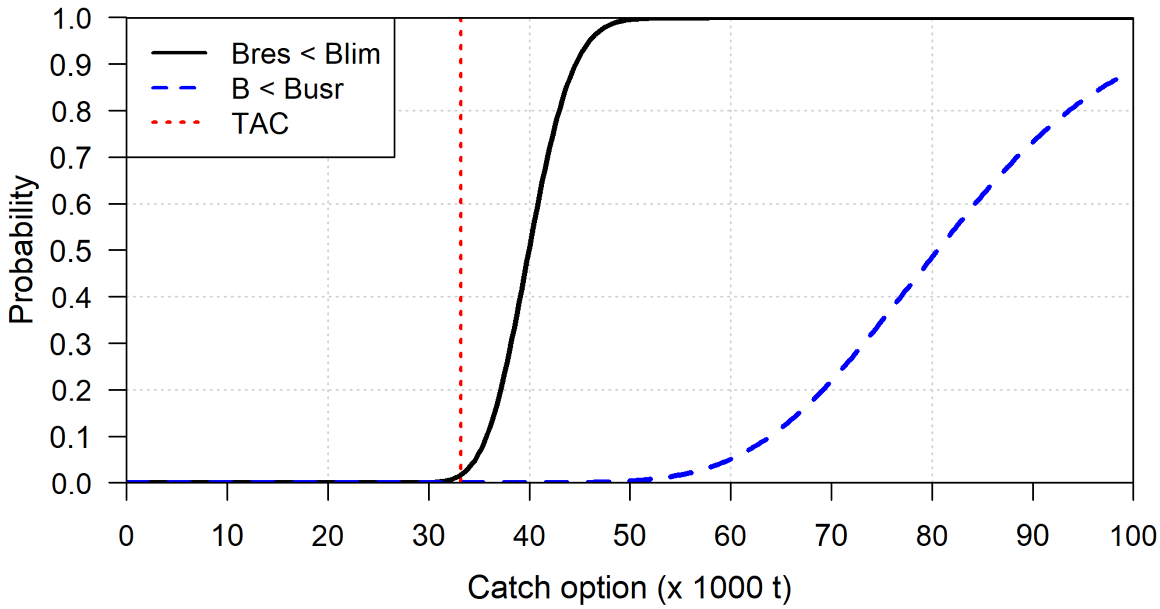

Figure 23. Risk analyses showing the probability that the residual commercial biomass falls below limit reference point (black solid line) or that the total commercial biomass falls below the upper stock reference (blue dashed line) point after the 2022 fishing season. TAC for 2022 is shown by the dashed red line.

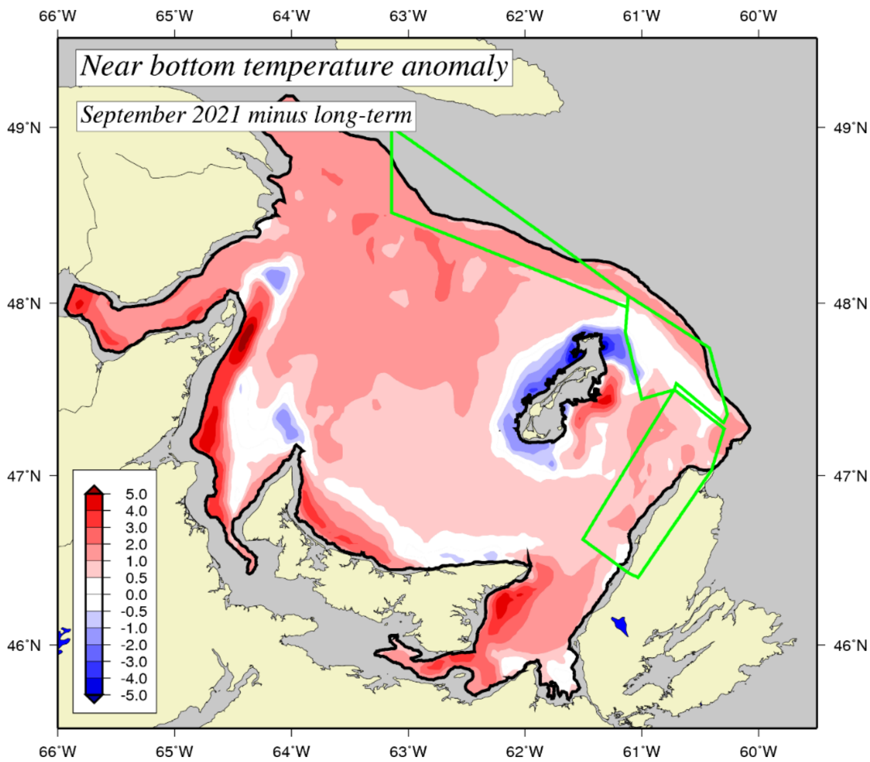

Figure 24. Difference between September 2021 local bottom temperatures and their long-term means from the period from 1991 to 2021. Blue areas represent colder-than-normal temperatures while red regions represent warmer-than-normal conditions. Differences are in °C.

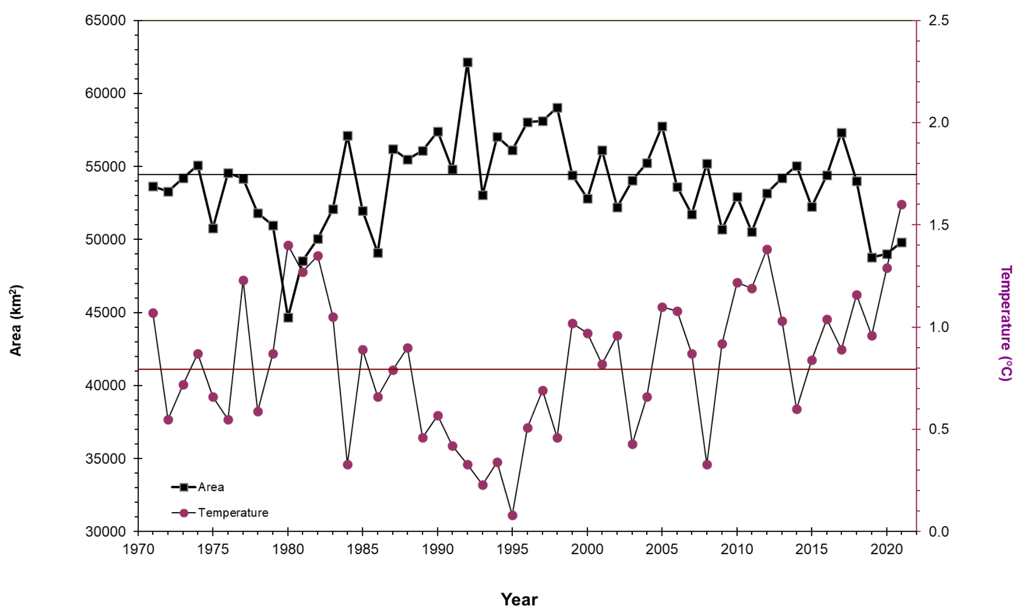

Figure 25. Surface area of the sGSL with bottom temperatures colder than 3 °C, an index of snow crab habitat, along with the mean temperature within the area.