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The 2019 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F)

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Foreword

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

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ABSTRACT

The 2019 assessment of the southern Gulf of St. Lawrence (sGSL) snow crab, *Chionoecetes opilio*, stock (Areas 12, 19, 12E and 12F) is presented. Snow crab in the sGSL is considered as a single stock unit for assessment purposes. The 2019 assessment was conducted as per the recommendations of the Snow Crab Assessment Methods Framework Science Review held in November 2011. The catchability for commercial-sized adult male snow crab in the snow crab bottom trawl survey is assumed to be constant over the time series and equal to one. The snow crab indices from the 2019 trawl survey are likely positively biased, resulting from a change in vessel and trawl fishing procedures in 2019. The trawl may have been fishing and catching snow crab over a larger area than estimated using the standardization procedures in this assessment. For the purpose of the assessment, the estimates of the commercial biomass and all abundances of males and females presented here have not been corrected according to this bias. The exploitation rate of the 2019 fishery in the sGSL was 39.3 %. The 2019 post-fishery survey biomass of commercial-sized adult male crabs was estimated at 79,066 t (95 % confidence intervals 69,072 to 90,091 t), which is similar to 2018 (80,746 t). The available biomass for the 2020 fishery, derived from the 2019 survey, is within the healthy zone of the Precautionary Approach (PA) Framework. The residual biomass from the 2019 survey was estimated at 20,291 t, a decrease of 5.3 % compared to the 2018 survey estimate (21,432 t). Seventy-five percent (75 %) of the 2019 survey biomass, available for the 2020 fishery, is composed of new recruitment (58,995 t). The recruitment to the commercial biomass from the 2019 survey is similar to 2018 (59,609 t). Based on the agreed harvest decision rule, the point estimate of the biomass in the 2019 survey of 79,066 t corresponds to an exploitation rate of 40.6 % and a total allowable catch of 32,101 t for the 2020 fishery. At this harvest level, there is zero chance of residual biomass post-fishery in 2020 being in the critical zone. A risk assessment to attainment of PA objectives of potential positive biases in the 2019 commercial biomass estimate is provided. Despite the possible overestimation concerns of the 2019 assessment, the biomass of commercial-sized adult males is considered to be at a high level and in the healthy zone of the PA. There is a broad distribution of snow crab in the sGSL and continued positive signs of sustained recruitment and high female abundances.

1.0. INTRODUCTION

Snow crab, *Chionoecetes opilio*, has been commercially exploited in the southern Gulf of St. Lawrence (sGSL) since the mid-1960s. Until 1994, the snow crab fishery in Area 12 (Fig. 1) was exploited by 130 mid-shore crab harvesters from New Brunswick, Québec and Nova Scotia. In 1997, the Prince Edward Island (PEI) coastal fishery (formerly called Areas 25/26) was integrated into Area 12. In 2003, a portion of the coastal fishery off Cape Breton (formerly called Area 18) was also integrated into Area 12, and a northern part of Area 18 was set as a buffer zone (non-snow crab fishing zone, label C in Fig. 1). For the purpose of this assessment, Area 12 refers to the new management unit (Fig. 1). In 1978, Area 19 (Fig. 1) was established for the exclusive use of Cape Breton inshore crab harvesters with vessels less than 13.7 m (45 ft) in length. Areas 12E and 12F were introduced in 1995 as exploratory fishery areas. A two nautical mile buffer zone was created between Area 12F and the adjacent Area 19 in 1996 (label B in Fig. 1). In 2002, the status of Areas 12E and 12F was changed from exploratory to commercial.

Currently, there are four individually managed fishing areas (Areas 12, 19, 12E and 12F) (Fig. 1), with Area 12 being the largest in area, number of participants, and landings. There is no biological basis for the delimitations of snow crab management areas in the sGSL (Chiasson and Hébert 1990; Hébert et al. 2008; DFO 2009). Crabs in the above four management areas are considered part of a single biological population and the sGSL is considered as a single unit for assessment purposes (Hébert et al. 2008).

Management of these fisheries is based on quotas (by management area and distributed among license holders) and effort controls (number of licenses, trap allocations, trap dimensions, and seasons).

In Areas 12, 12E and 12F, the fishing season generally starts as soon as the sGSL is clear of ice in late April to early May and lasts either until the closure of the fishing season in mid-July or when the quota is caught. In Area 19, the fishing season starts in July and ends in mid-September or when the quota is caught. The landing of females is prohibited and only hard-shelled males ≥ 95 mm carapace width (CW) are commercially exploited. Different limits on the number of traps apply to each license depending on the harvesters group and fishing area.

New management measures were introduced in 1990 following the premature closure of the Area 12 fishery in 1989 due to a rapid decline in catch rates and high incidence of soft-shelled crabs in catches. One of the measures was to set the total allowable catch (TAC) or quota as some proportion of the biomass of adult male crab ≥ 95 mm CW, as estimated from a trawl survey. Another management strategy was to close portions of the fishery based on the percentage of soft- or white crabs to maximize yield and reproductive potential by limiting the capture of soft-shelled males.

This assessment follows recommendations from the Framework Science Peer Review of stock assessment methods for the sGSL snow crab stock held on November 21-25, 2011 (DFO 2012a).

The present report presents the assessment and commercial biomass estimates for the 2020 snow crab fishery in the sGSL (Areas 12, 19, 12E and 12F). Biomass estimates and population characteristics by life stage are derived from a trawl survey conducted after the fishery covering the sGSL snow crab habitat. Risk analysis of catch options for the 2020 fishery relative to the commercial biomass and removal reference points is also presented.

2.0. SYNOPSIS OF SNOW CRAB BIOLOGY

In the sGSL, molting of snow crab occurs from December to April, prior to the fishery (Watson 1972; Conan et al. 1988; Sainte-Marie et al. 1995; Benhalima et al. 1998; Hébert et al. 2002). Crab normally molt annually until they reach the adult phase via a final or “terminal” molt (Conan and Comeau 1986). Males reach adulthood at sizes ranging from 40 to 150 mm CW and females at 30 to 95 mm CW (Conan and Comeau 1986). Estimates of longevity of adult males are (after reaching the terminal molt) between 5 (Sainte-Marie et al. 1995) and 8 years (Fonseca et al. 2008).

In contrast to immature females, pubescent (adolescent) females have a wider abdomen and fully developed orange gonads in the fall. These females then undergo a terminal molt between December and April and become nulliparous females having a fully enlarged abdomen and ripe ovaries. Generally, they mate immediately after molting, while their carapace is still soft, and then extrude fertilized eggs for the first time, becoming primiparous females (Watson 1969; Moriyasu and Conan 1988). Multiparous refers to females which are repeat spawners (second brood or more). Their mating season occurs from late-May to early-June, after their eggs have hatched (Conan and Comeau 1986; Moriyasu and Conan 1988; Sainte-Marie and Hazel 1992; Moriyasu and Comeau 1996; Sainte-Marie et al. 1999). In the sGSL, mature females normally carry their eggs under the abdomen for two years (Mallet et al. 1993; Moriyasu and Lanteigne 1998), while a negligible portion of mature females follow a one-year cycle in Baie Sainte-Marguerite (Sainte-Marie et al. 1995). However, Khun and Choi (2011) reported that over 80 % of mature females were estimated to follow a one-year reproductive cycle on the Scotian Shelf.

Mature females, both primiparous and multiparous, may produce more than one viable brood from sperm stored in their spermathecae from the first mating, without any subsequent mating (Sainte-Marie and Carrière 1995). However, the probability that a single mating was sufficient to fertilize a female’s lifetime production of eggs has been shown to be low (Rondeau and Sainte-Marie 2001). Mating after egg hatching seems to be a general rule for snow crab in the sGSL (Conan et al. 1988).

After molting, crabs have a soft shell engorged with water. It takes about 8-10 months for the carapace of an adult soft-shelled male to harden (Hébert et al. 2002) and one year to attain maximal meat yield (Dufour et al. 1997). Adult soft-shelled males are not able to mate during their postmolt period, but become active in reproductive activities with nulliparous females in February of the following year and in May-June with multiparous females (Conan et al. 1988; Moriyasu et al. 1988). Adult soft-shelled males of legal size represent the annual recruitment to the fishery, as they become commercially marketable in the following fishing season (Conan and Comeau 1986; Sainte-Marie et al. 1995; Comeau et al. 1998; Hébert et al. 2002).

Following Sainte-Marie et al. (1995), we use the term “adolescent” and “adult” to refer to what was formerly called morphometrically immature and mature, respectively (Conan and Comeau 1986).

3.0. METHODS

3.1. TRAWL SURVEY SAMPLING FOR BIOMASS ESTIMATION

There have been progressive changes in the sampling design and protocols of the sGSL trawl survey since its inception in 1988. Originally, the survey area was sub-divided using a lattice of 10 by 10 minute latitude-longitude grids. One or two sampling locations were then randomly selected and used as fixed stations in subsequent survey years. Initially, the survey area only covered Area 12 but was expanded to Area 19 in 1990. Area 12 was sampled before its fishery

(July to October) for all years (except 1996 where there was no survey) and Area 19 was sampled before its fishery from 1990 to 1992 and then after its fishery from 1993 onward (Moriyasu et al. 2008).

In 1997, the survey area was again extended to include the new management Areas 12E and 12F. New stations were added randomly within grids as the survey polygon expanded or if areas were targeted for more intensive sampling to reduce the variance. Further details of these survey design changes are provided by Moriyasu et al. (2008).

The sampling design from 2006 to 2011 was modified in accordance with recommendations from the 2005 Assessment Framework Workshop on the sGSL snow crab (DFO 2006; Moriyasu et al. 2008). A new design was introduced to achieve spatial sampling homogeneity. While this survey design was spatially unbiased in the sense that the expected number of stations per 10 by 10 minute grid was proportional to its surface area, in practice the realized number of stations per grid was either one or two stations, and grids along the survey area margins often had zero stations. Past survey stations were retained as much as possible, but others were removed or added to the grid as prescribed by the sampling method (Hébert et al. 2007; Moriyasu et al. 2008).

In 2012, the sampling design was again modified following recommendations from the 2011 Snow Crab Assessment Methods Framework Science Review (DFO 2012a). The boundaries of the survey area were extended to the 20 and 200 fathom isobaths, encompassing the vast majority of favorable snow crab habitat (i.e. bottom temperatures less than 5°C) and thus the sGSL biological unit. To further improve spatial homogeneity, grids were set to be square rather than rectangular with dimensions defined as a function of the number of total samples, so that each grid included only a single sampling station (DFO 2012a). This protocol resulted in an entirely new set of sampling stations. The revised survey sampling design in 2012 is presented in Wade et al. (2014). For 2013, the number of stations increased from 325 to 355 following recommendations from the snow crab advisory committee to increase the precision of the biomass estimates in smaller fishing zones. The survey area was partitioned into square grids of 12.7 km x 12.7 km and a new set of sampling stations was generated.

Since 2014, the number of target sampling stations has remained at 355 and the successfully sampled stations from the previous year survey were used as fixed stations. A new set of sampling stations was generated randomly when sampling stations were abandoned or if the sampling stations were outside of their assigned square grids.

3.1.1. Trawl survey in 2019

In 2019, the number of target sampling stations remained at 355. The 351 successful sampling stations from the 2018 trawl survey were used as fixed stations in 2019 and a new set of four sampling stations (the one sampling station that was abandoned and three sampling stations that were conducted outside their assigned square grid areas in 2018) was generated randomly (Fig. 2).

The trawl survey was conducted between July 12 and September 25 and covered Areas 12, 19, 12E and 12F (Fig. 2). A new vessel, the "*Avalon Voyager II*", a 65 foot stern-trawling (850 HP) fiberglass boat, was used to conduct the trawl survey in 2019. The former vessel, the ''Jean-Mathieu'', a 65 foot stern trawling (750 HP) steel boat, was used to conduct the trawl survey from 2013 to 2018. A side-by-side vessel comparison was conducted at 40 pre-determined stations at the southeastern portion of sGSL, off of Cape Breton. A total of 352 stations were successfully trawled in 2019; three sampling squares had to be abandoned due to failures to successfully trawl the area.

A Bigouden Nephrops bottom trawl net, originally developed for Norway lobster (*Nephrops norvegicus*) fisheries in France, was used (20 m opening with a 28.2 m foot rope). The net is made of 2.5 mm diameter braided nylon twine and the mesh sizes are 80 mm in the wings, 60 mm in the belly and 40 mm in the cod-end (see Moriyasu et al. 2008 for more details on the description of the trawl).

All stations were trawled during the interval between morning and evening civil twilight hours. A predetermined amount of warp was let out (three times the distance of the depth) before the winch drums were locked. The start time of a standard tow was based on the information reported by the eSonar depth and height sensors, later revised using data from Star-Oddi temperature-depth and tilt probes attached to the trawl. The target duration of each tow was five minutes at a target speed of two knots. The horizontal opening of the trawl was recorded every four seconds with the eSonar distance sensors. The swept distance of the trawl was estimated from the position (latitude/longitude) measured every second with a Differential Global Positioning System. The swept area for each tow was calculated by multiplying the swept distance and the horizontal opening of the trawl over the duration of the tow.

Tows were rejected if the net was damaged, the eSonar system generated no usable data to determine the beginning of the tow, or the duration of the tow was less than five minutes. A replacement tow was conducted near the original start point or at the alternate sampling stations within the assigned grid (Fig. 2).

If the tow satisfied trawl survey protocols but the data signal quality from the eSonar sensors was deemed to be inadequate to calculate the swept area, the swept area of the tow was set to the average of the values of the 10 nearest stations.

3.1.1.1 High catches in 2019

Snow crab catches in the 2019 survey seemed to be unexpectedly high, with a record total of 46,328 snow crabs caught, 25.7 % above the previous record observed in 1999, and 37.5 % above last year's total of 33,684 crabs, a year for which the population was already considered to be in high abundance. This increase was observed throughout the sGSL, for all sizes and sexes. However, this observation was in contrast to preliminary results from the comparative survey catches, which seemed to indicate no major differences between the two survey vessels. To investigate these record high catches, we checked for possible differences in vessel or trawl behavior between the 2017, 2018 and 2019 surveys.

In particular, we verified whether there was any evidence of the trawl being dragged after the nominal 5-minute trawling period. Currently, the swept area is calculated from when the winches are locked and the trawl touches the bottom until the stop signal is given at the 5 minute mark, whereupon the vessel slows and the trawl winches are activated. To clarify this discussion, we divide the period where the trawl lies on the sea bottom into an active trawling phase and a passive trawling phase (Fig. 3).

- Active phase: After reaching the predetermined target amount of warp, the winches are locked and the vessel slows to the target trawling speed of two knots. When the trawl reaches the bottom, as determined from the e-Sonar depth, height and distance sensors attached to the trawl, the active trawling phase begins with a duration of five minutes (300 seconds), where upon a stop signal is given by the chief scientist.
- Passive trawling phase: After the stop signal, the winches are unlocked and start to reel in the trawl. During this phase, the vessel slows and the trawl remains on the bottom and continues to be dragged by the forward movement of the vessel as well as the action of the winches. This phase ends when the trawl lifts off the bottom, as determined by the tilt Star-Oddi sensor attached to the footrope of the trawl.

3.1.1.2 Passive phase analysis

Vessel and trawl behavior characteristics during the passive trawling phase during the 2019 survey were compared to those of 2017 and 2018. The data recorded and methods used were identical between years. The swept area during the passive phase can be calculated by multiplying the covered distance by the trawl on the bottom and the trawl width monitored by the distance eSonar sensors. The forward movement of the trawl is due to a combination of two forces: the forward movement of the vessel plus that of the winches pulling the trawl towards the vessel. If we assume the vessel has more or less the same bearing during the passive phase, we can calculate the vessel's contribution to the trawl movement l_v using $l_v = v_p \times t_p$, where v_p is the vessel's average speed and t_p is the duration of the passive phase. When the winches speed v_w is known, the distance that the winch drags the trawl across the sea floor is given by:

$$l_w = \sqrt{c_0^2 - d^2} - \sqrt{\left(c_0 - v_w \times t_p\right)^2 - d^2}$$

where d is the water depth, c_0 is the warp cable length during regular trawling (i.e. $c_0 \approx 3d$). The total swept area of the passive phase for each tow is given by $s = w \times (l_v + l_w)$, where w is the average trawl wing spread. The lift off angle between the trawl cables and the sea bottom are given by $\phi = \arcsin\left(\frac{d}{c_0 - v_w t_p}\right)$. For a 3:1 warp ratio, $\phi \approx 20^o$ during regular trawling up to the beginning of the passive phase. As the trawl approaches the vessel, ϕ will increase up to some value until the trawl finally lifts off the bottom (Fig. 4).

3.1.2. Biological sampling

The trawl catches were sorted on the vessel deck. Snow crabs were put aside for detailed sampling. All other organisms were sorted by species or species group and counted. Since 2010, individual length measurements for all fish species were made at 100 randomly selected stations. Fish length sampling was based on random sub-samples of up to 100 individuals of each fish species in a selected tow. Starting in 2013, all species or species groups were weighed.

The following information was recorded for all snow crabs: carapace width (CW), chela height (CH) for males only to the nearest 0.1 mm and carapace condition (Hébert et al. 1997). For females, the color (orange, dark orange, brown or black) and quantity (in percentages) of external eggs on ovigerous females, as well as the color (white, beige or orange) of the gonads of immature females were also noted.

The size frequency distributions for the population were derived from the samples weighted by the swept area (km²) of each corresponding tow.

3.1.3. Estimation of snow crab abundance

The assessment follows the recommendations from the November 2011 Framework Science Peer Review of stock assessment methods for the sGSL snow crab stock (DFO 2012a).

The survey area polygon has a total area of 57,842.8 km^2 (Fig. 5) and the four corresponding management areas have areas of 48,074 km^2 for Area 12, 3,813 km^2 for Area 19, 2,436.9 km^2 for Area 12E and 2,426.8 km^2 for Area 12F (Fig. 5). An additional unassigned zone A (above Areas 12E and 12F, Fig. 5) is included in the expanded polygon and located where no fishing activities were observed. This zone has an area of 667.9 km^2, while the buffer zones B and C (Fig. 5) cover an area of 134.2 and 289.5 km^2, respectively.

The sGSL biomass estimates includes the unassigned zone A and the buffer zones B and C (no fishing zones) (Fig. 5). Commercial biomass estimates in each management zone 12, 19, 12E and 12F were calculated excluding the buffer zones.

Commercial biomass estimates were also calculated for each of the buffer zones (B and C) and for the unassigned zone (A).

The current model, kriging with external drift (KED) using depth as a secondary variable, used for the snow crab assessment is considered suitable for biomass estimates (DFO 2012a).

A three-year average for the global variogram was calculated as this has been considered a more stable method for modeling the autocorrelation between the samples (Wade et al. 2014).

The 1997 to 2019 time series of estimated biomasses for the sGSL, using the expanded polygon of 57,842.8 km^2, was considered as a standardized time series for the purpose of stock assessment, development of reference points and provision of catch advice.

Kriging analyses were performed using the language programming version R 3.4 for the 2019 stock assessment.

Biomass was estimated using KED on commercial-sized adult catch weights (Wade et al. 2014), with the weight estimated using the size-weight relationship:

$$W = (2.665 \times 10^{-4})\ CW^{3.098}$$

where W is the weight in grams and CW is the carapace width in mm (Hébert et al. 1992).

Total biomasses were estimated for the following categories of male crab:

- commercial-sized adult male ≥ 95 mm CW all carapace conditions,
- commercial-sized adult male crab ≥ 95 mm CW with carapace conditions 1 and 2 at the time of the survey, which represents the annual recruitment to the fishery (called R-1), and
- adult male crab ≥ 95 mm CW with carapace conditions 3, 4 and 5 (hard-shelled) at the time of the survey, which represent the residual or remaining biomass post- fishery.

The abundance indices of prerecruits at the time of the survey (R-4, R-3 and R-2) were used to forecast the recruitment to the fishery over the next four years. Stages R-4, R-3 and R-2 represent adolescent males with a CW range of 56-68 mm, 69-83 mm and larger than 83 mm, respectively, and they are expected to recruit (CW ≥ 95 mm) to the fishery in four, three and two years, respectively. The size increments from molting of pre-recruits R-4, R-3 and R-2 were set using a growth model for adolescent male snow crab (Hébert et al. 2002). The abundance of adolescent males of instar VIII, defined as those with a CW between 34 and 44 mm, was also estimated as an index of longer term recruitment. It takes at least six years for an adolescent male of instar VIII to reach the commercial size of 95 mm CW. In addition, the abundance indices of pubescent, primiparous and multiparous females were estimated.

3.2. ESTIMATION OF THE ANNUAL TOTAL MORTALITY AND EXPLOITATION RATES

Total annual mortality of commercial-sized adult males, expressed as a proportion, is estimated as:

$$N_t^{3,4,5} / N_{t-1}$$

Where N_t^{345} is the biomass of commercial-sized adult males with carapace conditions 3, 4 and 5 after the fishery in year *t* (the residual biomass) and $N_{(t-1)}$ is the abundance of commercial-sized males with carapace conditions 1 to 5 after the fishery in year *t-1* (the commercial biomass in the previous year).

The exploitation rates *(ER)* was calculated as the ratio of the catch *(t)* in the fishery of year *t* ($C_t^{3,4,5}$) and the commercial biomass (B_{t-1}) from the previous year.

$$ER = C_t^{3,4,5} / B_{t-1}$$

This exploitation rate does not take into account the natural mortality before and during the fishery.

3.3. RISK ANALYSIS AND CATCH OPTIONS

The Bayesian model described by Surette and Wade (2006) and Wade et al. (2014) was used to forecast the biomass of recruitment to the fishery (R-1) based on survey abundances of pre-recruits R-4, R-3 and R-2 from the sGSL, to project four, three and two year(s) into the future, respectively. The model incorporated uncertainties associated with observation errors.

4.0. RESULTS AND DISCUSSION

4.1. ESTIMATES OF BIOMASS AND EXPLOITATION IN 2019

4.1.1. Southern Gulf

4.1.1.1. Trawling characteristics during the 2019 survey

There were some differences between the “Avalon Voyager II’’ compared to the former vessel, the ‘’Jean-Mathieu’’. First, the winches aboard the “Avalon Voyager II’’ were limited to two speed settings, the higher speed setting used during the first survey trip resulted in gear entanglements, consequently leading the captain to use the lower speed setting. However, this speed was slower than that of the “Jean Mathieu’’. Second, the “Avalon Voyager II’’ was not equipped with a variable-pitch propeller speed controller, which led to a loss of fine speed control during trawling, i.e. the target trawling speed of 2 knots was more difficult to maintain.

In 2019, the median duration of the passive phase was 89 seconds on the “Avalon Voyager II’’, almost twice that of the “Jean-Mathieu’’ in 2017 (50.5 seconds) and 2018 (43 seconds) (Table 1). The mean vessel speed of the “Avalon Voyager II’’ during the passive phase in 2019 was similar to the “Jean-Mathieu” in 2018 and 2017 at 0.8 meters per second (1.6 knots). The increase in durations led to corresponding increases in the median distance travelled by the vessel during the passive phase, with 68.4 m in 2019 for the “Avalon Voyager II’’ while for the “Jean-Mathieu”, it was 35.4 m in 2017 and 32.7 m in 2018 (Fig. 6; Table 1). The median trawl width during the passive phase slightly declined in 2019 (6.4 m) on the “Avalon Voyager II’’ compared to 2017 (6.9 m) and 2018 (7.0 m) on the “Jean-Mathieu’’ (Table 1).

The calculated winch speeds were comparable during the 2017 and 2018 with median values of 1.26 meters per second, whereas the 2019 median dropped to 0.90 meters per second (Table 1). Liftoff angles increased slightly to a median of 34.0° in 2019, from 27.9° in 2017 and 28° in 2018 (Table 1). Higher liftoff angles in 2019 imply that the trawl was brought closer to the vessel before lifting off the bottom. Thus, we see a corresponding increase in the distance travelled by the trawl due to winch action to a median value of 87.6 m in 2019, up from 65.9 m in 2017 and 56.9 m in 2018 (Table 1).

The total swept area estimates for the passive trawling phase increased to 992 m^2 in 2019, from 688 m^2 (44 % increase) in 2017 and 605 in 2018 (64 % increase). Median passive swept area estimates represent 24.8 %, 22.3 % and 32.2 % of swept areas estimated for the active trawling phases, out of 2,278 m^2, 2,709 m^2 and 2,739 m^2, for 2017, 2018 and 2019, respectively (Table 1). This component of the swept area is currently unaccounted for in catch standardizations. Taking the passive trawling phase into account shows an increase in total swept area of 12.6 % from 2018 to 2019.

Slower winch speeds in 2019 led to increases in the length of time the trawl spends on the bottom during the passive trawling phase. The increased distance travelled by the trawl is due to two main factors: firstly the survey vessel travelled further along its path, and secondly the trawl had to be hauled closer to the vessel prior to lifting off during hauling.

4.1.1.2. Variogram

The variogram is a model which described the evolution of the variance in function to the distance between the samples and therefore, allows the modelling of the spatial autocorrelations between the data. The variogram has three properties, the nugget effect, the sill and the range. The nugget effect represents the variation between two very closed samples, which could be due to natural variability of the measured parameter, a variability in the measure instrument or a brutal variation of the measured parameter. The sill indicates the variance where the plateau is reached and the range represents the distance where there are no longer spatial auto-correlations between the samples. The three-year averaged variogram model for commercial-sized adult males in 2019 had a nugget value of 3.109×10^6, a sill at 3.978×10^6 and a range of 82.1 km (Fig. 7). The 2019 variogram has the same shape as 2018 showing a higher nugget effect, a lower sill and range. In 2019, the range of which there are no longer auto-correlations between the samples is 82.1 km (Fig. 7).

4.1.1.3. Biomass estimates

The catchability for commercial-sized adult male snow crab in the snow crab bottom trawl survey is assumed to be constant over the time series and equal to one. The snow crab indices from the 2019 trawl survey are likely positively biased, resulting from a change in vessel and trawl fishing procedures in 2019. The trawl may have been fishing and catching snow crab over a larger area than estimated using the standardization procedures in this assessment. For the purpose of the assessment, the estimates of the commercial biomass and all abundances of males and females presented here have not been corrected according to the this bias.

The 2019 southern Gulf commercial biomass estimate was 79,066 t (95 % confidence interval (C.I.) range of 69,072 to 90,091 t), which is similar to the 2018 estimate of 80,746 t (70,984 to 91,467 t) (Table 2). Based on the abundance of pre-recruits R-2 from the 2018 trawl survey, the projected commercial biomass for the 2020 fishery was estimated at 75,443 t (68,512-83,055 t). The recruitment to the fishery at the time of the 2019 survey was estimated at 58,995 t (50,215 to 68,863 t), which is similar to the 2018 estimate of 59,609 t (51,755 to 68,310 t) and represents 75 % of the commercial biomass (Table 2). The 2019 residual biomass (adult commercial-sized males with carapace conditions 3, 4 and 5) was estimated at 20,291 t (16,940 to 24,109 t), a decrease of 5.3 % compared to the 2018 estimate of 21,432 t (17,270 to 26,291 t) (Table 2).

In 2019, local concentrations of commercial crab were mainly observed in Bradelle Bank, Shediac valley, Area 12F, in the central and southern parts of the Magdalen channel and in the southeastern part of the sGSL (Fig. 8).

By carapace condition in the 2019 trawl survey, commercial crabs were comprised of 73 % fishery recruitment (carapace conditions 1 and 2) and 27 % residual biomass (carapace conditions 3, 4 and 5) (Table 3). Further split by carapace condition, the residual biomass is composed of 20 % of commercial crab with carapace condition 3, 6.5 % of crabs with carapace condition 4 and 0.5 % of crabs with carapace condition 5 (Table 3). This suggests that the composition of the commercial male population observed in the 2019 trawl survey is young and there is no sign of an ageing population at this time. Close monitoring of catch composition from the at-sea observer sampling and survey data is necessary to monitor the ageing of the commercial male population in the coming years.

A comparison between fishery recruitment predicted by the Bayesian model for the fishery of 2020 (49,820 t; 95 % C.I. 33,700 to 70,970 t) and the recruitment biomass from the 2019 survey (58,995 t; 50,215 to 68,863 t) indicated that the estimated recruitment for the 2020 fishery is within the limits of the 95 % credibility interval of the predicted value, but still represents a high increase compared to the predicted value (Table 4; Fig. 9). The relationship between the abundance of R-2 prerecruits in year *t* and the recruitment to the fishery in year *t + 1* is shown in Figure 10. A number of factors can account for the variability in this relationship, including variations in bycatch mortality, natural mortality, the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase), and sampling error. Since 1997, the proportion of skip molters larger than 83 mm CW, which are parts of the R-2 component, varied from 3.7 % in 1997 to 59.8 % in 2003, corresponding to its abundance (Fig. 11). In 2019, the proportion of the skip molters larger than 83 mm CW was at 29.8 % while it was at 52.6 % in 2015 (Fig. 11). More study is needed to better predict the arrival and growth of skip molters crabs into the population.

4.1.2. Estimation of the portion of total biomass in each management fishing zone and buffer zone

4.1.2.1. Area 12

The 2019 trawl survey estimate of commercial biomass for Area 12 was 67,590 t (58,787 to 77,331 t) (Table 5). This estimate corresponds to 86.2 % of the sum of the independently estimated commercial biomasses in the four management zones. Since 1997, this proportion has varied from 78.1 % (2013) to 92.8 % (2004) with an average of 86.6 %.

4.1.2.2. Area 19

The 2019 post-fishery trawl survey estimate of the commercial biomass was 5,639 t (3,834 to 8,004 t) (Table 5). This estimate corresponds to 7.2 % of the sum of the independently estimated commercial biomasses in the four management zones. Since 1997, this proportion has varied from 4.3 % (2004) to 15.0 % (2013) with an average of 9.1 %.

4.1.2.3. Areas 12E and 12F

Areas 12E and 12F lie at the margins of snow crab habitat in the sGSL and contain few sampling stations and have correspondingly uncertain biomass estimates with very large confidence intervals.

The Area 12E commercial biomass from the 2019 trawl survey was estimated at 554 t (50 to 2,342 t) (Table 5). This estimate corresponds to 0.7 % of the sum of the independently estimated commercial biomasses in the four management zones. Since 1997, this proportion has varied from 0.4 % (2016) to 3.1 % (1999) with an average of 1.1 %.

In Area 12F, the commercial biomass from the 2019 trawl survey was estimated at 4,613 t (3,202 to 6,439 t) (Table 5). This estimate corresponds to 5.9 % of the sum of the independently estimated commercial biomasses in the four management zones. Since 1997, this proportion has varied from 1.2 % (2008) to 7.1 % (2017) with an average of 3.2 %.

4.1.2.4. Buffer zones and unassigned zone

Commercial biomass estimates in the buffer zones and in the unassigned zone have very large confidence intervals given the low number of stations within these small zones.

The commercial biomass in the unassigned zone A above Areas 12E and 12F (Fig. 5) was 89 t (1 to 589 t) (Table 5). The commercial biomass in buffer zone B (2 nautical mile wide buffer zone) adjacent to Area 19 and 12F (Fig. 5) was estimated at 224 t (76 to 521 t) (Table 5). The commercial biomass in buffer zone C (5-miles buffer zone) located south of Area 19 (Fig. 5) was 427 t (124 to 1,086 t) (Table 5).

The sum of the commercial biomass estimates in the management, buffer, and unassigned zones in 2019 was 79,136 t, very close to the sGSL biomass estimate, 79,066 t (Table 4).

4.1.3. Exploitation rate

The exploitation rate in 2019 was 39.3 % (Table 6; Fig. 12). The exploitation rates have varied between 21.0 % and 44.7 % from 1998 to 2019.

4.1.4. Total annual mortality and difference in commercial-sized adult males

The total annual mortality of commercial-sized adult male snow crab in the sGSL was estimated at 74.9 % in 2019 and has varied between 46.1 % and 85.1 % from 1997 to 2019 (Fig. 12) except for 2011 where it was estimated at 11.3 % (Hébert et al. 2012).

Over the time series (1997-2019), the commercial biomass exceeded by an average 29.8 % the sum of the residual biomass and landings of the following year (Fig. 13). These differences could be attributed to a number of factors including misattribution of recruitment and residual groups, variability in survey estimates, natural mortality, by-catch mortality, unreported landings, as well as crab movement in and out of the sampling area. The difference was 35.6 % in 2019 (Fig. 13).

4.1.5. Reproductive potential

The abundance of all adult males increased from 1997 to 1999, remained stable until 2004 and gradually decreased until 2009 (Fig. 14). From 2009 to 2019, the abundance of adult males increased to levels comparable to those observed during the 1999-2005 period (Fig. 14). The abundance of mature females (primiparous and multiparous) in 2019 remained high relative to the low values observed during 2006 to 2009 (Fig. 15). Over the time series, the annual mean size of mature females varied from 56.5 mm in 2019 to 61.7 mm CW in 2005 (Fig. 16).

5.0. RISK ANALYSIS OF CATCH OPTIONS AND PROGNOSIS

Within the Precautionary Approach framework (DFO 2009), the limit reference point for biomass (B_{lim}) defines the critical / cautious zones and an upper stock reference point (B_{USR}) delimits the cautious / healthy zones on the stock status axis. A removal rate limit reference point (F_{lim}) defines the maximum removal rate in the healthy zone. Reference points which conform to the Precautionary Approach were developed in 2010 for the snow crab biological unit of the sGSL (DFO 2010). The change in methodology derived from the 2011 Snow Crab Assessment Methods Framework Science Review required the recalculation of the time series of biomass estimates and the Precautionary Approach reference points (DFO 2012b).

The rescaled B_{USR} is set at 41,400 t of commercial-sized adult males of all carapace conditions, which is 80 % of the biomass of maximum sustainable yield (B_{MSY}) with the proxy for B_{MSY} chosen as 50 % of the maximum estimated commercial biomass for the 1997 to 2008 time period (Table 7; Fig. 17). The rescaled B_{lim} value is 10,000 t (Table 7; Fig. 17). The B_{lim} was chosen as the lowest biomass of hard shelled commercial-sized adult males, which was observed in 2000 (residual biomass estimated from the trawl survey) (DFO 2010). The rescaled F_{lim} has been set at 34.6 % (Table 7; Fig. 17), which is the average annual exploitation rate calculated as catch (weight) in year *t+1* divided by the estimated biomass of commercial-sized adult male crab from the post-fishery trawl survey in year *t* for the 1997 to 2009 time period (DFO 2010).

5.1. RISK ANALYSIS OF CATCH OPTIONS FOR 2020

The estimated commercial biomass available for the 2020 fishery in the sGSL is 79,066 t (69,072 to 90,091 t; Table 2), which is in the healthy zone of the precautionary approach framework (Fig. 17). The predicted recruitment of commercial crab for the 2021 fishery based on the Bayesian prerecruit model (Surette and Wade, 2006; Wade et al., 2014), using the 2019 survey data, is 66,850 t (44,590 to 95,800 t) (Table 4; Fig. 18). This predicted recruitment of commercial crab for the 2021 fishery represents the highest of the time series and should be taken with cautious given the unexpected jump in the abundance of prerecruits R-2 observed during the 2019 trawl survey.

Harvest decision rules that conform to the precautionary approach have been developed (DFO 2014). These precautionary approach compliant harvest decision rules include rules for which the exploitation rate exceeds F_{lim} when the stock is in the healthy zone (DFO 2014). The Snow Crab Advisory Committee agreed on the proportional harvest decision rule (variant 4 in DFO 2014, Fig. 19) to derive the exploitation rate and the TAC based on the estimated biomass from the southern Gulf of St. Lawrence snow crab survey. This decision rule and the corresponding estimated commercial biomass from the 2019 survey of 79,066 t, results in a selected exploitation rate of 40.6 %, corresponding to a TAC of 32,101 t for the 2020 fishery (Fig. 19).

A risk analysis was developed for the decision rule TAC and relative to other catch levels in 2020 (Table 7, Fig. 20). The risk analysis indicates that the TAC derived from the harvest decision rule will result in a near 100 % chance of the biomass for the next year's fishery being above B_{USR} and in the healthy zone of the PA (Table 7, Fig. 20). The risk analysis also provides predictions of the commercial biomass in the 2020 survey, assuming the corresponding catch level is taken in 2020.

The potential overestimation of the pre-recruits R-2 during the 2019 trawl survey may also overestimate the projection of the recruitment to the fishery for the 2021 fishing season, which was estimated at 66,850 t (44,590-95,800 t; Table 5) and corresponding commercial biomass for 2021 shown in Table 7 under different catch options in the 2020 fishery. Despite the possible overestimation, the biomass of commercial-sized adult males is still expected to be at a high level, with positive signs of recruitment and productivity (number of females). Using the commercial-sized adult males biomass of 79,066 t estimated from the 2019 trawl survey as per the usual method to calculate the quota for the 2020 fishery should not put the stock at great risks.

The bias introduced by the prolonged trawling during the passive phase may overestimates the predicted recruitment of commercial crab for the 2021 fishery and this will affect the probabilities for the B_{USR} component and corresponding commercial biomass for the 2021 fishery according to different catch options for the 2020 fishery.

A number of factors can account for the variation in the recruitment rate of the prerecruits to the commercial-sized adult stage including unaccounted bycatch mortality, sampling uncertainties, natural mortality and variations in the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase), especially if density-dependent phenomena occur. In addition, in these two-year commercial biomass projections, we used a forecast survivorship rate of 0.7, which is a five-year moving average. In the past, the survivorship rate has varied considerably from one year to the next which affects directly the commercial biomass projections.

There was a vessel change in 2019 and a large number of the snow crab catch rate indices and trawl fishing performance metrics suggest that there may have been an overestimation of the survey indices in 2019 relative to 2018. It is estimated that the increase in 2019 from 2018 in the total swept area, which includes a previously unaccounted for swept area, was on average 12.6 %. If the swept area was underestimated by that amount, then the snow crab indices including the commercial male adult biomass estimates may be inflated by a similar amount.

No correction to the 2019 biomass estimate is provided. Rather, a risk assessment to the attainment of the PA objectives associated with an overestimation of the biomass is presented in Table 8. In the case of potential positive bias in the estimation of the commercial biomass, the greater concern is of the residual biomass falling into the critical zone. At 10 % or less positive bias of the 2019 commercial-sized adult male biomass, there is less than a 2 % chance of the residual biomass after the fishery in 2020 being in the critical zone if the TAC of 32,101 t derived from the harvest decision rule and the 2019 estimate of 79,066 t is applied in the 2020 fishery. At 15 % bias, the probability of the residual biomass in the survey of 2020 being in the critical zone increases to 8 % (Table 8).

5.2. PROGNOSIS

Small pulses of juvenile males, between 12 to 17 mm, 17 and 25 mm and to 25 and 30 carapace width were observed in the 2019 survey (Fig. 21). The abundance of males with a CW between 34 and 44 mm in 2019, which will reach the commercial size in 6 years, increased compared to 2018 (Fig. 22). The abundance of prerecruits ≥ 56 mm CW (R-4, R-3, R-2) increased in 2019 (Table 4). The area occupied by these crabs in the 2019 survey was mostly in Chaleur Bay, in Shediac valley, on Bradelle Bank and in the southeastern part of sGSL (Fig. 23).

The estimated abundances of immature and pubescent females in the population increased from 2001 to 2012, decreased in 2013 and 2014 and increased since 2014 (Figs. 15 and 24). The abundance of mature females increased in 2019 relative to the low values observed during 2006 to 2009 (Figs. 15 and 24).

6.0. UNCERTAINTIES

6.1. CHANGE IN THE SURVEY PROTOCOL AND VARIABILITY IN THE COMPOSITION OF COMMERCIAL BIOMASS

The estimated abundances of snow crab, all life stages, in the assessment model are considered to be an unbiased, proportional index of the snow crab population in the sGSL over the time series 1997 to 2019. As such, the catchability for commercial-sized male snow crab is assumed to be constant over the time series and in the case of this assessment equal to one. Biases in the indices of abundance, resulting from directional changes in catchabilities over time could arise from a number of factors in the snow crab trawl survey.

The assumption of homogeneity of the biomass time series may have been weakened through the introduction of bias via changes in survey design, vessel and gear operation. However, the identification of a source of bias is not necessarily of concern if it can be assumed that the scale of the bias does not change through time.

There have been five different boats have been used to conduct the trawl survey:

- the “Emy-Serge” (1988-1998), a 65-foot side-trawling (375 HP) wooden boat,
- the “Den C. Martin” (1999-2002), a 65-foot stern-trawling (402 HP) steel boat,
- the “Marco-Michel’’ (2003-2012), a 65 feet stern-trawling (660 HP) fiberglass boat,
- the “Jean-Mathieu” (2013-2018), a 65-foot stern trawling (750 HP) steel boat,
- and the ‘’Avalon Voyager II’’ used in 2019, a 65 foot stern trawling (850 HP) fiberglass boat.

Individual survey catches are standardized by trawl swept area using wing spread data from trawl acoustic monitoring sensors (Moriyasu et al. 2008). However, there are possible sources of bias in this standardization. For example, it has been shown that swept area of the passive trawling phase, which is currently unaccounted for, varies as a function of winch speed, which in turn may vary depending on the vessel and operator. It may also vary as a function of the vessel manoeuvers at the end of each tow. It is presently unknown whether these characteristics and/or manoeuvers have changed through time (Fig. 6).

Other factors might be affecting the catchability of crab encountering the trawl. For example, it is known that the trawling speed is generally faster during the passive trawling phase than in the active trawling phase. In addition, the configuration of the trawl may be less than optimal during the passive phase, leading to possibly lower catchability. In particular, asymmetry between the warp cables during winching would lead to a possibly lower effective wing spread, and thus to lower effective swept areas.

Passive phase swept areas represent a source of previously unaccounted bias in our biomass and abundance indices. The results in this document strongly suggest that the large increase in overall catches of snow crab in 2019 relative to 2018 is at least partially due to increases in the swept area of the passive trawling phase. We note that while the passive phase has been highlighted as a source of negative bias for abundance and biomass estimates, there are a number of other sources which are presently ignored in the standardization. Chief among these is the catchability of the trawl, which for larger crab is assumed to be 1, and therefore represents a source of positive bias with respect to estimates.

It should be noted that passive swept area estimates rely on a number of simplifying assumptions, the violation of which would lead to biases in its estimation. The trigonometric model outlined relies on the warp cables being a straight line to the survey vessel when in reality they will sag under their own weight. This implies that the trawl is generally closer to the survey vessel than we consider here, making the distance travelled due to winching, and thus its contribution to the swept area, smaller by comparison. Also, estimates of lift off times, though calculated using the same method for all years considered, may be somewhat overestimated. The lifting off of the footrope is a more protracted process, unlike the touch down. In particular, the contact of the footrope in locations other than its center, which is monitored by the tilt probe, is unknown during the lifting of the trawl, which may be lifting the trawl wings.

For the upcoming 2020 survey, efforts will made to render the duration of the passive trawling phase comparable to that of the “Jean Mathieu”.

The kriging polygon or the area over which the abundance or biomass is estimated has increased over the years. The difference between the survey area, i.e. over which trawl samples are extracted, and the latest kriging polygon is more pronounced farther back in time. Thus there is more extrapolation and potential for bias during earlier years.

Over the period 1997 to 2019, five vessels have been used and until 2019 no comparative experiments were conducted to assess for differences in catchability between vessels. Catchability of the trawl and the trawl fishing process has not been estimated directly but is assumed to be constant over the time series. Benoit and Cadigan (2016) modelled the snow crab trawl survey data simultaneously with the research vessel multi-species groundfish bottom trawl survey data and indicated that there were estimable differences in catchabilities among vessels with a lower catchability for the Jean-Mathieu relative to the previous vessels, an effect which is presently not included in the development of the biomass time series.

A comparative survey at 40 stations was conducted with the new vessel and the previous vessel in 2019. Although there was no statistically significant difference in the estimated catch rates of commercial-sized adult male snow crab between the two vessels in the 2019 experiment, the systematic increase in the catches of female snow crab and of sub-legal male snow crab in 2019 relative to 2018 over the entire sGSL samples, suggested that there may have been a difference in catchability in 2019 from 2018. One trawling performance metric that was different in 2019 compared to 2018 and 2017 that would have impacted the estimated area sampled, and hence the catchability, is the longer duration of the passive phase in which the trawl is still fishing. The trawl may have continued to catch snow crab during this phase which may account for some of the relative increase in catch rates in 2019 compared to 2018.

A number of metrics of trawl configuration are currently monitored on the snow crab survey and these are used to directly estimate the swept area of each individual tow. Individual survey catches are standardized by trawl swept area during the active phase using these wing spread data and bottom contact data from trawl acoustic monitoring sensors. However, not all aspects of trawl configuration during fishing are well understood. Other than the observations of the increased mean duration of the passive phase in 2019 relative to 2018 and 2017, it is presently unknown how the other characteristics of trawl behavior may have varied over time, nor their effect on the abundance indices time series.

Catchability, independent of vessel changes, may also have changed as a result of the station selection protocol. The replacement of a primary station with an unsuccessful tow by an alternate station that is successfully trawled in a sampling square in subsequent years could result in a systematic bias over time to sampling only in trawlable areas. Trawlable substrate, soft muddy bottoms or sand in contrast to boulder or bedrock areas, may also be more favorable habitat for snow crab. If there is a systematic drift over years of sampling more of these primary habitats, the catchability may increase over time, independent of trawl and vessel effects.

Predicting recruitment to the fishery is uncertain because of a number of factors including variations in catchability of survey indices among years, variations in mortality, growth among stages and the variation in the proportion of pre-recruits that molt in any given year. The high abundance index of R-2 in 2019 was unexpected based on the abundance index of R-3 in 2018 and may be high as a result of a higher catchability in 2019 associated with the change in survey vessel. The predicted recruitment of R-1 to the survey in 2020 is consequently high and any estimation of biomass available for the fishery in 2021 should be treated with caution. Prognosis for the 2021 fishery would be best assessed using the upcoming 2020 survey assessment.

Environmental conditions in the sGSL vary annually and these changes can affect a number of life history processes including molting and growth, reproduction, and larval development. Warming of the deep water of the Laurentian Channel may influence bottom temperatures in adjacent areas and the impacts on the snow crab population remain uncertain. Snow crab in the peripheral areas of the sGSL adjacent to the slope of the Laurentian Channel and the troughs along western Cape Breton Island would be particularly susceptible to these warming trends.

The fishery performance catch per unit effort indices are not used to infer on abundance of the commercial adult male snow crab. The unstandardized catch per unit effort from the fishery correlates weakly with the estimated biomass from the assessment. This results in differences in perception of stock abundance based on fishing industry observations (catch per unit of effort variations within season and between years) from those of the assessment.

6.2. GROWTH

Recruitment to the fishery for snow crab is highly variable from year to year (Comeau and Conan 1992; Sainte-Marie et al. 1995; Comeau et al. 1998; Moriyasu et al. 1998) depending on environmental conditions, predation and population levels. In sGSL snow crab stocks, the biomass of commercial-sized adult male crab appears to fluctuate from periods of three to four years of high recruitment followed by three to four years of low recruitment (Sainte-Marie et al. 1995; Comeau et al. 1998; Moriyasu et al. 1998). Since molting activity peaks in January for adolescent skip-molters and in March for normal molters, most postmolt males are potentially catchable as soon as the fishery starts (generally at the end of April). Soft-shelled males in the commercial catches are found from late April to August in the sGSL (Hébert et al. 2002).

The mechanism of molting to terminal phase is complex. Conan et al. (1988), and Comeau et al. (1998) hypothesized that the molt to terminal phase for a given size group may be density-dependent rather than genetically determined. Waiwood and Elner (1982) hypothesized that the removal of large old crab would release the snow crab population from a “stagnant” to a “dynamic” high-growth phase. Comeau et al. (1998) suggested that a high abundance of large mature (adult) males in the population may trigger molting to another larger juvenile (adolescent) instar stage instead of molting to the terminal phase. Alternatively growth could be inhibited resulting in an increased abundance of skip-molters. The annual trawl survey showed a very high (up to 50–60 % in peak years) skip-molting rate in adolescent males larger than 50 mm CW. Such a high percentage of skip-molters may reflect a density-dependent effect on the molting schedule of larger adolescent males. Dawe et al. (2012) showed that the frequency of skip-molting is strongly and directly related to body size (i.e. larger than 50mm CW), and it is also inversely related to water temperature. Prediction of a given size of male crab belonging to the near-future recruitment population (R-1, R-2 and R-3) is difficult, which increases uncertainty of predicted and measured abundance of recruitment to the fishery. This may be a driving factor affecting the strength and timing of recruitment to the fishery.

6.3. ENVIRONMENTAL CONSIDERATIONS

Environmental factors, such as water temperature, can affect molting, reproductive dynamics and the movement of snow crab. Chassé and Pettipas (2009) reported that bottom temperatures over most of the sGSL are typically between -1 and 3 ºC, a temperature range suitable for snow crab. Data collected during research surveys indicate that the bottom temperatures in deeper waters of Areas 12E and 12F are higher (1 to 5 ºC) than on the crab grounds (-1 to 2 ºC) in Area 12. Bottom temperatures in Area 19 are usually 1 to 2 ºC warmer than on the traditional crab grounds in Area 12 (Chassé and Pettipas 2009).

In September 2019, near-bottom temperatures were near the mean value of the period 1981 to 2010 in most of Area 12 as well as in Chaleur Bay (Fig. 25). However, the bottom waters in periphery of Area 12, the Area 19, the deeper parts of Area 12E and 12F, and the western portion of the sGSL were warmer than normal. The channels connecting the slope of the Laurentian Channel to the mouth of Chaleur Bay were also warmer than normal. Colder-than-normal bottom waters were present in the western portion of Chaleur Bay and in the coastal waters northeast of PEI.

Most of the snow crab fishing grounds in the main portion of Area 12 had similar temperatures, or slightly cooler, in 2019 compared to 2018 except at the mouth of Chaleur Bay and in the western of the sGSL were temperatures were warmer in 2019. The area at the eastern entrance of Northumberland Strait (including St. George's Bay) and Area 19 also had significantly warmer waters in 2019 compared to 2018 (Fig. 25). Although higher than normal, Area E and Area F temperatures in 2019 were similar to those observed in 2018 (Fig. 25).

In September 2019, the snow crab habitat index (bottom area with temperatures from -1 to 3 °C) was the third lowest of the 1971-2019 time series. It was 10 % below the 1981-2010 average in 2019 and decreased by 9 % from 2018 value and 13 % from the 2017 value (Fig. 26). The mean temperature (1.0 °C) within the defined snow crab habitat area index (-1 to 3 °C) in 2019 decreased by about 0.2 °C compared to 2018 (1.2 ºC, Fig. 26). The mean temperature was at the highest of the 48 year time series in 2012, decreased in 2013 and 2014, and remained above the normal since then (Fig. 26).

Snow crab is a stenothermic species with a preference for colder water temperatures. A temperature regime shift from cold to warm may have impacts on population dynamics of snow crab such as shortened reproductive cycles, increased per capita fecundity, and increased size at maturity, greater natural mortality, spatial contraction of habitat, and skewed sex ratio for reproduction. The outcome of climate change on snow crab population dynamics can be relatively abrupt and even detrimental, and the direction of the effect may be difficult to predict (Sainte-Marie et al. 2008).

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TABLES

Table 1. Summary statistics of the duration, the covered distance, the speed of the vessel and the wing spread of the trawl during the passive phase from the 2017, 2018 and 2019 trawl survey.

			Percentiles					
year	**variable**	**units**	**2.5 %**	**25 %**	**50 %**	**75 %**	**97.5 %**	**average**
2017	vessel speed	m/s	0.24	0.61	0.82	0.99	1.44	0.81
2018	vessel speed	m/s	0.32	0.66	0.81	1.00	1.32	0.82
2019	vessel speed	m/s	0.46	0.65	0.81	1.03	1.45	0.86
2017	Duration	s	9	25	50	82	439	82.1
2018	Duration	s	8	24	43	75	441	74.6
2019	Duration	s	15	58.75	89	117	544	116.2
2017	vessel distance	m	25.5	60.0	102.6	154.7	715.2	149.2
2018	vessel distance	m	22.2	57.1	89.9	137.7	749.7	135.6
2019	vessel distance	m	39.4	113.5	158.5	202.8	965.4	203.1
2017	winch speed	m/s	1.01	1.21	1.26	1.30	1.39	1.25
2018	winch speed	m/s	1.03	1.22	1.26	1.30	1.36	1.25
2019	winch speed	m/s	0.71	0.84	0.90	0.97	1.31	0.92
2017	liftoff angle	degrees	19.1	24.9	27.9	32.2	56.1	29.3
2018	liftoff angle	degrees	19.7	24.7	28.0	31.5	47.6	29.2
2019	liftoff angle	degrees	20.5	26.7	34.0	42.6	64.2	35.5
2017	winch distance	m	13.0	35.8	65.9	105.4	511.1	100.3
2018	winch distance	m	11.9	33.5	56.9	89.3	515.3	89.9
2019	winch distance	m	20.9	58.4	87.6	113.8	482.6	112.1
2017	wing spread	m	4.5	6.3	6.9	7.5	9.4	6.9
2018	wing spread	m	4.2	6.4	7.0	7.5	9.5	6.9
2019	wing spread	m	3.3	5.5	6.5	7.2	8.9	6.3
2017	swept area	m^2	160	425	688	1118	4932	1014
2018	swept area	m^2	135	394	605	945	4781	938
2019	swept area	m^2	227	613	992	1392	6067	1270

Table 2. Estimated biomass (t, mean and 95 % confidence interval in parentheses) of commercial-sized adult male snow crab, Chionoecetes opilio*, in the southern Gulf of St. Lawrence (all zones) by kriging, based on trawl survey data from 1997 to 2019. Recruitment refers to snow crab with carapace conditions 1 and 2 whereas residual biomass refers to snow crab with carapace conditions 3 to 5.*

Survey year	Commercial biomass	Recruitment biomass	Residual biomass
1997	64,518 (54,105-76,345)	37,910 (30,911-46,018)	27,688 (21,982-34,422)
1998	57,813 (45,856-71,931)	30,603 (22,695-40,384)	28,295 (21,497-36,566)
1999	56,757 (47,641-67,102)	26,015 (20,709-32,265)	31,177 (25,044-38,356)
2000	50,621 (41,843-60,692)	40,734 (33,592-48,942)	9,979 (6,987-13,827)
2001	60,328 (49,851-72,351)	42,358 (33,800-52,422)	17,612 (13,853-22,077)
2002	79,228 (67,983-91,791)	66,076 (55,416-78,180)	13,060 (10,793-15,662)
2003	84,448 (73,486-96,574)	58,270 (50,270-67,175)	26,993 (22,124-32,613)
2004	103,146 (92,426-114,758)	83,764 (74,392-93,981)	21,259 (17,343-25,794)
2005	82,565 (73,514-92,415)	59,939 (53,551-66,870)	23,496 (18,902-28,868)
2006	73,645 (65,681-82,302)	54,541 (48,235-61,438)	19,621 (16,697-22,907)
2007	66,371 (59,971-73,264)	40,048 (35,286-45,269)	26,829 (23,232-30,821)
2008	52,921 (47,167-59,178)	32,241 (27,929-37,027)	20,981 (17,989-24,327)
2009	31,015 (27,519-34,829)	20,618 (17,747-23,818)	10,454 (8,687-12,474)
2010	35,929 (32,049-40,147)	20,477 (17,815-23,423)	15,490 (13,022-18,289)
2011	62,841 (55,985-70,299)	29,643 (25,676-34,045)	33,679 (28,430-39,613)
2012	74,778 (64,881-85,748)	49,010 (40,382-58,931)	25,615 (21,607-30,147)
2013	66,709 (54,294-81,108)	39,988 (31,504-50,055)	27,092 (22,041-32,952)

Survey year	Commercial biomass	Recruitment biomass	Residual biomass
2014	67,990 (59,802-76,978)	44,285 (37,440-52,014)	23,863 (20,356-27,799)
2015	58,927 (51,368-67,278)	34,982 (29,145-41,643)	24,106 (20,290-28,429)
2016	98,394 (87,150-110,677)	74,124 (64,811-84,392)	24,309 (20,876-28,143)
2017	65,738 (57,221-75,157)	51,127 (43,976-59,103)	14,650 (12,134-17,534)
2018	80,746 (70,984-91,467)	59,609 (51,755-68,310)	21,432 (17,271-26,291)
2019	79,066 (69,072-90,091)	58,995 (50,215-68,863)	20,291 (16,940-24,109)

Table 3. Abundance (number by 10^6; mean and 95 % confidence interval) of commercial-sized adult male crabs by carapace condition (CC 1+2, CC3, CC4 and CC5) in the southern Gulf of St. Lawrence based on trawl survey data from 1997 to 2019.

Survey year	Carapace condition 1+2			Carapace condition 3			Carapace condition 4			Carapace condition 5		
	Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval	
1997	59.069	47.129	73.109	28.326	21.710	36.327	17.726	13.242	23.246	5.184	3.071	8.215
1998	51.382	38.994	66.464	24.903	18.569	32.709	16.030	11.367	21.975	8.608	5.213	13.411
1999	48.144	38.377	59.636	32.735	25.346	41.608	16.810	13.091	21.259	7.830	5.292	11.172
2000	68.440	57.669	80.631	10.295	7.750	13.410	7.406	4.336	11.845	2.522	1.701	3.605
2001	76.373	61.187	94.183	28.091	22.978	34.000	5.360	3.017	8.834	1.579	0.546	3.619
2002	112.257	95.352	131.282	21.725	18.201	25.730	4.308	2.925	6.125	0.892	0.477	1.529
2003	100.276	86.379	115.761	38.003	31.365	45.626	11.660	7.928	16.553	1.755	0.882	3.142
2004	143.279	127.523	160.430	28.162	22.442	34.895	9.862	7.794	12.311	1.156	0.785	1.643
2005	99.125	88.636	110.505	29.991	23.604	37.392	10.507	8.172	13.302	0.574	0.277	1.058
2006	84.164	74.958	94.181	29.213	24.788	34.197	5.762	4.408	7.402	1.009	0.636	1.523
2007	62.847	55.660	70.699	31.499	26.656	36.963	13.993	11.240	17.215	1.036	0.646	1.579
2008	49.118	42.877	56.008	23.030	19.338	27.219	11.420	9.172	14.052	3.034	2.099	4.245
2009	31.675	27.381	36.449	12.531	10.433	14.926	5.261	3.713	7.240	1.268	0.711	2.095
2010	32.789	28.700	37.294	20.640	16.940	24.906	4.179	3.271	5.260	1.565	1.012	2.314
2011	52.955	46.067	60.576	44.301	36.962	52.665	9.845	7.754	12.325	1.794	1.147	2.677

Survey year	Carapace condition 1+2			Carapace condition 3			Carapace condition 4			Carapace condition 5		
	Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval	
2012	86.737	71.647	104.057	37.886	31.920	44.640	5.706	4.192	7.590	1.195	0.678	1.957
2013	63.668	48.784	81.669	30.117	22.610	39.324	18.335	14.516	22.850	0.660	0.341	1.159
2014	73.424	59.839	89.165	29.594	23.955	36.160	13.078	10.490	16.110	0.646	0.335	1.132
2015	56.250	46.833	66.999	27.205	21.810	33.530	17.265	14.431	20.490	0.504	0.208	1.032
2016	125.923	109.938	143.565	30.564	25.904	35.817	14.700	11.999	17.826	0.071	0.011	0.245
2017	90.108	77.318	104.399	21.561	17.650	26.080	6.110	4.908	7.518	0.376	0.160	0.756
2018	105.779	91.984	121.047	34.588	28.017	42.233	4.493	3.326	5.939	0.765	0.437	1.247
2019	105.179	90.101	122.045	28.839	24.456	33.778	9.347	6.126	11.371	0.768	0.402	1.335

Table 4. Data used in the risk analysis of catch options: point estimates of abundance (number x 10^6) of snow crab male prerecruits (R-4, R-3 and R-2), the estimated (with 95 % confidence intervals) and forecast (from the Bayesian model with 95 % credible intervals) values for recruitment biomass (t; R-1), estimated residual biomass (t) and estimated commercial biomass (t) in the southern Gulf of St. Lawrence based on trawl survey data, and survivorship rates (S) between years used for the forecast model of commercial biomass. S is calculated based on a 5-year moving average.

Survey Year	Prerecruits (number)			Recruitment to the fishery (t)	Forecast recruitment (t)	Residual biomass (t)	Commercial biomass (t)	Survivorship rates
	R – 4	R - 3	R - 2	R - 1	R-1	Res	B	S
1997	114.0	98.2	59.7	37,910 (30,911-46,018)	na	27,688 (21,982-34,422)	64,518 (54,105-76,345)	na
1998	135.3	91.3	60.3	30,603 (22,695-40,384)	na	28,295 (21,497-36,566)	57,813 (45,856-71,931)	na
1999	195.6	151.1	112.9	26,015 (20,709-32,265)	na	31,177 (25,044-38,356)	56,757 (47,641-67,102)	na
2000	237.5	159.1	88.4	40,734 (33,592-48,942)	na	9,979 (6,987-13,827)	50,621 (41,843-60,692)	na
2001	310.8	227.3	136.3	42,358 (33,800-52,422)	na	17,612 (13,853-22,077)	60,328 (49,851-72,351)	na
2002	164.3	242.2	202.2	66,076 (55,416-78,180)	na	13,060 (10,793-15,662)	79,228 (67,983-91,791)	na
2003	133.2	202.3	178.5	58,270 (50,270-67,175)	na	26,993 (22,124-32,613)	84,448 (73,486-96,574)	na
2004	85.8	122.9	144.1	83,764 (74,392-93,981)	na	21,259 (17,343-25,794)	103,146 (92,426-114,758)	na
2005	62.2	79.8	117.2	59,939 (53,551-66,870)	60,500 (38,800-86,000)	23,496 (18,902-28,868)	82,565 (73,514-92,415)	na
2006	54.1	49.6	65.7	54,541 (48,235-61,438)	49,700 (33,200-73,000)	19,621 (16,697-22,907)	73,645 (65,681-82,302)	na
2007	56.5	47.6	55.4	40,048 (35,286-45,269)	35,200 (21,300-55,000)	26,829 (23,232-30,821)	66,371 (59,971-73,264)	na
2008	80.6	54.6	45.8	32,241 (27,929-37,027)	29,000 (18,500-42,000)	20,981 (17,989-24,327)	52,921 (47,167-59,178)	na
2009	88.5	69.3	43.8	20,618 (17,747-23,818)	27,700 (17,800-38,000)	10,454 (8,697-12,474)	31,015 (27,519-34,829)	na
2010	140.8	110.3	72.5	20,477 (17,815-23,423)	25,900 (17,100-37,000)	15,490 (13,022-18,289)	35,929 (32,049-40,147)	0.64
2011	91.4	99.2	88.2	29,643 (25,676-34,045)	33,700 (22,900-47,000)	33,679 (28,430-39,613)	62,841 (55,985-70,299)	0.64
2012	95.7	86.4	80.5	49,010 (40,382-58,931)	40,700 (31,300-52,400)	25,615 (21,607-30,147)	74,778 (64,881-85,748)	0.69

Survey Year	Prerecruits (number)			Recruitment to the fishery (t)	Forecast recruitment (t)	Residual biomass (t)	Commercial biomass (t)	Survivorship rates
	R – 4	R - 3	R - 2	R - 1	R-1	Res	B	S
2013	103.1	85.1	79.4	39,988 (31,504-50,055)	40,380 (31,670-50,380)	27,092 (22,041-32,952)	66,709 (54,294-81,108)	0.72
2014	105.1	93.6	117.2	44,285 (37,440-52,014)	37,893 (28,568-49,114)	23,863 (20,356-27,799)	67,990 (59,802-76,978)	0.72
2015	107.1	124.7	127.5	34,982 (29,145-41,643)	42,300 (32,760-51,840)	24,309 (20,876-28,143)	58,927 (51,368-67,278)	0.73
2016	113.1	124.8	101.6	74,124 (64,811-84,392)	50,000 (36,400-66,900)	24,650 (21,369-28,793)	98,394 (87,150-110,677)	0.75
2017	113.0	119.6	103.3	51,127 (43,976-59,103)	46,200 (31,400-64,230)	14,759 (12,134-17,534)	65,738 (57,221-75,157)	0.74
2018	135.6	116.5	108.3	59,609 (51,755-68,310)	47,700 (33,800-64,880)	21,432 (17,270-26,291)	80,746 (70,984-91,467)	0.71
2019	190.7	185.9	185.7	58,995 (50,215-68,863)	49,820 (33,790-70,970)	20,291 (16,940-24,109)	79,066 (69,072-90,091)	0.71
2020	na	na	na	na	66,850 (44,590-95,800)	na	na	0.70

Table 5. Estimated snow crab commercial biomass (t, mean and 95 % confidence interval) in 2019 using kriging with external drift for the southern Gulf overall, by management Areas 12, 19, 12E and 12F, and in buffer zones based on the trawl survey data.

Areas	Surface area (km^2)	Commercial biomass (t)	
		Mean	95 % confidence interval
Southern Gulf	57,842.8	79,066	(69,072-90,091)
Area 12	48,074	67,590	(58,787-77,331)
Area 19	3,813	5,639	(3,834-8,004)
Area 12E	2,436.9	554	(50-2,342)
Area 12F	2,426.8	4,613	(3,202-6,439)
Sum of management areas	56,750.7	78,396	na
Unassigned zone above 12E **(A)**	667.9	89	(1-589)
Buffer zone 19/12F **(B)**	134.2	224	(76-521)
Buffer zone 12/ 19 **(C)**	289.5	427	(124-1,086)
Sum of total areas and zones	57,842.7	79,136	na

Table 6. Data (from the trawl survey data, 1997 to 2008, using kriging in weights) used in the development of reference points for the snow crab fishery of the southern Gulf and exploitation rates for the fisheries in 1998 to 2019.

Year of the fishery	Landings (t)	Southern Gulf of St. Lawrence		
		Estimated commercial biomass (t) from survey in year-1	Estimated residual biomass (t) from survey in year-1	Exploitation rate (%) (landings fishery year t / commercial biomass fishery year t-1)
1998	13,575	64,518 (54,105-76,345)	27,688 (21,982-34,422)	21.0
1999	15,110	57,813 (45,856-71,931)	28,295 (21,497-36,566)	26.1
2000	18,712	56,757 (47,641-67,102)	31,177 (25,044-38,356)	33.0
2001	18,262	50,621 (41,843-60,692)	9,979 (6,987-13,827)	36.1
2002	25,691	60,328 (49,851-72,351)	17,612 (13,853-22,077)	42.6
2003	21,163	79,228 (67,983-91,791)	13,060 (10,793-15,662)	26.7
2004	31,675	84,448 (73,486-96,574)	26,993 (22,124-32,613)	37.5
2005	36,118	103,146 (92,426-114,758)	21,259 (17,343-25,794)	35.0
2006	29,121	82,565 (73,514-92,415)	23,496 (18,902-28,868)	35.3
2007	26,867	73,645 (65,681-82,302)	19,621 (16,697-22,907)	36.5
2008	24,458	66,371 (59,971-73,264)	26,829 (23,232-30,821)	36.9
2009	23,642	52,921 (47,167-59,178)	20,981 (17,989-24,327)	44.7
2010	9,549	31,015 (27,519-34,829)	10,454 (8,697-12,474)	30.8
2011	10,708	35,929 (32,049-40,147)	15,490 (13,022-18,289)	29.8
2012	21,956	62,841 (55,985-70,299)	33,679 (28,430-39,613)	34.9

Year of the fishery	Landings (t)	Southern Gulf of St. Lawrence		
		Estimated commercial biomass (t) from survey in year-1	Estimated residual biomass (t) from survey in year-1	Exploitation rate (%) (landings fishery year t / commercial biomass fishery year t-1)
2013	26,049	74,778 (64,881-85,748)	25,615 (21,607-30,147)	34.8
2014	24,479	66,709 (54,294-81,108)	27,092 (22,041-32,952)	36.7
2015	25,911	67,990 (59,802-76,978)	23,863 (20,356-27,799)	38.1
2016	21,725	58,927 (51,368-67,278)	24,309 (20,876-28,143)	36.9
2017	43,656	98,394 (87,150-110,677)	14,650 (21,369-28,793)	44.4
2018	24,260	65,738 (57,221-75,157)	14,759 (12,134-17,534)	36.9
2019	31,707	80,746 (70,984-91,467)	21,432 (17,270-26,291)	39.3
2020	na	79,066 (69,072-90,091)	20,291 (16,940-24,109)	na

Table 7. Risk analyses for different catch options in 2020 for the southern Gulf of St. Lawrence snow crab fishery showing probabilities of the commercial-sized adult male biomass falling below the limit reference point for biomass (B_{lim}), and being over the upper stock reference point (B_{USR}) after the fishery in 2020. ***In bold*** *is the catch option (exploitation rate of 40.6 % corresponding to the commercial biomass of 79,066 t) according to the agreed decision rule of the Precautionary Approach (variant 4, DFO 2014b).*

Catch option (t) for 2020	Probability		Predicted commercial biomass for 2021 (t)
	< B_{lim} (10,000 t)	≥ B_{usr} (41,400 t)	
28,000	0	1	93,522 (67,097-120,002)
29,000	0	1	92,522 (66,097-119,002)
30,000	0	1	91,522 (65,097-118,002)
31,000	0	1	90,522 (64,097-117,002)
32,000	0	1	89,522 (63,097-116,002)
32,101	**0**	**1**	**89,422 (62,996-115,901)**
33,000	0	1	88,522 (62,097-115,002)
34,000	0	1	87,522 (61,097-114,002)
35,000	0	1	86,522 (60,097-113,002)
36,000	0	1	85,522 (59,097-112,002)
37,000	0	1	84,522 (58,097-111,002)
38,000	0	1	83,522 (57,097-110,002)
39,000	0.1	1	82,522 (56,097-109,002)
40,000	0.1	1	81,522 (55,097-108,002)
41,000	0.2	1	80,522 (54,097-107,002)
42,000	0.2	1	79,522 (53,097-106,002)
43,000	0.3	1	78,522 (52,097-105,002)
44,000	0.4	1	77,522 (51,097-104,002)
44,800	0.5	1	76,722 (50,297-103,202)
72,440	1	0.5	49,082 (22,657-75,562)

Table 8. Risk analyses accounting for possible overestimation of the 2019 commercial-sized adult male biomass (positive bias) assuming the TAC from the harvest decision rule applied to the 2019 uncorrected estimate of 79,066 t (69,072-90,091 t) is applied to bias adjusted exploitable biomass values. Shown in the table are the mean biomass values corrected for bias amounts ranging from 0 % to 30 %, the realized exploitation rate on the bias corrected biomass values, and the probabilities of the residual commercial-sized adult male biomass after the fishery in 2020 falling below the limit reference point for biomass ($B_{lim;}$ probability of being in the critical zone), and of the total commercial-sized adult male biomass in the survey of 2020 being above the upper stock reference point (B_{USR}; in the healthy zone).

Bias (%)	True biomass (t) (corrected for bias)	Exploitation rate (%) assuming TAC of 32,101 t	Probability of residual biomass post-fishery < Blim	Probability of total commercial-sized adult male biomass in the survey in 2020 > Busr
0	79,066	40.6	0	1
5	75,113	42.7	0	1
10	71,159	45.1	0.015	0.999
15	67,206	47.8	0.078	0.997
20	63,253	50.8	0.279	0.992
25	59,300	54.1	0.639	0.978
30	55,346	58.0	0.925	0.941

FIGURES

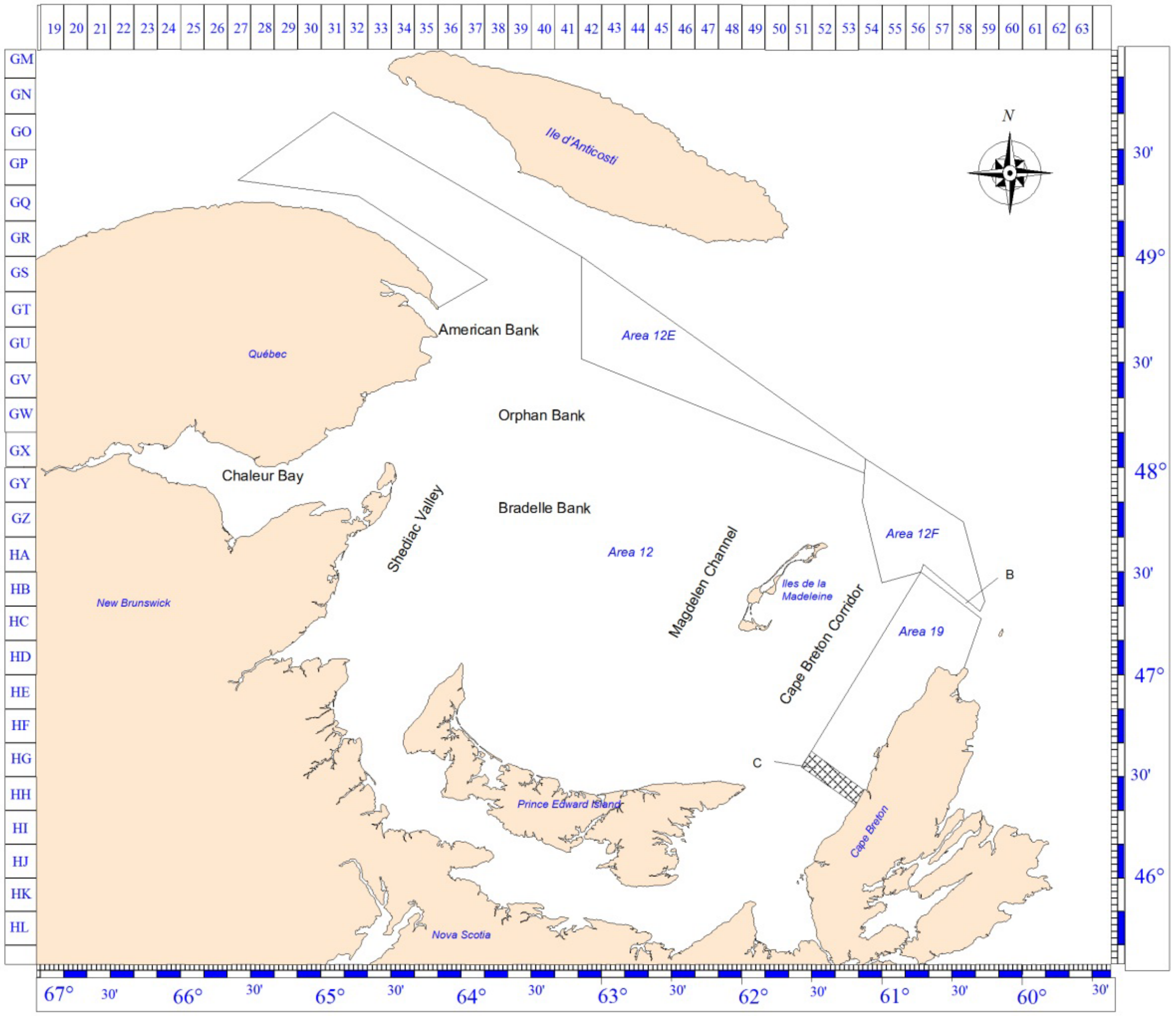


*Figure 1. Map of the southern Gulf of St. Lawrence showing the snow crab (*Chionoecetes opilio*) fishing areas fishing grounds, and management buffer zones (labels B and C, shaded areas).*

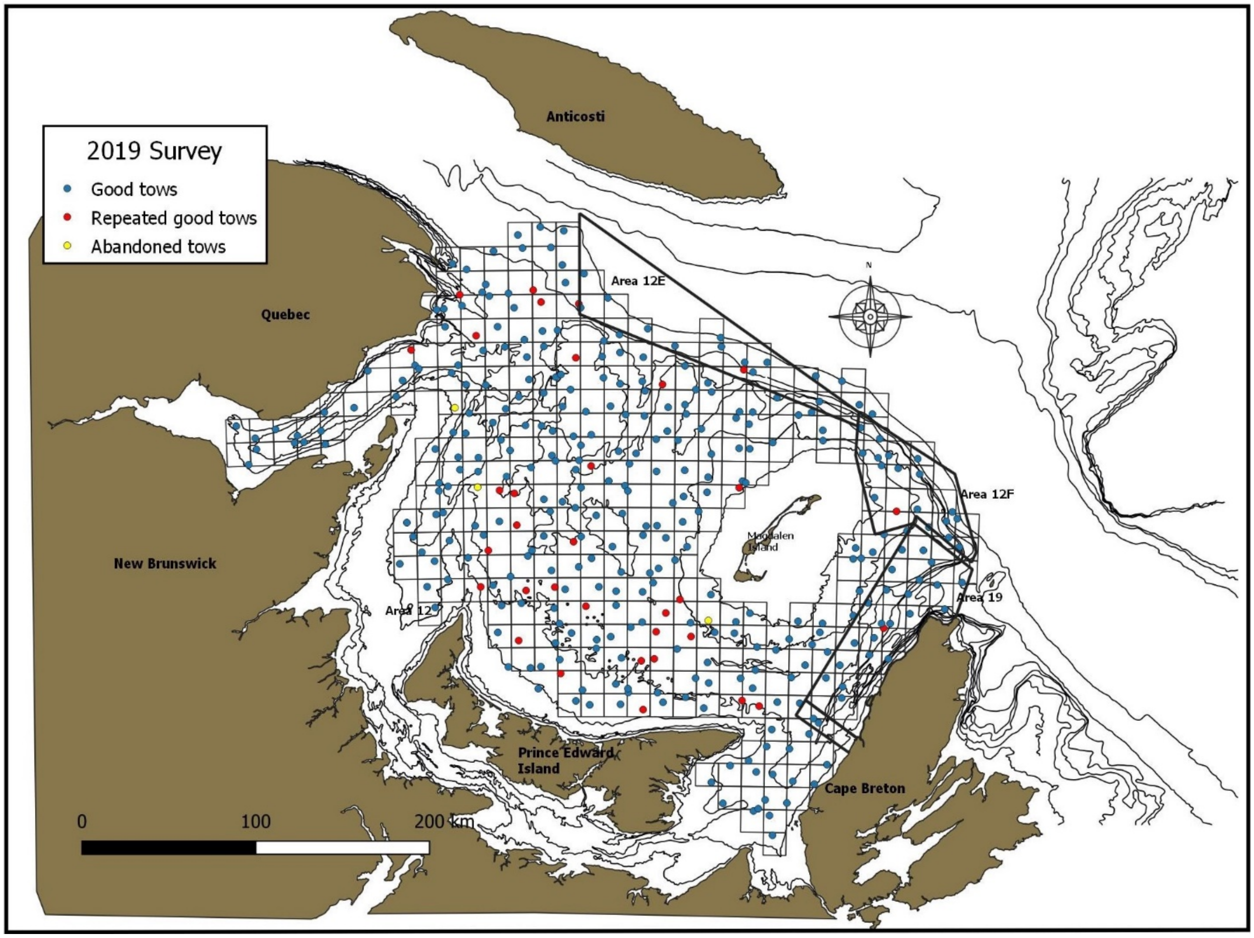


*Figure 2. Locations of the 2019 snow crab (*Chionoecetes opilio*) trawl survey stations within the estimation polygon of 57,842.8 km^2 in the southern Gulf of St. Lawrence. The blue points are successful tows, red points are successful repeat tows and yellow points are abandoned tows.*

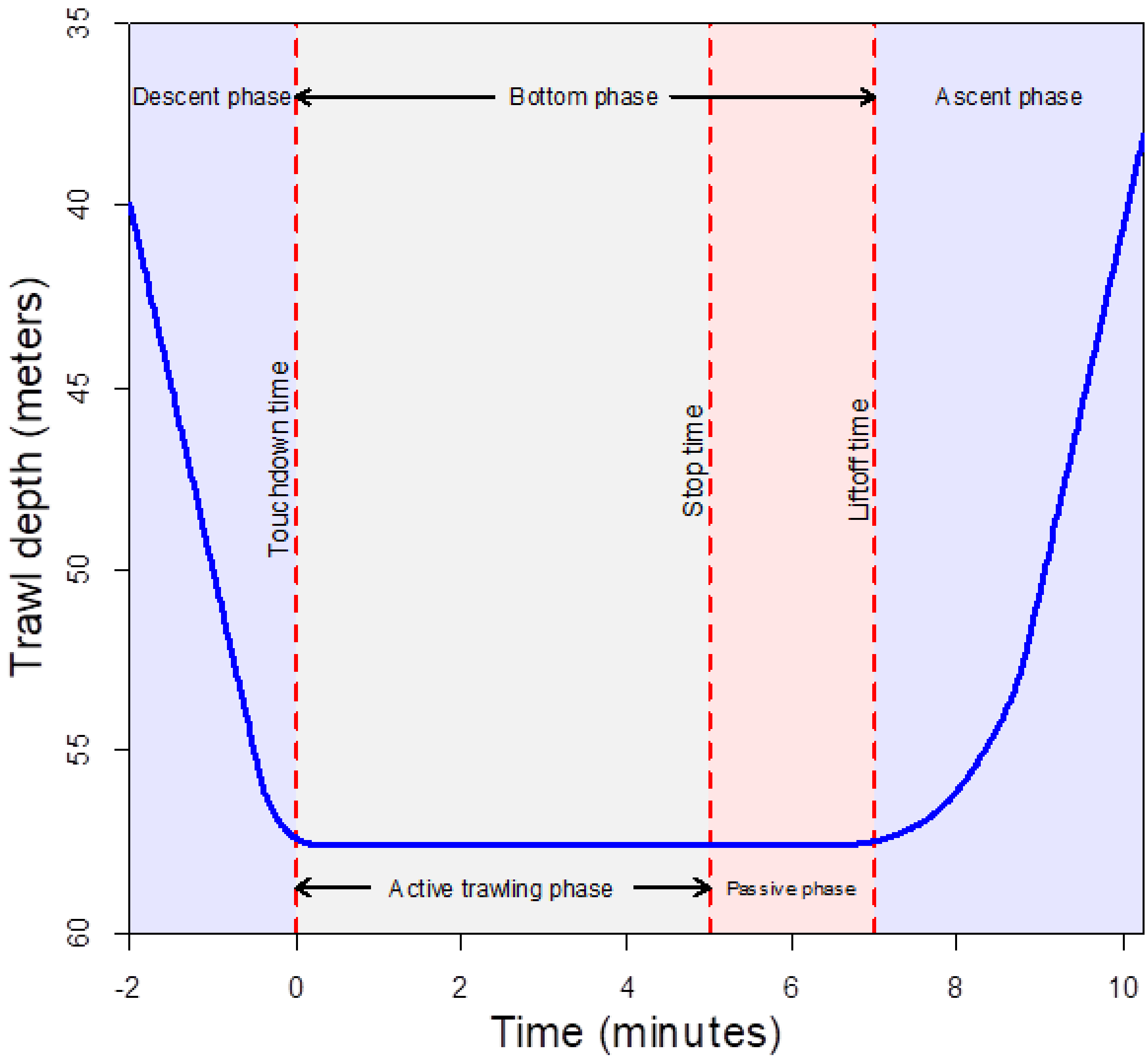


Figure 3. Trawl depth profile of a typical snow crab survey tow, showing the four phases of trawling.

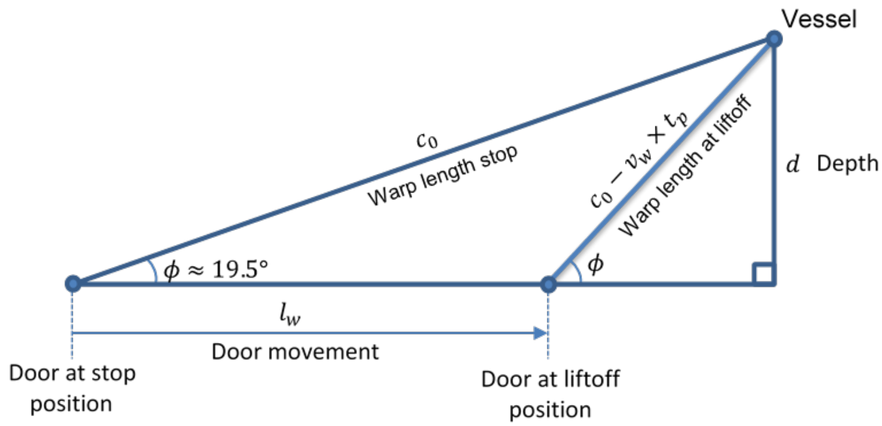


Figure 4. Vessel and trawl movement characteristic during the passive phase for the 2019 snow crab trawl survey.

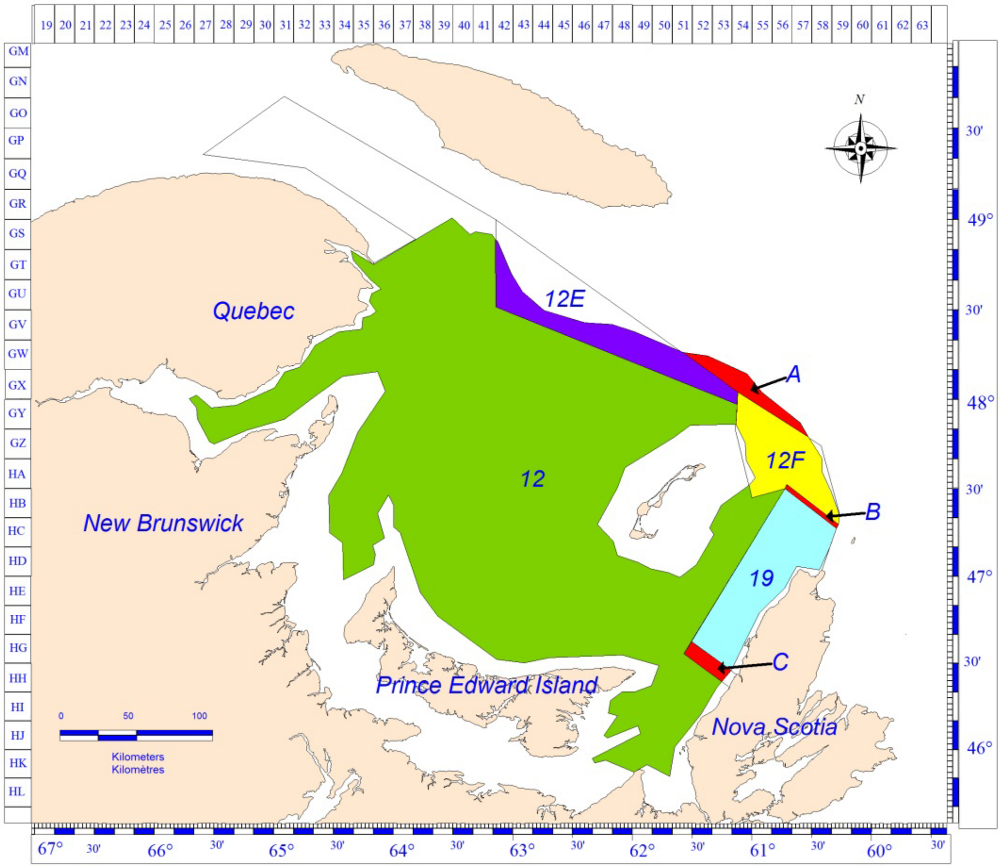


*Figure 5. The estimation polygon of 57,842.8 km² used for the 2019 snow crab (*Chionoecetes opilio*) stock assessment in the southern Gulf of St. Lawrence (all coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F and 19). The unassigned zone north of Areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.*

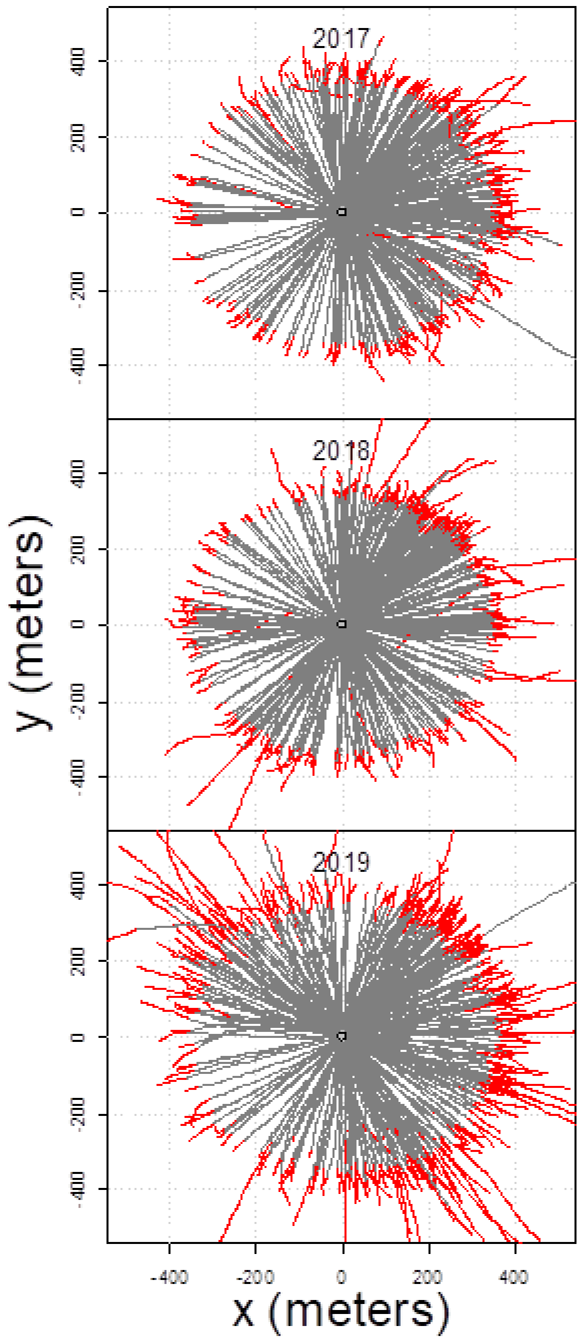


Figure 6. Survey vessel tracks during the active trawling phase (grey lines) and during the passive phase (red lines). Tracks are shifted relative to the vessel position at the tilt touchdown time (center point).

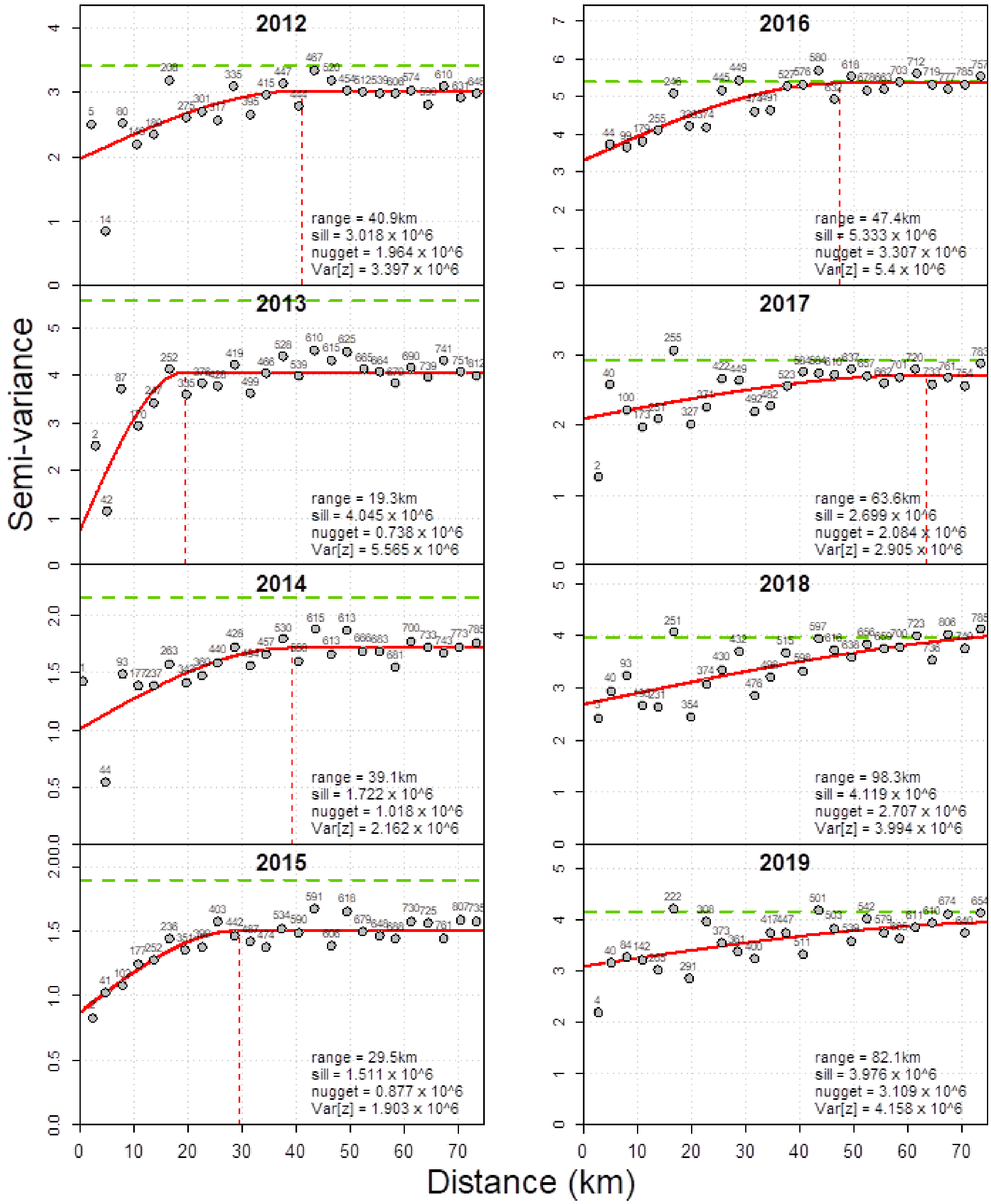


Figure 7. Three-year moving average variogram models for commercial-sized adult male snow crab (Chionoecetes opilio) *in the southern Gulf of St. Lawrence, 2012 to 2019. Indicated is the number of paired observations used per distance lag semi-variance calculation. The red dashed lines indicate the range value on the abscise axis and the nugget and sill values on the y axis. The green dashed line indicates the variance on the y axis.*

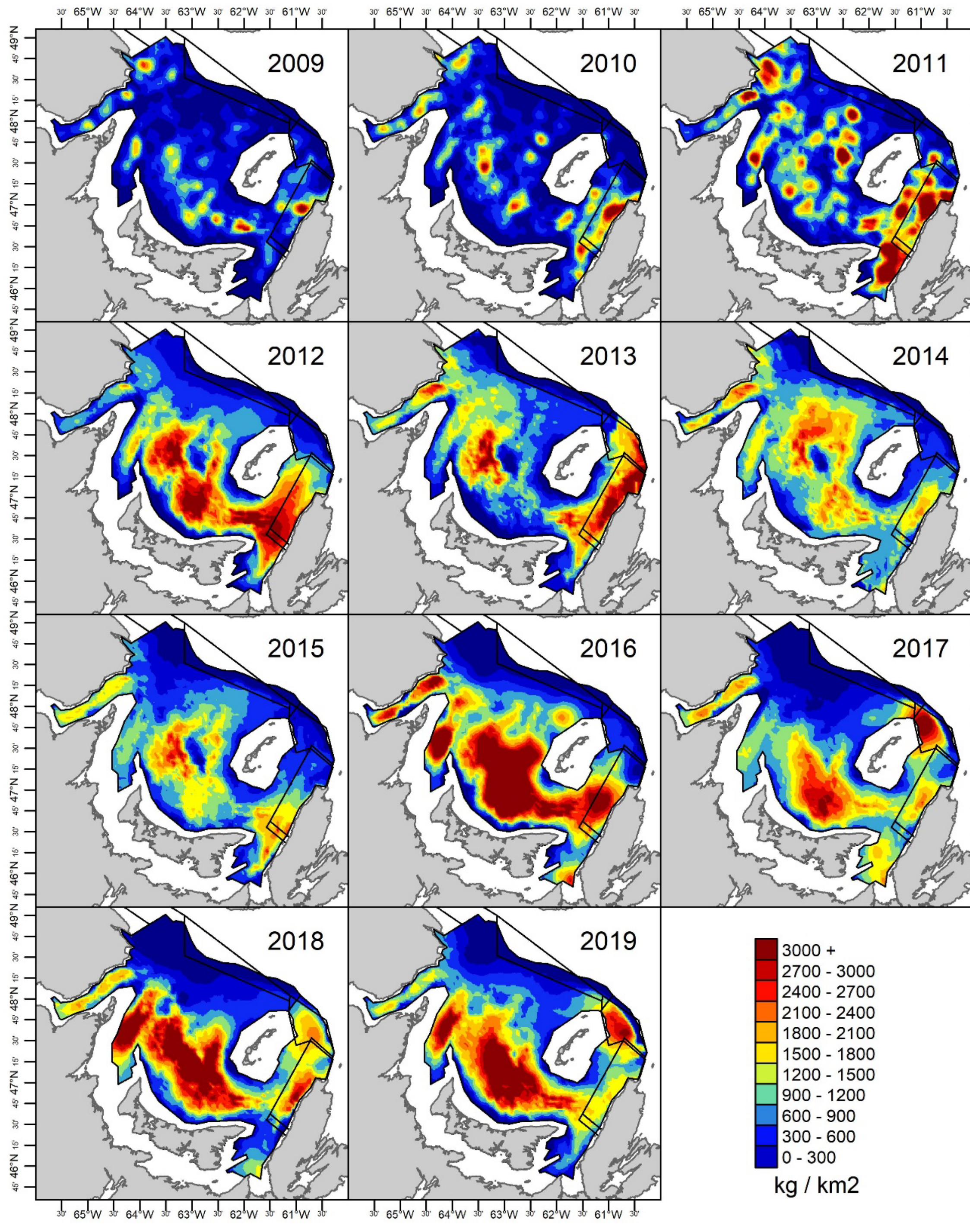


*Figure 8. Density (kg per km²) contours of commercial-sized (≥ 95 mm of carapace width) adult male snow crab (*Chionoecetes opilio*) based on trawl survey data in the southern Gulf of St. Lawrence, 2009 to 2019.*

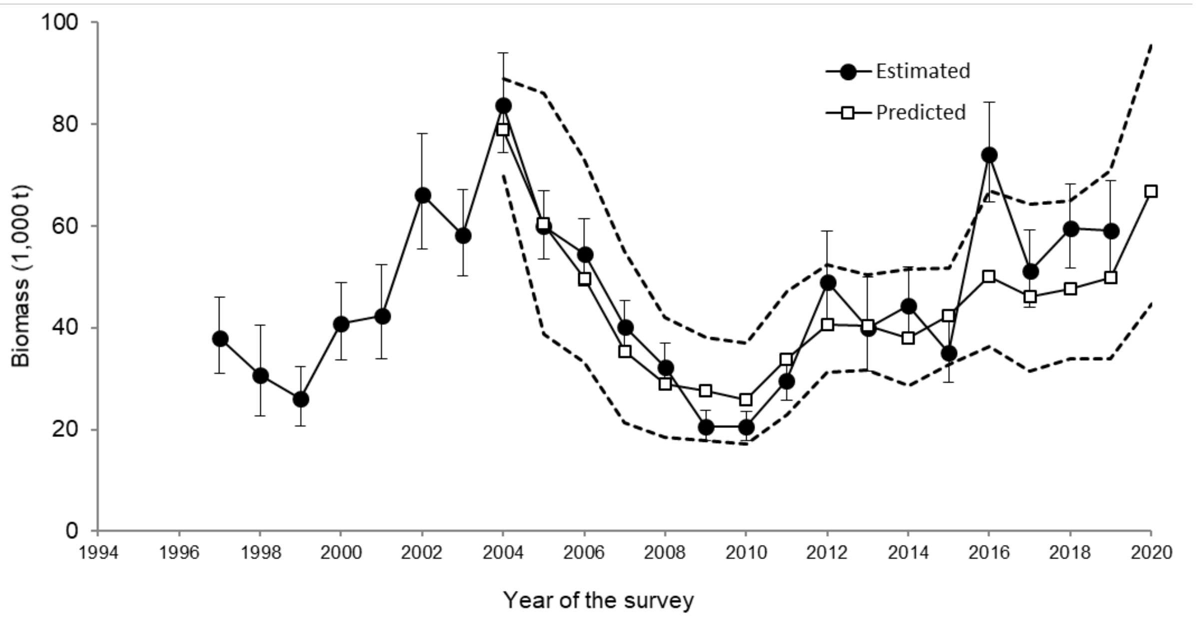


*Figure 9. Comparison between the observed (mean with 95 % confidence intervals) and forecasted (mean with 95 % confidence intervals) recruitment (R-1) of male snow crab (*Chionoecetes opilio*) based on the Bayesian model on prerecruits (Surette and Wade 2006; Wade et al. 2014).*

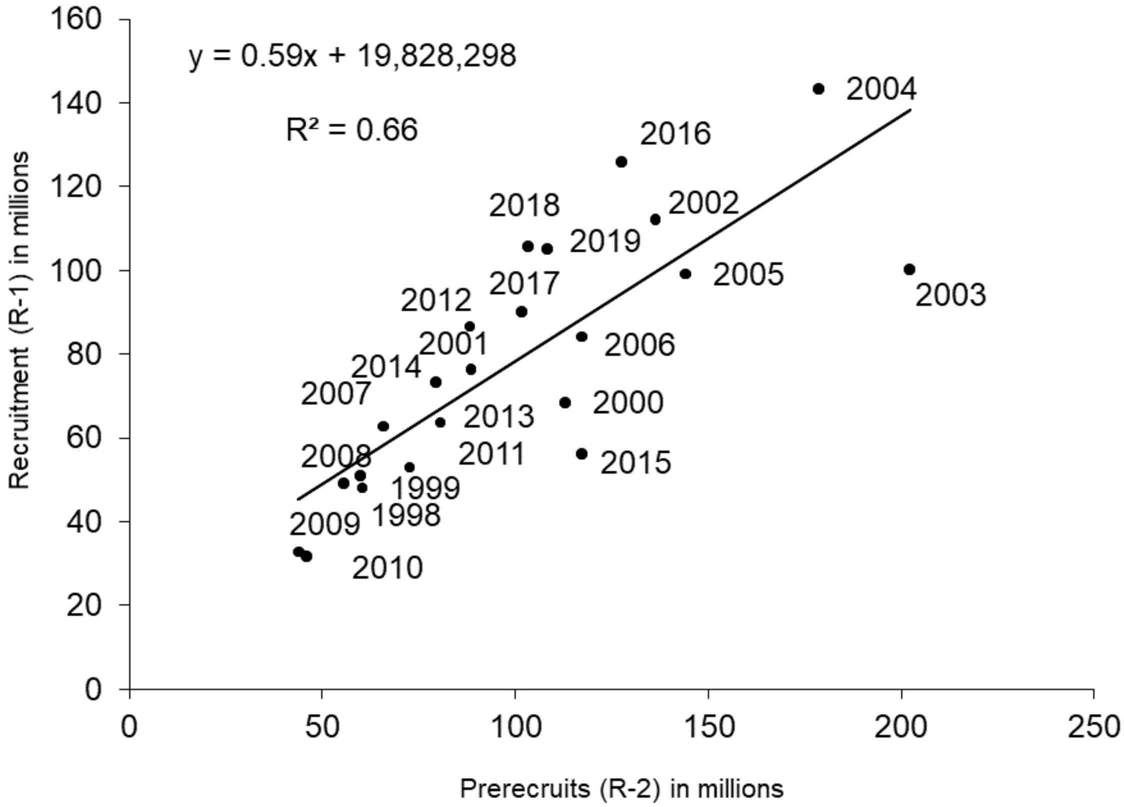


*Figure 10. Relationship between the estimated abundance of prerecruits R-2 in year t - 1 and the estimated abundance of the recruitment to the fishery (R-1) in year t from the trawl survey data for the snow crab (*Chionoecetes opilio*) assessment in the southern Gulf of St. Lawrence.*

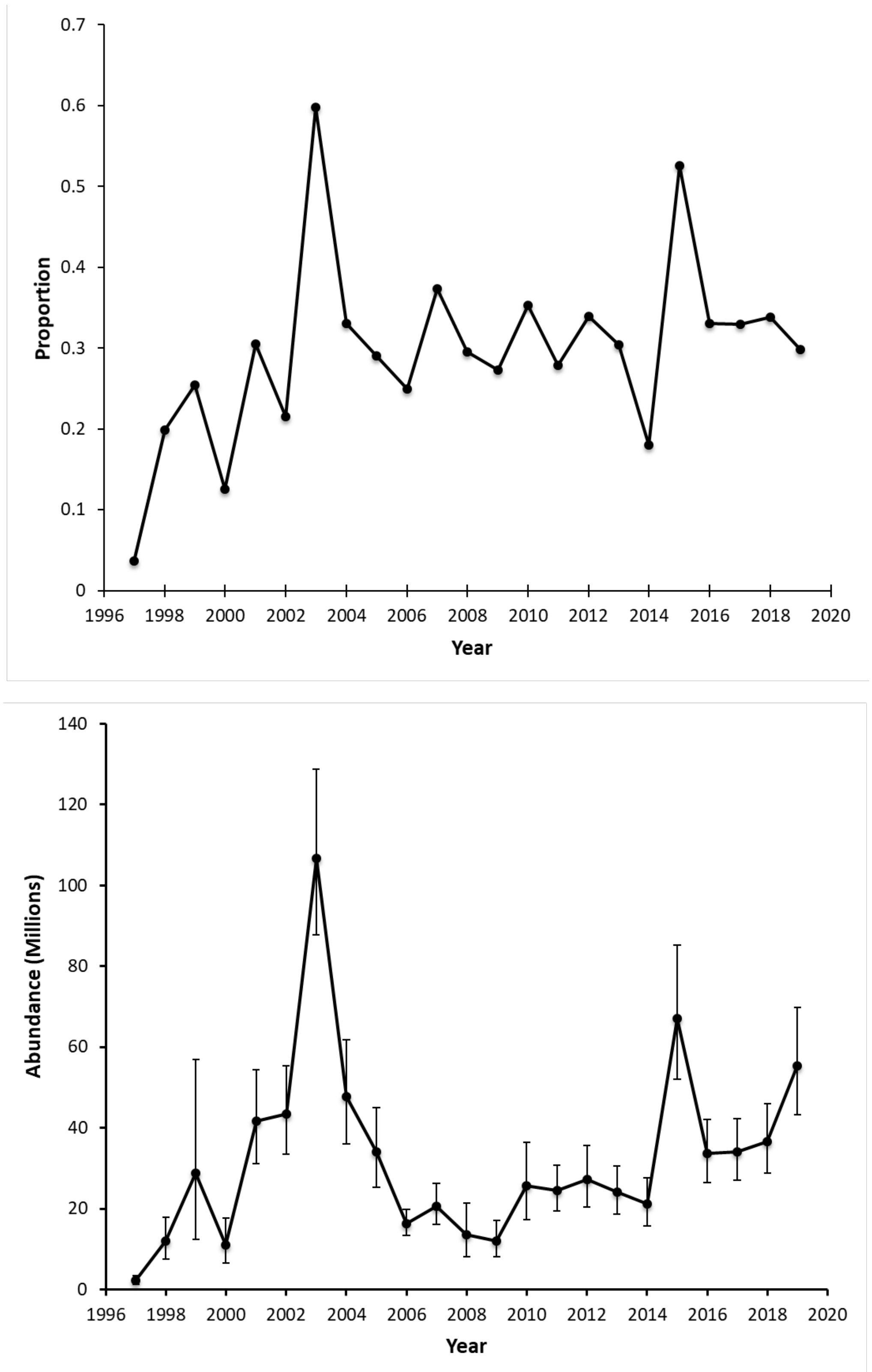


Figure 11. Abundance (in millions) (upper panel) and proportion (lower panel) of R-2 adolescent skip molters in the southern Gulf of St. Lawrence estimated from the trawl survey from 1997 to 2019.

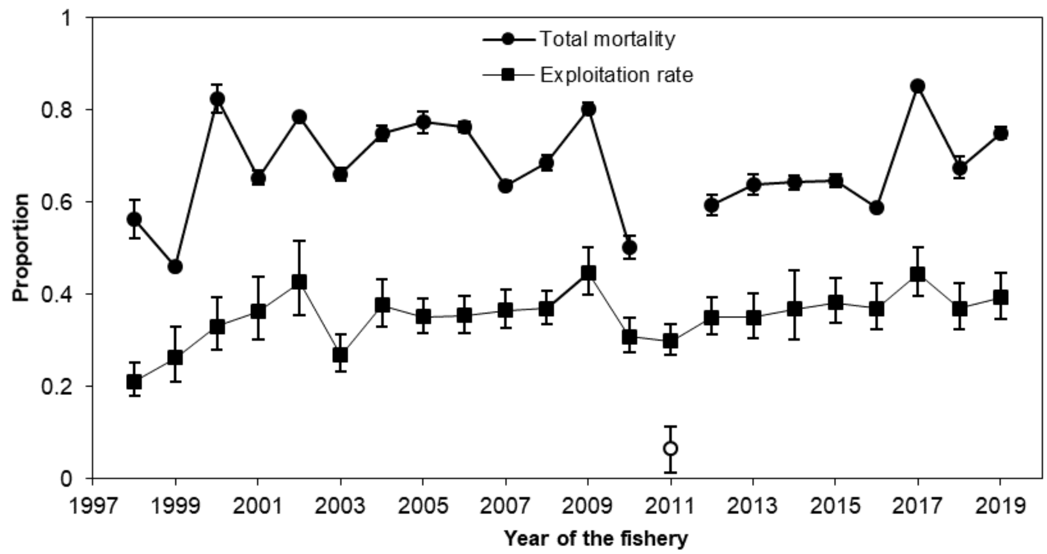


*Figure 12. Estimated annual rates of exploitation and total loss of commercial-sized adult male snow crab (*Chionoecetes opilio*) in the southern Gulf of St. Lawrence, 1997 to 2019. The 2011 total mortality value is not reliable (Hébert et al. 2012).*

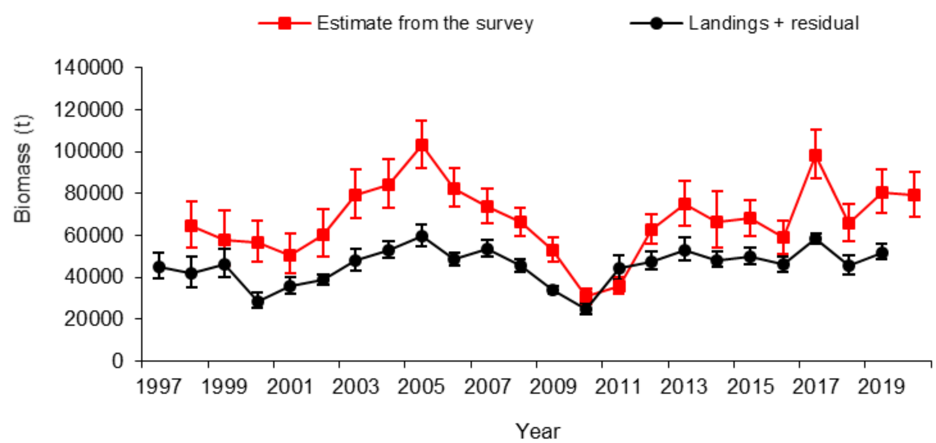


*Figure 13. Comparison of the post-fishery calculated biomass (t; residual biomass plus the landings in year t+1) and the pre-fishery commercial-sized adult male snow crab (*Chionoecetes opilio*) biomass (t; recruitment plus residual biomass in year t) estimated from the trawl survey in the southern Gulf of St. Lawrence.*

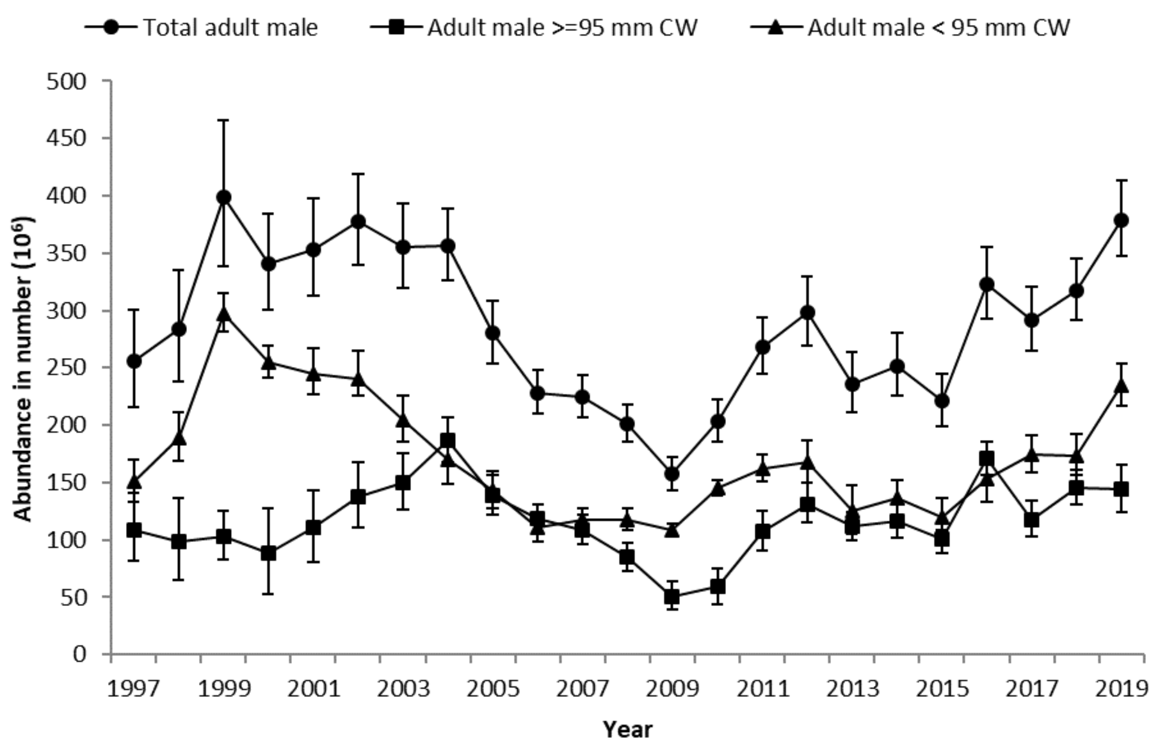
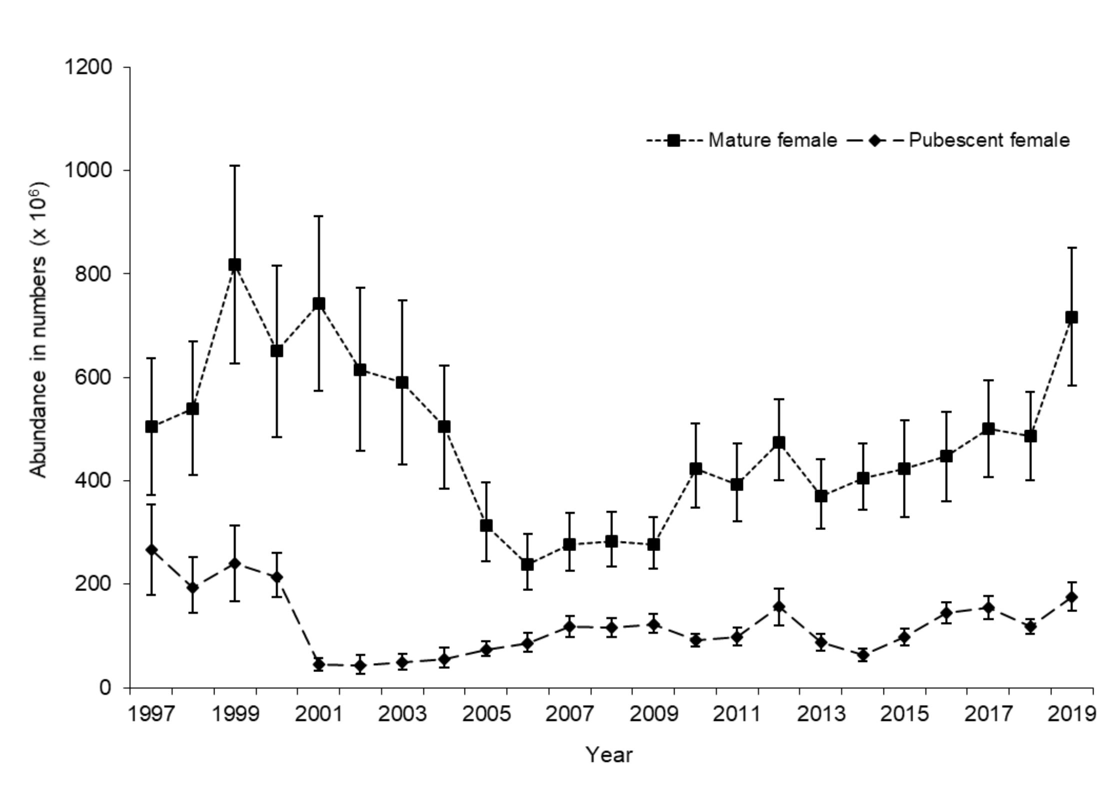


*Figure 14. Estimated abundance (number in millions) of snow crab (*Chionoecetes opilio*) adult males in the southern Gulf of St. Lawrence, 1997 to 2019. CW = Carapace width.*



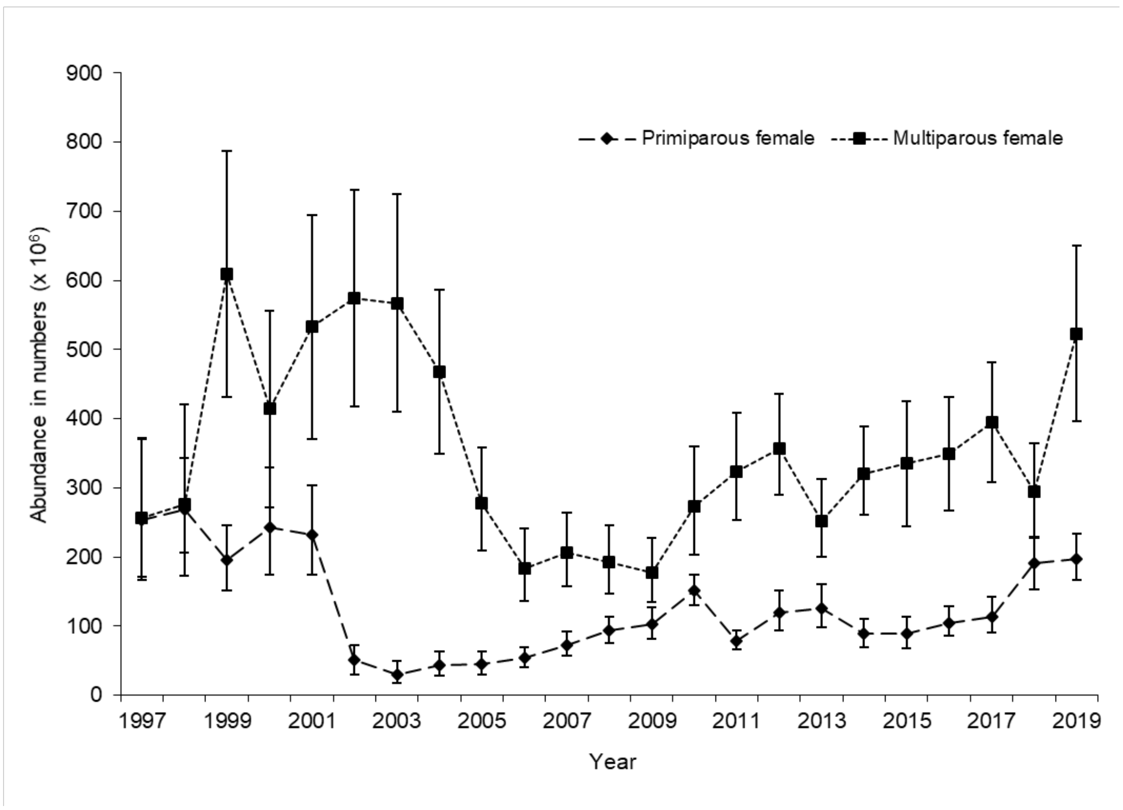


*Figure 15. Abundance (number in millions) of mature and pubescent (above), and primiparous, and multiparous (i.e. mature; below) snow crab (*Chionoecetes opilio*) females in the southern Gulf of St. Lawrence, 1997 to 2019.*

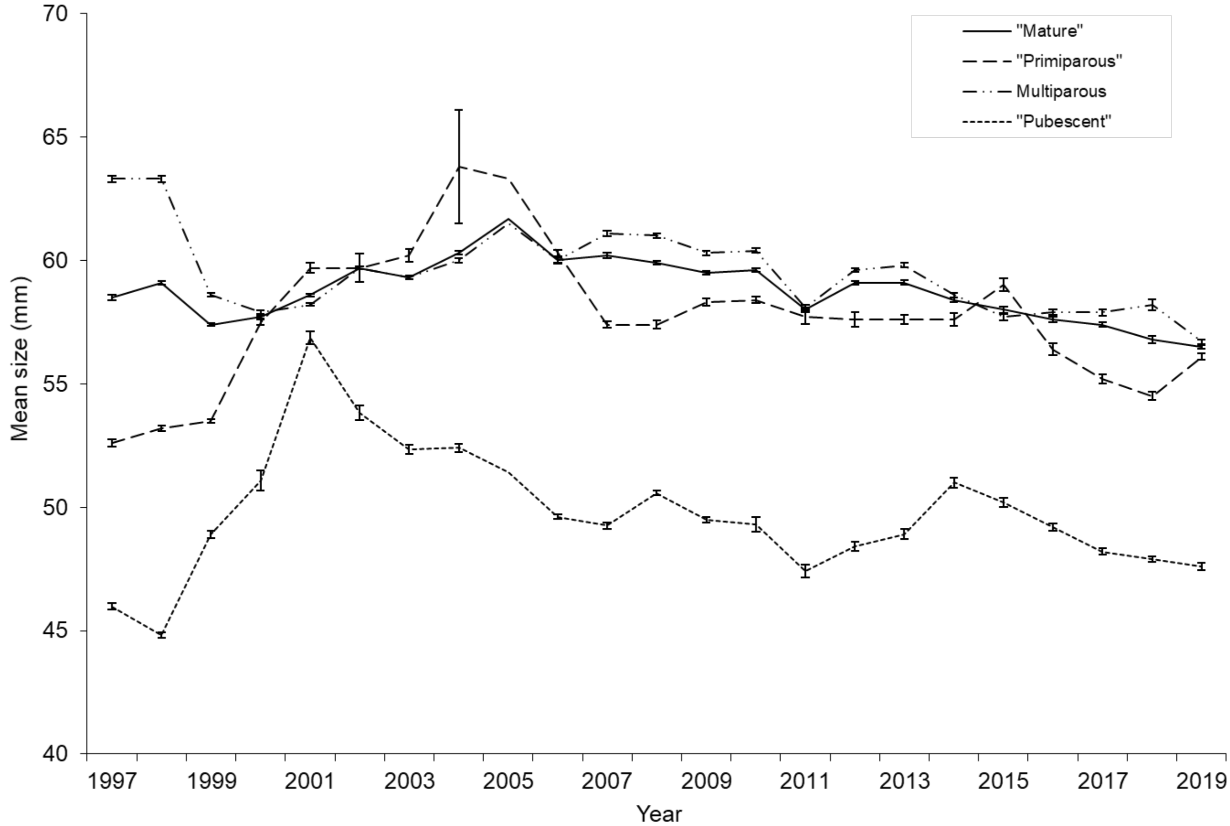


*Figure 16. Mean size (carapace width in mm) with standard errors of pubescent, primiparous, multiparous and mature snow crab (*Chionoecetes opilio*) females based on samples from the trawl surveys, 1997 to 2019.*

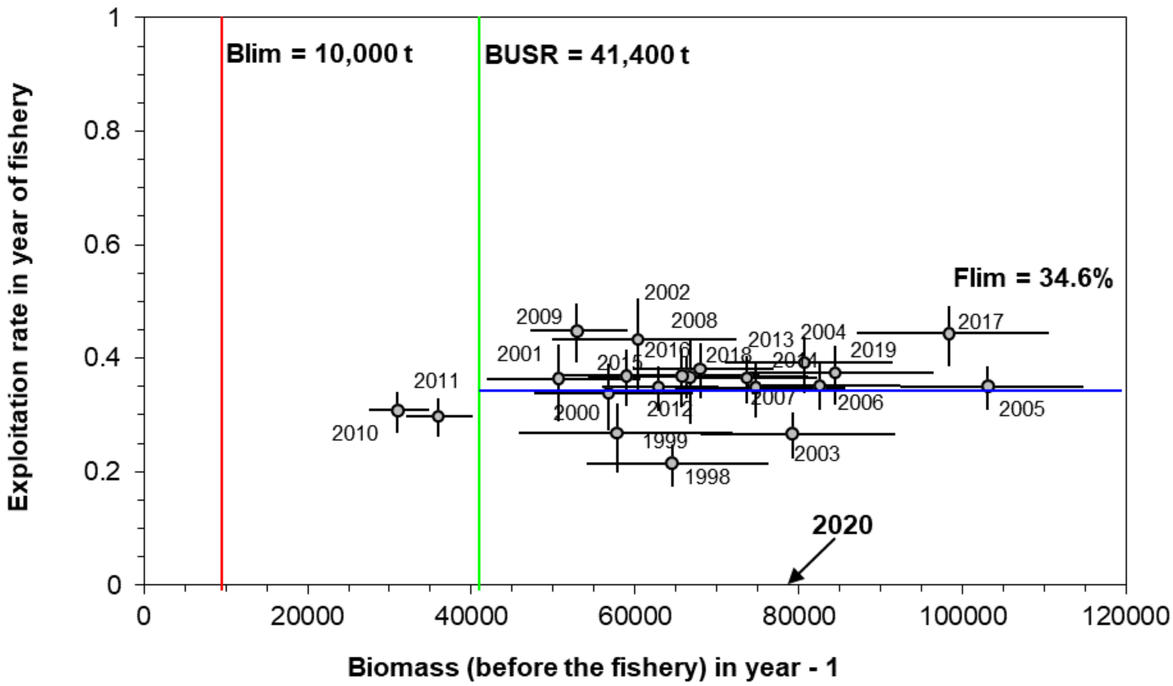


*Figure 17. Trajectory of stock abundance (biomass of commercial-sized adult male snow crab (*Chionoecetes opilio*) as estimated from the trawl survey in year t – 1 versus exploitation rate of this biomass in the fishery of year t. Year of the fishery is labelled on the figure. B_{lim} = The limit reference point for biomass; Flim = Fishing removal rate limit reference point; B_{USR} = The upper stock reference point.*

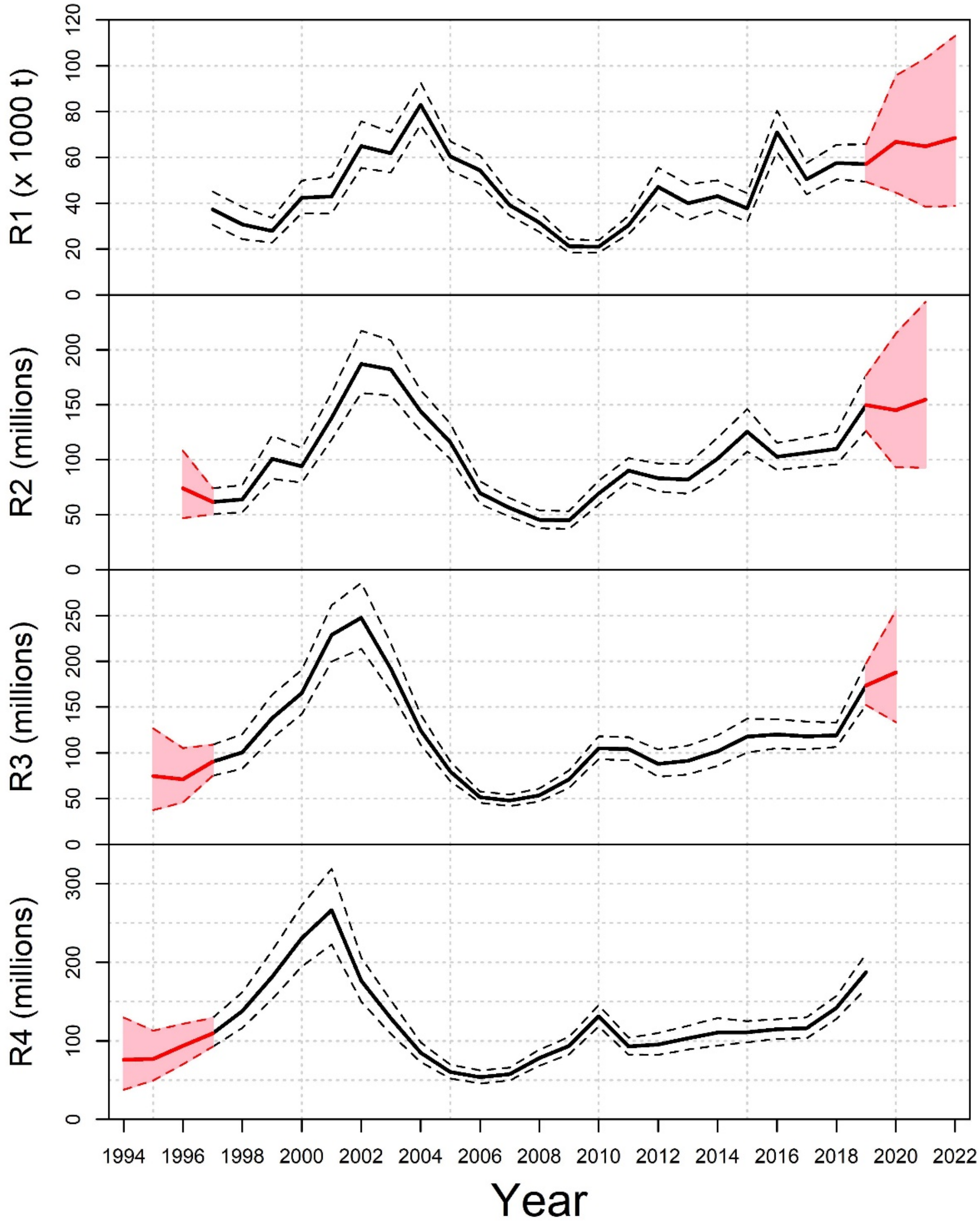


*Figure 18. Snow crab (*Chionoecetes opilio*) recruitment (R) abundance (mean with 95 % confidence intervals) by pre-recruit stages (Rj), where j =1,…,4 years until recruitment to the fishery based on the survey data estimates. Shaded areas are forecasted abundance from the Bayesian model (Wade et al. 2014).*

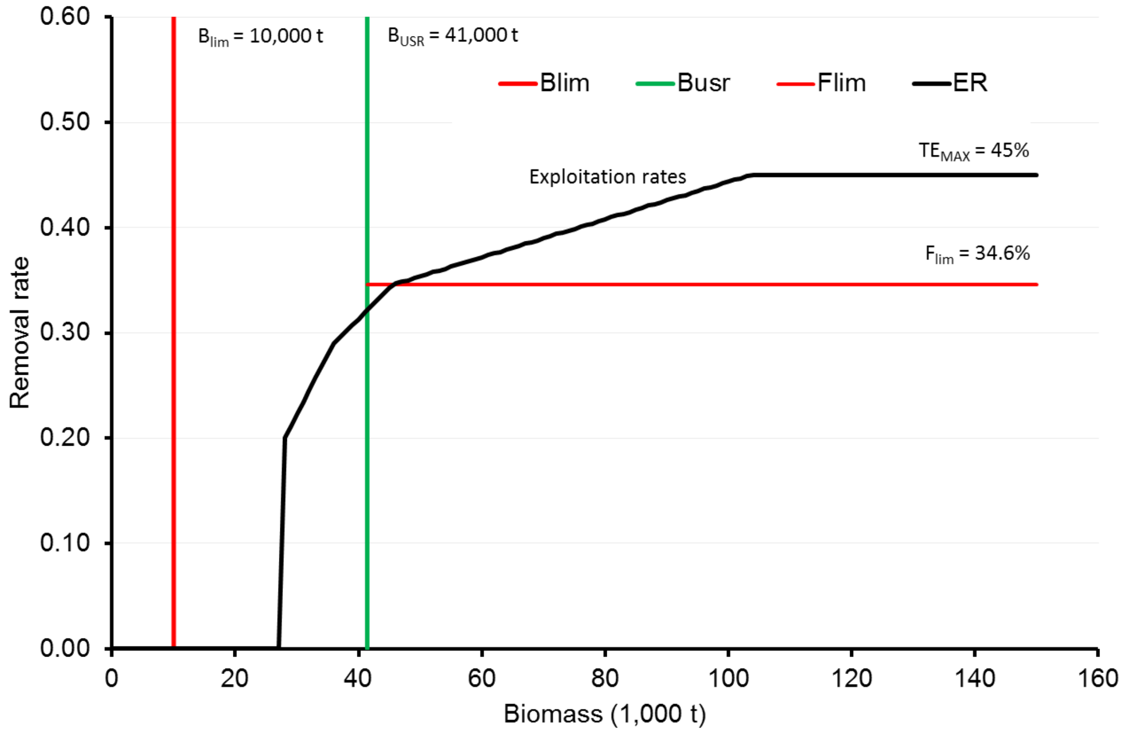


*Figure 19. Harvest proportional decision rule (variant 4) compliant with the precautionary approach for the southern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) fishery (DFO 2014a). B_{lim} = The limit reference point for biomass; F_{lim} = Fishing removal rate limit reference point; B_{USR} = The upper stock reference point; ER = The exploitation rates based on the proportional harvest decision rule; TE_{max} = The maximum exploitation rate based on the proportional harvest decision rule.*

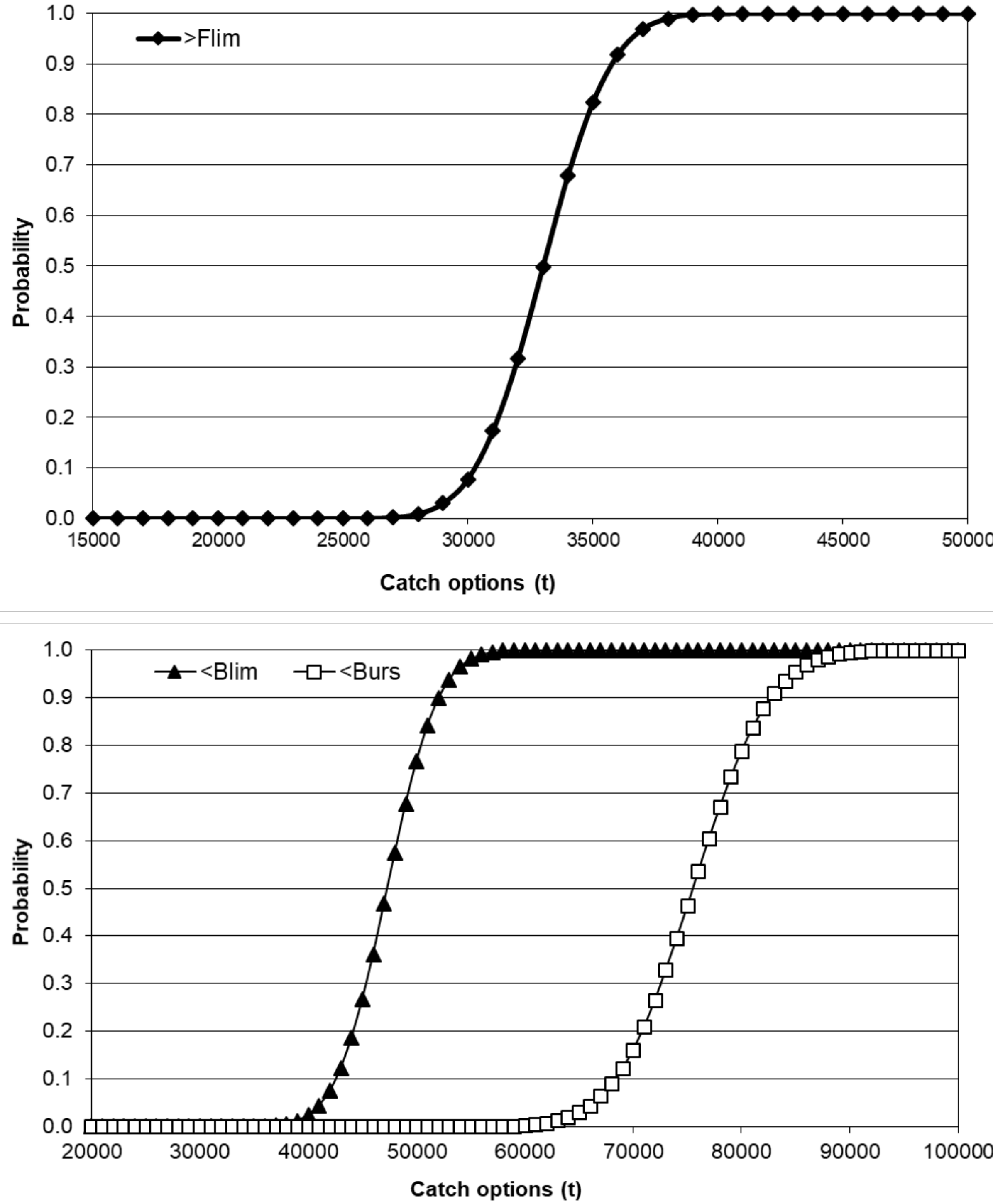


Figure 20. Risk analysis of catch options (t) for the 2019 fishery based on the expanded polygon for the southern Gulf of St. Lawrence snow crab, Chionoecetes opilio*, showing probabilities of exceeding the fishing removal rate limit reference point (F_{lim}), of the hard-shelled commercial-sized adult male residual biomass in 2020 falling below the limit reference point for biomass (B_{lim}) and of the commercial-sized adult male biomass in 2020 will be below the upper reference point (B_{USR}) after the 2020 fishing season.*

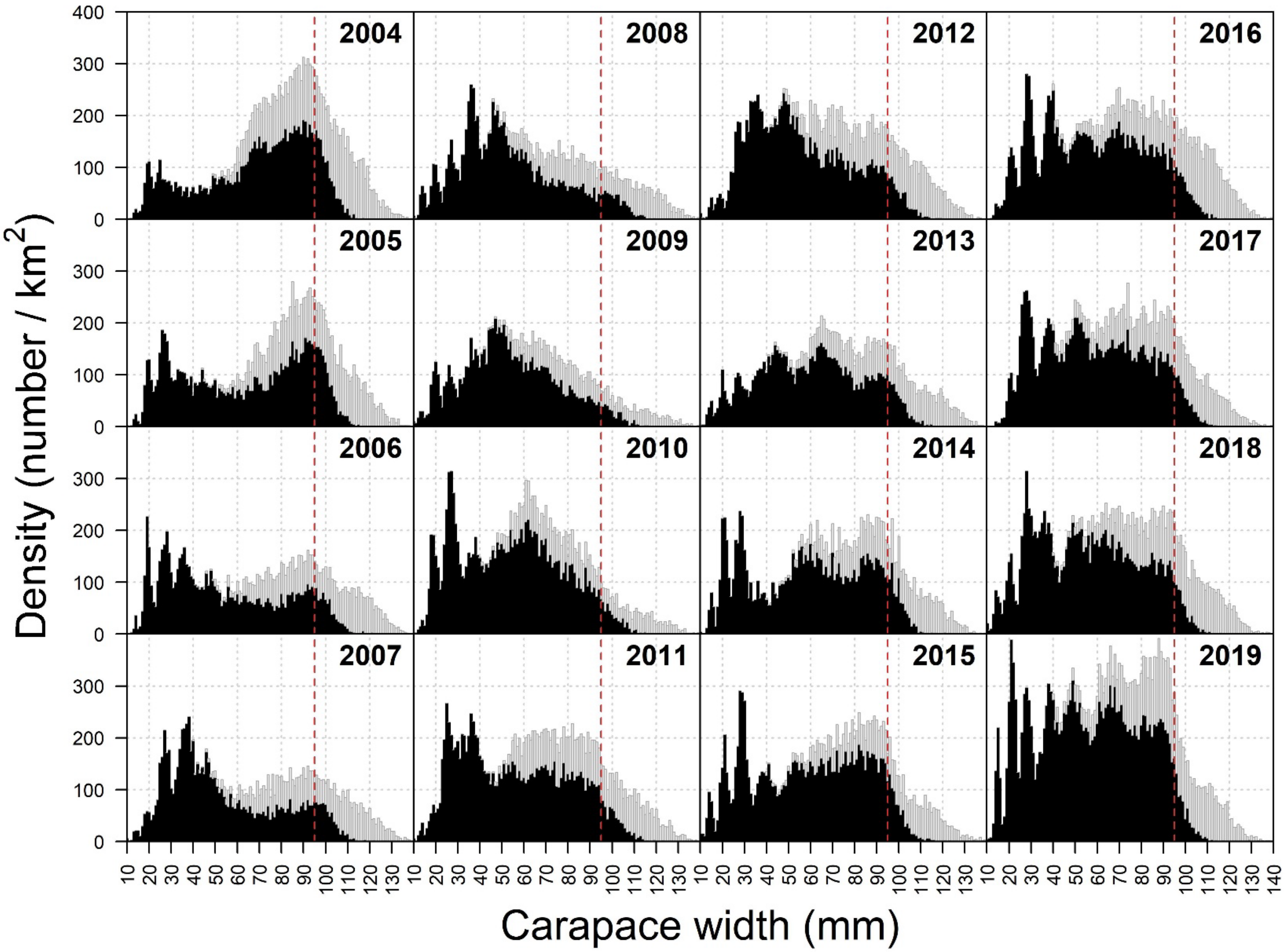


Figure 21. Size frequency distributions (by 1 mm carapace width interval) for male snow crabs (white bars are adult males and black bars are adolescent males) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 2004 to 2019. These size frequency distributions represent the mean number of male snow crab (Chionoecetes opilio) *per km² based directly on samples in the trawl survey. The red dotted line represents the minimum legal size of 95 mm of carapace width,*

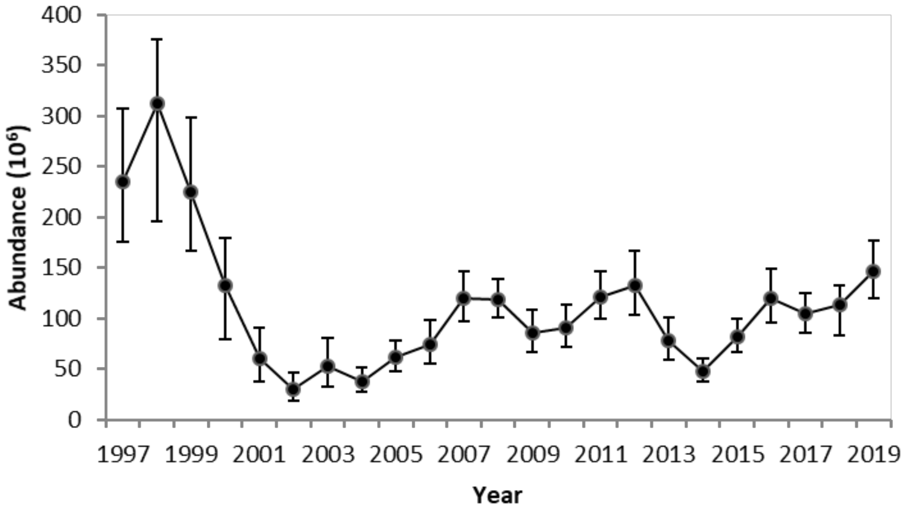


*Figure 22. Abundance indices of small adolescent male snow crab (*Chionoecetes opilio*) with carapace width between 34 to 44 mm estimated from the trawl survey data in the southern Gulf of St. Lawrence, 1997 to 2019. These are crabs which reach legal size in approximately 6 years.*

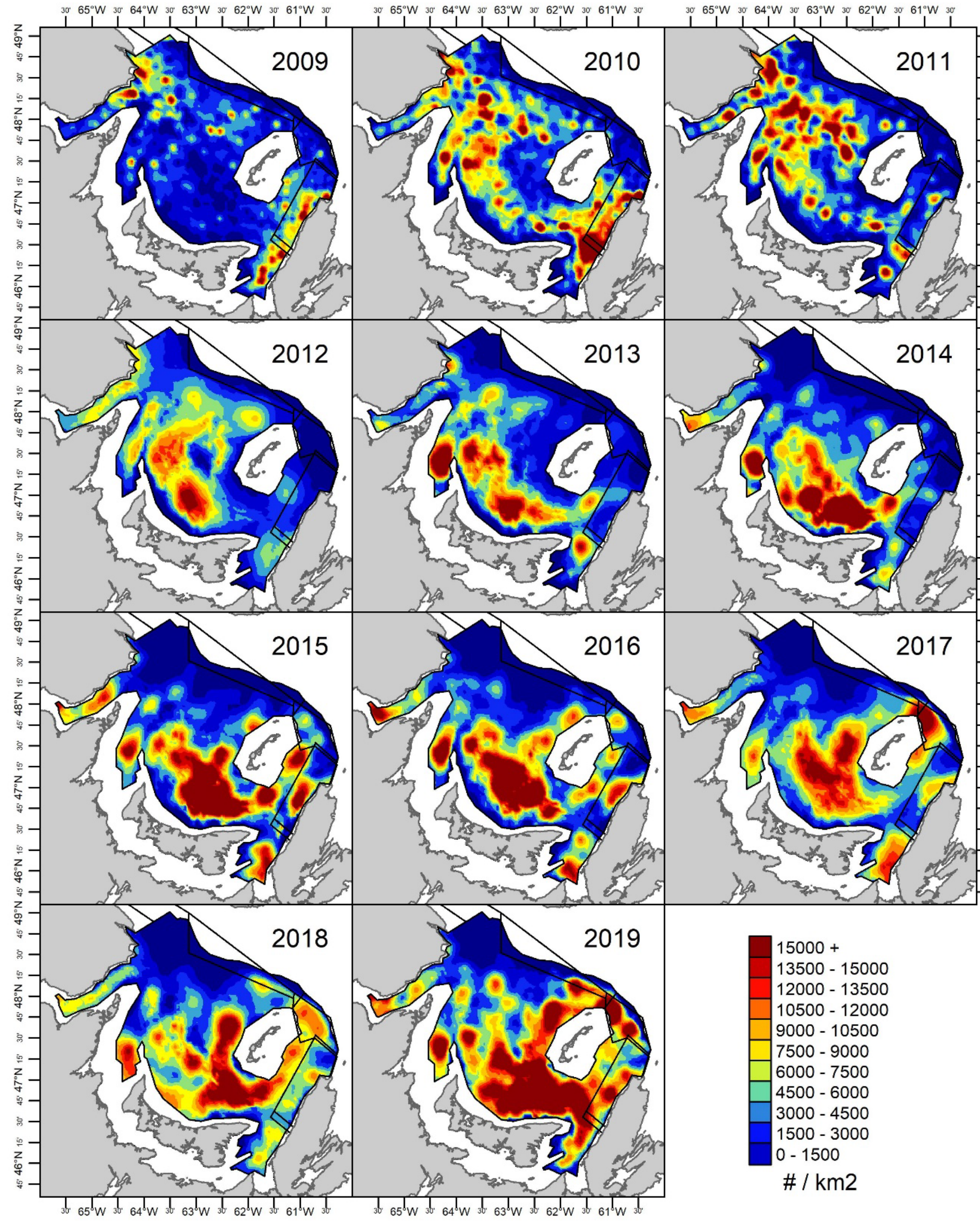


*Figure 23. Density (number per km²) contours of adolescent male (R-4, R-3 and R-2) snow crab, (*Chionoecetes opilio*), ≥ 56 mm of carapace width, based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 2008 to 2019.*

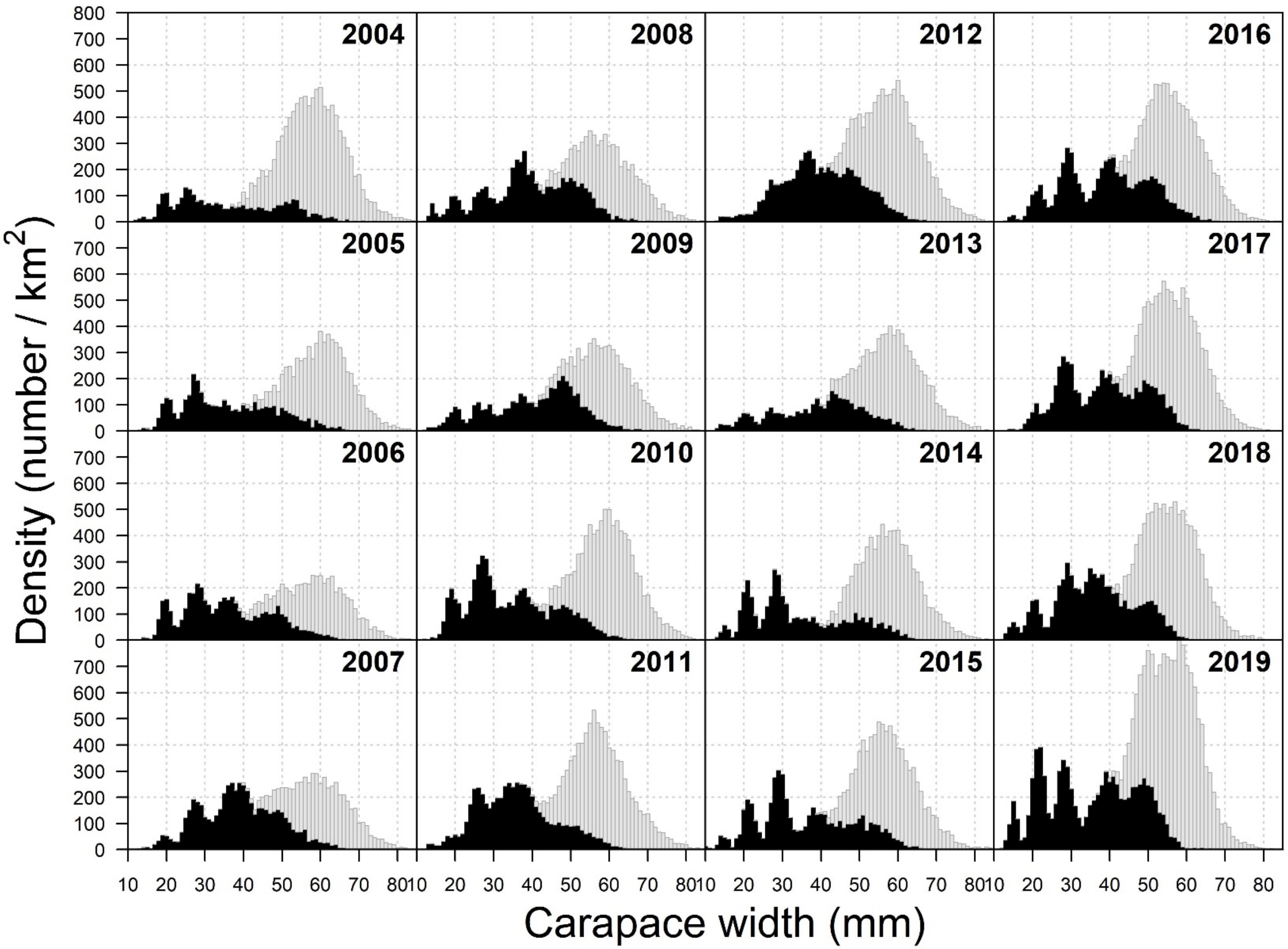


*Figure 24. Size frequency distributions (carapace width by 1 mm interval) for female (white bars are mature females and black bars are pubescent and immature females) snow crab (*Chionoecetes opilio*) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 2004 to 2019. These size frequency distributions represent the mean number of female crab per km² directly based on samples in the trawl survey.*

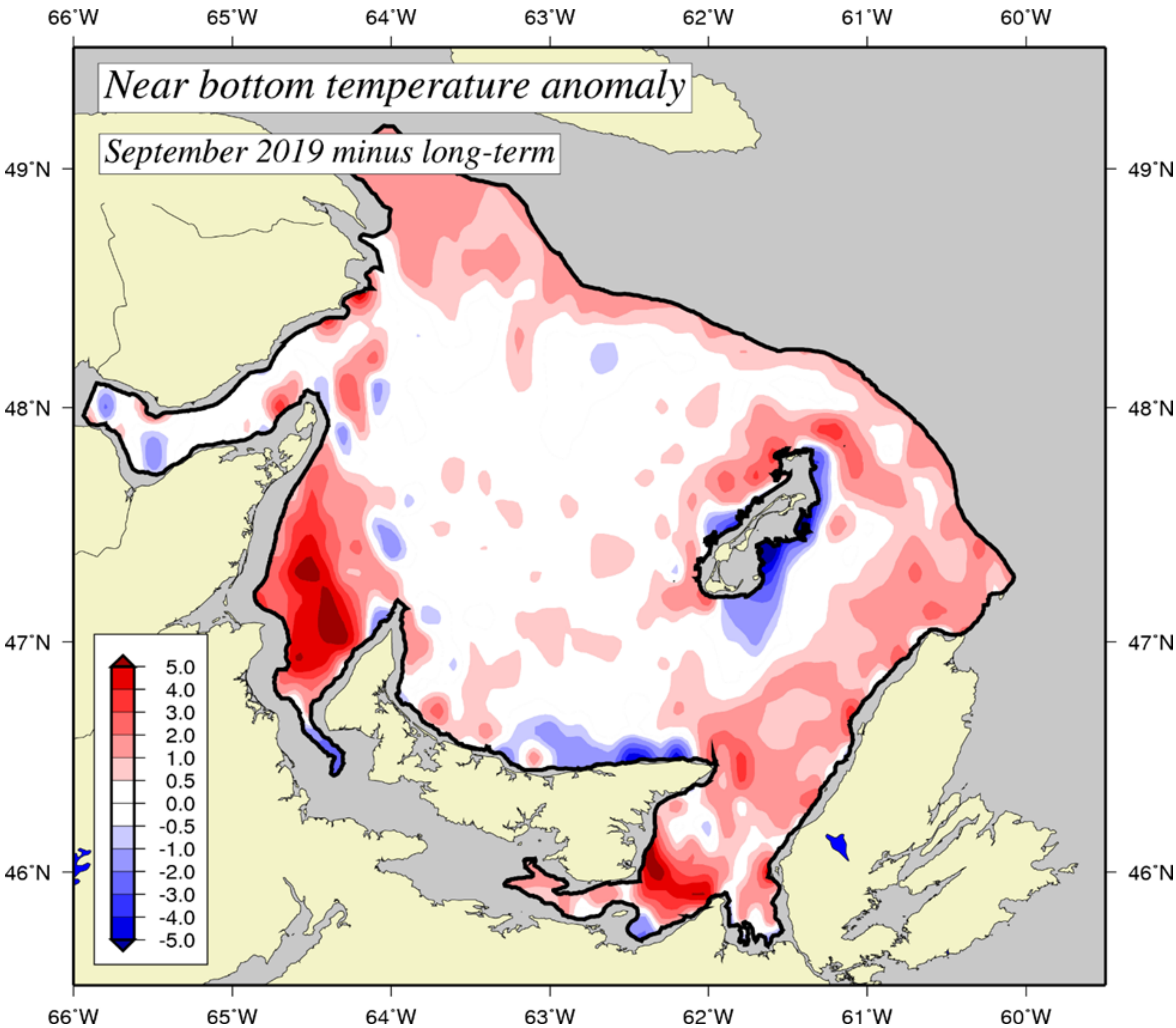


Figure 25. Near-bottom temperature departure (°C) from the long-term (1981-2010) mean in the southern Gulf of St. Lawrence during the 2019 September multi-species survey. Blue areas represent colder-than-normal temperatures while red regions represent warmer-than-normal conditions.

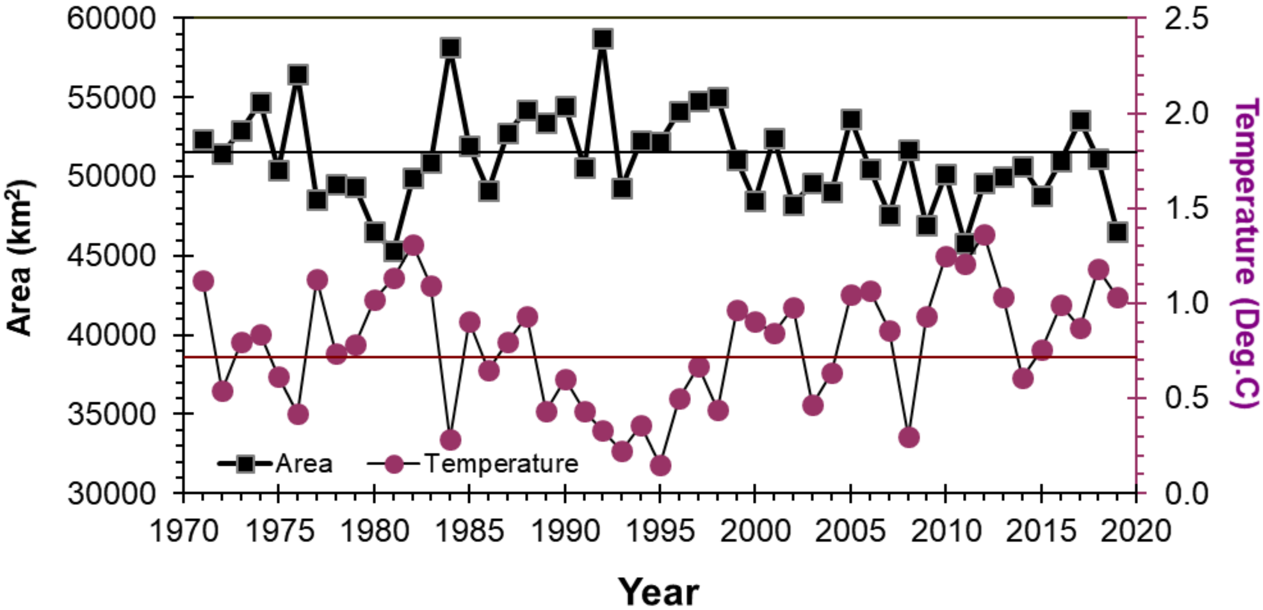


Figure 26. Snow crab temperature habitat area index (km²) that encompasses water temperatures of -1 to 3°C (upper panel) and the mean temperature (°C) within the temperature area index (lower panel) in the southern Gulf of St. Lawrence, 1971 to 2019.