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Gulf Region

ASSESSMENT OF SNOW CRAB (*CHIONOECETES OPILIO*) IN THE SOUTHERN GULF OF ST. LAWRENCE (AREAS 12, 19, 12E AND 12F) TO 2019 AND ADVICE FOR THE 2020 FISHERY

Snow crab (Chionoecetes opilio). Credit: Fisheries and Oceans Canada

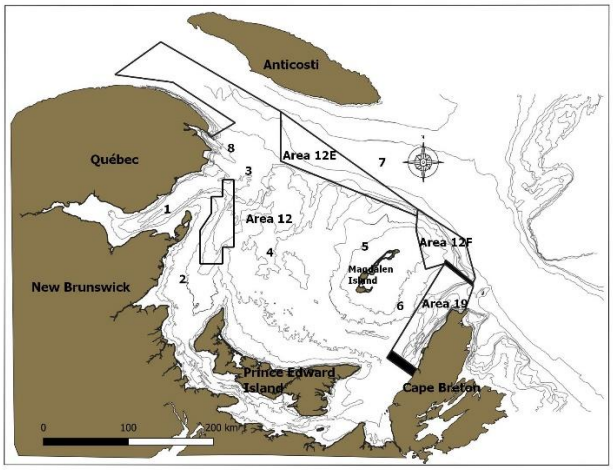

Figure 1. Map of the southern Gulf of St. Lawrence showing the Crab Fishing Areas (12, 12E, 12F, and 19), the 2019 static closure zone within Area 12 to minimize fishery interactions with North Atlantic right whales, fishing grounds, and management buffer zones (shaded area). Fishing grounds are labeled as follows: 1) Chaleur Bay, 2) Shediac Valley, 3) Orphan Bank, 4) Bradelle Bank, 5) Magdalen Channel, 6) Cape Breton Corridor, 7) Laurentian Channel, and 8) American Bank.

Context:

Snow crab, Chionoecetes opilio, has been commercially exploited in the southern Gulf of St. Lawrence since the mid-1960s. There are four individually managed fishing areas among which Area 12 (Figure 1) is the largest fishery in terms of its fishable surface, number of participants and landings. In Areas 12, 12E and 12F, the fishing season generally starts in April or May as soon as the Gulf is clear of ice and continues into early summer. In Area 19, the fishery opens after June 30 and typically ends in mid-September. The landing of females is prohibited and only hard-shelled males ≥ 95 mm of carapace width are commercially exploited.

DFO Gulf Region Fisheries and Aquaculture Management requested an assessment of the resource status in 2019 and catch advice for the 2020 fishery. This document provides an overview of the assessment results and the science advice. Catch rates and other fishery performance indicators are reported. The assessment of the status of the southern Gulf snow crab resource (Areas 12, 19, 12E and 12F) is based on fishery independent trawl surveys that provide indicators of: abundance (commercial biomass), reproductive potential (abundance of mature females), and recruitment. A science peer review meeting was conducted February 5-6, 2020 in Riverview, New Brunswick. Participants at the science review were from DFO Science, DFO Fisheries and Aquaculture Management, academia, fishing industry, Indigenous organizations, and provincial governments.

SUMMARY

- Snow crab in the southern Gulf of St. Lawrence (sGSL) is considered as a single stock unit for assessment purposes. This stock unit comprises snow crab fishing areas 12, 19, 12E, and 12F.
- The landings of snow crab from the sGSL in 2019 were 31,707 tonnes (t) from a revised quota of 32,215 t.
- The exploitation rate of the 2019 fishery in the sGSL was estimated at 39.3%.
- 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 overestimated due to an unplanned change in trawl hauling procedures in 2019. This resulted in the trawl fishing and catching snow crab over a larger area than estimated using the standardization procedures in this assessment.
- The 2019 post-fishery survey biomass of commercial-sized adult male crabs (carapace width (CW) >= 95mm) was estimated at 79,066 t (95% confidence interval of 69,072 to 90,091 t), which is similar to 2018. The estimated biomass for the 2020 fishery, derived from the 2019 survey, is within the healthy zone of the Precautionary Approach (PA) framework.
- Total commercial biomass in the 2019 survey was composed 75% of new recruitment (58,995 t) and 25% of residual biomass (20,291 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 (TAC) 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 given 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.

BACKGROUND

Species Biology

Snow crab (*Chionoecetes opilio*) 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 molting. After molting, 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-molted 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 molt 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 southern Gulf of St. Lawrence (sGSL). The eggs hatch in late spring or early summer and the newly-hatched crab larvae spend 12-15 weeks in the water column. At the end of this period, they settle on the bottom. It takes at least 8-9 years (post-settlement) for males to reach legal commercial size.

Fishery

Until 1994, the snow crab fishery in Area 12 (Figure 1) involved 130 mid-shore crab harvesters from New Brunswick, Quebec, and Nova Scotia. Since 1997, the Prince Edward Island (PEI) coastal fishery, (formerly Areas 25/26) has been integrated into Area 12. In 2003, a portion of the coastal fishery off Cape Breton (formerly Area 18) was also integrated into Area 12. For the purpose of this assessment, Area 12 refers to the management unit that includes snow crab fishing zones 12, 18, 25, and 26 (as defined in regulation) (Figure 1). The number of allocation shares in Area 12 was 244 in 2019 (Table 1).

Area 19 (Figure 1) was established in 1978 for the exclusive use of Cape Breton inshore fish harvesters with vessels less than 13.7 meters (45 feet) in length. There were 159 allocation shares in Area 19 in 2019.

Areas 12E and 12F were introduced in 1995 as exploratory fisheries. In 2002, the status of Areas 12E and 12F was changed from exploratory to commercial fishing areas. There were four snow crab allocation shares in Area 12E (from New Brunswick, PEI and Quebec) in 2019. In Area 12F, there were 15 allocations for regular licenses and 19 temporary allocations in 2019 (from Nova Scotia and Quebec). For 2019, harvesters in Area 12F requested a lower Total Allowable Catch (TAC) than the value originally assigned for the area based on the decision rule.

Table 1. Number of allocation shares, vessels, traps, revised quotas, opening dates, and dates of the last landing of the snow crab fishery by management area in the southern Gulf of St. Lawrence in 2019.

Characteristics	Area 12	Area 12E	Area 12F	Area 19	Southern Gulf
Allocation shares [1]	244	4	34	159	441
Number of active vessels	321	4	26	109	460
Total number of traps allowed	36,998	475	1,395	1,699	40,567
Opening date	May 2	May 2	April 18	July 5	-
Date of the last landing	July 1	June 19	June 30	August 15	-
Revised quota (t) [2]	28,051	217	1,155	2,792	32,215 [3]
Landings (t)	27,554	224	1,166	2,763	31,707

[1] The number of quota allocations among which the Total Allowable Catch (TAC) is divided (Source: DFO Administrative List for Snow Crab Areas 12, 12E, 12F, and 19).
[2] For reasons of interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quota does not necessarily correspond to the TAC in the notice to harvesters.
[3] Quota includes 450 t set aside to finance the trawl survey in 2019 (under Section 10 of the Fisheries Act).

The minimum legal CW for this male only fishery is 95 mm; soft-shelled and white crab are not targeted by the fishery. Baited traps, constructed of wire or tubular steel, are used to catch crab

mainly on mud or sand-mud bottoms and at depths ranging from 50 to 280 m. The fishery takes place from spring to early summer in Areas 12, 12E and 12F and after June 30 in Area 19.

Management of these fisheries is based on quotas and effort controls (trap allocations, trap dimensions, and seasons). At-sea soft-shelled and white crab catch monitoring protocols allow for the closure of portions of fishing areas when the proportion of these males exceeds 20% in the catch. The protocols are in place to maximize the yield and the reproductive potential of the resource. In 2019, in order to minimize fishery interactions with North Atlantic right whales (an endangered species listed under the *Species At Risk Act*), a closure zone (static) was implemented in Area 12 (Figure 1). Temporary closures were also implemented in the area adjacent to the static closure zone (DFO 2019), at different times during the fishing season, based on confirmed observations of North Atlantic right whales. These closures displaced some of the fishing effort from traditional grounds in 2019, similar to 2018.

The landings from the sGSL were low in the 1970s and increased with four periods of high landings: 1981-1986, 1994-1995, 2002-2009, and more recently 2012 to 2019 (Figure 2). Snow crab landings from the sGSL in 2019 were 31,707 t from a revised quota of 32,215 t.

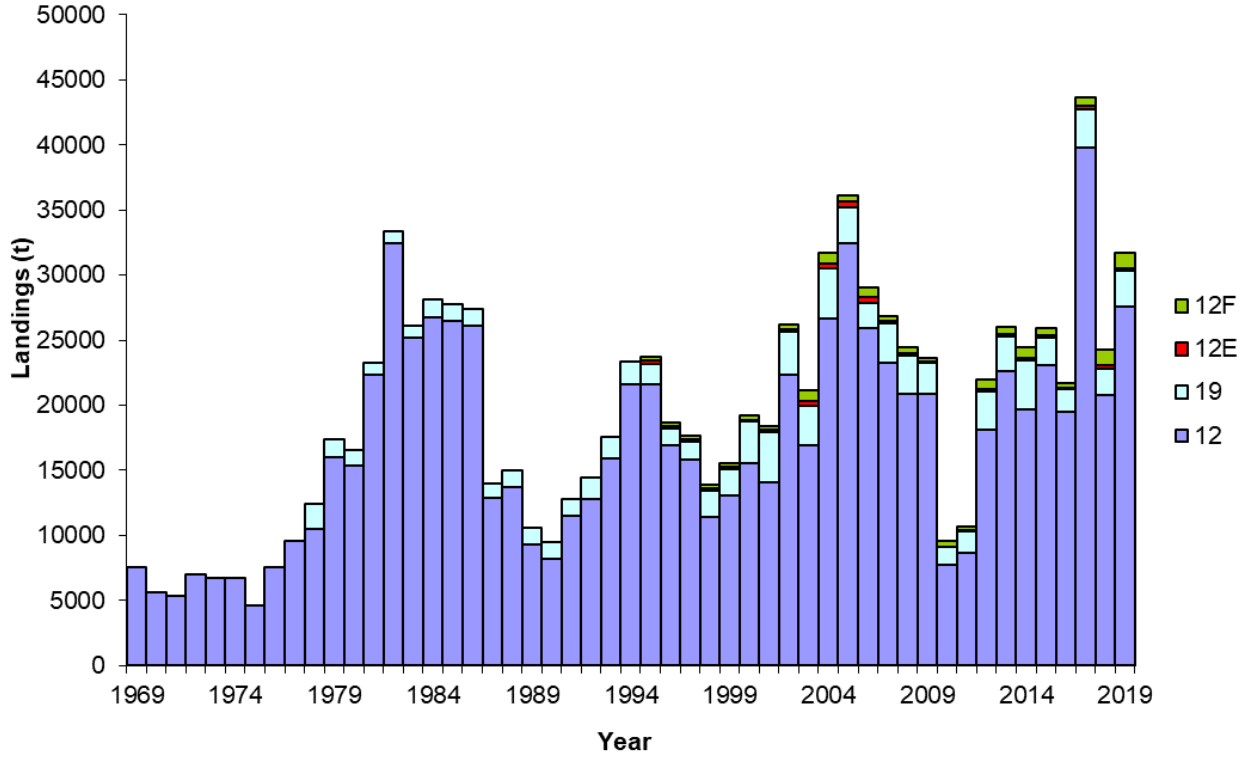

Figure 2. Landings (tonnes; t) in the southern Gulf of St. Lawrence snow crab fishery by fishing area from 1969 to 2019.

The 2019 fishing season in Area 12 opened on May 2 and the last landings were recorded on July 1 with reported landings of 27,554 t from a revised quota of 28,051 t (Tables 1 and 2; Figure 2). In accordance with the soft-shelled crab protocol, nine grids that were open to fishing were closed during the 2019 fishing season compared to four in 2018. The fishing effort estimated from logbooks has varied from 161,148 to 553,125 trap hauls between 1987 and 2019, with the lowest effort in 2010 and the highest effort in 2017 (Hébert et al. 2020). The

fishing effort was 496,468 trap hauls in 2019, an increase from 2018 (469,887 trap hauls) (Table 2).

Table 2. Quota and landings (tonnes; t), catch per unit of effort (CPUE; kg/trap-haul), fishing effort (trap hauls), soft-shelled crab percentages, and associated closed grids for the snow crab fishery in Area 12, 2011 to 2019.

Fishery descriptor	2011	2012	2013	2014	2015	2016	2017	2018	2019
Quota (t) [1]	8,585	18,143	22,548	19,409	23,021	19,393	39,651	20,909	28,051
Landings (t)	8,618	18,159	22,645	19,633	23,080	19,499	39,825	20,769	27,554
CPUE (kg/trap-haul) [2]	53.0	68.0	76.4	61.8	67.9	64.0	72.0	44.2	55.5
Effort (trap hauls)	162,604	267,044	296,398	317,689	339,912	304,624	553,125	469,887	496,468
Soft-shelled crab (%) in catches [3]	6.2	3.7	2.8	4.4	4.9	5.3	6.0	4.4	5.2
Grids closed (total of 323)	233	7	5	8	41	5	57	4[4]	9[4]

[1]Since 2012, quotas were revised for interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quotas do not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentages are based on durometer readings < 68. Catches are defined as male crabs of all sizes.
[4] Grids closed according to the soft-shelled crab protocol. Additional closures to minimize fishery interactions with North Atlantic right whales are not accounted for in this table.

The 2019 fishing season in Area 19 opened on July 5 and the last date of landings was August 15 with reported landings of 2,763 t from a revised quota of 2,792 t (Tables 1 and 3; Figure 2). In accordance with the white crab protocol, four sectors within Area 19 were closed during the 2019 fishing season. Since 2011 and as per industry request, the white crab protocol in Area 19 is based on a durometer reading of < 72 units instead of < 78 durometer units as per the original white crab definition (Hébert et al. 2020). The fishing effort in Area 19 has varied from 11,138 to 56,517 trap hauls between 1987 and 2019, with the lowest effort in 2010 and the highest effort in 2004 (Hébert et al. 2020). The effort in 2019 was 24,518 trap hauls, an increase from 2018 (Table 3).

Table 3. Quota and landings (tonnes; t), catch per unit of effort (CPUE; kg/trap-haul), fishing effort (trap hauls), white crab percentages, and associated closed sectors for the snow crab fishery in Area 19, 2011 to 2019.

Fishery descriptor	2011	2012	2013	2014	2015	2016	2017	2018	2019
Quota (t) [1]	1,703	2,907	2,654	3,745	2,130	1,701	2,945	2,046	2,792
Landings (t)	1,701	2,906	2,657	3,745	2,129	1,701	2,944	2,048	2,763
CPUE (kg/trap-haul) [2]	133.3	178.1	148.5	147.4	144.8	142.5	142.8	156.1	112.7
Effort (trap hauls)	12,761	16,317	17,890	25,407	14,703	11,937	20,616	13,120	24,518
White crab (%) in catches [3]	11.5	4.5	3.0	1.0	5.5	8.2	11.6	8.8	20.9
Sectors closed [4]	0/9	0/9	0/9	0/9	2/9	4/9	3/9	1/9	4/9

[1]Since 2012, quotas were revised for interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quotas do not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentages are based on durometer readings < 72. Catches are defined as male crabs of all sizes.
[4] Total number of sectors was changed from 4 to 9 in 2009.

The 2019 fishing season in Area 12E began on May 2 and the date of last landings was June 19 with reported landings of 224 t from a revised quota of 217 t (Tables 1 and 4; Figure 2). The fishing effort in Area 12E has varied from 1,825 to 10,074 trap hauls between 1995 and 2019, with the lowest effort in 2010 and the highest effort in 2006 (Hébert et al. 2020). The fishing effort in Area 12E decreased from 5,579 trap hauls in 2018 to 3,415 trap hauls in 2019. In accordance with the soft-shelled protocol, no grids within Area 12E were closed during the 2019 fishing season.

Table 4. Quota and landings (tonnes; t), catch per unit of effort (CPUE; kg/trap-haul), fishing effort (trap hauls), soft-shelled crab percentages, and associated closed grids for the snow crab fishery in Area 12E, 2011 to 2019.

Fishery descriptor	2011	2012	2013	2014	2015	2016	2017	2018	2019
Quota (t) [1]	75	251	204	170	189	144	199	266	217
Landings (t)	76	185	204	178	192	144	203	260	224
CPUE (kg/trap-haul) [2]	31.5	32.9	40.1	47.3	65.8	51.5	60.9	46.6	65.7
Effort (trap hauls)	2,413	5,623	5,097	3,765	2,918	2,796	3,333	5,579	3,415
Soft-shelled crab (%) in catches [3]	8.4	3.3	15.9	7.8	9.8	1.1	2.0	4.6	3.1
Grids closed (total of 8)	0	0	0	0	0	0	0	0	0

[1]Since 2012, quotas were revised for interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quotas do not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentages are based on durometer readings < 68. Catches are defined as male crabs of all sizes.

In Area 12F, the fishery in 2019 opened on April 18 and the last date of recorded landings was June 30 with reported landings of 1,166 t from a revised quota of 1,155 t (Tables 1 and 5; Figure 2). The fishing effort in Area 12F has varied from 4,437 to 23,163 trap hauls between 1995 and 2019, with the lowest effort in 2002 and the highest effort in 2014 (Hébert et al. 2020). The fishing effort increased from 17,120 trap hauls in 2018 to 18,083 trap hauls in 2019. In accordance with the soft-shelled protocol, no sector within Area 12F was closed during the 2019 fishing season.

Table 5. Quota and landings (tonnes; t), catch per unit of effort (CPUE; kg/trap-haul), fishing effort (trap hauls), soft-shelled crab percentages, and associated closed sectors for the snow crab fishery in Area 12F, 2011 to 2019.

Fishery descriptor	2011	2012	2013	2014	2015	2016	2017	2018	2019
Quota (t) [1]	314	706	543	906	516	373	680	1,218	1,155
Landings (t)	313	706	543	882	510	381	684	1,183	1,166
CPUE (kg/trap-haul) [2]	32.5	41.8	49.0	38.1	38.2	43.9	72.6	69.1	64.5
Effort (trap hauls)	9,631	16,890	11,086	23,163	13,351	8,667	9,421	17,120	18,083
Soft-shelled crab (%) in catches [3]	2.6	9.4	2.4	1.7	3.3	10.4	1.9	1.3	2.1
Sectors closed (total of 3)	0	0	0	0	0	0	0	0	0

[1]Since 2012, quotas were revised for interannual quota adjustments, reconciliations, and re-distribution of the scientific quota among areas, the revised quotas do not necessarily correspond to the TAC in the notice to harvesters.
[2] CPUE values are not standardized and do not account for changes in management measures.
[3] The percentages are based on durometer readings < 68. Catches are defined as male crabs of all sizes.

Catch per unit of effort (CPUE; expressed as kilogram per trap-haul (kg/th)) is considered an index of fishery performance and is calculated directly from logbook data as the ratio of total landings (kg) to total effort (trap-hauls). CPUE values are not standardized and do not account for changes in management measures and fishing practices and as a result may not be directly proportional to biomass. In Area 12, the annual mean CPUE increased in 2019 (55.5 kg/th) compared to 2018 (Table 2; Figure 3). In Area 19, the CPUE (112.7 kg/th) in 2019 decreased compared to 2018 (Table 3; Figure 3). The CPUE increased in Area 12E (65.7 kg/th) in 2019 compared to 2018 while in Area 12F, the CPUE (64.5 kg/th) in 2019 decreased compared to 2018 (Tables 4 and 5; Figure 3).

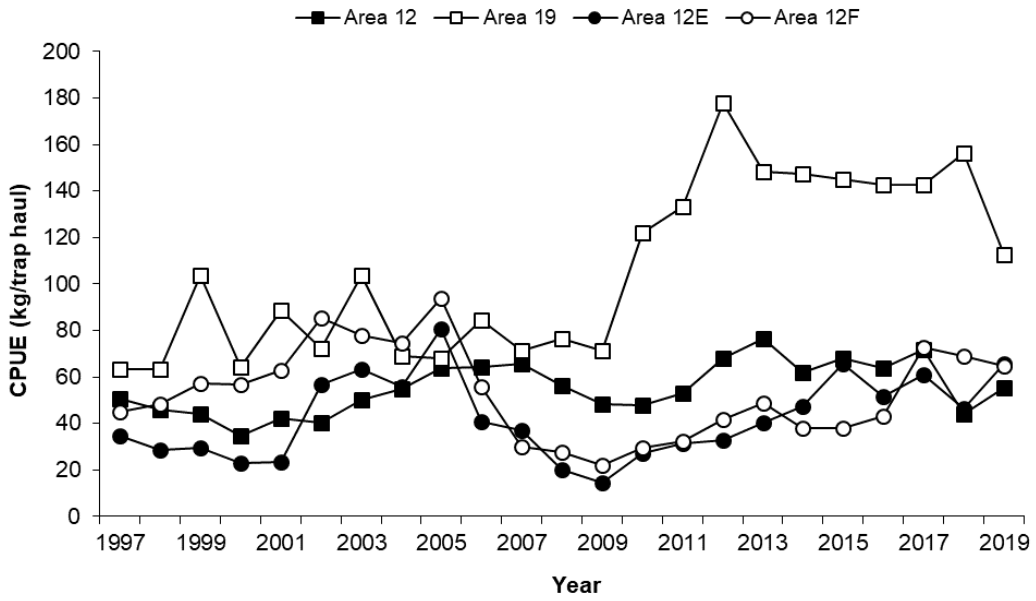

Figure 3. Catch per unit effort (CPUE; kg / trap-haul) in the southern Gulf of St. Lawrence snow crab fishery, Areas 12 (black squares), 19 (open squares), 12E (black circles) and 12F (open circles), based on logbooks, 1997 to 2019.

The percentage of soft-shelled crab and white crab is calculated using data collected from the at-sea observer program. The incidence of soft-shelled crab and white crab in catches is strongly influenced by the fishing strategy used by harvesters during the season, as well as the abundance of hard-shell commercial-sized adult crab in the area.

The percentage of soft-shelled crab in Area 12 in 2019 was 5.2%, an increase from 2018, and has remained low since 2008 (Hébert et al. 2020; Table 2). In Area 19, the percentage of white crab was 20.9% in 2019, an increase from 2018 (Table 3). The percentage of soft-shelled crabs in Area 12E in 2019 was 3.1%, comparable to 2018 (Table 4). In Area 12F, the percentage of soft-shelled crabs in 2019 was 2.1%, comparable to 2018 (Table 5).

ASSESSMENT

Snow crab in the sGSL is considered as a single stock unit for assessment purposes. This stock unit comprises snow crab fishing areas 12, 19, 12E, and 12F.

The survey in 2019 was financed through a collaborative agreement with the fishing industry under Section 10 of the Fisheries Act.

The survey design and biomass estimation polygon cover the entire area of the sGSL defined by the 20 to 200 fathoms depth contours. The polygon corresponds to the areal extent of bottom temperatures <5 ˚Celsius (˚C) which are considered favorable for all life stages of snow crab and encompassing the area of the sGSL stock unit (Figure 4). The survey spatial sampling design partitioned this area into square grids of 12.7 km x 12.7 km (DFO 2012a). In 2019, the number of sampling stations remained targeted at 355. As per the recommendations from the 2014 scientific peer review (DFO 2014a), the 351 successful sampling stations from the 2018 trawl survey were used as fixed stations and a new set of four sampling stations (i.e. the one station that was abandoned and the three sampling stations that were conducted outside their assigned grids in 2018) was generated randomly. A total 352 stations were successfully trawled in 2019; three sampling square grids had to be abandoned due to failures to successfully trawl the area. The survey was conducted between July 12 and September 25, 2019. Sampling protocols were identical to previous years.

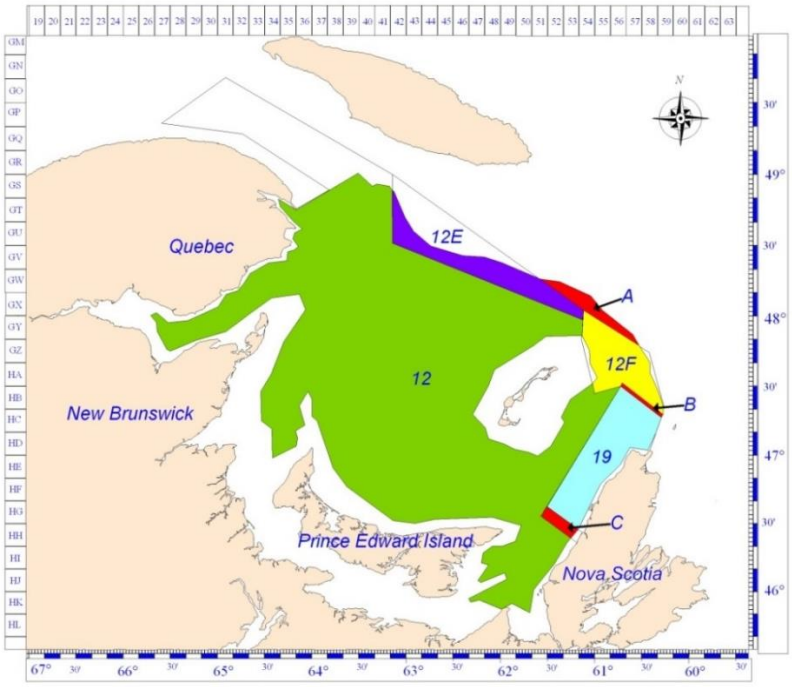

Figure 4. The survey and estimation polygon of 57,842.8 km² used for the 2019 snow crab stock assessment in the southern Gulf of St. Lawrence (all of the coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F, and 19). The unassigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

The standardized catch rates (crab weight per swept area) are used to estimate the total biomass of the commercial-sized adult male snow crab with a geostatistical model that uses kriging with external drift (KED) with depth as a secondary variable. The statistical model is the same as was recommended in the snow crab assessment framework of 2011 (DFO 2012a). Details of the statistical model are described in DFO (2012a) and Wade et al. (2014). The 1997 to 2019 time series of estimated biomasses for the sGSL, using the expanded polygon of 57,842.8 km², is considered as a standardized time series for the purpose of stock assessment, the development of reference points, and the provision of catch advice.

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 steel stern trawler (750 HP), was used to conduct the trawl survey from 2013 to 2018. A comparative

survey at 40 stations was conducted in September 2019 between these two vessels. The catch rates (crab per km^2) of commercial-sized adult male crab were not significantly different between the two vessels at those 40 stations. Over all the stations sampled in the sGSL during the regular survey, the total catches and catch rates of commercial-sized adult male crab in 2019 with the new vessel were similar to those of 2018. In contrast, the total catches of snow crab in 2019, male and female of all carapace sizes, were 26% above the highest catches of the time series beginning in 1997 with large catches noted for female and non-commercial-sized male crabs.

The standard protocol is a five minute tow at a target speed of two knots. This active phase is defined by the time when the winch is locked and the trawl first touches bottom to the time the stop signal is given. The passive phase encompasses the time from when the stop signal is given, which initiates the retrieval of the gear, and the trawl footrope leaves the bottom (Figure 5). An analysis of the behavior of the trawling phase data for 2017 to 2019 at all stations indicated that the passive trawling phase (retrieval phase after the five minute tow duration) in 2019 took longer than in the previous two years. The passive phase of the trawling process has never been included in the estimation of swept area which is used to standardize the catches to estimate the biomass. Assuming the trawl behavior during the passive phase is similar to the behavior during the active phase, the difference in passive phase duration in 2019 relative to 2018 amounted to an additional 12.6% of total swept area (from combined active and passive phases) in 2019. The consequences of these are further described in the Uncertainties section.

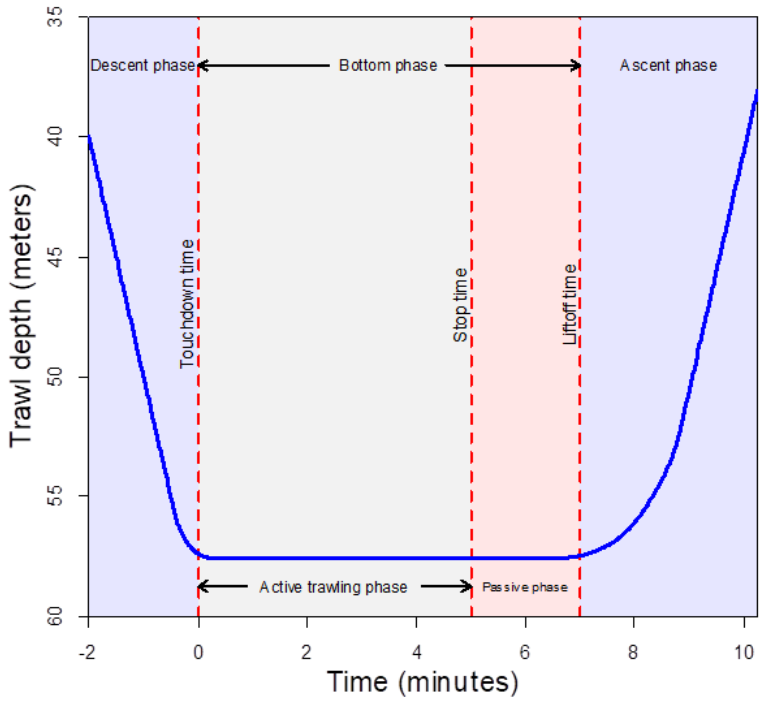

Figure 5. Illustration of a typical trawling process in the snow crab survey showing the four phases of trawling referenced in the assessment.

Stock Trends and Current Status in the sGSL

Interpretation of stock status is based on inferences of abundance data from the snow crab trawl surveys usually conducted during July to October, over the entire area of snow crab distribution in the sGSL. The surveys provide estimates of commercial biomass which are

comprised of residual biomass (hard-shelled adult males of legal size remaining after the fishery) and recruitment biomass (soft-shelled adult males >= 95 mm CW defined as R-1 that will be available to the fishery the following fishing season). The snow crab trawl survey also provides indices of future male recruitment to the fishery (pre-recruits defined as R-4, R-3 and R-2). The pre-recruits R-4, R-3 and R-2 represent adolescent male crabs with a CW range of 56-68, 69-83, and larger than 83 mm, respectively. A portion of these crabs could be available to the fishery in 4, 3 and 2 years, respectively. An index of abundance of small male crabs (34-44 mm CW) is also presented as an indicator of potential long-term recruitment. It takes at least six years for these small male crabs to reach the commercial size of 95 mm CW. Variations in catchability for these small size crabs could however affect this index.

Spawning stock abundance consists of females (pubescent and mature). The term pubescent refers to females that will molt to maturity and mate the following year and become primiparous females (first brood). The term multiparous refers to females which are carrying a brood for the second time or more. The term mature females, includes primiparous and multiparous females.

The biomass of commercial-sized adult males in the sGSL from the 2019 trawl survey was estimated at 79,066 t (95% confidence interval (CI) range of 69,072 t to 90,091 t) (Table 6; Figure 6). The 2019 commercial biomass in the sGSL decreased by 2.1% compared to the 2018 estimate.

The recruitment to the fishery at the time of the 2019 survey was 58,995 t (95% CI 50,215 t to 68,863 t), comprising 75% of the commercial biomass (Table 6; Figure 6). The recruitment to the fishery in 2019 is similar to the 2018 estimate. The residual biomass (carapace conditions 3 to 5) of commercial-sized adult male crabs after the 2019 fishery was estimated at 20,291 t (95% CI 16,940 t to 24,109 t), a decrease of 5.3% compared to the 2018 estimate (Table 6; Figure 6).

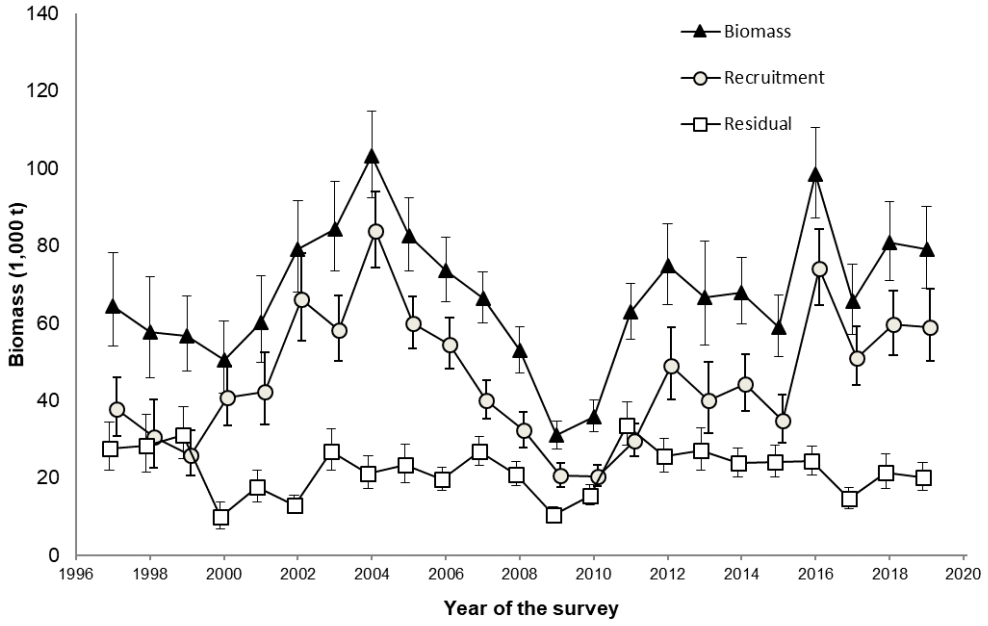

Figure 6. Total commercial biomass (black triangles), recruitment commercial biomass (open circles), and residual commercial biomass (open squares; in 1,000 t; means with 95% confidence intervals) in the southern Gulf of St. Lawrence, 1997 to 2019.

Table 6. Total commercial, recruitment, and residual biomass (t; means with 95 % confidence intervals) of commercial-sized adult male crabs (>= 95 mm carapace width) in the southern Gulf of St. Lawrence, 2009 to 2019.

Year of the survey	Commercial Biomass (t)	Recruitment Biomass (t)	Residual Biomass (t)
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
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	24,108 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

In the 2019 trawl survey, concentrations of commercial-sized adult males were located in Bradelle Bank, in Chaleur Bay, in the central and southern parts of the Magdalen Channel, in Area 12F and in the southeastern part of the sGSL (Figure 7). The spatial distributions of commercial-sized adult males have varied annually during increasing and decreasing phases of the commercial biomass (Figure 8).

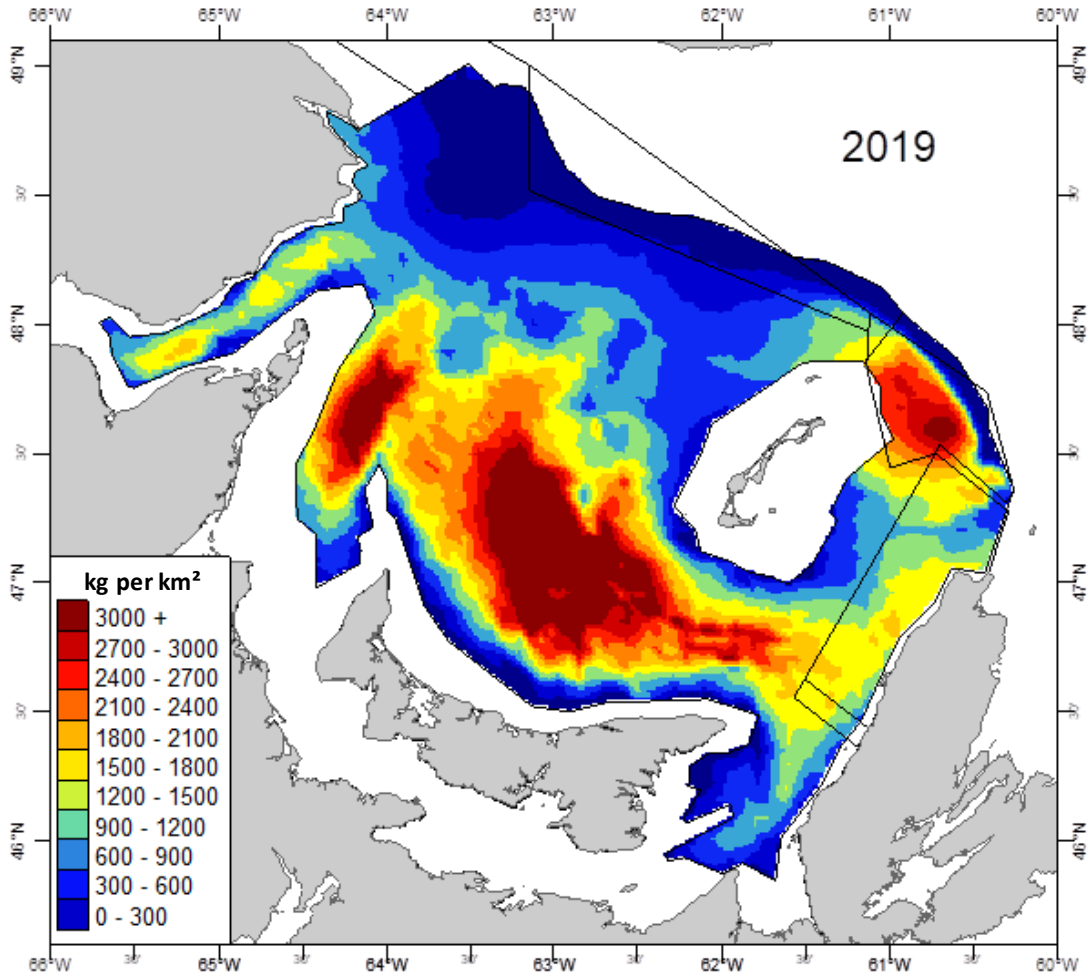

Figure 7. Density (kg per km²) contours of commercial-sized adult male crabs with a carapace width equal to or larger than 95 mm in the southern Gulf of St. Lawrence in 2019, based on the snow crab trawl survey.

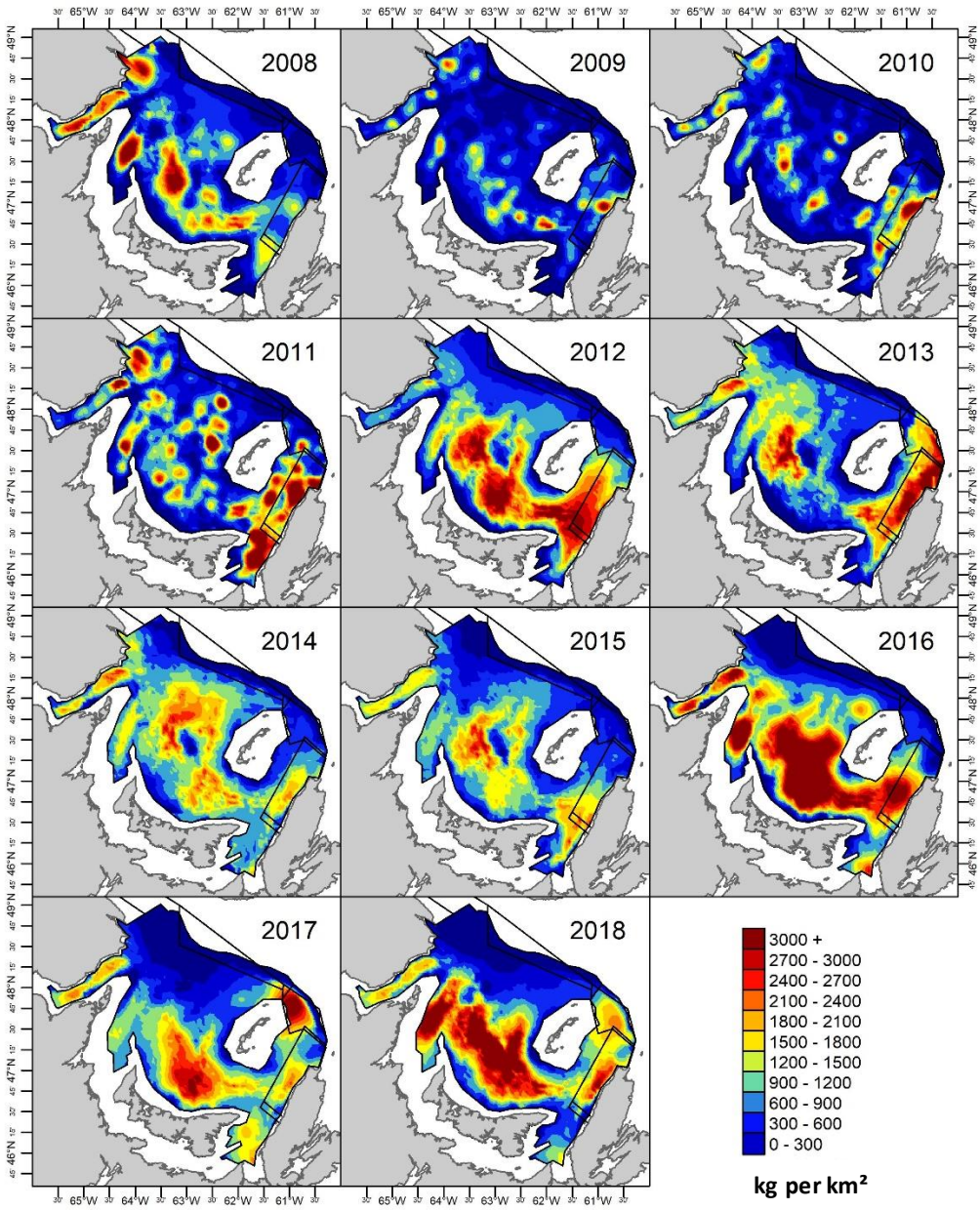

Figure 8. Density (kg per km^2) contours of commercial-sized adult male crabs with a carapace width equal to or larger than 95 mm in the southern Gulf of St. Lawrence, 2008 to 2018.

The exploitation rate in the sGSL is calculated as the ratio between the catch of the fishery in the year of the assessment and the commercial biomass estimated from the trawl survey in the previous year. Exploitation rates have varied between 21.0% and 44.7% from 1998 to 2019 (Figure 9). In 2019, the exploitation rate was 39.3%.

Total annual mortality of commercial-sized adult male crab is calculated as one minus the proportion of the residual biomass estimated from the survey in the year of the assessment divided by the biomass available to the fishery as estimated in the previous year's survey. In 2019, total mortality was estimated at 74.9% (Figure 9). The total mortality has varied between

46.1% and 85.1% during 1998 to 2019, except for 2011 when it was estimated at 11.3% (Figure 9).

Over the time series, the estimated commercial biomass from the survey has been on average 29.8% higher than the sum of the residual biomass and the landings of the following year. This difference (termed non-fishing directed mortality) and the associated inter-annual variability 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.

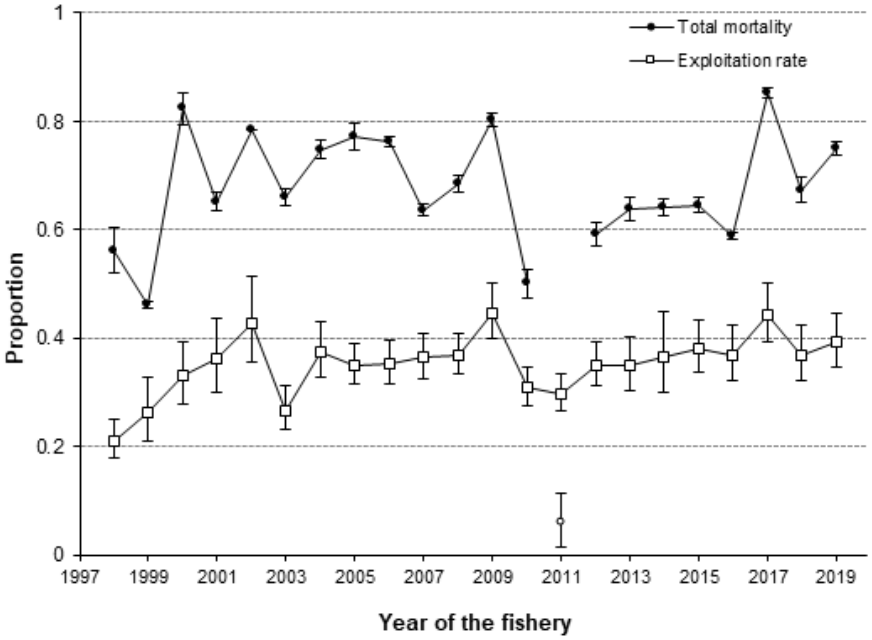

Figure 9. Exploitation rates (open squares; means and 95% confidence intervals) by the fishery and total mortality (black circles) of commercial-sized adult male snow crab (≥ 95 mm carapace width) in the southern Gulf of St. Lawrence, 1998 to 2019. The 2011 total mortality point (open circle) is isolated from the series due to uncertainties.

The 2019 commercial biomass estimates in the snow crab fishing areas (12, 19, 12E and 12F), the two buffer zones (between Areas 12F and 19, between Areas 12 and 19) and the unassigned zone (north of Areas 12E and 12F), as shown in Figure 4, are summarized in Table 7. The majority (86.2%) of the biomass in 2019 was located in Area 12, followed by Area 19, 12F, 12E, buffer zones, and the unassigned zone (Table 7). The percentages of the commercial biomass estimated in each of the four zones in 2019 are within the range of percentages estimated over the time series 1997 to 2019 (Table 7). The estimates of the commercial biomass by fishing area have greater uncertainty than for the sGSL overall. This higher uncertainty is more pronounced in small fishing areas, as they contain fewer sampling stations.

Table 7. Estimates of commercial biomass (t; means and 95% confidence intervals) in 2019 for the southern Gulf of St. Lawrence estimation polygon of 57,842.8 km² and for each of the snow crab fishing areas 12, 19, 12E, 12F, the buffer zones, and the unassigned zone. Also shown are the percentages of the mean estimated biomass in each of the four snow crab fishing areas to the sum of the biomass estimates in those four zones in 2019 as well as the average percentage and range, over the time series 1997 to 2019. Zone labels are referenced to those in Figure 4.

Area	Surface area (km²)	Commercial biomass (t) Mean	95% confidence intervals	% in 2019	Average percentage (range) of commercial biomass by zone 1997-2019
Southern Gulf [1]	57,842.8	79,066	69,072 – 90,091	na	na
Area 12	48,074	67,590	58,787 – 77,331	86.2	86.6 (78.1 to 92.8)
Area 19	3,813	5,639	3,834 – 8,004	7.2	9.1 (4.3 to 15.0)
Area 12E	2,436.9	554	50 – 2,342	0.7	1.1 (0.4 to 3.1)
Area 12F	2,426.8	4,613	3,202 – 6,439	5.9	3.2 (1.2 to 7.1)
Subtotal of crab fishing areas	56,750.7	78,396	na	100	na
Unassigned zone above 12E and 12F (label A)	667.9	89	1 – 589	na	na
Buffer zone 19 / 12F (label B)	134.2	224	76 - 521	na	na
Buffer zone 12 / 19 (label C)	289.5	427	124 – 1,086	na	na
Total of all individual area estimates [1]	57,842.7	79,136	na	na	na

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

Based on abundances of adolescent males of R-4, R-3 and R-2 from recent surveys, the predicted recruitment of commercial-sized adult male crabs for the 2020 survey, available for the 2021 fishery, was estimated at 66,850 t (95% CI 44,590 to 95,800 t) (Figures 10 and 11). Over the past four years, the estimated abundance of the commercial-sized adult male recruitment has been higher, but within the uncertainty intervals, than the predicted values.

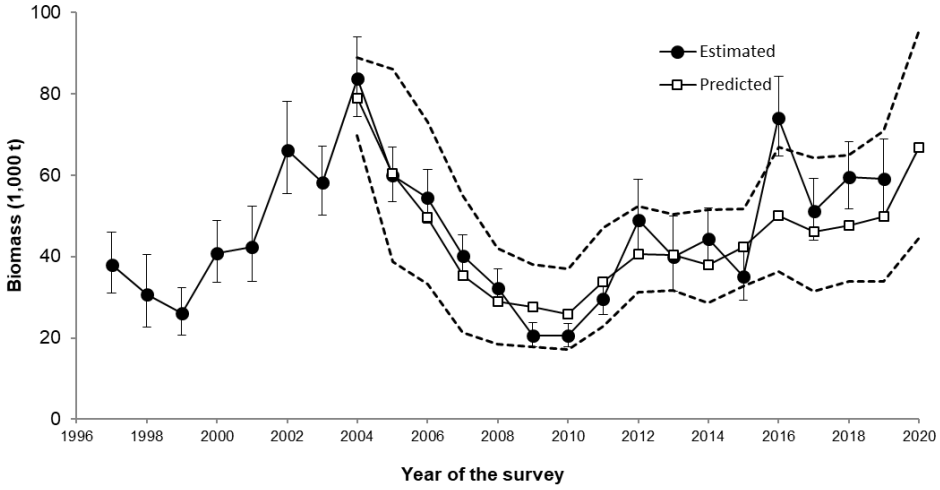

Figure 10. Estimated (black circles are the means with 95% confidence interval vertical bars) and predicted (open squares are the means with the 95% confidence interval bands as dashed lines) biomasses of R-1 (adult male crabs >= 95 mm carapace width of carapace condition 1 and 2) snow crab in the year of the survey, 1997 to 2019. 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. Prediction of R-1 biomass for 2020 is based on abundances of R-2 estimated in 2019 and shown in Figure 10.

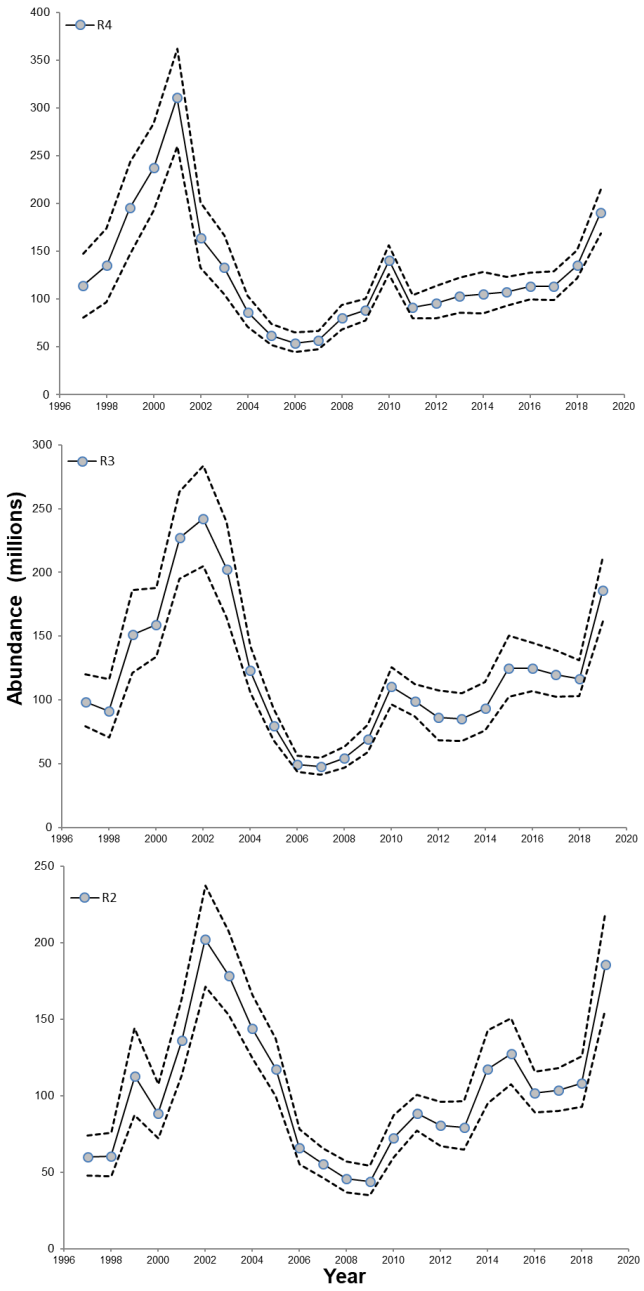

Figure 11. Estimated abundances (in millions; means and 95% confidence intervals) of R-4 (upper panel), R-3 (middle panel) and R-2 (lower panel) adolescent male crabs in the southern Gulf of St. Lawrence for the survey years 1997 to 2019.

The high predicted value for 2020 is driven by the high estimated abundance of R-2 crab estimated from the survey in 2019; the extent to which the high recruitment will be realized in 2020 is very uncertain and the abundances of R-2 and sub-legal size stages in 2019 were likely overestimated resulting from the change in vessel and fishing patterns in 2019.

Estimated abundances of R-3 and R-2 stages in 2019 are greater than the estimated abundances of R-4 and R-3 stages, respectively in 2018, an observation which is inconsistent with cohort tracking and accounting for mortality over the years (Figure 11). This inconsistency

from 2019 may be a consequence of the difference in the passive trawling phase component quantified in 2019.

The index of abundance of small male crabs (34-44 mm of CW) from the trawl survey in 2019 increased compared to the index estimated in 2018 (Figure 12).

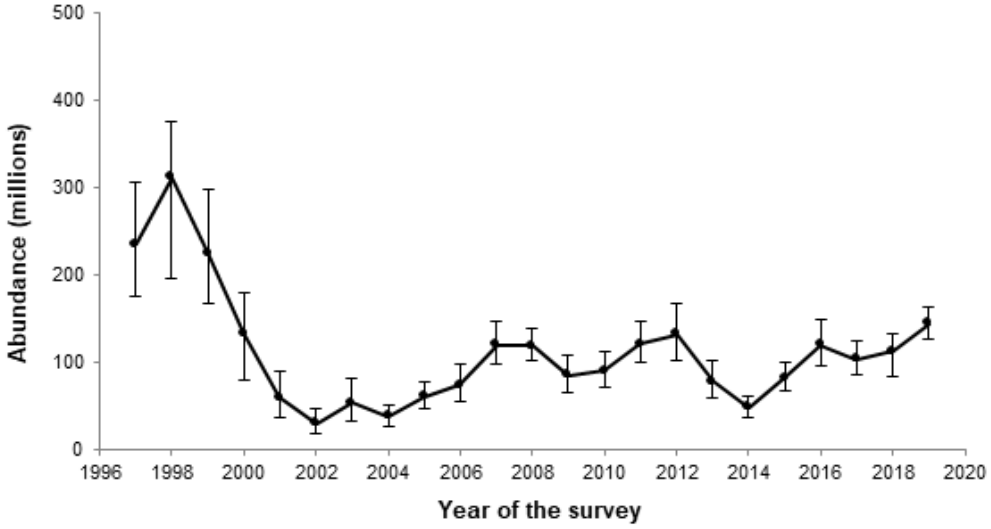

Figure 12. Index of abundance (in millions; means with 95% confidence intervals) of small male crabs of 34 to 44 mm of carapace width, based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 1997 to 2019.

Female abundance

The abundance of mature females is showing an increasing trend since 2006 (Figure 13), with a sharp increase in 2019. The abundance of pubescent females remained high in 2019 compared to the lowest value observed in the time series (Figure 13).

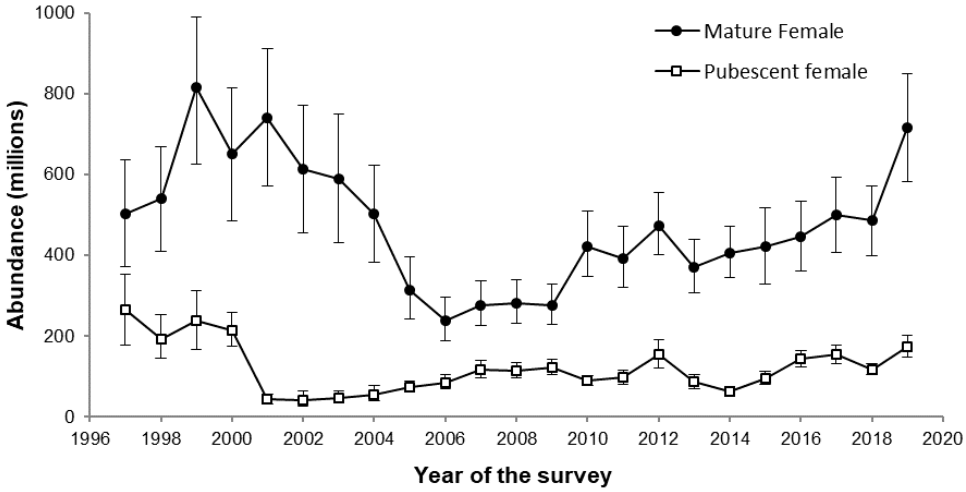

Figure 13. Estimated abundances (in millions; means and 95% confidence intervals) of mature female (black circles) and pubescent females (open squares) in the southern Gulf of St. Lawrence based on the trawl surveys from 1997 to 2019.

Environmental Considerations

In September 2019, near-bottom temperatures were near the mean (normal) value of the period 1981 to 2010 in most of Area 12 as well as in Chaleur Bay. However, the bottom waters in periphery of Area 12, 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 part of the sGSL where 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. Although higher than normal, Area 12E and Area 12F temperatures in 2019 were similar to those observed in 2018.

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 (Figure 14). 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 (1.2ºC, Figure 14). The mean temperature was at the highest of the 48 year time series in 2012, decreased in 2013 and 2014, and has remained above normal since then (Figure 14).

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).

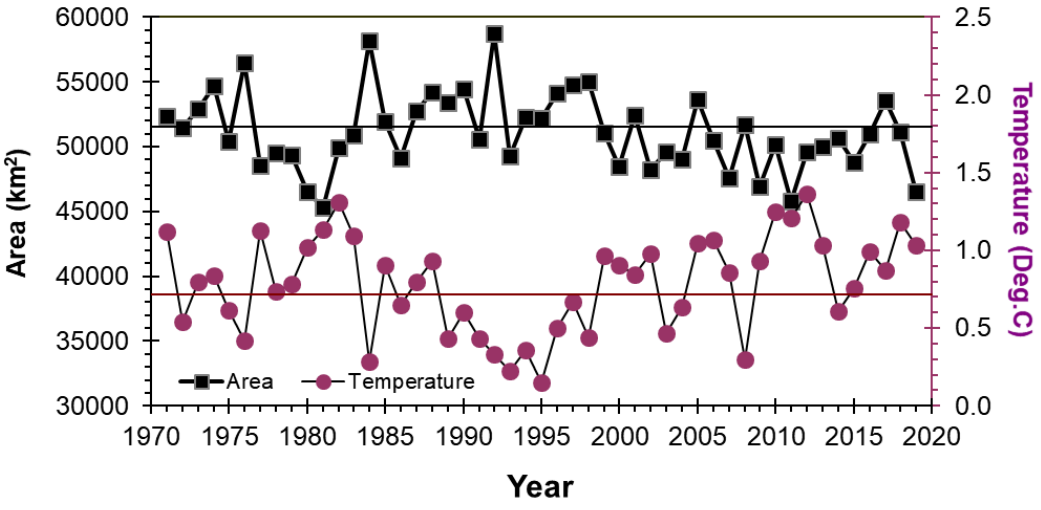

Figure 14. Habitat area index (water temperatures of -1 to 3 ºC; km²; square symbols) for commercial-sized adult male snow crab in the southern Gulf of St. Lawrence and the mean temperature (ºC; circle symbols) within the index area from 1971 to 2019.

Sources of Uncertainty

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.

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 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 protocols. 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 productive 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 is best assessed using the 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.

CONCLUSIONS AND ADVICE

Within the PA framework (DFO 2009), the Limit Reference Point for biomass (B_{lim}) defines the boundary between the critical and cautious zones and the upper stock reference (B_{USR}) delimits the cautious and healthy zones along the stock status axis. The upper stock reference point (B_{USR}) is 41,400 t of commercial-sized adult males of all carapace conditions as estimated from the trawl survey (Figure 15; DFO 2012b). The biomass limit reference point (B_{lim}) value is 10,000 t (Figure 15; DFO 2012b). The biomass limit reference point was chosen as the lowest biomass of hard shelled commercial sized adult males which produced good recruitment rates of small male crabs of 34-44 mm CW (referred to as Instar VIII) (DFO 2010). The removal reference point (F_{lim}) is 34.6% (Figure 15; DFO 2012b). The sGSL commercial biomass estimate from the trawl survey is used for evaluating catch options relative to the defined reference points.

The trajectory of stock abundance (biomass of commercial-sized adult male crabs as estimated from the trawl survey in the year before the fishery) versus exploitation rate in the fishery year for snow crab from the sGSL is shown in Figure 15. The commercial biomass has varied between 31,015 t and 103,146 t over the period 1997 to 2019. Over this same period, exploitation rates varied between 21.0% and 44.7%. The estimated biomass from the 2019 snow crab survey, which would be available to the fishery in 2020, is 79,066 t (95% CI 69,072 – 90,091 t). The 2019 survey biomass estimate is in the healthy zone.

Harvest decision rules that conform to the PA have been developed (DFO 2014b). Compliance to the PA was assessed based on the criterion that there must be a very low probability (<= 5%) of the stock falling into or remaining in the critical zone due to fishing exploitation. These PA compliant harvest decision rules include rules for which the exploitation rate exceeds F_{lim} when the stock is in the healthy zone (DFO 2014b). The Snow Crab Advisory Committee agreed on the proportional harvest decision rule (variant 4 in DFO 2014b, Figure 16) to derive the exploitation rate and the TAC based on the estimated biomass from the sGSL 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% and a corresponding TAC of 32,101 t for the 2020 fishery (Figure 16).

A risk analysis was developed for the decision rule TAC and relative to other catch levels in 2020 (Table 8). The risk analysis indicates that the TAC derived from the harvest decision rule will result in a near zero chance of the residual biomass after the fishery being less than B_{lim} and 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 8). The risk analysis also provides predictions of the commercial biomass in the 2020 survey, assuming the corresponding catch level is taken in 2020.

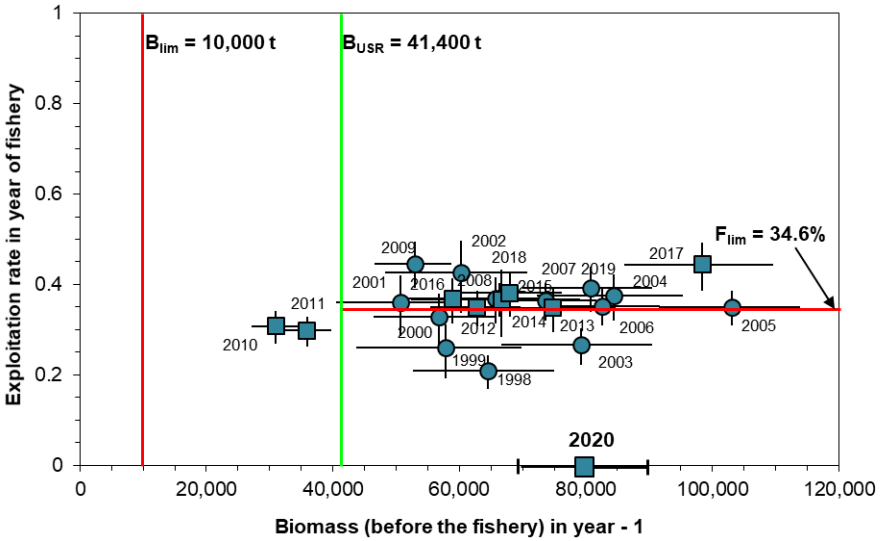

Figure 15. Trajectory of stock abundance (biomass of commercial-sized adult male crabs as estimated from the trawl survey in the year before the fishery) versus exploitation rate in the fishery year for snow crab from the southern Gulf of St. Lawrence. Year of the fishery is labeled on the figure. Error bars are 95% confidence intervals. Circle symbols are biomass and exploitation rate levels used to define the reference points. The squares are the years when the reference points were used within the PA to decide on the fishery quota. The biomass estimate available for the 2020 fishery (with 95% confidence interval) is also shown.

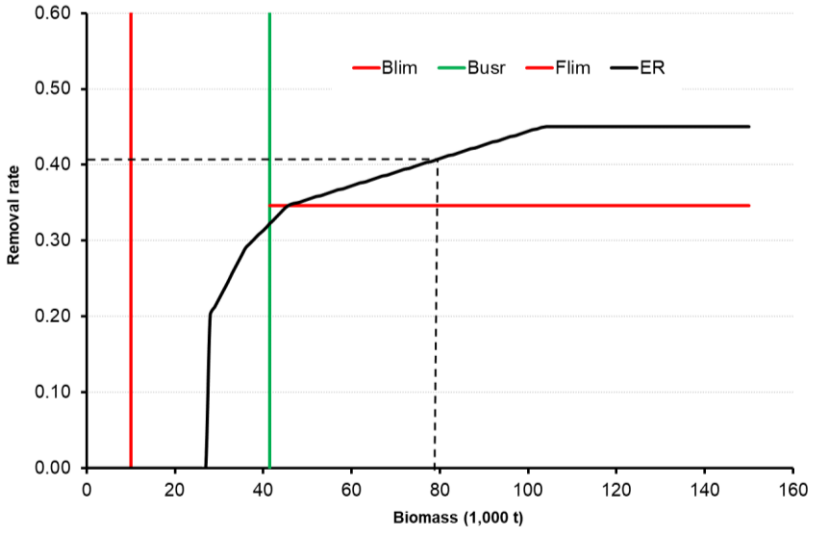

Figure 16. Harvest decision rule (solid black line; proportional variant 4; DFO 2014b) for the southern Gulf of St. Lawrence snow crab fishery and corresponding exploitation rate (0.406) for the 2020 fishery resulting from the commercial biomass estimate of 79,066 (dashed-dotted line).

Table 8. Risk analysis of catch options in 2020 for the southern Gulf of St. Lawrence snow crab fishery showing probabilities of the hard-shell commercial-sized adult male remaining biomass falling below B_{lim}, and of the total commercial-sized adult male biomass being equal to or above B_{USR} post-fishery in 2020. The catch level of 32,101 t based on the agreed harvest decision rule is highlighted in the table. Also shown is the predicted (mean; 95% confidence interval range) commercial biomass from the 2020 survey assuming each corresponding catch level is fished.

	Probability		
Catch level (t)	< B_{lim} (10,000 t)	>= B_{USR} (41,400 t)	Expected biomass for the 2020 post-fishery survey
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)
44,800	0.5	1	76,722 (50,297-103,202)
72,440	1	0.5	49,082 (22,657-75,562)

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 9. 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 9).

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. The snow crab habitat index (area of water < 3 ºC) was lower in 2019 compared to the time series average but covered most of the habitat in the sGSL. There is a broad distribution of snow crab in the sGSL and continued positive signs of sustained recruitment and high female abundances.

Table 9. 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	Prob. Residual biomass post-fishery < Blim	Prob. 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

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SOURCES OF INFORMATION

This Science Advisory Report is from the February 5-6, 2020 regional advisory meeting on the Stock assessment of the southern Gulf of St. Lawrence snow crab stock to 2019 and catch advice for the 2020 fishery. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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Aussi disponible en français :

MPO. 2020. Évaluation du crabe des neiges (Chionoecetes opilio) du sud du golfe du Saint-Laurent (zones 12, 19, 12E et 12F) jusqu'en 2019 et avis pour la pêche de 2020. Secr. can. de consult. Sci. du MPO, Avis sci. 2020/014.