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ASSESSMENT OF SNOW CRAB (*CHIONOECETES OPILIO*) IN THE SOUTHERN GULF OF ST. LAWRENCE (AREAS 12, 19, 12E AND 12F) TO 2018 AND ADVICE FOR THE 2019 FISHERY

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

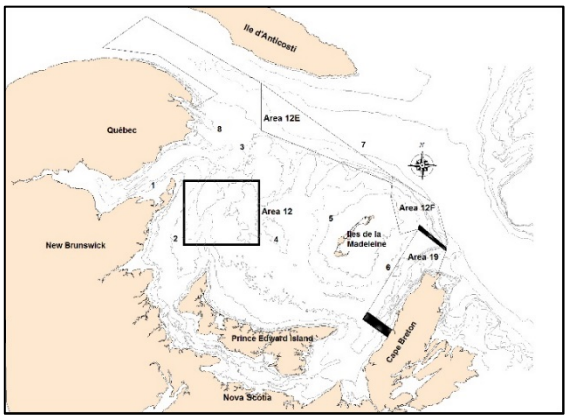

Figure 1. Map of the southern Gulf of St. Lawrence showing the Crab Fishing Areas (12, 12E, 12F, and 19), the 2018 static closure zone (box) to minimize fishery interactions with North Atlantic right whales, fishing grounds, and management buffer zones (shaded area). Fishing grounds are labeled as follows: 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 2018 and catch advice for the 2019 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 January 23-24, 2019 in Moncton, New Brunswick. Participants at the science review were from DFO Science, DFO Fisheries and Aquaculture Management, 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 of fishing areas 12, 19, 12E, and 12F.
- The landings of snow crab from the sGSL in 2018 were 24,260 tonnes (t) from a revised quota of 24,439 t.
- The exploitation rate of the 2018 fishery in the sGSL was estimated at 36.9%.
- The 2018 post-fishery survey biomass of commercial-sized adult male crabs (carapace width (CW) >= 95mm) was estimated at 80,746 t (95% confidence interval of 70,984 to 91,467 t), an increase of 22.8% from 2017. The estimated biomass for the 2019 fishery, derived from the 2018 survey, is within the healthy zone of the Precautionary Approach (PA) framework.
- Total commercial biomass in the 2018 survey was composed 74% of new recruitment (59,609 t) and 26% of residual biomass (21,432 t). The estimated recruitment to the commercial biomass increased by 16.6% relative to the previous year.
- Based on the agreed harvest decision rule which has been assessed as compliant with the PA, the point estimate of the biomass in the 2018 survey of 80,746 t corresponds to an exploitation rate of 40.9% and a Total Allowable Catch (TAC) of 33,025 t for the 2019 fishery.
- The risk analysis indicates that the 2019 TAC derived from the harvest decision rule would result in a near 100% chance of the biomass for the 2020 fishery being above B_{USR} and in the healthy zone of the PA.

Fishery performance in 2018 in Area 12:

- The 2018 landings in Area 12 were 20,769 t from a revised quota of 20,909 t.
- The catch per unit effort (CPUE; expressed as kg per trap haul, kg/th) in 2018 (44.2 kg/th) decreased compared to 2017 (72.0 kg/th).
- The incidence of soft-shelled crab was low in 2018 (4.4%), a decrease compared to 2017 (6.0%).

Fishery performance in 2018 in Area 19:

- The 2018 landings in Area 19 were 2,048 t from a revised quota of 2,046 t.
- The CPUE in 2018 (156.1 kg/th) increased compared to 2017 (142.8 kg/th).
- The incidence of white-crab decreased from 11.6% in 2017 to 8.8% in 2018.

Fishery performance in 2018 in Area 12E:

- In Area 12E, the landings were 260 t from a revised quota of 266 t.
- The CPUE in 2018 (46.6 kg/th) decreased compared to 2017 (60.9 kg/th).
- The incidence of soft-shelled crab in 2018 remained low, at 4.6% compared to 2.0% in 2017.

Fishery performance in 2018 in Area 12F:

- The 2018 landings in Area 12F were 1,183 t from a revised quota of 1,218 t.

- The CPUE remained high in 2018 (69.1 kg/th), comparable to 2017 (72.6 kg/th).
- The incidence of soft-shelled crab was low in 2018 (1.3%), comparable to 2017 (1.9%).

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, Québec, 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 245 in 2018.

Area 19 (Figure 1) was established in 1978 for the exclusive use of Cape Breton inshore fish harvesters with vessels less than 13.7 metres (45 feet) in length. There were 158 allocation shares in Area 19 in 2018.

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 Québec) in 2018. In Area 12F, there were 16 allocations for regular licenses and 28 temporary allocations in 2018 (from Nova Scotia and Québec). For 2018, harvesters in Area 12F requested a lower Total Allowable Catch (TAC) than the value originally assigned for the area based on the decision rule.

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 2018, in order to minimize fishery interactions with North Atlantic right whales, a closure zone (static) was implemented in Area 12 (Figure 1) which represented 28 fishing grids measuring 6,490 km^2 (DFO 2018). Temporary closures were also implemented, affecting 36 additional grids in the area adjacent to the static closure zone (DFO 2018), 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 2018.

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 2018.

Characteristics	Area 12	Area 12E	Area 12F	Area 19	Southern Gulf
Allocation shares [1]	245	4	44	158	451
Number of active vessels	322	4	23	108	457
Total number of traps allowed	36,534	475	2,152	1,699	40,860
Opening date	April 29	April 26	April 19	July 11	-
Date of the last landing	July 1	June 30	June 27	August 1	-
Revised quota (t) [2]	20,909	266	1,218	2,046	24,439 [3]
Landings (t)	20,769	260	1,183	2,048	24,260

[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 459 t set aside to finance the trawl survey in 2018 (under Section 10 of the Fisheries Act).

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 2018 (Figure 2). Snow crab landings from the sGSL in 2018 were 24,260 t from a revised quota of 24,439 t.

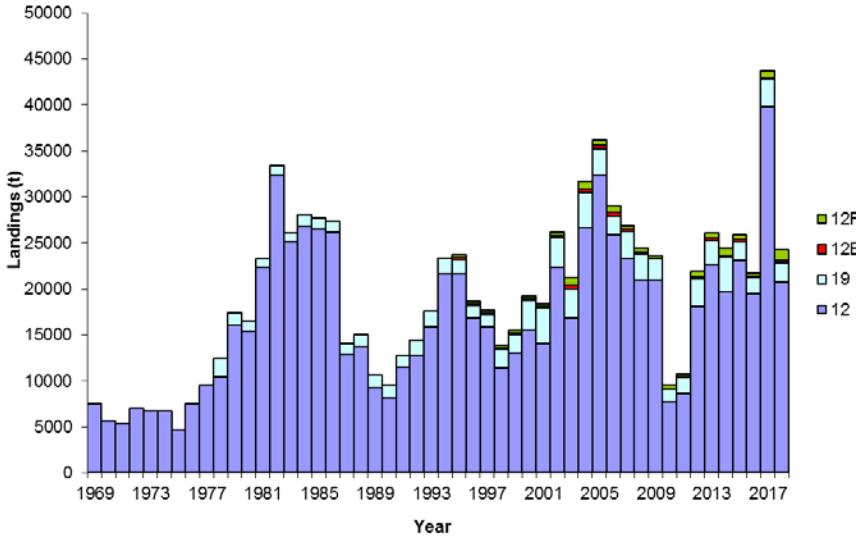

Figure 2. Landings (tonnes; t) in the southern Gulf of St. Lawrence snow crab fishery by fishing area from 1969 to 2018.

The 2018 fishing season in Area 12 opened on April 29 and the last landings were recorded on July 1 with reported landings of 20,769 t from a revised quota of 20,909 t (Tables 1 and 2; Figure 2). In accordance with the soft-shelled crab protocol, four grids that were open to fishing were closed during the 2018 fishing season compared to 57 in 2017. The fishing effort estimated from logbooks has varied from 161,148 to 553,125 trap hauls between 1987 and 2018, with the lowest effort in 2010 and the highest effort in 2017 (Hébert et al. 2018). The fishing effort was 469,887 trap hauls in 2018, a decrease from 2017 (553,125 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, 2010 to 2018.

Fishery descriptor	2010	2011	2012	2013	2014	2015	2016	2017	2018
Quota (t) [1]	7,700	8,585	18,143	22,548	19,409	23,021	19,393	39,651	20,909
Landings (t)	7,719	8,618	18,159	22,645	19,633	23,080	19,499	39,825	20,769
CPUE (kg/trap-haul) [2]	47.9	53.0	68.0	76.4	61.8	67.9	64.0	72.0	44.2
Effort (trap hauls)	161,148	162,604	267,044	296,398	317,689	339,912	304,624	553,125	469,887
Soft-shelled crab (%) in catches [3]	6.5	6.2	3.7	2.8	4.4	4.9	5.3	6.0	4.4
Grids closed (total of 323)	74	233	7	5	8	41	5	57	4[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 2018 fishing season in Area 19 opened on July 11 and the last date of landings was August 1 with reported landings of 2,048 t from a revised quota of 2,046 t (Tables 1 and 3; Figure 2). In accordance with the white crab protocol, one sector within Area 19 was closed

during the 2018 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. 2012). The fishing effort in Area 19 has varied from 11,138 to 56,517 trap hauls between 1987 and 2018, with the lowest effort in 2010 and the highest effort in 2004 (Hébert et al. 2018). The effort in 2018 was 13,120 trap hauls, a decrease from 2017 (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, 2010 to 2018.

Fishery descriptor	2010	2011	2012	2013	2014	2015	2016	2017	2018
Quota (t) [1]	1,360	1,703	2,907	2,654	3,745	2,130	1,701	2,945	2,046
Landings (t)	1,360	1,701	2,906	2,657	3,745	2,129	1,701	2,944	2,048
CPUE (kg/trap-haul) [2]	122.1	133.3	178.1	148.5	147.4	144.8	142.5	142.8	156.1
Effort (trap hauls)	11,138	12,761	16,317	17,890	25,407	14,703	11,937	20,616	13,120
White crab (%) in catches [3]	6.4	11.5	4.5	3.0	1.0	5.5	8.2	11.6	8.8
Sectors closed [4]	4/9	0/9	0/9	0/9	0/9	2/9	4/9	3/9	1/9

[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 2018 fishing season in Area 12E began on April 26 and the date of last landings was June 30 with reported landings of 260 t from a revised quota of 266 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 2018, with the lowest effort in 2010 and the highest effort in 2006 (Hébert et al. 2018). The fishing effort in Area 12E increased from 3,333 trap hauls in 2017 to 5,579 trap hauls in 2018. In accordance with the soft-shelled protocol, no grids within Area 12E were closed during the 2018 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, 2010 to 2018.

Fishery descriptor	2010	2011	2012	2013	2014	2015	2016	2017	2018
Quota (t) [1]	67	75	251	204	170	189	144	199	266
Landings (t)	50	76	185	204	178	192	144	203	260
CPUE (kg/trap-haul) [2]	27.4	31.5	32.9	40.1	47.3	65.8	51.5	60.9	46.6
Effort (trap hauls)	1,825	2,413	5,623	5,097	3,765	2,918	2,796	3,333	5,579
Soft-shelled crab (%) in catches [3]	14.7	8.4	3.3	15.9	7.8	9.8	1.1	2.0	4.6
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 2018 opened on April 19 and the last date of recorded landings was June 27 with reported landings of 1,183 t from a revised quota of 1,218 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 2018, with the lowest effort in 2002 and the highest effort in 2014 (Hébert et al. 2018). The fishing effort increased from 9,421 trap hauls in 2017 to 17,120 trap hauls in 2018. In accordance with the soft-shelled protocol, no sector within Area 12F was closed during the 2018 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, 2010 to 2018.

Fishery descriptor	2010	2011	2012	2013	2014	2015	2016	2017	2018
Quota (t) [1]	420	314	706	543	906	516	373	680	1,218
Landings (t)	420	313	706	543	882	510	381	684	1,183
CPUE (kg/trap-haul) [2]	29.3	32.5	41.8	49.0	38.1	38.2	43.9	72.6	69.1
Effort (trap hauls)	14,335	9,631	16,890	11,086	23,163	13,351	8,667	9,421	17,120
Soft-shelled crab (%) in catches [3]	8.6	2.6	9.4	2.4	1.7	3.3	10.4	1.9	1.3
Sectors closed (total of 3)	2	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), an index of fishery performance, expressed as kilogram (kg) per trap-haul (kg/th), 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 decreased in 2018 (44.2 kg/th) compared to 2017 (Table 2; Figure 3). In Area 19, the CPUE (156.1 kg/th) in 2018 increased compared to 2017 (Table 3, Figure 3). The CPUE decreased in Area 12E (46.6 kg/th) in 2018 compared to 2017 while in Area 12F, the CPUE (69.1 kg/th) in 2018 is comparable to 2017 (Tables 4 and 5; Figure 3).

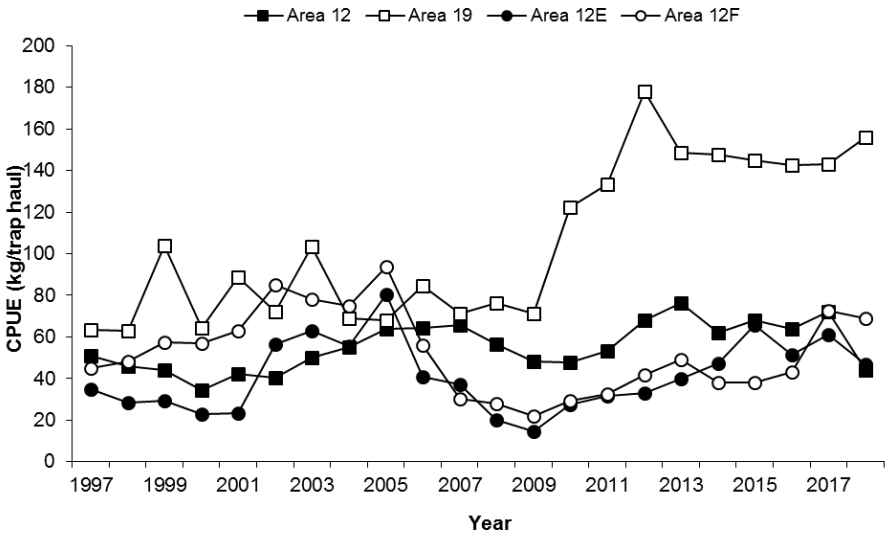

Figure 3. Catch per unit effort (CPUE; kg / trap-haul) in the southern Gulf of St. Lawrence snow crab fishery, Areas 12 (black squares), 19 (open squares), 12E (black circles) and 12F (open circles), based on logbooks, 1997 to 2018.

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 2018 was 4.4%, a decrease from 2017, and has remained low since 2008 (Hébert et al. 2018; Table 2). In Area 19, the percentage of white crab was 8.8% in 2018, a decrease from 2017 (Table 3). The percentage of soft-shelled crabs in Area 12E in 2018 was 4.6%, comparable to 2017 (Table 4). In Area 12F, the percentage of soft-shelled crabs in 2018 was 1.3%, comparable from 2017 (Table 5).

ASSESSMENT

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

The survey in 2018 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 (which approximately 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 2018, the number of sampling stations remained targeted at 355. As per the recommendations from the 2014 scientific peer review (DFO 2014a), the 350 successful sampling stations from the 2017 trawl survey were used as fixed stations and a new set of five sampling stations (i.e. the two stations that were abandoned and the three sampling stations that were conducted outside their assigned grids in 2017) was generated randomly. A total 354 stations were successfully trawled in 2018; one sampling square grid had to be abandoned due to failures to

successfully trawl the area. The survey was conducted between July 19 and September 16, 2018. Sampling protocols were identical to previous years.

Small adjustments were made to the 2018 polygons used for kriging. The sGSL survey polygon has been revised to 57,842.8 km^2 compared to the previous value of 57,840 km^2. An error in the coding, which resulted in incorrect sill and nugget parameters used in the kriging, was corrected. The entire time series of snow crab biomass and abundance estimates since 1997 was re-estimated. The consequences to the annual estimated commercial biomass values are minor; with differences ranging from -2.0% to 1.2%. Adjustments to the PA reference points (and associated harvest decision rule) were not considered to be required.

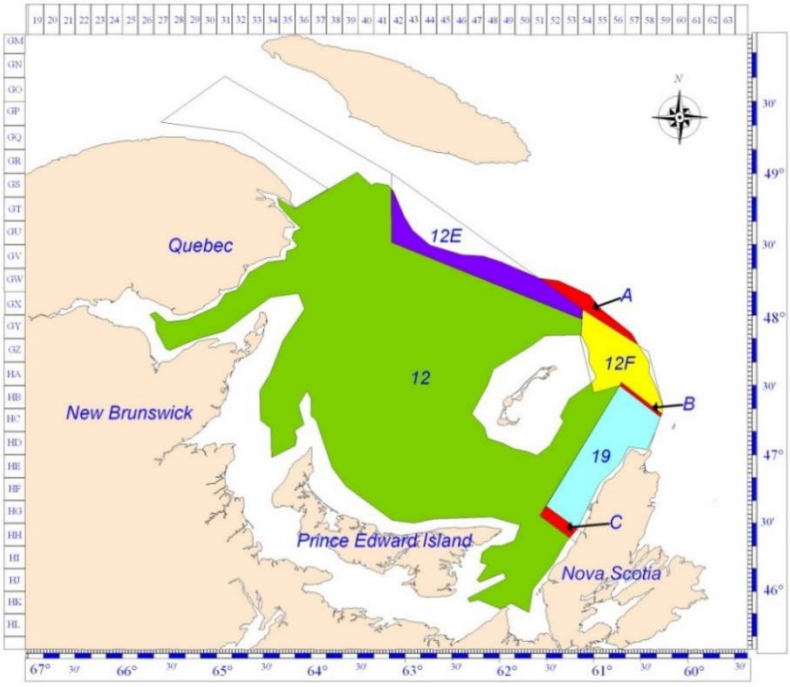

Figure 4. The survey and estimation polygon of 57,842.8 km^2 used for the 2018 snow crab stock assessment in the southern Gulf of St. Lawrence (all of the coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F, and 19). The unassigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.

Stock Trends and Current Status in the sGSL

Interpretation of stock status is based on inferences from abundance data from the snow crab trawl surveys usually conducted from 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.

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 2018 trawl survey was estimated at 80,746 t (95% confidence interval (CI) range of 70,984 t to 91,467 t) (Table 6; Figure 5). The 2018 commercial biomass in the sGSL increased by 22.8% relative to the 2017 estimate.

The recruitment to the fishery at the time of the 2018 survey was 59,609 t (95% CI 51,755 t to 68,310 t), comprising 74% of the commercial biomass (Table 6; Figure 5). The recruitment to the fishery in 2018 increased by 16.6% compared to the 2017 estimate. The residual biomass (carapace conditions 3 to 5) of commercial-sized adult male crabs after the 2018 fishery was estimated at 21,432 t (95% CI 17,270 t to 26,291 t), an increase of 46.3% compared to the 2017 estimate (Table 6; Figure 5).

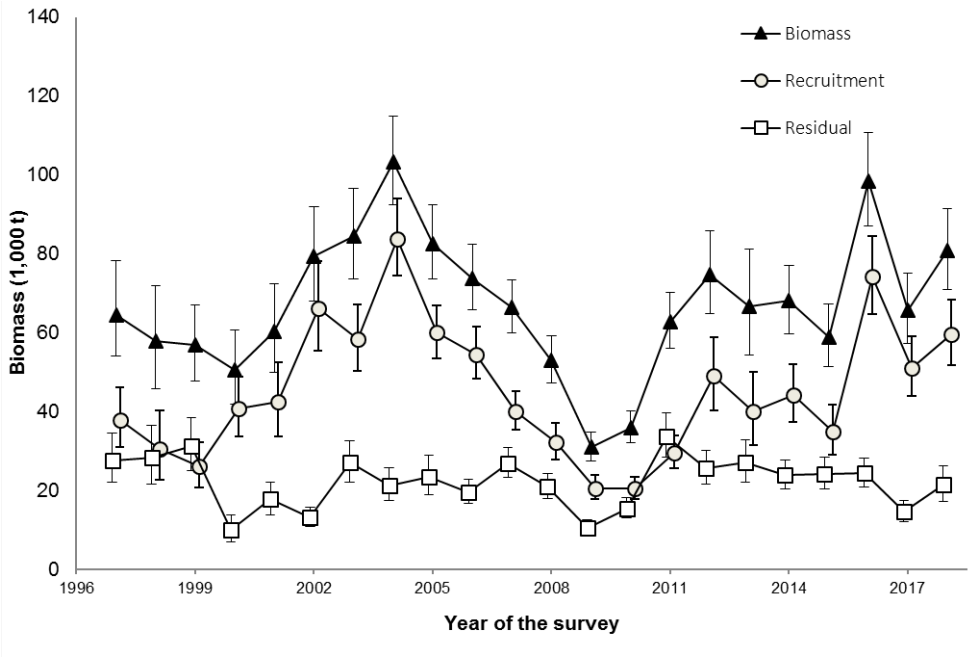

Figure 5. Total commercial biomass (black triangles), recruitment commercial biomass (open circles), and residual commercial biomass (open squares; in 1,000 tonnes, t; means with 95% confidence intervals) in the southern Gulf of St. Lawrence, 1997 to 2018.

In the 2018 trawl survey, geographic concentrations of commercial-sized adult males were located in Bradelle Bank, in Chaleur Bay, in the central and southern parts of the Magdalen Channel and in the southeastern part of the sGSL (Figure 6). The spatial distributions of commercial-sized adult males have varied annually during increasing and decreasing phases of the commercial biomass (Figure 7).

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 2018 (Figure 8). In 2018, the exploitation rate was 36.9% as specified with the use of the approved harvest decision rule.

Table 6. Total commercial, recruitment, and residual biomass (in tonnes, t; means with 95 % confidence intervals) of commercial-sized adult male crabs (>= 95 mm carapace width) in the southern Gulf of St. Lawrence, 2008 to 2018.

Year of the survey	Commercial Biomass (t)	Recruitment Biomass (t)	Residual Biomass (t)
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
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

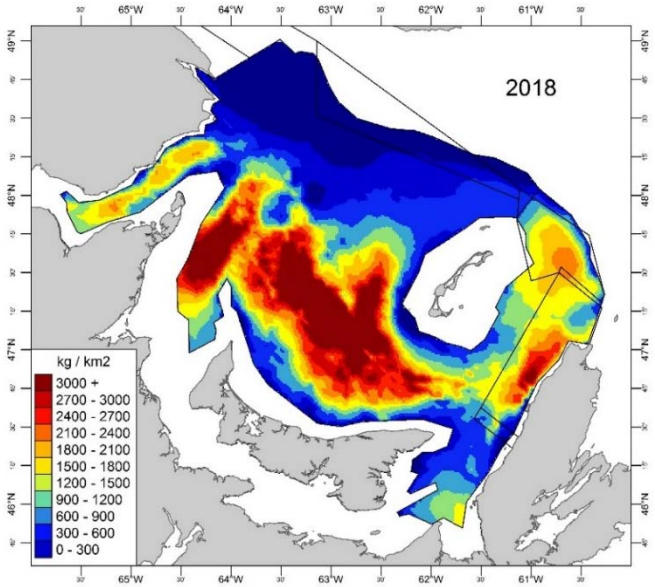

Figure 6. Density (kg per km^2) contours of commercial-sized adult male crabs with a carapace width equal to or larger than 95 mm in the southern Gulf of St. Lawrence in 2018, based on the snow crab trawl survey.

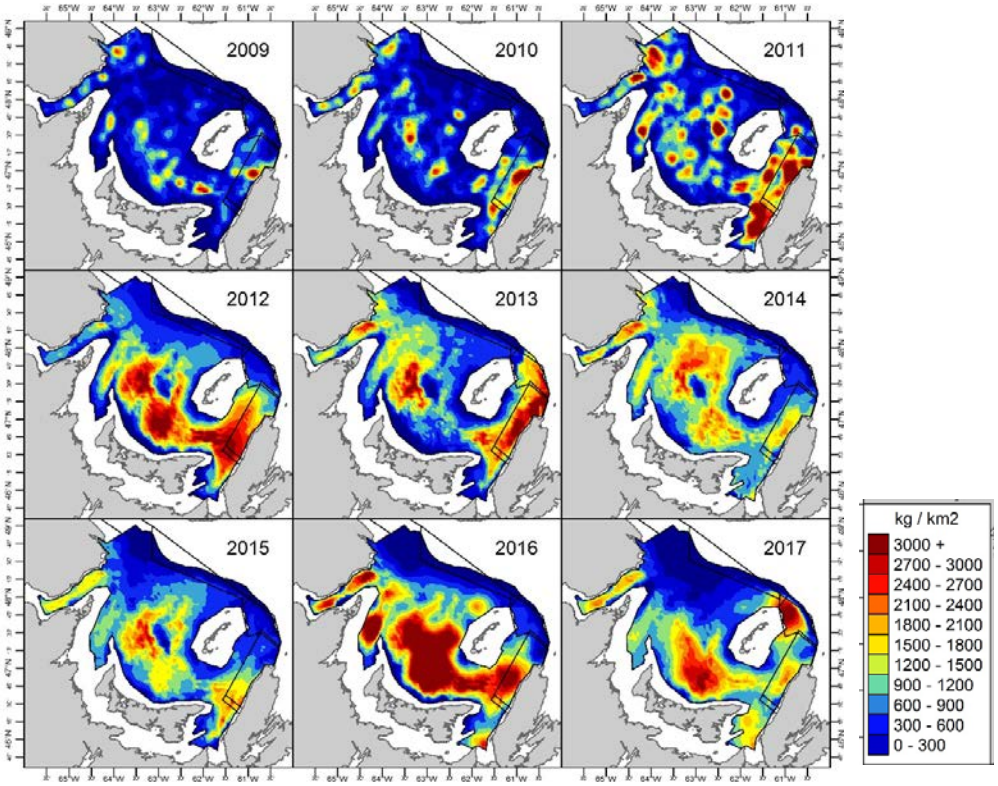

Figure 7. Density (kg per km^2) contours of commercial-sized adult male crabs with a carapace width equal to or larger than 95 mm in the southern Gulf of St. Lawrence, 2009 to 2017.

Total annual mortality 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 2018, total mortality was estimated at 67.4% (Figure 8). The total mortality has varied between 46.1% and 85.1% from 1998 to 2018, except for 2011 when it was estimated at 6.3% (Figure 8).

Over the time series, the estimated commercial biomass from the survey was 29.5% 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.

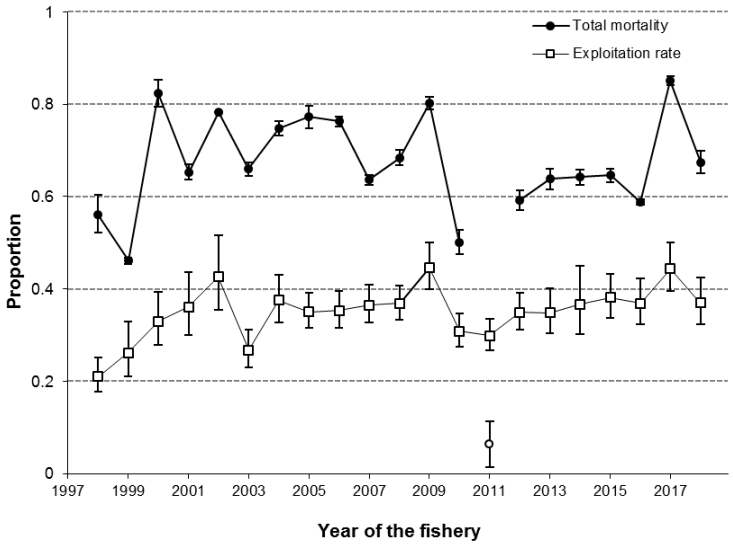

Figure 8. Exploitation rates (open squares; means and 95% confidence intervals) by the fishery and total mortality (black circles) of commercial-sized adult male snow crab (≥95 mm carapace width) in the southern Gulf of St. Lawrence, 1998 to 2018. The 2011 total mortality point (open circle) is isolated from the series due to uncertainties.

The 2018 commercial biomass estimates in snow crab fishing areas (12, 19, 12E and 12F), 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 of biomass was found in Area 12, followed by Area 19, 12F, 12E, buffer zones, and the unassigned zone (Table 7). Estimating the commercial biomass by fishing area results in values with larger confidence intervals. This situation of high uncertainty is more pronounced in small fishing areas, as they contain fewer sampling stations.

Table 7. Estimates of commercial biomass (in tonnes, t; means and 95% confidence intervals) in 2018 for the southern Gulf of St. Lawrence estimation polygon of 57,842.8 km^2 and for each of the snow crab fishing areas 12, 19, 12E, 12F, the buffer zones, and the unassigned zone. Labels refer to those in Figure 4.

Area	Surface area (km^2)	Commercial biomass (t)	
		Mean	95% confidence intervals
Southern Gulf [1]	57,842.8	80,746	70,984 – 91,467
Area 12	48,074	68,953	60,344 – 78,439
Area 19	3,813	6,825	4,955 – 9,173
Area 12E	2,436.9	425	21 – 2,155
Area 12F	2,426.8	3,883	2,452 – 5,855
Subtotal of crab fishing areas	56,750.7	80,086	na
Unassigned zone above 12E and 12F (label A)	667.9	214	11 – 1,074
Buffer zone 19 / 12F (label B)	134.2	234	84 - 523
Buffer zone 12 / 19 (label C)	289.5	255	35 – 923
Total of all individual area estimates [1]	57,842.7	80,789	na

[1] Small difference in the sum of all individual area estimates compared to the southern Gulf estimates 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 2019 survey, available for the 2020 fishery, was estimated at 49,820 t (95% CI 33,790 to 70,970 t) (Figures 9 and 10).

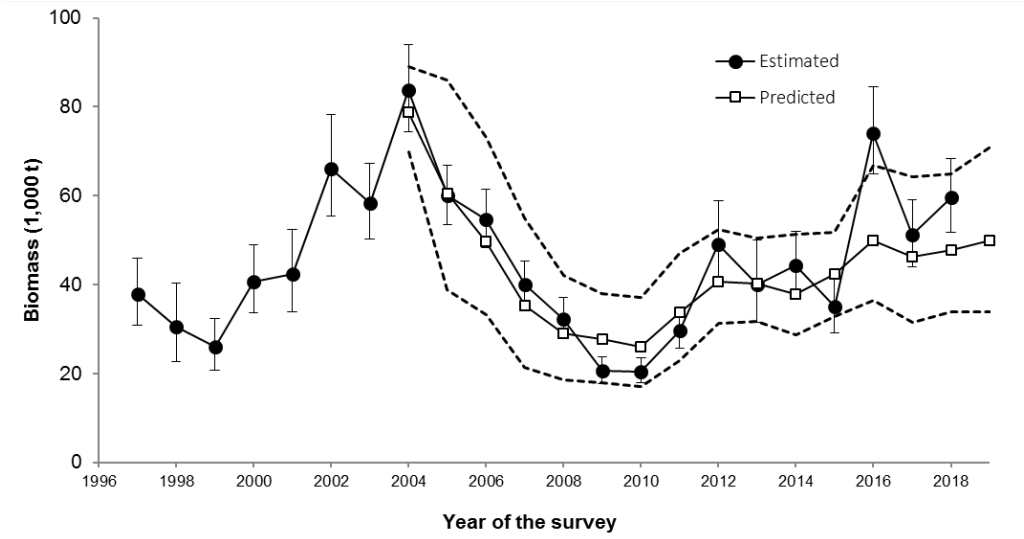

Figure 9. Estimated (black circles are the means with 95% confidence interval vertical bars) and predicted (open squares are the means with the 95% confidence interval bands as dashed lines) biomasses of R-1 (adult male crabs >= 95 mm carapace width of carapace condition 1 and 2) snow crab in the year of the survey, 1997 to 2018. 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 2019 is based on abundances of R-2 estimated in 2018 and shown in Figure 10.

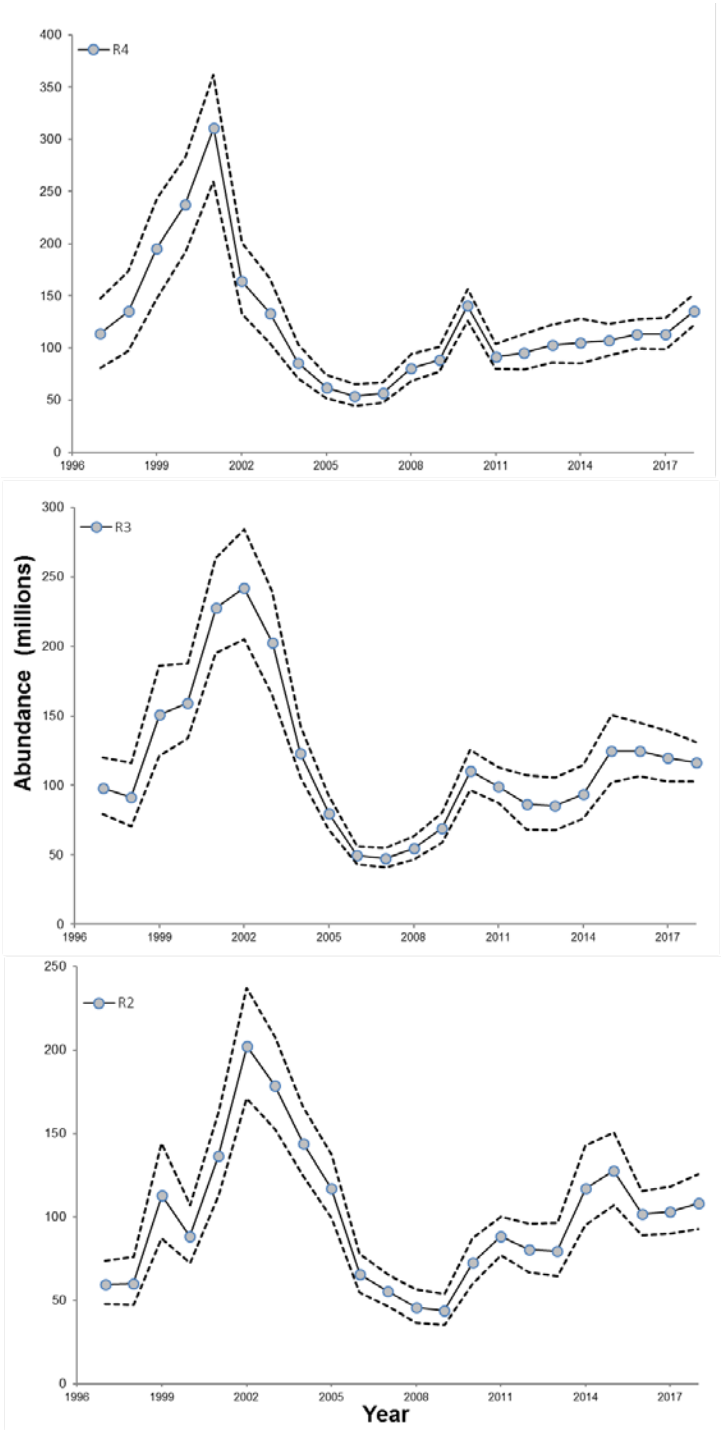

Figure 10. Estimated abundances (in millions; means and 95% confidence intervals) of R-4 (upper panel), R-3 (middle panel) and R-2 (lower panel) adolescent male crabs in the southern Gulf of St. Lawrence for the survey years 1997 to 2018.

The index of abundance of small male crabs (34-44 mm of CW) from the trawl survey in 2018 remained at the same level to the index estimated in 2017 (Figure 11).

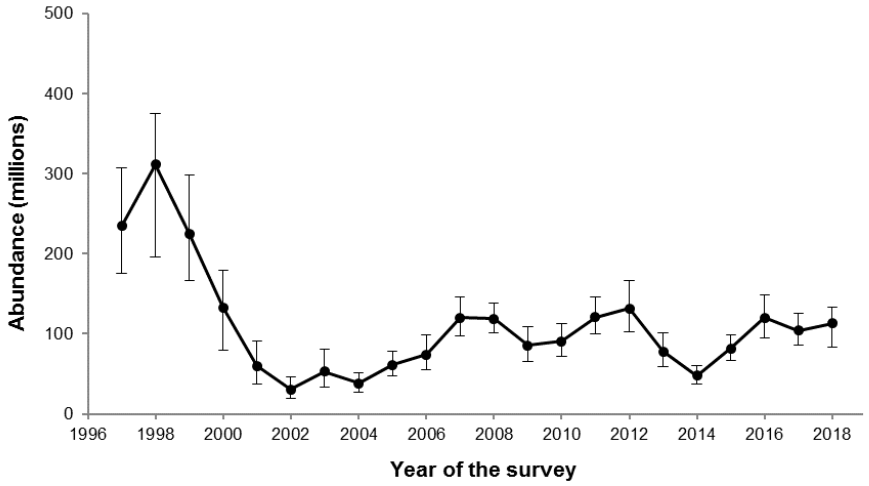

Figure 11. Index of abundance (in millions; means with 95% confidence intervals) of small male crabs of 34 to 44 mm of carapace width, based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 1997 to 2018.

Female abundance

The abundance of mature females is showing an increasing trend since 2006 (Figure 12). The abundance of pubescent females remained high in 2018 compared to the lowest value observed in the time series(Figure 12).

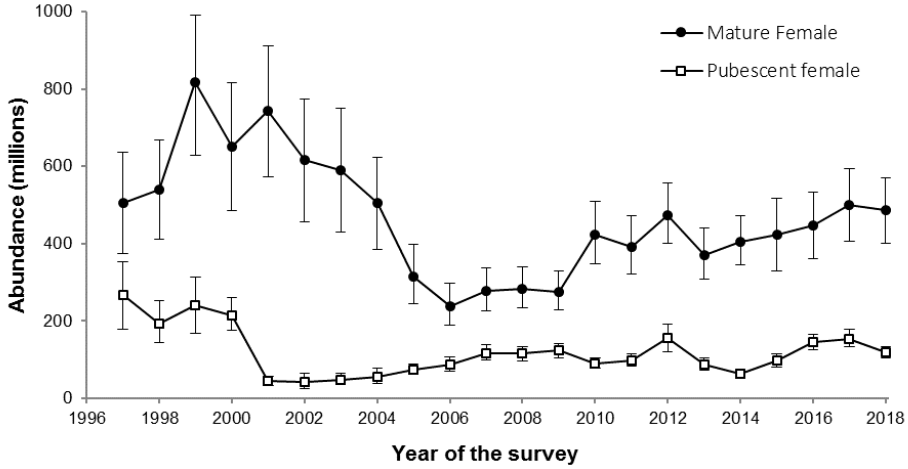

Figure 12. Estimated abundances (in millions; means and 95% confidence intervals) of mature female (black circles) and pubescent females (open squares) in the southern Gulf of St. Lawrence based on the trawl surveys from 1997 to 2018.

Environmental Considerations

In September 2018, near-bottom temperatures were near the mean value of the period 1981 to 2010 in most of the northern portion of Area 12 as well as in Area 19. However, the bottom waters in the southern portion in Area 12, in Area 12E, Area 12F and the northwestern portion of the sGSL (channels connecting the slope of the Laurentian Channel to the Magdalen Shallows) were warmer than normal. Bottom waters outside of Miramichi Bay were also warmer than average. There was a band of cooler-than-normal bottom waters in the southwestern part

of Area 12 that was stretching down from Miscou Island to the east entrance of Northumberland Strait including St. George's Bay. Most of the snow crab fishing grounds in the northern portion of Area 12 had similar temperatures, or slightly cooler, in 2018 compared to 2017 except at the head of Chaleur Bay where cooler bottom waters were present. The southern portion of Area 12 had bottom waters that were significantly warmer in 2018 than in 2017. Area 19 bottom water temperatures in 2018 were similar to those observed in 2017. Areas 12E and 12F had a tendency to be cooler in 2018 than in 2017. The snow crab habitat index (bottom area with temperatures from -1 to 3°C) for commercial-sized adult male crab was just below the 1981-2010 average (1% below) in 2018 and decreased by 5% from 2017 and was similar to the 2016 value (Figure 13). In 2018, the mean temperature (1.2°C) within the defined snow crab habitat area index (-1 to 3°C) increased by about 0.3°C compared to 2017 (0.9ºC), (Figure 13). 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.

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).

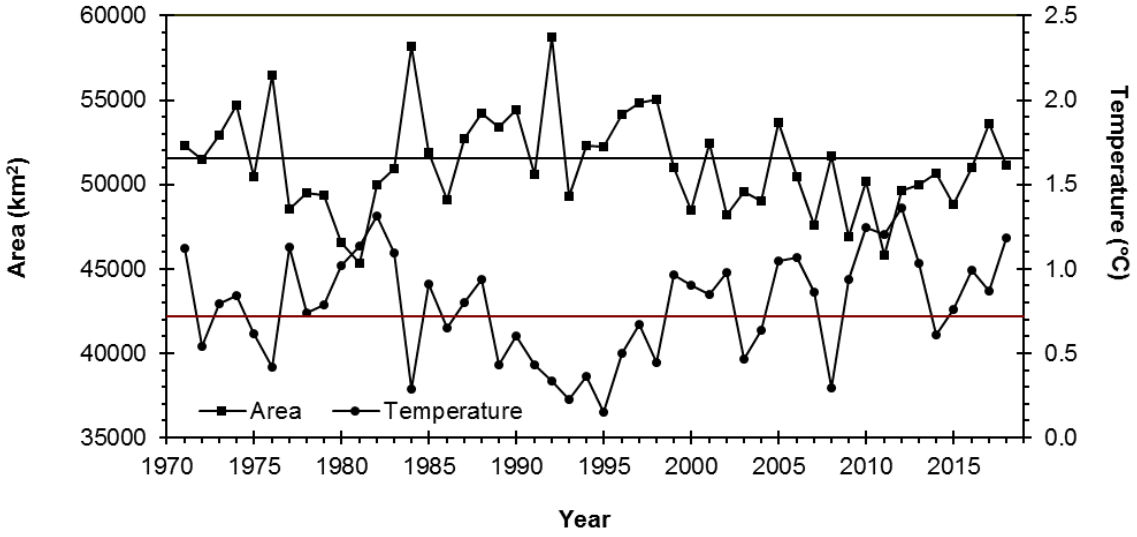

Figure 13. Habitat area index (km²; square symbols) for commercial-sized adult male snow crab in the southern Gulf of St. Lawrence (water temperatures of -1 to 3 ºC) and the mean temperature (ºC; circle symbols) within the index area from 1971 to 2018.

Sources of Uncertainty

There have been changes in snow crab survey vessels over the 1997 to 2018 assessment period, including a change in vessel in 2013 from the vessel which had been used from 2003 to 2012. There have never been any comparative experiments to assess if there were changes in catchability between vessels. Changes in survey catch rates over time may not accurately reflect changes in stock size if survey vessels have different catchabilities.

Swept areas, which are used to standardize survey catches, are calculated from trawl wing-spread measurements. Uncertainty associated with swept area calculations for tows with insufficient wing-spread data remains unknown.

The unstandardized catch per unit effort from the fishery is weakly correlated with the estimated biomass from the assessment. This can result in differences in perception of stock abundance from the fishing industry observations (catch per unit of effort variations within the season and between years) from those of the commercial biomass estimate from the survey.

There was some discrepancy in the identification of carapace condition 2 during the 2018 survey, increasing the uncertainty in fishery recruitment and residual biomass estimates, as well as the mortality rates and the prediction of future recruitment in the risk analyses. Development and utilization of objective methods to assess carapace condition will ensure a comparable standard in future surveys.

The distribution of snow crab within the sGSL and the proportions of the estimated abundance of commercial sized adult male crabs in each of the management areas show high inter-annual variations. The factors determining these relative distributions are not known but are seemingly related to movements of crab and recruitment pulses rather than survival or exploitation. Changes in the environment, particularly the size of the Cold Intermediate Layer, are likely important factors but the influence of these factors on the movements and recruitment dynamics of crab are presently not known.

In 2018, no snow crab fishing activities took place within the closed areas implemented to minimize interactions with North Atlantic right whales. Consequently, snow crab located outside of the closed areas were proportionally fished more intensively to catch the Area 12 fishery allocation. As expected, the residual biomass in the static closure zone was higher in 2018 than in recent years. However, the residual biomass estimates and proportions vary annually and the 2018 numbers are within the time series' ranges. The potential effects of annual closures on the production and recruitment of the sGSL snow crab population are unknown.

Predicting recruitment is uncertain because of a number of factors including variations in mortality, growth among stages and the variation in the proportion of pre-recruits that molt in any given year. In 2015, there was a high abundance and proportion of skip molters (crab that did not molt that year) in the R-2 stage compared to previous years and it appears that this high abundance of skip molters resulted in a much higher molting rate and/or survival rate to the recruitment stage. The high incidence of skip molters (R-2) was not observed since 2015. Additional information on the factors that lead to skip molting in snow crab, either through density dependence (competition for resources) or annual variations in food availability, for example, are needed.

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.

CONCLUSIONS AND ADVICE

Within the PA framework (DFO 2009), the Limit Reference Point for biomass (B_{lim}) defines the critical / cautious zones and an upper stock reference (B_{USR}) delimits the cautious / healthy zones on 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 14; DFO 2012b). The biomass limit reference point (B_{lim}) value is 10,000 t (Figure 14;

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 14; 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 14. The commercial biomass has varied between 31,015 t and 103,146 t during 1997 to 2018. Over this same period, exploitation rates have varied between 21.0% and 44.7%. The estimated biomass from the 2018 snow crab survey, which would be available to the fishery in 2019, is 80,746 t (95% CI 70,984 – 91,467 t). The 2018 survey biomass estimate is in the healthy zone.

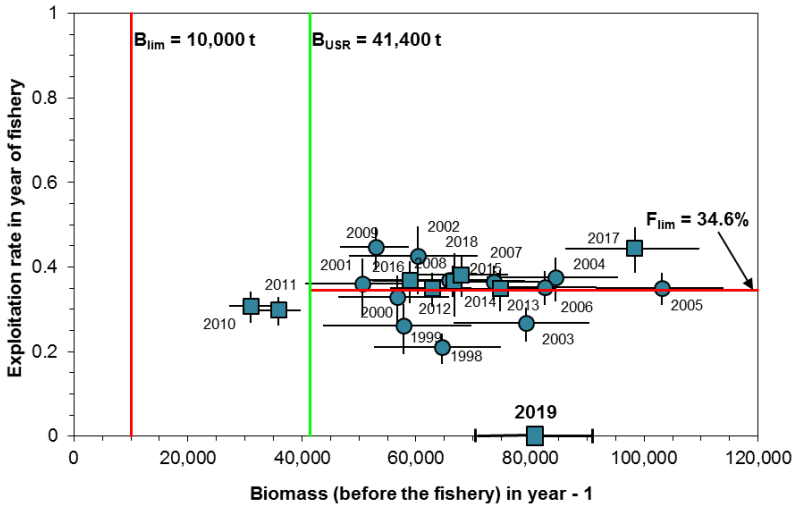

Figure 14. Trajectory of stock abundance (biomass of commercial-sized adult male crabs as estimated from the trawl survey in the year before the fishery) versus exploitation rate in the fishery year for snow crab from the southern Gulf of St. Lawrence. Year of the fishery is labeled on the figure. Error 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 2019 fishery (with 95% confidence interval) is also shown.

Harvest decision rules that conform to the PA have been developed (DFO 2014b). 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 15) 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 2018 survey of 80,746 t, results in a selected exploitation rate of 40.9% and corresponding to a TAC of 33,025 t for the 2019 fishery (Figure 15).

A risk analysis was developed for the decision rule TAC and relative to other catch levels in 2019 (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 2019 survey, assuming the corresponding catch level is taken in 2019. At the decision rule TAC value of 33,025 t for the 2019 fishery, the commercial biomass predicted for the 2019 post-fishery survey and for the 2020 fishery, is 83,850 t, with a 95% confidence interval range of 72,820 to 94,870 t, comparable to the 2018 survey estimates, and in the healthy zone of the PA framework.

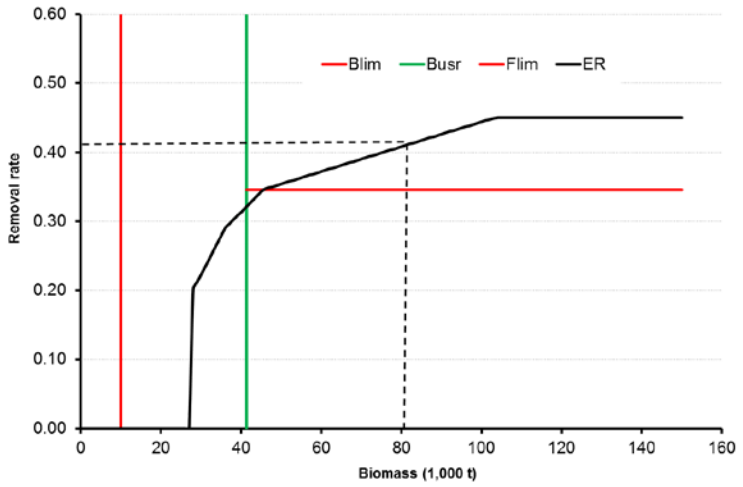

Figure 15. Harvest decision rule (solid black line; proportional variant 4; DFO 2014b) for the southern Gulf of St. Lawrence snow crab fishery and corresponding exploitation rate (0.409) for the 2019 fishery resulting from the commercial biomass estimate of 80,746t (dashed-dotted line).

Table 8. Risk analysis of catch options in 2019 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 2019. The catch level of 33,025 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 2019 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 2019 post-fishery survey
30,000	0	1	86,880 (75,840-97,900)
31,000	0	1	85,880 (74,840-96,900)
32,000	0	1	84,880 (73,840-95,900)
33,000	0	1	83,880 (72,840-94,900)
33,025	0	1	83,850 (72,820-94,870)
34,000	0	1	82,880 (71,840-93,900)
35,000	0	1	81,880 (70,840-92,900)
36,000	0	1	80,880 (69,840-91,900)
37,000	0	1	79,880 (68,840-90,900)
38,000	0	1	78,880 (67,840-89,900)
39,000	0	1	77,880 (66,840-88,900)
40,000	0	1	76,880 (65,840-87,900)
41,000	0	1	75,880 (64,840-86,900)
47,326	0.5	1	69,550 (58,510-80,570)
75,518	1	0.5	41,360 (30,320-52,380)

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SOURCES OF INFORMATION

This Science Advisory Report is from the regional advisory meeting of January 23-24, 2019 Stock assessment of the southern Gulf of St. Lawrence snow crab stock to 2018 and catch advice for the 2019 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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MPO. 2019. Évaluation du crabe des neiges (Chionoecetes opilio) du sud du golfe du Saint-Laurent (zones 12, 19, 12E et 12F) jusqu'en 2018 et avis pour la pêche de 2019. Secr. can. de consult. Sci. du MPO. Avis sci. 2019/010.