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The 2012 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F)

M. Hébert, E. Wade, P. DeGrâce, J.-F. Landry, and M. Moriyasu

Science Branch, Gulf Region
Fisheries and Oceans Canada
P. O. Box 5030
Moncton, New Brunswick
E1C 9B6

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Foreword

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

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

The 2012 assessment of the southern Gulf of St. Lawrence (sGSL) snow crab, *Chionoecetes opilio*, stock (Areas 12, 19, 12E and 12F) is presented. Snow crab management Areas 12, 19 12E and 12F comprise a single biological population and the sGSL stock is considered as one unit for assessment purposes. The 2012 assessment was conducted as per the recommendations of the Snow Crab Assessment Methods Framework Science Review held November 2011. The major change to the assessment methodology in 2012 was a revised sampling design that distributed sampling effort equally among 325 sampling grids. The exploitation rate of the 2012 fishery in the sGSL was 34.8%. The 2012 post-fishery survey biomass of commercial-sized adult male crabs was estimated at 74,997 t (95% confidence intervals 65,822 to 85,086 t), an increase of 18.7% from 2011. The available biomass for the 2013 fishery, derived from the 2012 survey, is within the healthy zone of the PA Framework. The residual biomass (26,028 t) from the 2012 survey decreased by 22.9% compared to 2011. Sixty-five percent (65%) of the 2012 survey biomass, available for the 2013 fishery, is composed of new recruitment (48,969 t). The recruitment to the commercial biomass from the 2012 survey increased by 66.7% relative to the previous year. The available predictions of recruitment of commercial-sized adult male crab indicate that they should remain at levels comparable to that of 2012 until the 2016 fishery. A risk analysis of catch options relative to reference points for the 2013 fishery is provided.

RESUME

L'évaluation de stock du crabe des neiges, *Chionoecetes opilio*, du sud du golfe du Saint-Laurent (sgSL) en 2012 est présentée (zones 12, 19 12E et 12F). Les crabes des neiges des zones de gestion 12, 19, 12E et 12F font partie d'une seule population biologique, et le sgSL est considéré comme une unité aux fins d'évaluation. L'évaluation de 2012 a été effectuée selon les recommandations suite à l'examen cadre des méthodes d'évaluation du stock de crabe des neiges dans le sgSL tenu en novembre 2011. En 2012, le changement majeur apporté à la méthode d'évaluation a été un plan d'échantillonnage révisé qui distribue l'effort d'échantillonnage de façon égale parmi 325 grilles d'échantillonnage. Le taux d'exploitation pour la pêche de 2012 dans le sgSL était de 34,8%. Selon le relevé effectué après la pêche de 2012, la biomasse de crabes adultes de taille commerciale a été estimée à 74 997 t (intervalle de confiance de 95%, 65 822 t à 85 086 t), une augmentation de 18,7% par rapport à 2011. Le niveau de la biomasse pour la pêche de 2013, provenant du relevé de 2012, se situe dans la zone saine du cadre de l'approche de précaution. La biomasse résiduelle (26 028 t) estimée à partir du relevé de 2012 a diminué de 22,9% par rapport à 2011. Soixante-cinq pourcent (65%) de la biomasse du relevé de 2012 exploitable pour la pêche de 2013 est composée de nouvelles recrues (48 969 t). Le recrutement à la biomasse commerciale estimé à partir du relevé de 2012 a augmenté de 66,7% par rapport à l'année précédente. Les prédictions disponibles du recrutement des mâles adultes de taille commerciale indiquent qu'ils devraient demeurer à des niveaux comparables à celui de 2012 jusqu'à la saison de pêche de 2016. Une analyse de risque sur les options de captures par rapport aux points de référence pour la saison de pêche de 2013 est fournie.

1.0. INTRODUCTION

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

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

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

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

Following the early closure of the Area 12 fishery in 1989 due to a rapid decline in catch rates and an increased incidence of soft-shelled crabs in the catches, new management measures were introduced in 1990. One of the strategies used was to determine the total allowable catch (TAC) or quota based on the biomass of adult male crab ≥ 95 mm CW as estimated from a trawl survey. Another management strategy was to maximize yield and reproductive potential by limiting the capture of soft-shelled males by setting a fishery closure based on the percentage of soft- or white crabs.

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

This report presents the assessment and commercial biomass estimates for the 2013 snow crab resource in the sGSL (Areas 12, 19, 12E and 12F). Biomass estimates and population characteristics by life stage are derived from a trawl survey conducted after the 2012 fishery covering the sGSL snow crab habitat. A risk analysis of catch options for the 2013 fishery relative to the commercial biomass and removal reference points is also presented.

2.0. SYNOPSIS OF SNOW CRAB BIOLOGY

In the sGSL, molting of snow crab occurs from December-April, prior to the fishery (Watson 1972; Conan et al. 1988; Sainte-Marie et al. 1995; Benhalima et al. 1998; Hébert et al. 2002). Crab normally molt every year until they reach the adult phase via a final or "terminal" molt (Conan and Comeau 1986). Males reach the terminal molt at sizes ranging from 40 to 150 mm CW, whereas females reach terminal molt at smaller sizes, ranging from 30 to 95 mm CW (Conan and Comeau 1986). The longevity of adult males (after reaching the terminal molt) is approximately 5 (Sainte-Marie et al. 1995) to 7.7 years (Fonseca et al. 2008).

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

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

After molting, crabs have a soft shell engorged with water. It takes about 8-10 months for the carapace of an adult soft-shelled male to harden (Hébert et al. 2002) and one year to attain maximal meat yield (Dufour et al. 1997). Adult soft-shelled males, not being able to mate during their postmolt period, are ready to participate in reproductive activities with nulliparous females in February of the following year and in May-June with multiparous females (Conan et al. 1988; Moriyasu et al. 1988). Adult soft-shelled males of legal size represent the annual recruitment to the fishery, as they will become commercially marketable in the following fishing season (Conan and Comeau 1986; Sainte-Marie et al. 1995; Comeau et al. 1998a; Hébert et al. 2002). The terminology described by Sainte-Marie et al. (1995) relating to morphometric maturity is used in this paper: the term "adolescent" was formerly called morphometrically immature and "adult" was formerly called morphometrically mature (Conan and Comeau 1986).

3.0. METHODS

3.1. TRAWL SURVEY BIOMASS ESTIMATION

There have been progressive changes in the procedures of the sGSL trawl survey since its inception in 1988 (Moriyasu et al. 2008). Area 12 has been sampled every year after the fishery (July to October), with the exception of 1996.

The trawl survey coverage extended to Area 19 starting in 1990. From 1990 to 1992, Area 19 was surveyed in the spring prior to the fishery. Since 1993, the trawl survey in Area 19 was conducted after the fishery (Moriyasu et al. 2008).

In 1997, the trawl survey coverage was expanded to cover the new management Areas 12E and 12F. Details of the changes in survey coverage are provided by Moriyasu et al. (2008).

From 1997 to 2005, a random sampling design was used to determine the location of trawl stations (Moriyasu et al. 1998). One to two stations were randomly chosen among nine sub-grids with the station in the center of a grid within each grid of 10 by 10 minutes latitude-longitude.

The trawl survey sampling design from 2006 to 2011 was in accordance with recommendations from the 2005 Assessment Framework Workshop on the sGSL snow crab (DFO 2006; Moriyasu et al. 2008). The goal of the sampling design in 2006 was to achieve spatial sampling homogeneity. Stations were sequentially assigned to each grid by simulations and by assigning the number of stations with a probability proportional to its surface area. Once the number of stations per grid was been set, we determined whether the number of stations per grid used in the 2005 sampling design was lower, equal or exceeded the target number. Where the number of stations was lower than the one of 2005, new random locations were assigned within the grid and a random selection of station was made. Where the number of stations was equal, it was left unchanged. In the case where the number of stations exceeded the 2005 number, stations were randomly removed (Hébert et al. 2007, Moriyasu et al. 2008).

For the 2011 assessment, the trawl survey was conducted using the same procedure defined in the Assessment Framework Workshop of 2005 (DFO 2006), while the survey data were processed according to the recommendations from the 2011 Snow Crab Assessment Methods Framework Science Review (DFO 2012a). The major changes were the expansion of the biomass estimation polygon (20 to 200 fathoms corresponding to the areal extent of bottom temperature of < 5°C which are favorable for snow crab) to cover the sGSL biological unit and the use of kriging with external drift (KED) applied to catches in weights. The change in methodology required a recalculation of the time series of biomass estimates, exploitation rates and the Precautionary Approach references points.

3.1.1. Trawl survey in 2012

In 2012, a revised sampling plan based on square grids with equal distances and a random sampling design to assign one sampling station per grid was used to slightly reduce the variance on the estimated biomass (DFO 2012a). The revised survey sampling design in 2012 is presented in Wade et al. 2013.

In 2012, the post-fishery trawl survey was conducted between July 10 and September 23 and covered Areas 12, 19, 12E and 12F (Fig. 2). The survey coverage includes the areas between the 36 meters (20 fathoms) and 365 meters (200 fathoms) isobaths. The description of the 2012 trawl survey is provided in Landry et al. 2013.

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

All stations were trawled during the interval between morning and evening twilight hours. A predetermined amount of warp was let out (three times the distance of the depth) before the winch drums were locked. The start time of a standard tow was determined when the trawl touched the bottom, based on the information reported by the Netmind® depth sensor (signal received at 7 second interval) and/or the Minilog® temperature-depth probe (data recorded every second), both attached to the trawl. The duration of each tow was 5 minutes at a target speed of two knots. The horizontal opening of the trawl was recorded every four seconds with

the Netmind® distance sensors. The swept distance of the trawl was estimated from the position (latitude/longitude) measured every second with a DGPS system. The swept area for each tow was calculated by multiplying the swept distance and the horizontal opening of the trawl over the duration of the tow.

When the net was damaged or there was no signal from the Netmind® system at the beginning of the tow, or the duration of the tow was less than four minutes, the tow was rejected and a replacement tow was conducted near the original start point or at the alternate sampling stations within the assigned grid (Fig. 2).

When the tow was considered good according to the trawl survey protocol but the data from the Netmind® sensors were deemed to be not usable to calculate the tow swept area (lack of data due to the loss of Netmind® signal during the tow), the swept area of the tow was estimated by using the mean swept area of the neighboring 10 stations.

3.1.2. Biological sampling

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

The following information was recorded for all snow crabs: from males, CW, chela height (CH) to the nearest 0.1 mm and carapace condition (Hébert et al. 1997), and from females, CW, width of the 5th abdominal segment to the nearest 0.1 mm, and carapace condition. In addition, the color (orange, dark orange, brown or black) and quantity (in percentage) of external eggs on ovigerous females, as well as the color (white, beige or orange) of the gonads of immature females were noted.

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

3.1.3. Estimation of snow crab abundance

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

The survey polygon of 57,840 km2 covers isobaths between 20 and 200 fathoms (Fig. 3). The kriging polygon areas in management zones were defined by the same depth criteria (20-200 fathoms) and are as follow: 48,028 km2 for Area 12, 3,833 km2 for Area 19, 2,443 km2 for Area 12E and 2,438 km2 for Area 12F (Fig. 3). An additional unassigned zone A (above Areas 12E and 12F, Fig. 3) is included in the expanded polygon and located where no fishing activities were observed. This zone has an area of 674 km2, while the two buffer zones B and C (Fig. 3) cover an area of 112 and 310 km2, respectively.

The current model (kriging with external drift (KED) using depth as a secondary variable) used for the snow crab assessment is considered to be theoretically correct and suitable for biomass estimates (DFO, 2012a, Wade et al. 2013).

An average over three years of a global variogram was calculated as this has been considered better suited for modeling the autocorrelation between the samples (Wade et al. 2012, Wade et al. 2013).

The 1997 to 2010 time series of estimated biomass for the Gulf expanded polygon of 57,840 km2 was considered as a standardized time series for the purpose of stock assessment, development of reference points and provision for catch advice.

For biomass estimation, KED using catches in weight was performed (Wade et al, 2012, Wade et al. 2013). To this end, the weight of each sampled commercial-sized adult crab is estimated using a size-weight relationship.

The sGSL biomass estimates include the unassigned zone A and the buffer zones B and C (no fishing zones) (Fig. 3). The commercial biomass estimates in each management zones 12, 19, 12E and 12F were, however, calculated excluding the buffer zones.

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

The data were analysed using an integrated MATLAB toolbox (MPOGEOS), developed by the Ecole Polytechnique de Montréal, which incorporates all the functions required to perform a geostatistical analysis. A menu driven application permits the user to perform the data transformations, variogram analysis, ordinary kriging interpolation and mapping functions. The latest improvements to this toolbox occured in 2006 and included a provision to include KED using depth as a secondary variable, as well as the kriged size frequency histograms (Wade et al. 2012).

The weight of each sampled commercial-sized adult male was estimated using a size-weight relationship for adult hard-shelled males (Hébert et al. 1992) and the CW (mm) from sampling.

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

where W is the weight in grams and CW is the carapace width in mm.

The sGSL biomasses were estimated for the following categories of male crab:

(1) commercial-sized adult male ≥ 95 mm CW all carapace conditions,

(2) commercial-sized adult male crab ≥ 95 mm CW with carapace conditions 1 and 2 at the time of the survey which represent the annual recruitment to the fishery (also termed R-1), and

(3) adult male crab ≥ 95 mm CW with carapace conditions 3, 4 and 5 (hard-shelled) at the time of the survey which represent the residual biomass post- fishery.

The abundance indices of prerecruits at the time of the survey (R-4, R-3 and R-2) were used to forecast the recruitment to the fishery over the next four years. Stages R-4, R-3 and R-2 represent adolescent males with a CW ranges of 56-68 mm, 69-83 mm and larger than 83 mm, respectively and they are expected to recruit (CW ≥ 95 mm) to the fishery in 4, 3 and 2 years, respectively. The abundance of adolescent males of instar VIII with a CW between 34 and 44 mm was also estimated as an index of longer term recruitment. It takes at least six years for an adolescent male of instar VIII to reach the commercial size of 95 mm CW. In addition, the abundance indices of pubescent, primiparous and multiparous females were estimated.

3.2. ESTIMATION OF THE ANNUAL MORTALITY (Z) AND EXPLOITATION RATES

The estimation of the annual mortality rate (Z) of commercial-sized adult male crab was estimated from the biomass estimates derived from the post-fishery trawl survey.

$$Z = - Ln(N_t^{3,4,5} / N_{t-1}^{1,2,3,4,5})$$

- $N_{t-1}^{1,2,3,4,5}$: the estimated abundance of commercial-sized adult crab with carapace conditions 1 to 5 after the fishery in year t-1,

- $N_t^{3,4,5}$: the estimated abundance of commercial-sized adult crab with carapace conditions 3, 4 and 5 after the fishery in year t.

The proportion of annual loss is calculated as

$(1 - \exp^{-Z})$ or simply $(N_{t-1} – N_t) / (N_{t-1})$.

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

$$ER_t = C_t^{3,4,5} / B_{t-1}^{1,2,3,4,5}$$

The exploitation rate does not consider any changes in unfished biomass due to natural mortality.

3.3. RISK ANALYSIS AND CATCH OPTIONS

The Bayesian model described by Surette and Wade (2006) was used to forecast the biomass of the recruitment to the fishery (R-1, commercial-sized adult male crab of carapace conditions 1 and 2) based on the estimated abundances of pre-recruits R-4, R-3 and R-2 for the sGSL from the trawl survey, three, two and one year into the future, respectively. The model incorporated uncertainties associated with observation errors, process errors, and diffuse priors on the distributions (Surette and Wade 2006; Wade et al. 2013).

The size increments from molting of pre-recruits R-4, R-3 and R-2 were set using a growth model for adolescent male snow crab (Hebert et al. 2002).

The Bayesian model to forecast the recruitment to the fishery is described in Wade et al. (2013).

4.0. RESULTS AND DISCUSSION

4.1. ESTIMATES OF BIOMASS AND EXPLOITATION IN 2012

4.1.1. Southern Gulf

4.1.1.1 Variogram

The variogram model averaged over 3 years for commercial-sized adult males in 2012 showed a nugget value at 1.977×10^6 of semi-variance, a sill situated at 1.045×10^6 of semi-variance and a range of 41.91 km (Fig. 4). The annual variogram model for 2012 showed a nugget value of 1.182×10^6, a sill at 1.806×10^6 of semi-variance and a range of 8.98 km (Fig. 5).

4.1.1.2 Biomass estimates

The 2012 sGSL trawl survey kriging estimate of the commercial biomass was 74,997 t (95% confidence interval (C.I.) range of 65,822 to 85,086 t), an increase of 18.7% relative to the 2011 estimate of 63,162 t (55,965 - 71,022 t) (Table 1). The recruitment to the fishery at the time of the 2012 survey was estimated at 48,969 t (38,667 – 61,173 t), an increase of 66.7% relative to the 2011 of 29,394 t (20,909 - 40,190 t) and represents 65.3% of the commercial biomass (Table 1). The 2012 residual biomass (adult commercial-sized males with carapace conditions 3, 4 and 5) was estimated at 26,028 t (21,950 - 30,641 t), a decrease of 22.9% compared to the 2011 estimate of 33,768 t (28,297 - 39,985 t) (Table 1).

The geographic concentrations of the commercial-sized adult crab abundance from the 2012 trawl survey were mainly observed in Bradelle bank, in the central and southern parts of the Magdalen channel and in Area 19 (Fig. 6).

The abundance of commercial-sized adult male crabs by carapace condition the sGSL estimated from the 2012 trawl survey shows that 65.6% is recruitment to the fishery (carapace conditions 1 and 2) and 34.4% is residual biomass (carapace conditions 3, 4 and 5), (Table 2).

The 2012 residual biomass is composed of 29.4% of commercial-sized adult male crabs with carapace condition 3, 4.2% of crabs with carapace condition 4 and 0.9% of crabs with carapace condition 5 (Table 2). This suggests that the composition of the commercial-sized adult male population observed in the 2012 trawl survey is young and there is no sign of an ageing population at this moment (5.1% of commercial-sized adult male crabs of carapace condition 4 and 5). Close monitoring of the catch composition from the at-sea observer sampling and survey data is necessary to monitor the ageing of the commercial-sized adult male population in the coming years.

A comparison between the Bayesian model predicted fishery recruitment in 2012 (40,700 t; C.I. 31,300 - 52,400 t) based on the abundance of prerecruits in 2011 and the estimated biomass of this recruitment from the 2012 survey (48,969 t; 38,667 - 61,173 t) indicated that the estimated recruitment in 2012 is within the 95% confidence interval of the predicted value (Table 3; Fig. 7). The relationship between the abundance of prerecruits R-2 at year t and the recruitment to the fishery at year t + 1 is shown in Figure 8. A number of factors can account for the variation in the recruitment rate of the prerecruits R-2 to the commercial-sized adult stage including unaccounted bycatch mortality, sampling uncertainties, natural mortality and variations in the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase) especially if density-dependent phenomena occur.

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

4.1.2.1. Area 12

The 2012 trawl survey estimate of commercial biomass for Area 12 was 64,238 t (56,254 - 73,031 t) (Table 4). The 2012 Area 12 biomass estimate corresponds to 86.9% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.2. Area 19

The 2012 post-fishery trawl survey estimate of the commercial biomass was 7,668 t (5,944 - 9,736 t) (Table 4). The 2012 Area 19 biomass estimate corresponds to 10.4% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.3. Areas 12E and 12F

In both areas 12E and 12F, crab concentrations occur at the limits of the distribution of sGSL snow crab and the biomass estimates were uncertain, with very large confidence intervals.

The Area 12E commercial biomass from the 2012 trawl survey was estimated at 577 t (68 - 2,214 t), (Table 4). The 2012 Area 12E biomass estimate corresponds to 0.8% of the sum of the independently estimated commercial biomasses in the four management zones.

In Area 12F, the commercial biomass from the 2012 survey was estimated at 1,450 t (480 - 3,409 t), (Table 4). The 2012 Area 12F biomass estimate corresponds to 1.9% of the sum of the independently estimated commercial biomasses in the four management zones.

4.1.2.4. Buffer zones and unassigned zone

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

The commercial biomass in the unassigned zone A above Areas 12E and 12F (Fig. 3) was 22 t (0 - 164 t) (Table 4). The commercial biomass in the buffer zone B (2 nautical miles buffer zone) adjacent to Area 19 and 12F (Fig. 3) was estimated at 109 t (34 - 268 t) (Table 4). The commercial biomass in the buffer zone C (5-miles buffer zone) located south of Area 19 (Fig. 3) was 913 t (635 - 1,274 t) (Table 4).

The sum of the commercial biomass estimates in the management zones and in the buffer and unassigned zones in 2012 was 74,977 t, very closed to the sGSL biomass estimate, 74,997 t (Table 4).

4.1.3. Exploitation rate

The exploitation rate in 2012 was 34.8% (Table 5; Fig. 9). The exploitation rates varied between 20.8% and 45% from 1998 to 2011 (Table 5; Fig. 9).

4.1.4. Annual mortality (Z) and difference in commercial-sized adult males

The annual mortality rate (Z), expressed as a proportion of commercial-sized adult male snow crab in the sGSL was estimated at 58.9 in 2012 and varied between 45.8% and 82.5% since 1997 except for 2011 where it was estimated at 5.6% (Fig. 9).

Over the time series, the estimated commercial biomass from the survey was 29% higher than the sum of the residual biomass and the landings of the following year (Fig. 10). This difference (termed non-fishing directed mortality) could be attributed to a number of factors including misattribution of recruitment and residual groups, variability in survey estimates, natural mortality, non-directed fishery induced mortalities, as well as crab movement in and out of the sampling area. The commercial biomass estimate from the trawl survey of 2011 was 24.0% higher than the sum of the residual biomass from the trawl survey in 2012 plus the landings in 2012 (Fig. 10). However, the commercial biomass estimate from the trawl survey of 2010 was 24.3% lower than the sum of the residual biomass from the trawl survey plus the landings in 2011 (Fig. 10).

The 2011 post-season trawl survey residual biomass was estimated at 33,768 t (28,297 - 39,985 t) representing 53.4% of the commercial biomass of 63,162 t. This estimate was abnormally high relative to the expected value from the 2010 survey and the 2011 fishery. Also, there is no drastic change in the catch composition of commercial-sized adult males from the at-sea observer data over the time series (see the 2012 fishery performance in Table 7 in Hébert et al. 2013). It was hypothesized that misclassification of carapace conditions 2 to 3 occurred due to a peak abundance of skip molters in the southeastern GSL in 2010 which should have molted in early 2011. These crabs pose some difficulties for carapace condition classification when the survey duration is spread out until October, as they harden the carapace and start to accumulate epibionts.

If the residual biomass estimated from the 2011 survey was correct, the abundance of older crabs (carapace conditions 4 and 5) estimated from the 2012 survey should show a notable increase. However, this was not the case based on the 2012 survey results (Table 2). The abundance of commercial-sized adult males with carapace condition 3 and 4 in 2011 was twice as large as that in 2010, whereas there was no corresponding increase in successive carapace condition 4 and 5 crabs in the 2012 survey results. In addition, based on the at-sea observer sampling during the 2012 fishing season, the majority of the catch composition of commercial-sized adult males was from crabs of carapace condition 3 in all zones (average of 88.2%) where the catch composition of carapace conditions 4 and 5 was only 9.4% (residual component after the 2011 fishery) and 2.4% for carapace conditions 1 and 2.

Therefore, it seems that the residual biomass from the 2011 trawl survey was overestimated and the recruitment to the fishery underestimated, as a result of a misclassification of some crabs with carapace condition 2 as carapace condition 3.

As the classification of carapace condition becomes more and more difficult in the fall because of carapace hardening process and epibiont accumulation, it will be important to minimize the duration of the survey.

4.1.5. Reproductive potential

The abundance of adult males increased from 1997 to 1999, remained stable until 2004 and gradually decreased until 2009 (Fig. 11). Since 2009, the abundance of adult males increased to the levels comparable to those observed during the 1999-2004 period (Fig. 11). The abundance of mature females remained high in 2012 relative to the low values observed during 2005 to 2009 (Fig. 12). The annual mean size of mature females varied from 57.4 mm in 1999 to 61.7 mm CW in 2005 (Fig. 13). The mean size of mature females was 59.1 mm CW in 2012 (Fig. 13).

5.0. RISK ANALYSIS OF CATCH OPTIONS AND PROGNOSIS

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

The rescaled B_{USR} is set at 41,400 t of commercial-sized adult males of all carapace conditions, which is 80% of the biomass of maximum sustainable yield (B_{MSY}) with the proxy for B_{MSY} chosen as 50% of the maximum estimated commercial biomass for the 1997 to 2008 time period (Table 6; Fig. 14). The rescaled Blim value is 10,000 t (Table 6; Fig. 14). The B_{lim} was chosen as the lowest biomass of hard shelled commercial-sized adult males, which was observed in 2000 (residual biomass estimated from the trawl survey) (DFO 2010b). The rescaled F_{lim} has been set at 34.6% (Table 6; Fig. 14), which is the average annual traditional exploitation rate calculated as catch (weight) in year t+1 divided by the estimated biomass of commercial-sized adult male crab from the post-fishery trawl survey in year t for the 1997 to 2008 time period (DFO 2010b).

5.1. RISK ANALYSIS OF CATCH OPTIONS FOR 2013

The risk analysis of catch options for the sGSL considers the probabilities of being below B_{lim} and the probability of exceeding F_{lim} for catch options in the 2013 fishery. As well, the probabilities of the commercial-sized adult male biomass estimated from the post-fishery trawl survey being less than B_{USR} for catch options in the 2013 fishery were also provided. The decision rules to put in practice the PA remain to be defined.

The estimated commercial-sized adult male biomass available for the 2013 fishery is 74,997 t (65,822 to 85,086 t). The estimated commercial biomass (74,997 t) in the sGSL is in the healthy zone of the precautionary approach framework (Fig. 14). When the stock is in the healthy zone, the exploitation regime should not exceed the F_{lim} = 34.6%.

The predicted recruitment of commercial-sized adult male crab in the 2013 trawl survey, which will be soft-shelled crab during the 2013 fishery season, was estimated using the Bayesian model described by Surette and Wade (2006) and applied to the data for the entire sGSL (Table 4; Fig. 15). The predicted recruitment for the 2014 fishery is 40,380 t (95% C.I. range of 31,670 to 50,380 t).

The risk analysis of catch options relative to the management objectives are summarized in Table 6 and Figure 16. A catch option of 25,949 t would give 50% chance of exceeding the F_{lim}

(34.6%), 0% chance of falling below B_{lim} (10,000 t) and 0.002% chance of being below the B_{USR} (41,400 t), (Table 6).

5.2. PROGNOSIS

The trend in the recruitment of commercial-sized adult male crab to the fishery is anticipated to remain stable at the levels comparable to those observed in 2012 until the 2016 fishery. This prognostic is based on the Bayesian model from the abundance of adolescent males of sizes larger than 83 mm (R-2), between 69 and 82 mm (R-3) and between 56 and 68 mm CW (R-4) from recent surveys (Table 3, Fig. 15). Based on the Bayesian model, the recruitment to the fishery is expected to be 40,380 t (31,670-50,380 t) for the 2014 fishery, (Table 3; Fig. 15). Two waves of small adolescent males of sizes between 34 to 44 mm and between 45-55 mm were observed in the 2012 trawl survey (Fig. 17). The abundance of males with a CW between 34 and 44 mm, which will reach the commercial size in 6 years, has been increasing since 2002 (Fig. 18). The surface area occupied by the prerecruits ≥ 56 mm CW in 2012 was less spread out compared to 2011, and was mostly observed in Bradelle bank, Shediac Valley, the central part of the Magdalen channel and Chaleur Bay (Fig. 19).

The estimated abundances of immature and pubescent females in the population have been increasing since 2001 (Figs. 12 and 20). This increase in pubescent females observed in the 2012 trawl survey suggests that the abundance of mature females will continue to increase in the coming years. The abundance of mature females remained high in 2012 relative to the low values observed during 2005 to 2009 (Figs. 12 and 20).

6.0. UNCERTAINTIES

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

Over the years, different boats have been used to conduct the trawl survey. From 1988 to 1998, the "Emy-Serge", a 65-foot side-trawling (375 HP) wooden boat was used. From 1999 to 2002, the "Den C. Martin", a 65-foot stern-trawling (402 HP) steel boat, was used. Since 2003, the vessel used has been the ''Marco-Michel'', a 65 feet stern-trawling (660 HP) fiberglass boat. Also, the number of sampling stations and survey study area has increased since 1988. The standardization for the tow length, trawl opening width and area polygon for the time series 1988 to 2006 is described in Moriyasu et al. (2008). Preliminary estimates based on a statistical model that includes the post-fishery snow crab survey and the September multispecies survey suggest that the vessels had different catchabilities, which can alter our perception of stock dynamics (Benoît and Cadigan 2013). Work is ongoing to refine the estimates of relative catchabilty of the vessels.

A Snow Crab Assessment Methods Framework Science Review was conducted in November 2011 to address concerns about the variations in survey design and sample coverage, the standardization of area swept, and the area of the estimation polygon to be used. Following the review, it was agreed that the biomass time series from 1997 to the present was a coherent time series to be used in assessing stock status and providing catch advice (DFO 2012a). Further work was required to determine if the earlier part of the time series between 1989 and 1996 for which survey coverage was much less than the coverage from 1997 to the present, could also be used to assess snow crab abundance in the southern Gulf.

6.2. GROWTH

Recruitment to the fishery for snow crab is highly variable from year to year (Comeau and Conan 1992; Sainte-Marie et al. 1995; Comeau et al. 1998a; Moriyasu et al. 1998) depending on environmental conditions. In sGSL snow crab stocks, the biomass of commercial-sized adult male crab appears to fluctuate and to be characterized by periods of 3 to 4 years of high recruitment to the population followed by 3 to 4 years of low recruitment (Sainte-Marie et al. 1995; Comeau et al. 1998a; Moriyasu et al. 1998). Since molting activities in adolescent males peak in January for skip molters and in March for normal molters, most of the postmolt males are potentially catchable as soon as the fishery starts (generally at the end of April). Soft-shelled males in the commercial catches were found from late April to August in the sGSL (Hébert et al. 2002).

The mechanism of molting to terminal phase is complex. Conan et al. (1988), and Comeau et al. (1998a) hypothesized that the molt to terminal phase for a given size group may be density-dependent rather than genetically determined. Waiwood and Elner (1982) hypothesized that the removal of large old crab would release the snow crab population from a "stagnant" to a "dynamic" high-growth phase. Comeau et al. (1998a) suggested that a high abundance of large mature (adult) males in the population may trigger molting to another larger juvenile (adolescent) instar stage instead of molting to the terminal phase. Alternatively growth could be inhibited resulting in an increased abundance of skip molters. The annual trawl survey since 1988 showed a very high (up to 50–60% in peak years) skip molting rate in adolescent males larger than 50 mm CW. Such a high percentage of skip molters may reflect a density-dependent effect on the molting schedule of larger adolescent males. This may be a driving factor affecting the strength and timing of recruitment to the fishery.

6.3. MOVEMENT

The spatial and temporal distribution of commercial-sized crabs was characterized by patchy concentrations of crab in the western and eastern portions of the sGSL which have expanded and contracted in area similarly throughout the last decade.

Tagging studies indicated a general and consistent exchange over the years between local fishing grounds and within management areas in the sGSL (Biron et al. 2008). The limitations in the interpretation of the tagging study results includes: 1) the traveled distance is between the release and recapture positions, 2) the recaptures are limited to fishing locations in any given year and 3) the tag return rates and mortality rates of tagged crab are unknown.

Tag-recapture results showed that crabs tagged in the peripheral areas during the period of decreasing biomass (southern part of Magdalen Channel in 1999 and in Area 12E in 1997), generally moved towards the main habitat, the center of Bradelle Bank (Biron et al. 2008). In Area 19, tag-recapture experiments were conducted during two different phases of stock condition: a decreasing biomass phase in 1993-1996 and an increasing biomass phase in 1997-2001. During the decreasing biomass phase, crabs tended to stay within Area 19, whereas crabs tagged during the increasing biomass phase tended to move greater distances, even outside the Gulf towards eastern Cape Breton (Area 20-22) (M. Biron, pers. comm.).There was a frequent exchange of crab, especially for adult crabs, in the central part of Area 12 (Bradelle Bank and Magdalen Channel) and the southeastern part between Cape Breton Island and the Magdalen Islands (Biron et al. 2008).

There is information showing that a movement of commercial-sized adult male snow crab from eastern Cape Breton (Areas 20-22) to western Cape Breton and adjacent areas occurred in 2012, and seemed to be more active compared to previous years (B. Zisserson, per. Comm.). The amount of immigration of crabs into western Cape Breton and adjacent areas and the

degree of emigration of commercial-sized adult males out of the sGSL can't presently be estimated.

More studies are needed to better understand the movement of snow crab between the western and eastern regions of the sGSL.

6.4. HIGHGRADING

Activities such as highgrading at sea of commercial-sized crabs during the fishing season could result in mortality of discarded crab due to handling. A selective exploitation of good commercial quality crabs by practicing highgrading at sea could increase the overall fishing effort, and thus may increase the unaccounted fishing mortality.

Discarding of soft-shelled crabs at sea can also result in an increase in non-lethal injury to crabs, such as leg loss, with negative consequences for stock productivity. Sainte-Marie et al. (1999) showed that snow crab males missing more than one walking leg have lower reproductive success. Abello et al. (1994) showed that loss of a chela constitutes a handicap for male green crab, *Carcinus maenas*, in obtaining or defending a female while mating. Comeau et al. (1998b) also observed while diving in the fjord of Bonne Bay, Newfoundland, that most of the males in mating pairs were large adults with a hard shell and few missing legs.

6.5. ENVIRONMENTAL CONSIDERATIONS

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

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 stock may be more vulnerable to commercial fishing pressure under climate-driven changes resulting in increasing temperatures. Furthermore, 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).

In 2012, near-bottom temperatures over most of Area 12, 12E and 12F were above normal and temperatures in Area 19 were above normal only in the north-eastern half while in the southern part, they were around normal values. The north-eastern part of Area 12 warmed up in 2012 compared to 2011, the western part of Area 12 and Area 19 cooled down and temperatures in Areas 12E and 12F were similar to 2011. The warmer bottom waters of 2012 resulted in a below normal Southern Gulf snow crab habitat index (bottom area with temperatures from -1 to 3ºC). In 2012, the habitat index slightly increased from 2011 and was 3.7% below the 1980-2010 average. However, the mean temperature (1.4ºC) within the defined snow crab habitat area index (-1 to 3°C) in 2012 increased compared to 2011 by about 0.2ºC. The 2012 mean temperature was the highest of the 42 year data series with 1982 exhibiting the second warmest value. The 2012 value is significantly higher than the long term mean and is above the 1999-2002 and 2005-2007 warm periods. The mean temperature has also been above normal over the last four years.

7.0. ACKNOWLEDGMENTS

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TABLES

Table 1. Estimated biomass (t, mean and 95% confidence interval) of commercial-sized adult male snow crab, Chionoecetes opilio, in the southern Gulf of St. Lawrence (all zones) by kriging in weight, 1997 to 2012. Recruitment refers to snow crab with carapace conditions 1 and 2 whereas residual biomass refers to snow crab with carapace conditions 3 to 5.

Survey year	Southern Gulf of St. Lawrence biomass (t) estimates; mean (95% confidence intervals)		
	Commercial	Recruitment	Residual
1997	**65310** (54801-77239)	**37619** (26376-52064)	**27690** (21995-34407)
1998	**57595** (45630-71735)	**29818** (17580-47435)	**27775** (21022-36013)
1999	**57051** (47946-67376)	**25874** (15918-39818)	**31177** (25051-38346)
2000	**49823** (40473-60682)	**39845** (30543-51093)	**9977** (6649-14401)
2001	**59150** (47740-72460)	**42243** (31198-55942)	**16905** (12657-22125)
2002	**79559** (66688-94181)	**66481** (53434-81746)	**13075** (10451-16157)
2003	**84423** (71964-98410)	**57503** (44809-72679)	**26919** (21223-33674)
2004	**103429** (91029-117036)	**83702** (70955-98069)	**19726** (15836-24280)
2005	**82537** (73487-92387)	**58398** (48417-69824)	**24140** (18726-30632)
2006	**74285** (66192-83087)	**54371** (46124-63660)	**19914** (16161-24275)
2007	**66660** (60183-73638)	**39635** (33089-47092)	**27025** (23354-31106)
2008	**52564** (46658-59006)	**31555** (25181-39048)	**21010** (17960-24426)
2009	**30920** (27237-34959)	**20520** (16848-24754)	**10399** (8560-12516)
2010	**35795** (31681-40291)	**20351** (15360-26450)	**15444** (12859-18394)
2011	**63162** (55965-71022)	**29394** (20909-40190)	**33768** (28297-39985)
2012	**74997** (65822-85086)	**48969** (38667-61173)	**26028** (21950-30641)

Table 2. Abundance (10^6; mean and 95% confidence interval) of commercial-sized adult male crabs by carapace condition (CC 1+2, CC3, CC4 and CC5) in the southern Gulf of St. Lawrence, 1997 to 2012.

Survey year	Carapace condition 1+2			Carapace condition 3			Carapace condition 4			Carapace condition 5		
	Mean	Confidence interval		Mean	Confidence interval		Mean	Confidence interval		Abundance	Confidence interval	
1997	61.272	51.848	71.906	27.858	22.644	33.910	17.144	13.556	21.391	5.675	4.154	7.574
1998	51.738	41.550	63.665	23.956	18.874	29.986	15.711	12.041	20.150	8.891	6.220	12.327
1999	49.755	40.294	60.766	32.840	25.189	42.086	16.258	12.637	20.594	7.874	5.239	11.380
2000	67.530	51.847	86.473	10.242	5.622	17.199	7.384	4.455	11.538	2.527	1.147	4.860
2001	76.238	60.652	94.604	26.667	21.371	32.876	5.134	2.502	9.401	1.474	0.393	3.917
2002	112.785	95.089	132.807	21.605	17.356	26.578	4.318	2.646	6.664	0.893	0.411	1.701
2003	99.346	84.820	115.635	38.180	30.183	47.646	11.431	7.097	17.466	1.715	0.717	3.485
2004	138.152	120.945	157.106	28.964	23.320	35.559	9.867	7.684	12.479	1.072	0.671	1.629
2005	97.311	87.537	107.870	30.516	23.465	39.022	10.679	8.049	13.895	0.567	0.217	1.222
2006	84.216	75.183	94.027	29.830	24.513	35.955	5.725	3.991	7.961	1.030	0.552	1.762
2007	62.530	55.515	70.179	32.053	25.962	39.141	14.243	10.714	18.566	1.004	0.523	1.752
2008	51.110	44.873	57.967	23.028	18.600	28.191	11.440	8.614	14.900	3.081	1.951	4.635
2009	31.729	27.218	36.771	12.714	10.170	15.701	5.393	3.832	7.379	1.276	0.685	2.179
2010	32.854	28.548	37.624	20.628	16.819	25.040	4.223	3.236	5.417	1.567	0.925	2.490
2011	53.387	46.199	61.369	45.065	37.545	53.646	9.979	7.706	12.713	1.778	1.024	2.878
2012	86.900	72.956	102.723	38.900	32.850	45.736	5.570	4.238	7.676	1.150	0.601	2.002

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

Survey Year	Prerecruits (number)			Recruitment to the fishery (t)	Forecast recruitment (t)	Residual biomass (t)	Commercial biomass (t)	Survivorship rates (S)
	R – 4	R - 3	R - 2	R - 1	R-1		B	S
1997	114.2	92.7	57.9	37619 (26376-52064)		27690 (21995-34407)	65310 (54801-77239)	
1998	139.5	91.6	57.1	29818 (17580-47435)		27775 (21022-36013)	57595 (45630-71735)	
1999	199.7	150.9	115.0	25874 (15918-39818)		31177 (25051-38346)	57051 (47946-67376)	
2000	238.7	159.4	89.3	39845 (30543-51093)		9977 (6649-14401)	49823 (40473-60682)	
2001	313.2	229.2	135.7	42243 (31198-55942)		16905 (12657-22125)	59150 (47740-72460)	
2002	166.7	241.8	199.7	66481 (53434-81746)		13075 (10451-16157)	79559 (66688-94181)	
2003	137.8	207.1	181.4	57503 (44809-72679)		26919 (21223-33674)	84423 (71964-98410)	
2004	86.4	122.8	142.5	83702 (70955-98069)		19726 (15836-24280)	103429 (91029-117036)	
2005	63.3	79.4	117.1	58398 (48417-69824)	60500 (38800-86000)	24140 (18726-30632)	82537 (73487-92387)	
2006	55.0	49.8	65.3	54371 (46124-63660)	49700 (33200-73000)	19914 (16161-24275)	74285 (66192-83087)	
2007	57.2	47.9	56.0	39635 (33089-47092)	35200 (21300-55000)	27025 (23354-31106)	66660 (60183-73638)	
2008	80.4	54.3	45.8	31555 (25181-39048)	29000 (18500-42000)	21010 (17960-24426)	52564 (46658-59006)	
2009	89.4	69.5	43.6	20520 (16848-24754)	27700 (17800-38000)	10399 (8560-12516)	30920 (27237-34959)	
2010	140.4	109.1	71.8	20351 (15360-26450)	25900 (17100-37000)	15444 (12859-18394)	35795 (31681-40291)	0.6460
2011	91.5	98.7	87.6	29394 (20909-40190)	33700 (22900-47000)	33768 (28297-39985)	63162 (55965-71022)	0.6865
2012	96.0	86.8	80.4	48857 (38981-60471)	40700 (31300-52400)	26028 (21950-30641)	74997 (65822-85086)	0.6915
2013					40380 (31670-50380)			0.7304

Table 4. Estimated of snow crab commercial biomass (t, mean and 95% confidence interval) in 2012 using kriging with external drift for the southern Gulf overall, by management areas 12, 19, 12E and 12F, and in buffer zones.

Areas	Surface area (km^2)	Commercial biomass (t)	
		Mean	95% confidence interval
Southern Gulf	57,840	74,997	(65,822-85,086)
Area 12	48,028	64,238	(56,254-73,031)
Area 19	3,833	7,668	(5,944-9,736)
Area 12E	2,443	577	(68-2214)
Area 12F	2,438	1,450	(480-3,409)
Sum of management areas	56,742	73,933	
Unassigned zone above 12E	674	22	(0-164)
Buffer zone 19/12F	112	109	(34 – 268)
Buffer zone 12/ 19	310	913	(635-1,274)
Sum of total areas	57,838	74,977	

Table 5. Data (from the trawl survey data, 1997 to 2008, using kriging in weights) used in the development of reference points for the snow crab fishery of the southern Gulf and exploitation rates for the fisheries in 1998 to 2012.

Year of the fishery	Landings (t)	Southern Gulf of St. Lawrence		
		Estimated commercial biomass (t) from survey in year-1	Estimated residual biomass (t) from survey in year-1	Exploitation rate (%) (landings fishery year t / commercial biomass fishery year t-1)
1998	13575	65310 (54801-77239)	27690 (21995-34407)	20.8
1999	15110	57595 (45630-71735)	27775 (21022-36013)	26.2
2000	18712	57051 (47946-67376)	31177 (25051-38346)	32.8
2001	18262	49823 (40473-60682)	9977 (6649-14401)	36.7
2002	25691	59150 (47740-72460)	16905 (12657-22125)	43.4
2003	21163	79559 (66688-94181)	13075 (10451-16157)	26.6
2004	31675	84423 (71964-98410)	26919 (21223-33674)	37.5
2005	36118	103429 (91029-117036)	19726 (15836-24280)	34.9
2006	29121	82537 (73487-92387)	24140 (18726-30632)	35.3
2007	26867	74285 (66192-83087)	19914 (16161-24275)	36.2
2008	24458	66660 (60183-73638)	27025 (23354-31106)	36.7
2009	23642	52564 (46658-59006)	21010 (17960-24426)	45.0
2010	9549	30920 (27237-34959)	10399 (8560-12516)	30.9
2011	10708	35795 (31681-40291)	15444 (12859-18394)	29.9
2012	21956	63162 (55965-71022)	33768 (28297-39985)	34.8
2013	-	74997 (65822-85086)	26028 (21950-30641)	-

Table 6. Risk analysis for different catch options in 2013 for the southern Gulf of St. Lawrence snow crab (Chionoecetes opilio) fishery showing probabilities of exceeding the fishing removal rate limit reference point (F_{lim}), of the hard-shelled commercial-sized male biomass falling below the limit reference point for biomass (B_{lim}), and of the total commercial-sized adult male biomass being below the upper stock reference point (B_{USR}) post-fishery in 2013.

Catch option (t)	Probability		
	> F_{lim} (34.6%)	< B_{lim} (10,000 t)	< B_{usr} (41,400 t)
21,000	0	0	0
21,500	0	0	0
22,000	0.01	0	0
22,500	0.02	0	0
23,000	0.04	0	0
23,500	0.07	0	0
24,000	0.12	0	0
24,500	0.20	0	0
25,000	0.29	0	0
25,949	0.50	0	0
27,000	0.73	0	0
28,000	0.89	0	0
29,000	0.96	0	0
30,000	0.99	0	0
31,000	1	0	0
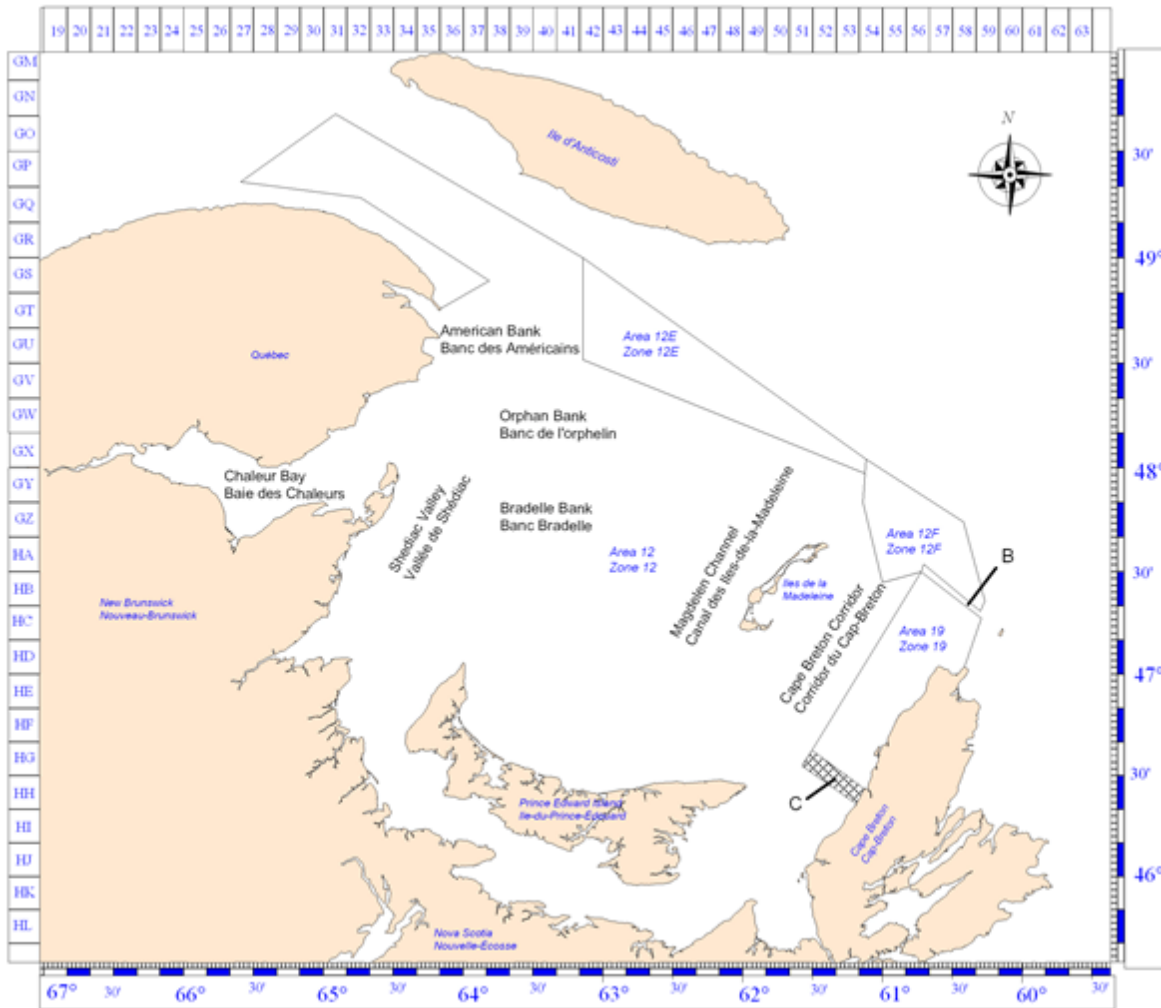
Figure 1. Map of the southern Gulf of St. Lawrence showing the snow crab (Chionoecetes opilio) fishing areas, fishing grounds, and management buffer zones (labels B and C, shaded areas).
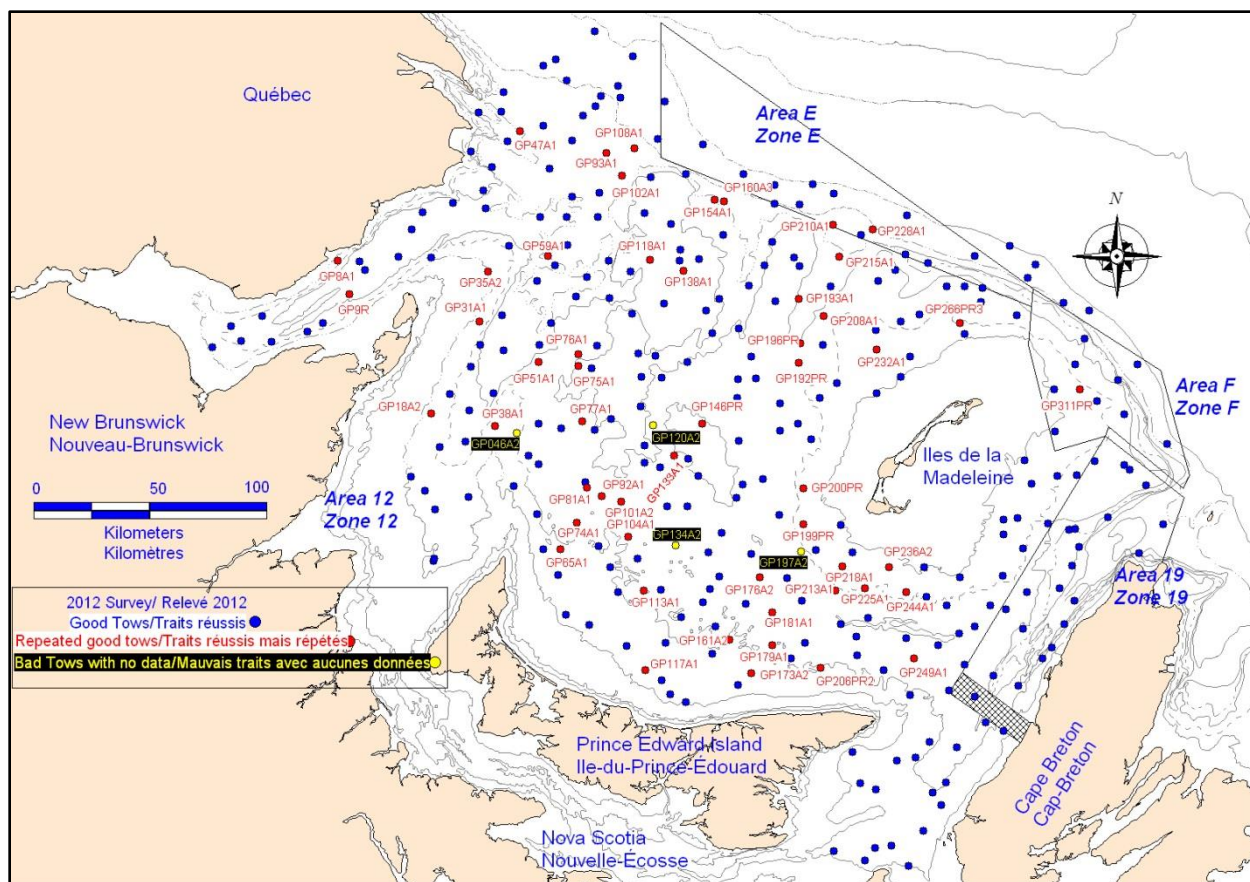
Figure 2. Locations of the 2012 snow crab (Chionoecetes opilio) trawl survey stations within the revised estimation polygon of 57,840 km² in the southern Gulf of St. Lawrence. The blue points are successful tows, red points are successful repeat tows and yellow points are abandoned tows.
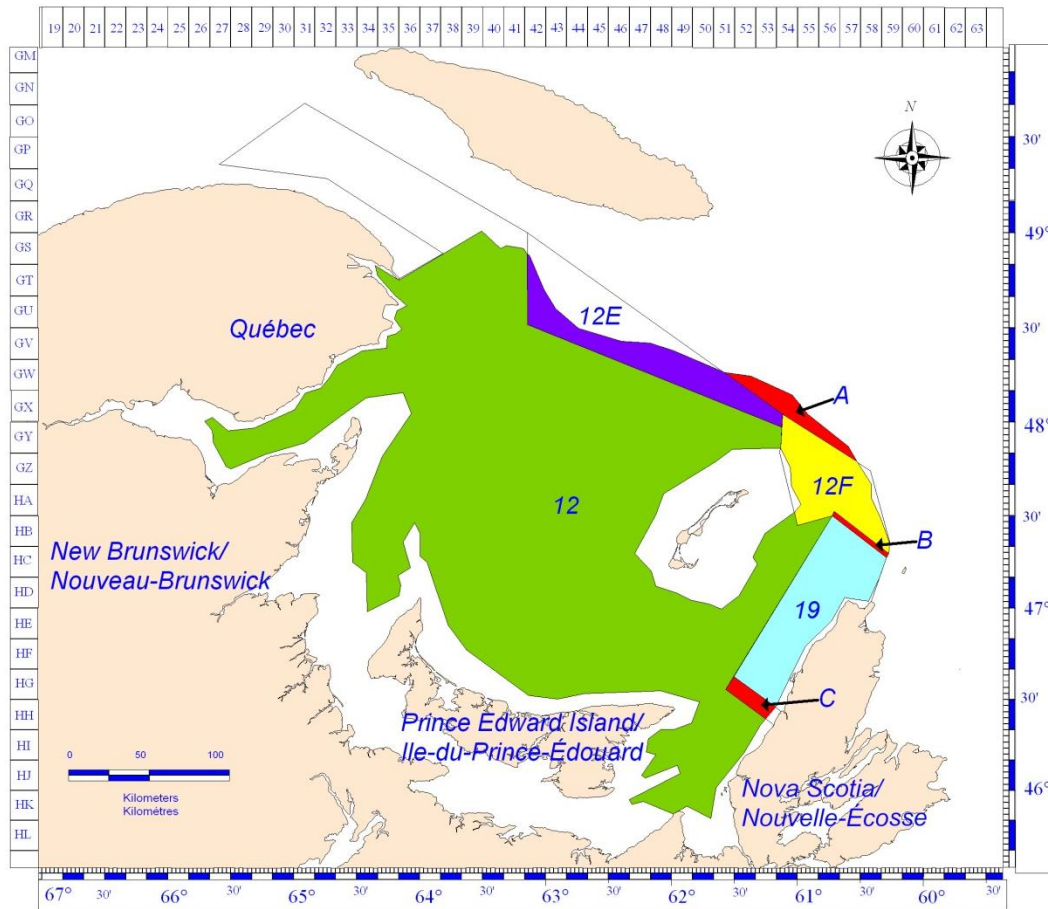
Figure 3. The estimation polygon of 57,840 km^2 used for the 2012 snow crab (Chionoecetes opilio) stock assessment in the southern Gulf of St. Lawrence (all coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F and 19). The unsigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.
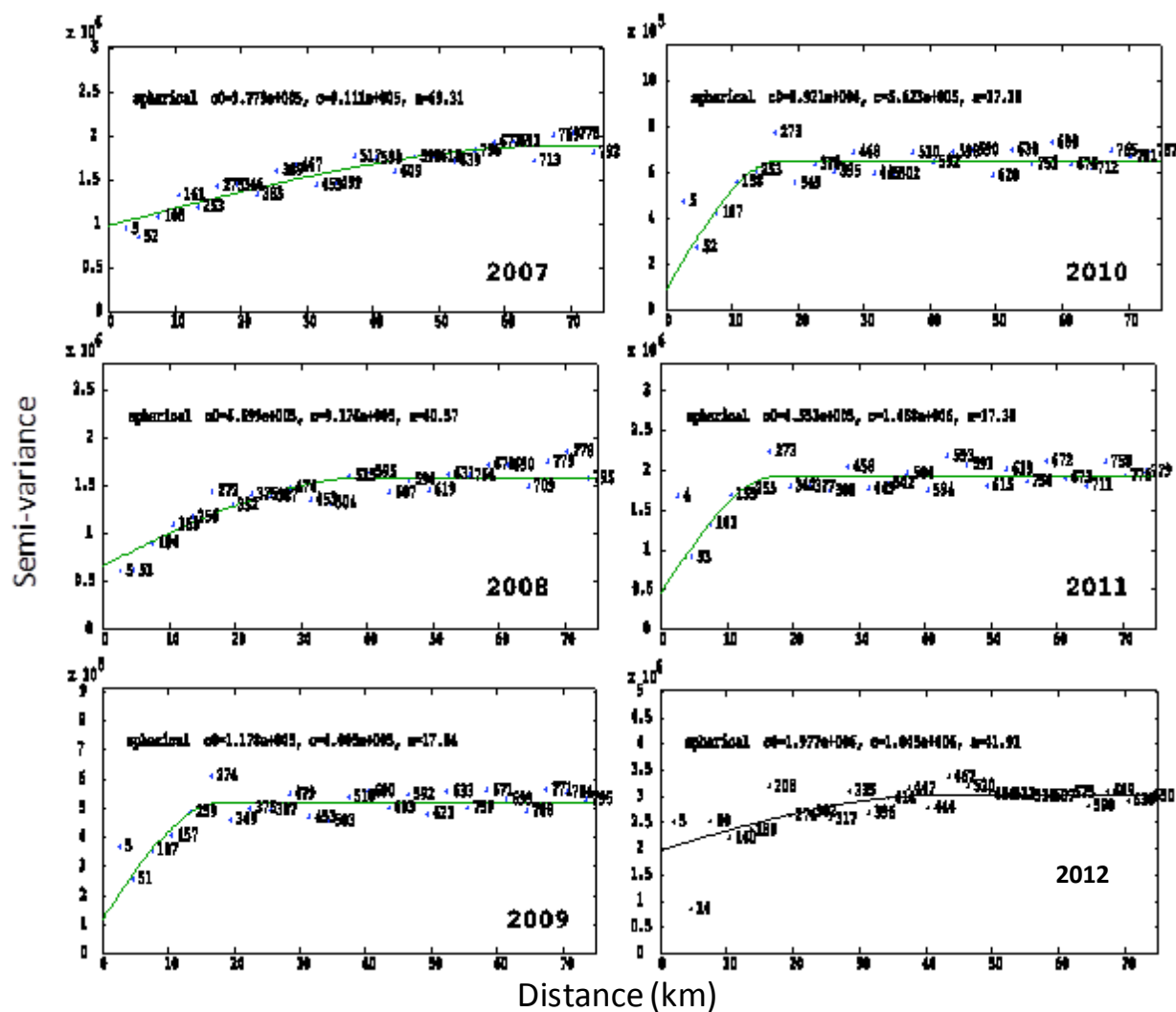
Figure 4. Variogram models with 3 years moving average for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2007 to 2012.
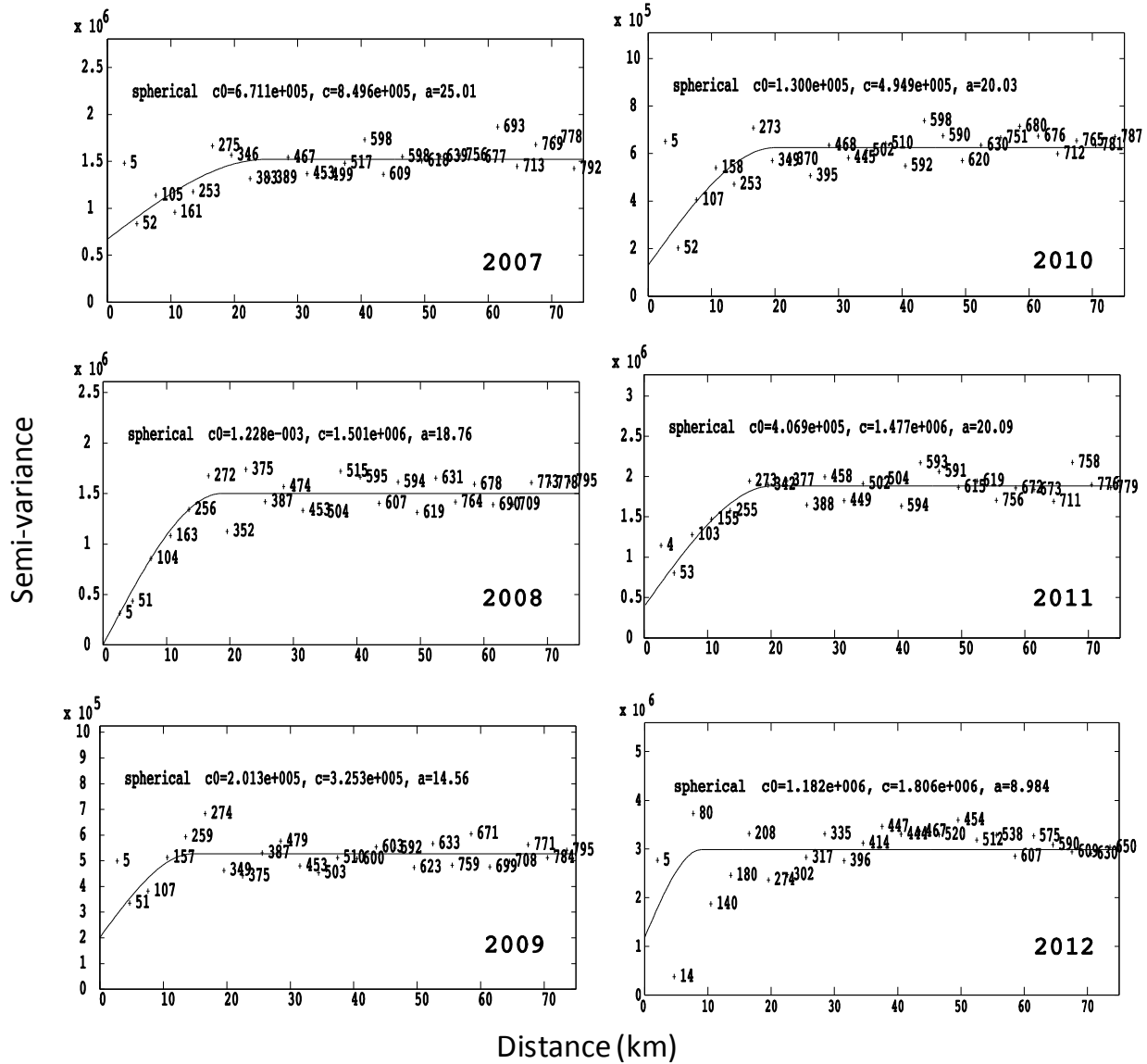
Figure 5. Annual variogram models for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2007 to 2012.
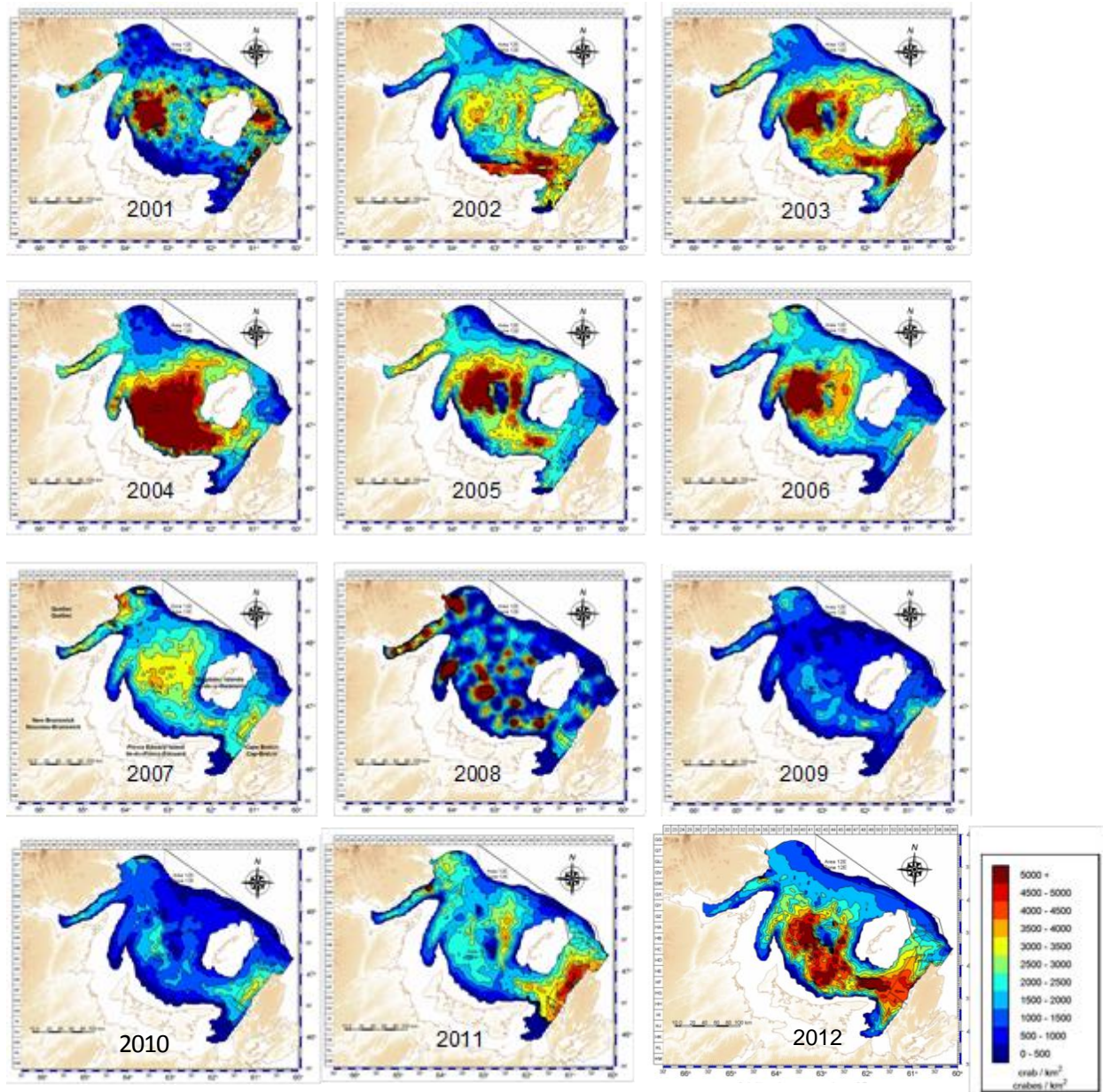
Figure 6. Density (number of crab per km²) contours of commercial-sized (≥ 95 mm of carapace width) adult male snow crab (Chionoecetes opilio) based on trawl survey data in the southern Gulf of St. Lawrence, 2001 to 2012.
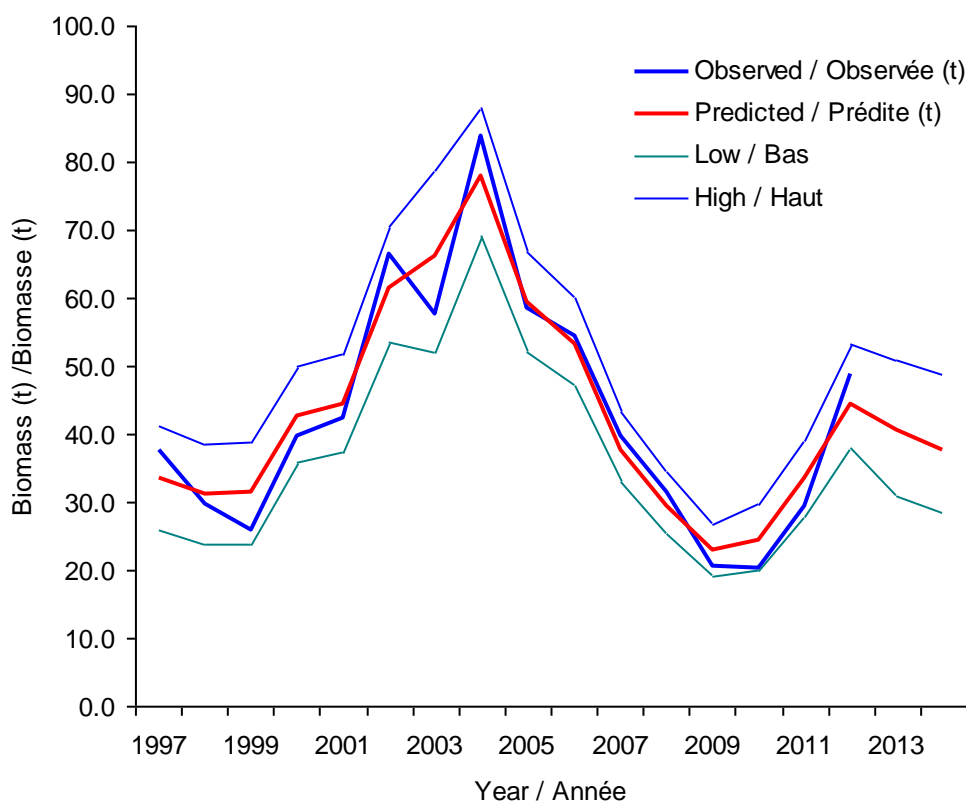
Figure 7. Comparison between the observed and predicted recruitment (R-1) of male snow crab (Chionoecetes opilio) based on the Bayesian model (Surette and Wade 2006; Wade et al. 2013). Low = Lower limit of the 95% confidence interval and High = Higher limit of the 95% confidence interval.
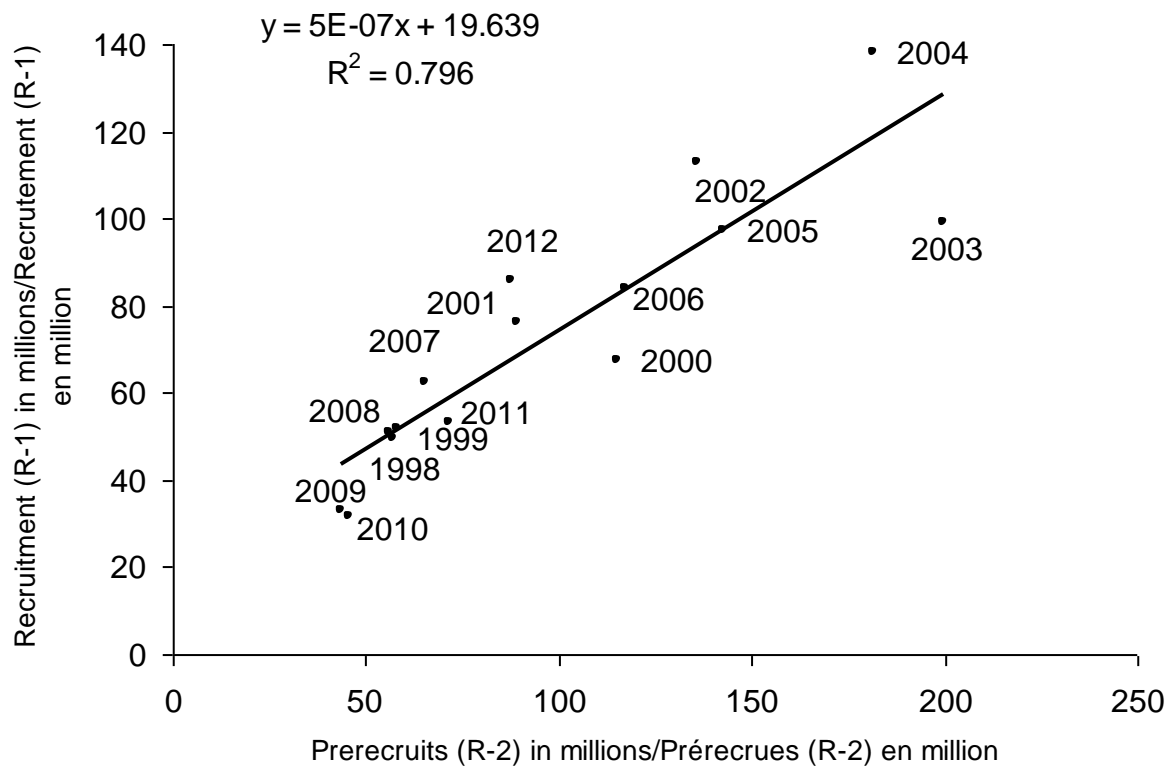
Figure 8. Relationship between the estimated abundance of prerecruits R-2 in year t and the estimated abundance of the recruitment to the fishery (R-1) in year t + 1 from the trawl survey data for the snow crab (Chionoecetes opilio) assessment in the southern Gulf of St. Lawrence.
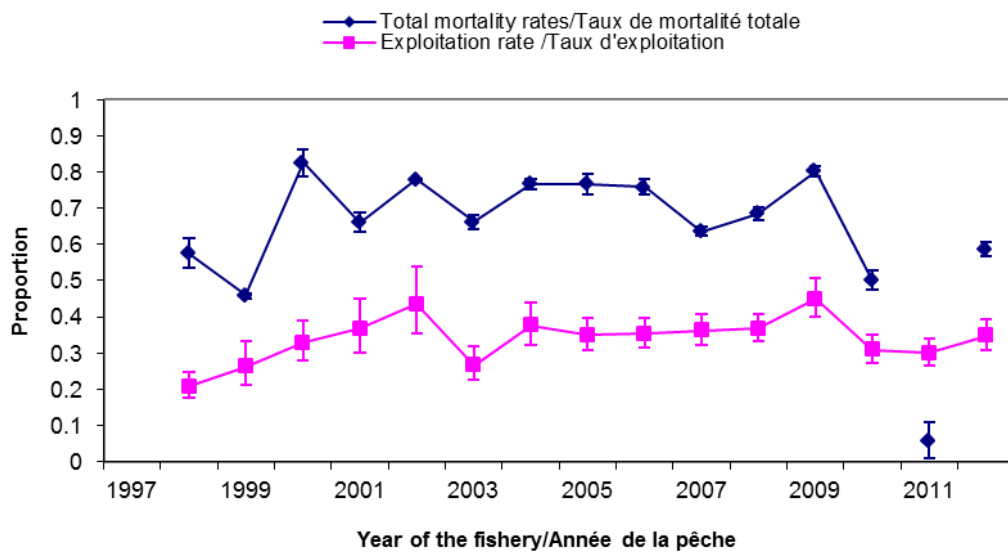
Figure 9. Estimated annual rates of exploitation and total loss of commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 1997 to 2012. The 2011 total mortality value is not reliable (Hébert et al. 2012).
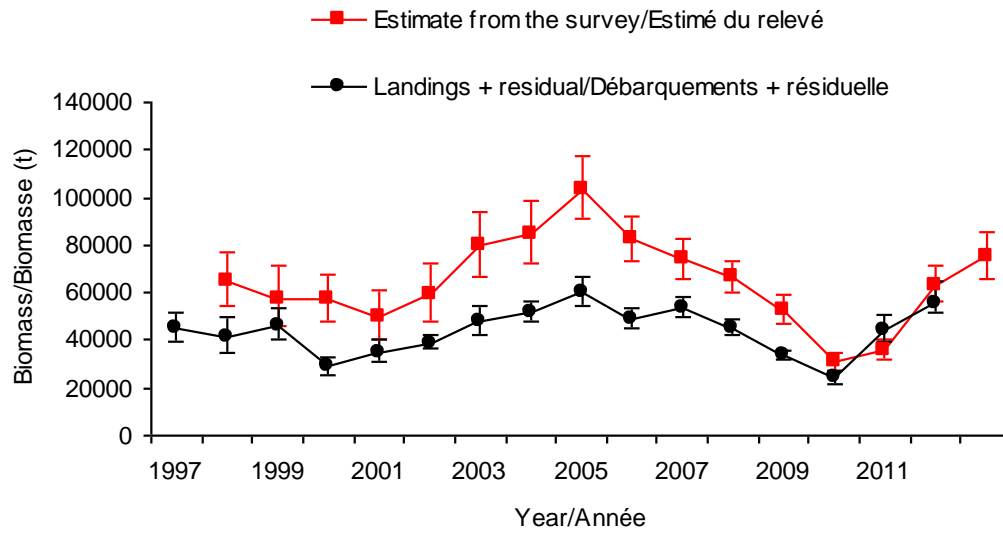
Figure 10. Comparison of the post-fishery calculated biomass (residual biomass plus the landings in year t+1) and the pre-fishery commercial-sized adult male snow crab (Chionoecetes opilio) biomass (recruitment plus residual biomass in year t) estimated from the trawl survey in the southern Gulf of St. Lawrence.
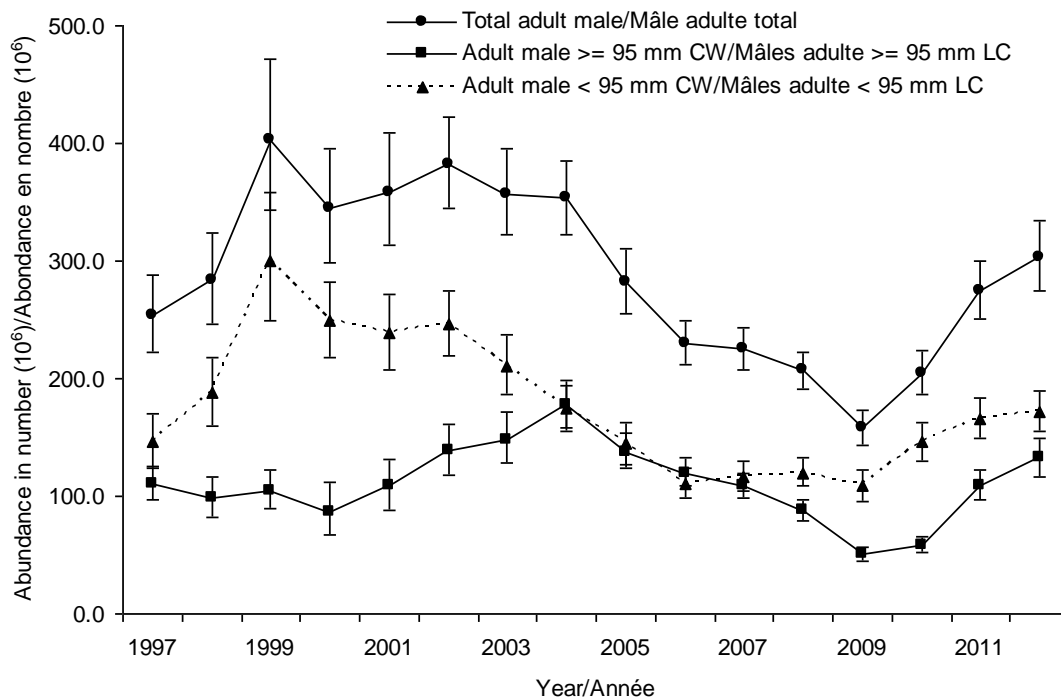
Figure 11. Estimated abundance of snow crab (Chionoecetes opilio) adult males in the southern Gulf of St. Lawrence, 1997 to 2012. CW = Carapace width.
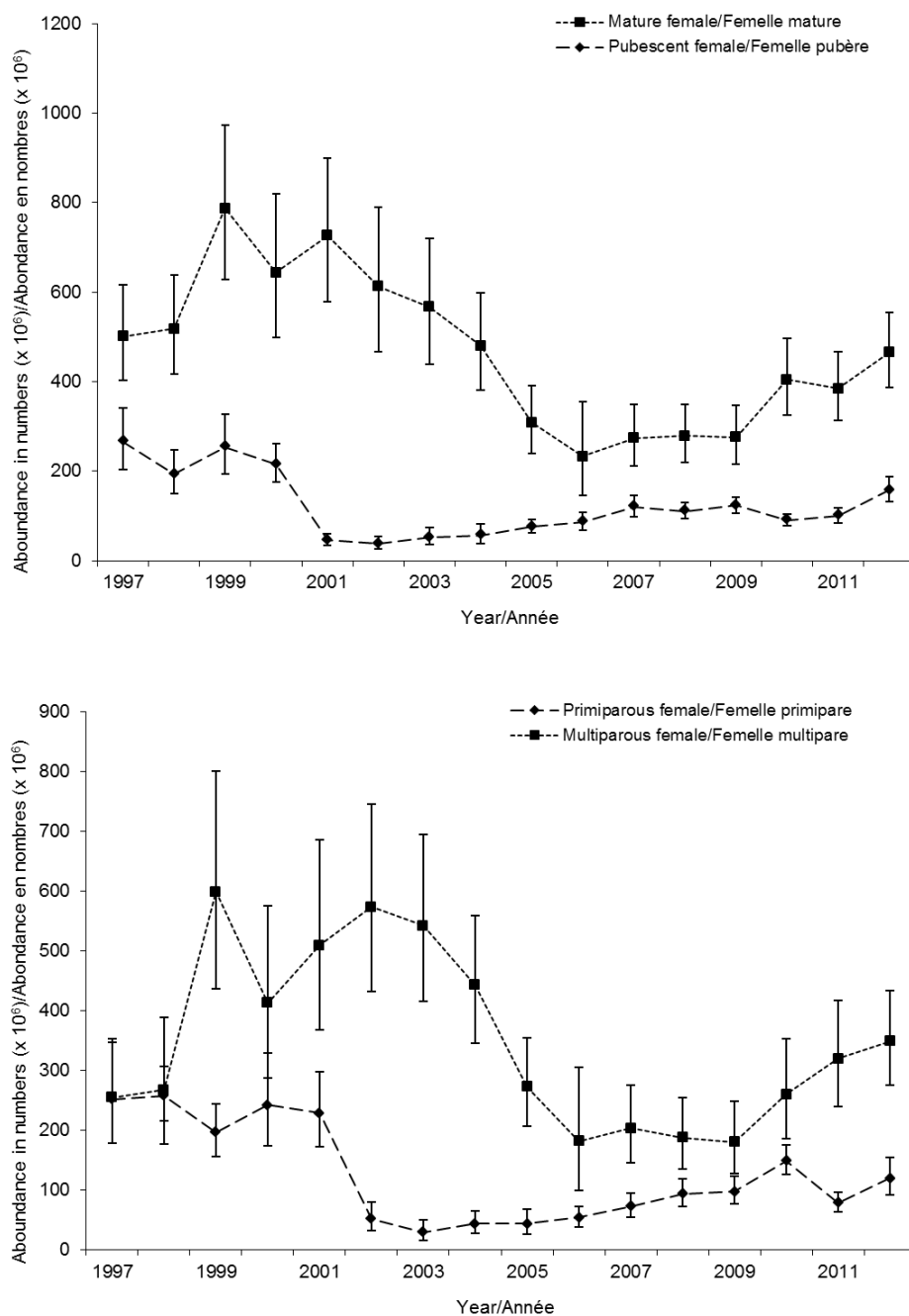
Figure 12. Abundance of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females in the southern Gulf of St. Lawrence, 1997 to 2012.
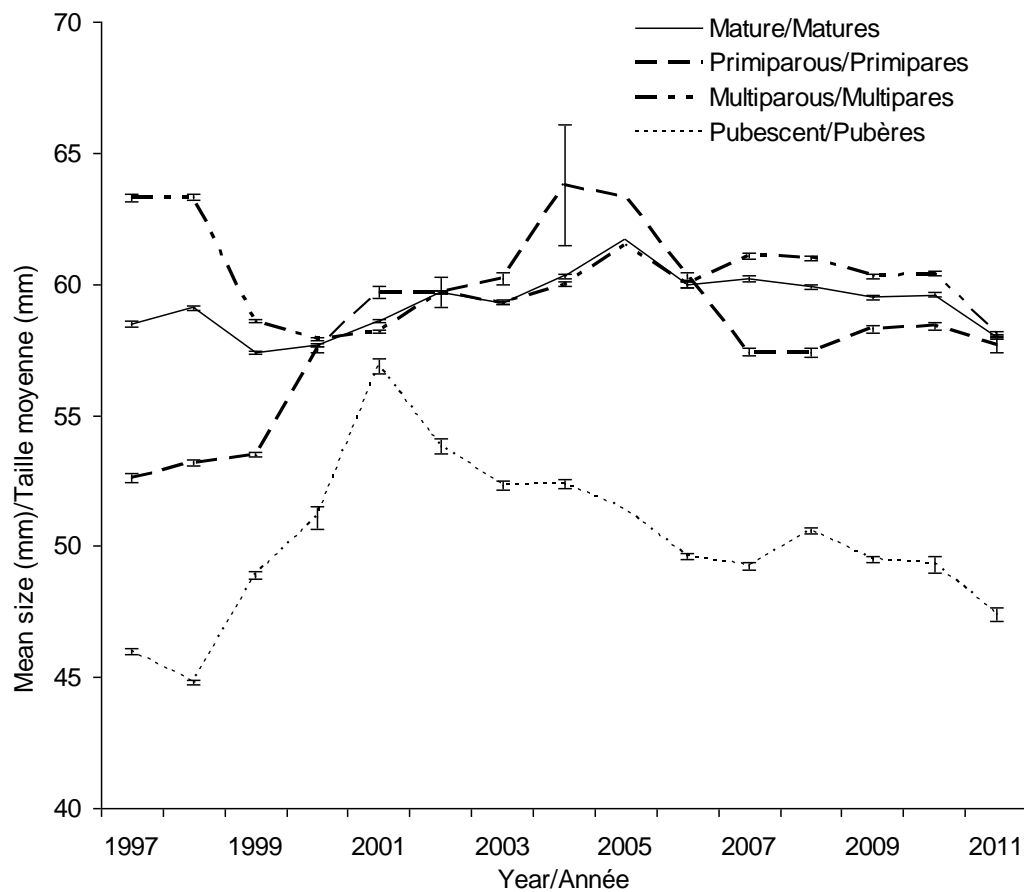
Figure 13. Mean size (carapace width in mm) with standard errors of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females based on samples from the trawl surveys, 1997 to 2012.
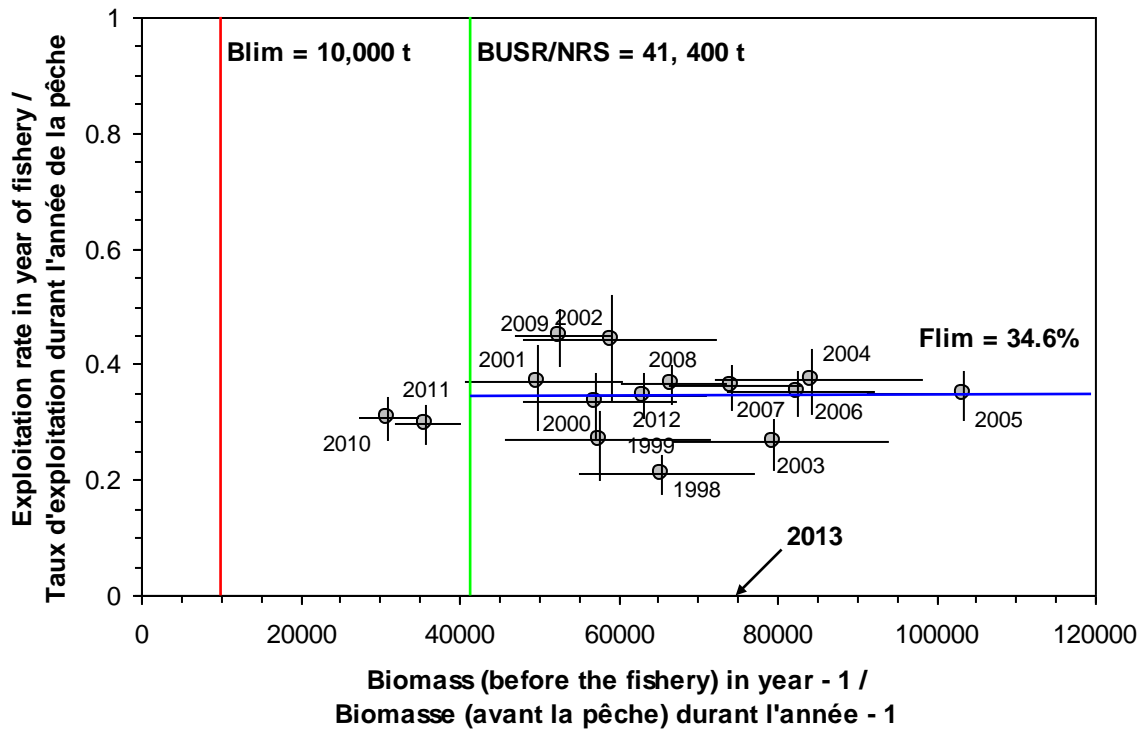
Figure 14. Trajectory of stock abundance (biomass of commercial-sized adult male snow crab (Chionoecetes opilio) as estimated from the trawl survey in year t – 1) versus exploitation rate of this biomass in the fishery of year t. Year of the fishery is labelled on the figure. B_{lim} = The limit reference point for biomass; F_{lim} = Fishing removal rate limit reference point; B_{USR} = The upper stock reference point.
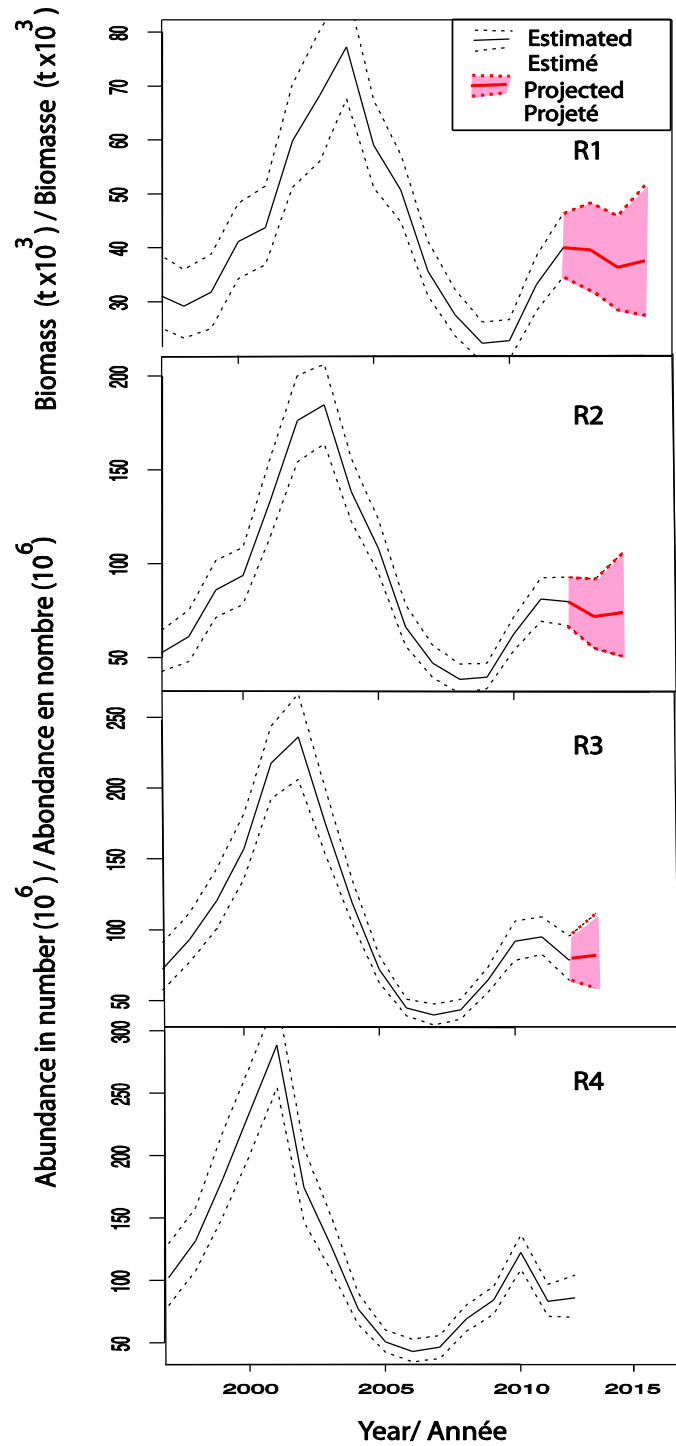
Figure 15. Snow crab (Chionoecetes opilio) recruitment (R) abundance (mean with 95% confidence intervals) for R (j), where j =1,…,4 years until recruitment to the fishery based on the survey data estimates. Shaded areas are forecasted abundance from the Bayesian model (Wade et al. 2013).
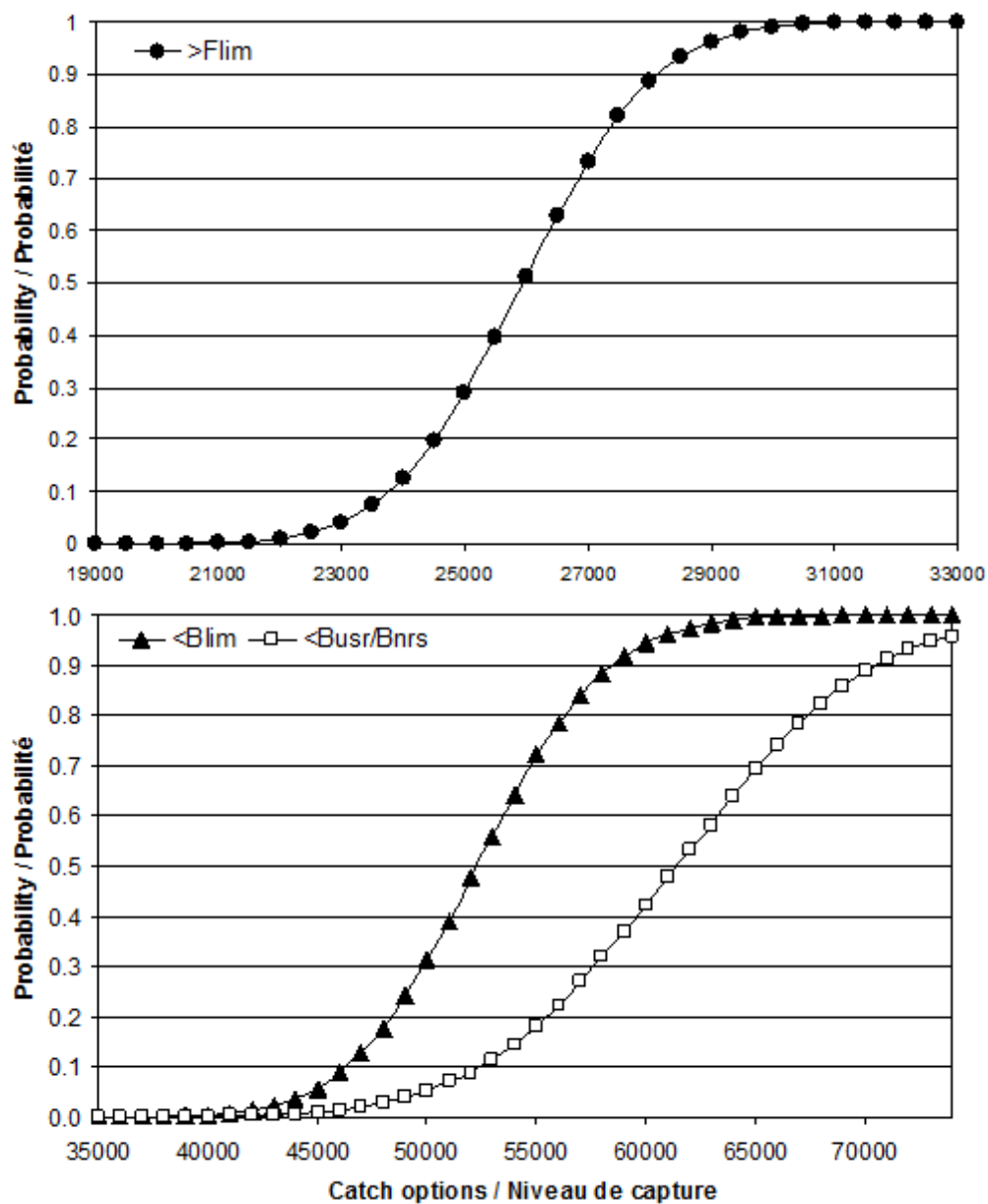
Figure 16. Risk analysis based on the expanded polygon for the southern Gulf of St. Lawrence snow crab, Chionoecetes opilio, fishery showing probabilities of exceeding the fishing removal rate limit reference point (F_{lim}), of the hard-shelled commercial-sized adult male remaining biomass in 2013 falling below the limit reference point for biomass (B_{lim}) and of the commercial-sized adult male biomass in 2013 will be below the upper reference point (B_{USR}) after the 2013 fishing season for different catch options in 2013.
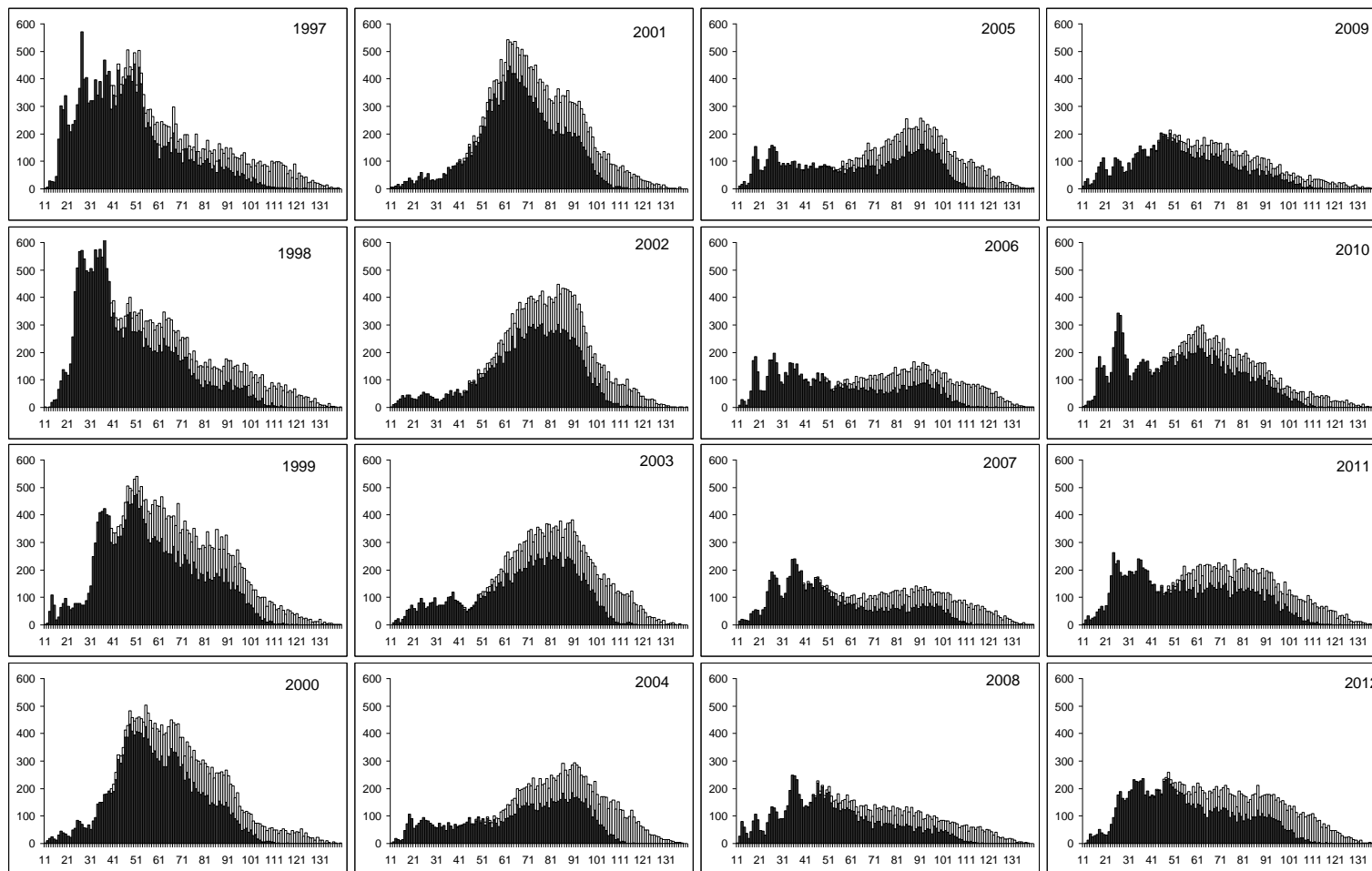
Figure 17. Size frequency distributions (by 1 mm interval) for male snow crabs (white bars are adult males and black bars are adolescent males) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1997 to 2012. These size frequency distributions represent the mean number of male snow crab (Chionoecetes opilio) per km^2 based on samples in the trawl survey and are not adjusted with geostatistic analysis (kriging) for total biomass.
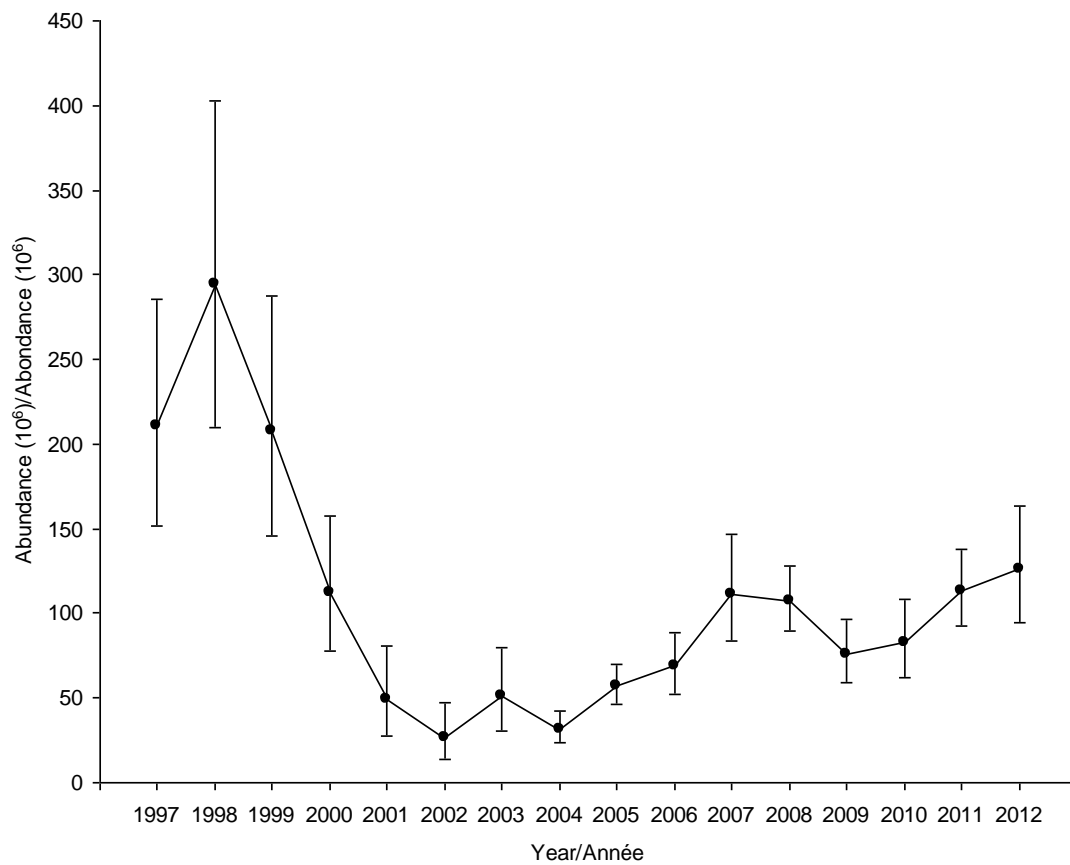
Figure 18. Abundance indices of small adolescent male snow crab, (Chionoecetes opilio) with carapace width between 34 to 44 mm estimated from the trawl survey data in the southern Gulf of St. Lawrence, 1997 to 2012. These crabs will reach the legal size in 6 years.
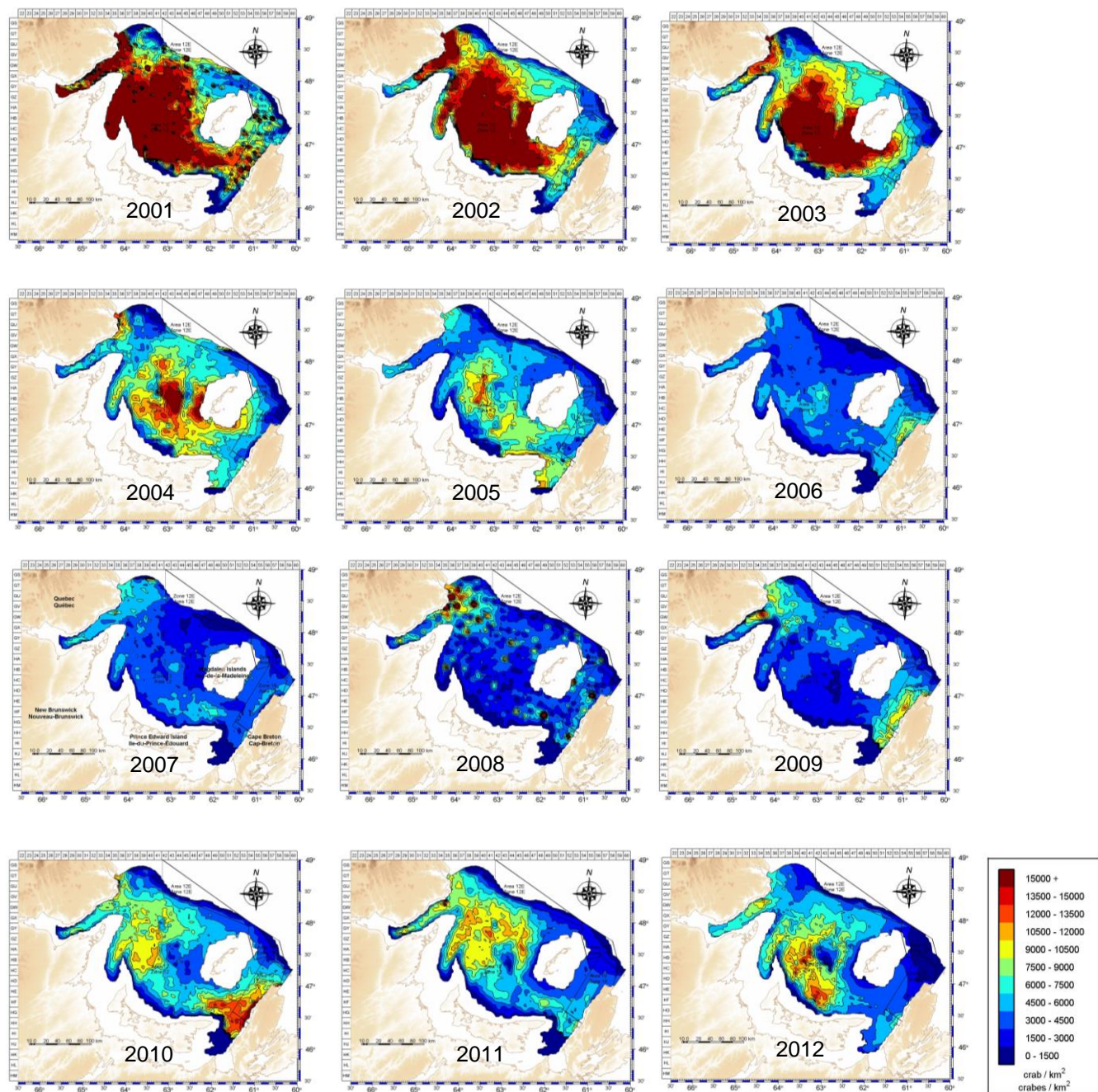
Figure 19. Density (number per km²) contours of adolescent male snow crab, (Chionoecetes opilio), ≥ 56 mm of carapace width based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 2001 to 2012.
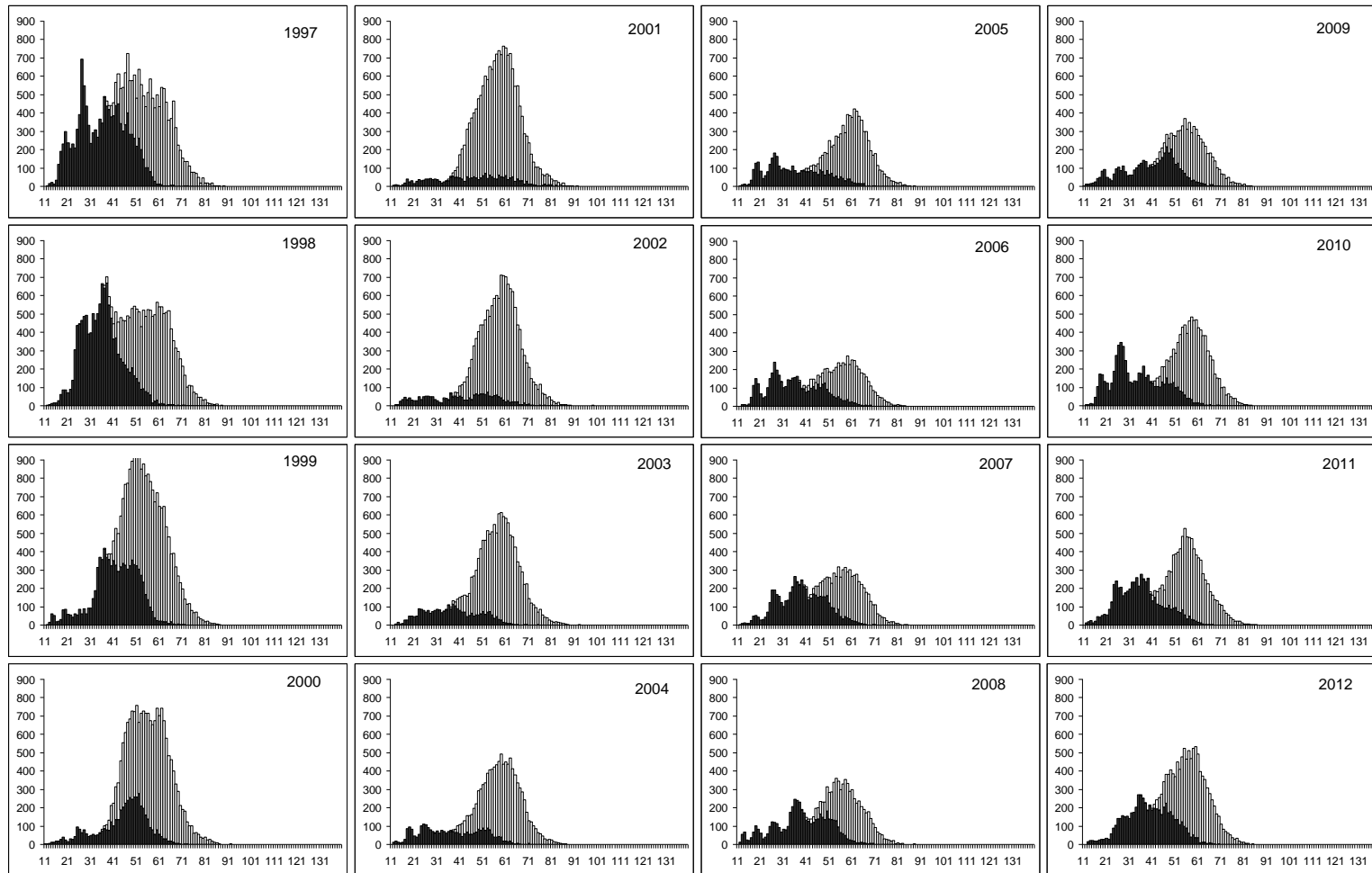
Figure 20. Size frequency distributions (carapace width by 1 mm interval) for female (white bars are mature females and black bars are pubescent and immature females) snow crab, (Chionoecetes opilio), based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1997 to 2012. These size frequency distributions represent the mean number of female crab per km^2 based on samples in the trawl survey and are not adjusted with geostatistic analysis (kriging) for total abundance.