Fisheries and Oceans Canada — Pêches et Océans Canada

Science — Sciences

**Canadian Science Advisory Secretariat (CSAS)**

**Research Document 2014/084**

**Gulf Region**

# The 2013 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, NB
E1C 9B6

December 2014

## 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.

**Published by:**

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON  K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca


ISSN 1919-5044

**Correct citation for this publication:**

Hébert, M., Wade, E., DeGrâce, P., Landry, J.-F., and Moriyasu, M. 2014. The 2013 assessment of the snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, 12E and 12F). DFO Can. Sci. Advis. Sec. Res. Doc. 2014/084. v + 45 p.

***Aussi disponible en français :***

*Hébert, M., Wade, E., DeGrâce, P., Landry, J.-F., et Moriyasu, M. 2014. Évaluation du stock de crabe des neiges (Chionoecetes opilio) dans le sud du golfe du Saint-Laurent (zones 12, 19, 12E et 12F) en 2013. Secr. can. de consult. sci. du MPO. Doc. de rech. 2014/084. v + 46 p.*

## TABLE OF CONTENTS

## ABSTRACT

The 2013 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 2013 assessment was conducted as per the recommendations of the Snow Crab Assessment Methods Framework Science Review held in November 2011. The major changes to the assessment methodology in 2013 from 2012 were the change of the trawl survey vessel and a revised sampling design that distributed sampling effort equally among 355 sampling grids. The exploitation rate of the 2013 fishery in the sGSL was 34.7%. The 2013 post-fishery survey biomass of commercial-sized adult male crabs was estimated at 65,868 t (95% confidence intervals 56,283 to 76,610 t), a decrease of 12.2% from 2012. The available biomass for the 2014 fishery, derived from the 2013 survey, is within the healthy zone of the PA Framework. The residual biomass (26,886 t) from the 2013 survey is comparable to 2012. Fifty-nine percent (59%) of the 2013 survey biomass, available for the 2014 fishery, is composed of new recruitment (38,981 t). The recruitment to the commercial biomass from the 2013 survey decreased by 20.4% relative to the previous year. The predicted recruitment of commercial-sized adult male crab for the 2015 fishery was estimated at 37,893 t (28,568 to 49,114 t). Risk analyses of catch options relative to reference points for the 2014 and 2015 fisheries are provided.

## RÉSUMÉ

Ce document présente l'évaluation de stock du crabe des neiges, *Chionoecetes opilio*, du sud du golfe du Saint-Laurent (sgSL) (zones 12, 19, 12E et 12F) pour l'année 2013. 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 2013 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 2013, les changements majeurs apportés à la méthode d'évaluation par rapport à 2012 comprennent le changement du bateau du relevé au chalut et un plan d'échantillonnage révisé dans lequel l'effort est réparti de façon égale parmi 355 grilles d'échantillonnage. Le taux d'exploitation pour la pêche de 2013 dans le sgSL était de 34,7%. Selon le relevé effectué après la pêche de 2013, la biomasse de crabes adultes de taille commerciale a été estimée à 65 868 t (intervalle de confiance de 95%, 56 283 t à 76 610 t), une diminution de 12,2% par rapport à 2012. Le niveau de la biomasse pour la pêche de 2014, provenant du relevé de 2013, se situe dans la zone saine du cadre de l'approche de précaution. La biomasse résiduelle (26 886 t) estimée à partir du relevé de 2013 est comparable à celle de 2012. Cinquante-neuf pourcent (59%) de la biomasse du relevé de 2013 exploitable pour la pêche de 2014 est composée de nouvelles recrues (38 981 t). Le recrutement à la biomasse commerciale estimé à partir du relevé de 2013 a diminué de 20,4% par rapport à l'année précédente. La prédiction du recrutement des mâles adultes de taille commerciale pour la saison de pêche de 2015 a été estimée à 37 893 t (28 568-49 114 t). Des analyses de risque sur les options de captures par rapport aux points de référence pour les saisons de pêche de 2014 et 2015 sont fournies.

# 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 mile 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 in area, number of participants, and landings. There is no biological basis for the delimitations of snow crab management areas in the sGSL (Chiasson and Hébert 1990; Hébert et al. 2008; DFO 2009). Crabs in these management areas are considered part of a single biological population and the sGSL is considered as a single unit for assessment purposes (Hébert et al. 2008).

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

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

New management measures were introduced in 1990 following the early closure of the Area 12 fishery in 1989 due to a rapid decline in catch rates and high incidence of soft-shelled crabs in catches. One of the measures was to set the total allowable catch (TAC) or quota as some proportion of the biomass of adult male crab ≥ 95 mm CW, as estimated from a trawl survey. Another management strategy, applied to maximize yield and reproductive potential by limiting the capture of soft-shelled males, was to close portions of the fishery 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 2014 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 2013 fishery covering the sGSL snow crab habitat. Risk analyses of catch options for the 2014 and 2015 fishery relative to the commercial biomass and removal reference points are also presented.

# 2.0. SYNOPSIS OF SNOW CRAB BIOLOGY

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

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

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

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

# 3.0. METHODS

## 3.1. TRAWL SURVEY BIOMASS ESTIMATION

There have been progressive changes in the sampling design and protocols of the sGSL trawl survey since its inception in 1988. Originally, the survey area was sub-divided using a lattice of 10 by 10 minute latitude-longitude grids. One or two sampling locations were then randomly selected and used as fixed stations in subsequent survey years. Initially, the survey area only covered Area 12 but was expanded to Area 19 in 1990. Area 12 was sampled before its fishery (July to October) for all years (except 1996 where there was no survey) and Area 19 was sampled before its fishery from 1990 to 1992 and then after its fishery from 1993 onward (Moriyasu et al. 2008).

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

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

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

### 3.1.1. Trawl survey in 2013

For 2013, the number of stations increased from 325 to 355 following recommendations from the snow crab advisory committee to increase the precision of the biomass estimates in smaller fishing zones. For this level of sampling intensity, the survey area was partitioned into square grids of 12.7 km x 12.7 km (Fig. 2) and a new set of sampling stations was generated. A different boat, the "*Jean-Mathieu*", a 65 foot stern-trawling (720 HP) steel boat, was used to conduct the trawl survey in 2013. No comparative study on catchability between the former survey vessel "Marco-Michel" and the "Jean-Mathieu" was performed. Also, a new acoustic trawl monitoring system "eSonar®", was used to monitor the placement and dimensions of the trawl net. The eSonar® system replaces the discontinued Netmind® system.

The trawl survey was conducted between July 9 and October 14 and covered Areas 12, 19, 12E and 12F (Fig. 2). A detailed description of the 2013 trawl survey is provided in Landry et al. (2014).

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

All stations were trawled during the interval between morning and evening civil twilight hours. A predetermined amount of warp was let out (three times the distance of the depth) before the winch drums were locked. The start time of a standard tow was based on the information reported by the eSonar® depth and height sensors, later revised using data from a Minilog®

temperature-depth probe attached to the trawl. The target duration of each tow was 5 minutes at a target speed of 2 knots. The horizontal opening of the trawl was recorded every four seconds with the eSonar® distance sensors. The swept distance of the trawl was estimated from the position (latitude/longitude) measured every second with a 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.

Tows were rejected if the net was damaged, the Sonar® system generated no usable data to determine the beginning of the tow, or the duration of the tow was less than four minutes. 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 followed the trawl survey protocols but the data signal quality from the eSonar® sensors were deemed to be inadequate to calculate the swept area, the swept area of the tow was set to the average of the values of the 10 nearest stations.

### 3.1.2. 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. Starting in 2013, all species or species group were weighted. 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: carapace width (CW), chela height (CH) for males and width of the 5th abdominal segment (AW) for females to the nearest 0.1 mm, carapace condition (Hébert et al. 1997), and individual weights of males larger than 95 mm CW. For females, the color (orange, dark orange, brown or black) and quantity (in percentages) of external eggs on ovigerous females, as well as the color (white, beige or orange) of the gonads of immature females were also noted.

The size frequency distributions for the population were derived from the samples weighted by the swept area ($km^2$) 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 kriging polygon (and the survey area) has a total area of 57,840 $km^2$ (Fig. 3) and is partitioned into the four management areas for our analyses: 48,028 $km^2$ for Area 12, 3,833 $km^2$ for Area 19, 2,443 $km^2$ for Area 12E and 2,438 $km^2$ 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 $km^2$, while the buffer zones B and C (Fig. 3) cover an area of 112 and 310 $km^2$, respectively.

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

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

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

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

The 1997 to 2009 time series of estimated biomasses for the Gulf, using the expanded polygon of 57,840 km$^2$, was considered as a standardized time series for the purpose of stock assessment, development of reference points and provision for catch advice.

The data were analyzed using an integrated MATLAB toolbox (MPOGEOS), developed at the Ecole Polytechnique de Montréal, which incorporates all the functions required to perform a complete geostatistical analysis (Wade et al. 2014).

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

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

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

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

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

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

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

Annual mortality rates (*Z*) of commercial-sized adult male crab were calculated from trawl survey abundance estimates:

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

where $N_{t-1}^{1,2,3,4,5}$ is abundance of commercial-sized adult crab with carapace conditions 1 to 5 after the fishery in year *t -1* and $N_t^{3,4,5}$ is the abundance of commercial-sized adult crab with carapace conditions 3, 4 and 5 after the fishery in year *t*. The corresponding proportion of annual loss is given by $1 - exp^{-Z}$.

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 ($B_{t-1}$) from the previous year *t – 1*.

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

This exploitation rate does not consider natural mortality before or during the fishery.

## 3.3. RISK ANALYSIS AND CATCH OPTIONS

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

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).

# 4.0. RESULTS AND DISCUSSION

## 4.1. ESTIMATES OF BIOMASS AND EXPLOITATION IN 2013

### 4.1.1. Southern Gulf

#### 4.1.1.1. Variogram

In the 2013 trawl survey, a station with a very high concentration of commercial-sized adult males (102 crabs) was observed in Area 12F near the border of Area 19. This data point was treated as an outlier and removed from the variogram fitting but was included for the kriging biomass estimates.

The three-year averaged variogram model for commercial-sized adult males in 2013 had a nugget value of $7.814 \times 10^5$, a sill at $3.298 \times 10^6$ and a range of 19.42 km (Fig. 4). The annual variogram model for 2013 had a nugget value of $1.767 \times 10^3$, a sill at $2.439 \times 10^6$ and a range of 16.04 km (Fig. 5).

#### 4.1.1.2. Biomass estimates

The 2013 kriged commercial biomass estimate was 65,868 t (95% confidence interval (C.I.) range of 56,283 to 76,610 t), a decrease of 12.2% from the 2012 estimate of 74,997 t (65,822 - 85,086 t) (Table 1). The recruitment to the fishery at the time of the 2013 survey was estimated at 38,981 t (28,969 – 51,346 t), a decrease of 20.4% from the 2012 estimate of 48,969 t (38,667 - 61,173 t) and represents 59.2% of the commercial biomass (Table 1). The 2013 residual biomass (adult commercial-sized males with carapace conditions 3, 4 and 5) was estimated at 26,886 t (22,909 - 31,352 t), an increase of 3.3% compared to the 2012 estimate of 26,028 t (21,950 – 30,641 t) (Table 1).

In 2013, local concentrations of commercial crab were mainly observed in Bradelle Bank, Orphan Bank and in the southeastern part of the sGSL, which includes the Cape Breton Corridor, Area 12F and Area 19 (Fig. 6).

By carapace condition in 2013, commercial crabs were comprised of 56.0% fishery recruitment (carapace conditions 1 and 2) and 44.0% residual biomass (carapace conditions 3, 4 and 5) (Table 2). Further split by caparace condition, the residual biomass is composed of 26.9% of commercial crab with carapace condition 3, 16.5% of crabs with carapace condition 4 and 0.6% of crabs with carapace condition 5 (Table 2). This suggests that the composition of the commercial male population observed in the 2013 trawl survey is young and there is no sign of an ageing population at this moment. Close monitoring of catch composition from the at-sea observer sampling and survey data is necessary to monitor the ageing of the commercial male population in the coming years.

A comparison between fishery recruitment predicted from the Bayesian model for 2014 (40,343 t; C.I. 31,218 - 51,464 t), which was based on the abundance of prerecruits from the 2012 trawl survey, and the recruitment biomass from the 2013 survey (38,981 t; 28,969 - 51,346 t) indicated that the estimated recruitment for the 2014 fishery is well within the 95% credibility interval of the predicted value (Table 3; Fig. 7). The relationship between the abundance of R-2 prerecruits in year *t* and the recruitment to the fishery in year *t + 1* is shown in Figure 8. A number of factors can account for the variability in this relationship, including variations in bycatch mortality, natural mortality, and the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase) or sampling error.

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

#### 4.1.2.1. Area 12

The 2013 trawl survey estimate of commercial biomass for Area 12 was 50,867 t (42,594 - 60,273 t) (Table 4). This estimate corresponds to 78.1% of the sum of the independently estimated commercial biomasses in the four management zones.

#### 4.1.2.2. Area 19

The 2013 post-fishery trawl survey estimate of the commercial biomass was 9,795 t (8,175 - 11,640 t) (Table 4). This estimate corresponds to 15.0% of the sum of the independently estimated commercial biomasses in the four management zones.

#### 4.1.2.3. Areas 12E and 12F

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

The Area 12E commercial biomass from the 2013 trawl survey was estimated at 409 t (19 - 2,083 t), (Table 4). This estimate corresponds to 0.6% 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 4,064 t (2,793 - 5,718 t), (Table 4). This estimate corresponds to 6.2% of the sum of the independently estimated commercial biomasses in the four management zones.

#### 4.1.2.4. Buffer zones and unassigned zone

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

The commercial biomass in the unassigned zone A above Areas 12E and 12F (Fig. 3) was 81 t (0 – 540 t) (Table 4). The commercial biomass in buffer zone B (2 nautical mile wide buffer zone) adjacent to Area 19 and 12F (Fig. 3) was estimated at 299 t (187 - 454 t) (Table 4). The commercial biomass in buffer zone C (5-miles buffer zone) located south of Area 19 (Fig. 3) was 483 t (190 - 1,018 t) (Table 4).

The sum of the commercial biomass estimates in the management, buffer, and unassigned zones in 2013 was 65,998 t, very close to the sGSL biomass estimate, 65,868 t (Table 4).

### 4.1.3. Exploitation rate

The exploitation rate in 2013 was 34.7% (Table 5; Fig. 9). The exploitation rates have varied between 20.8% and 45% from 1998 to 2012 (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 64.2% in 2013 and has 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 sum of commercial biomasses from the survey was 29.6% higher than the sum of the residual biomasses and 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.

### 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). From 2009 to 2012, the abundance of adult males increased to levels comparable to those observed during the 1999-2004 period (Fig. 11). The abundance of adult males decreased in 2013 to levels comparable to the 2005-2009 period (Fig. 11). The abundance of mature females decreased in 2013 but remained high relative to the low values observed during 2006 to 2009 (Fig. 12). Over the time series, 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 2013 (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 5; Fig. 14). The rescaled $B_{lim}$ value is 10,000 t (Table 5; 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 5; 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 2009 time period (DFO 2010b).

### 5.1. RISK ANALYSIS OF CATCH OPTIONS FOR 2014 AND 2015

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 2014 and 2015 fishery. As well, the probabilities of the commercial biomass estimated from the post-fishery trawl survey being less than $B_{USR}$ for catch options in the 2014 and 2015 fishery were also provided. The decision rules used to implement the PA remain to be defined.

The estimated commercial biomass available for the 2014 fishery in the sGSL is 65,868 t (56,283 to 76,610 t), which is in the healthy zone of the precautionary approach framework (Fig. 14).

The predicted recruitment of commercial crab for the 2015 and 2016 fisheries based on the Bayesian prerecruit model (Surette and Wade, 2006; Wade et al., 2014) (Table 3; Fig. 15) using the 2013 survey data are 37,893 t (28,568 to 49,114 t) and 37,730 t (28,310 to 47,150 t), respectively (Table 3; Fig. 15). Risk analyses of catch options relative to management objectives are summarized in Table 6 and Figures 16 and 17.

For the 2014 fishery, a catch option of 22,790 t would give 50% chance of exceeding the $F_{lim}$ (34.6%), 0% chance of falling below $B_{lim}$ (10,000 t) and 0% chance of being below the $B_{USR}$ (41,400 t, see Table 6). If the catch option for the 2014 fishery is 22,790 t, which represents an exploitation rate of 34.6%, the same used for the 2013 fishing season, the remaining biomass after the 2014 fishery would be expected to be 24,764 t (18,153 to 31,535 t). The remaining biomass after the 2014 fishery is calculated by multiplying the commercial biomass in 2014 (65,868 t; C.I. range 56,283 to 76,610 t) by the survivorship rate (0.72, in Table 3) minus the catch option in 2014 (22,790 t). Therefore, the predicted commercial biomass for the 2015 fishery (the sum of the predicted recruitment for 2015 and the remaining biomass after the 2014 fishery) would be 62,660 t (52,098 to 73,153 t). The commercial biomass projections for 2015 according to different catch options for the 2014 fishery are presented in Table 6.

The risk analysis for the 2015 fishery is based on a catch option of 22,790 t for the 2014 fishery, which represents an exploitation rate of 34.6% as used for the 2013 fishing season. For the 2015 fishery, a catch option of 21,679 t would give 50% chance of exceeding the $F_{lim}$ (34.6%), 0% chance of falling below $B_{lim}$ (10,000 t) and 0% chance of being below the $B_{USR}$ (41,400 t), (Table 6). Following the same risk level (50% chance of exceeding the $F_{lim}$) as in 2013 would give a catch option of 21,679 t on a projected commercial biomass of 62,660 t (52,098 to 73,153) for the 2015 fishing season. The remaining biomass after the 2015 fishery would be expected to be 23,436 t (15,832 to 30,991 t). The remaining biomass after the 2015 fishing season is calculated by multiplying the projected commercial biomass in 2015 (62,660 t; C.I. 52,098 to 73,153 t) by the survivorship rate of 0.72 (Table 3) minus the catch option taken in 2015 (21,679 t). Therefore, the predicted commercial biomass for the 2016 fishery (the sum of the predicted recruitment for 2016 and the remaining biomass after the 2015 fishery) would be 61,328 t (48,698 to 74,328 t). The commercial biomass projections for 2016 according to different catch options for the 2015 fishery are presented in Table 6.

A number of factors can account for the variation in the recruitment rate of the prerecruits to the commercial-sized adult stage including unaccounted bycatch mortality, sampling uncertainties, natural mortality and variations in the molting schedule of precreruits (skip molting, molting to adolescent phase or molting to adult phase) especially if density-dependent phenomena occur. In addition, in these two-year commercial biomass projections, we used a forecast survivorship rate of 0.72, which is a 5-year moving average. In the past, the survivorship rate has varied considerably from one year to the next which affect directly the commercial biomass projections.

## 5.2. PROGNOSIS

The fishery recruitments are expected to be 37,893 t (28,568 to 49,114 t) for the 2015 fishery and 37,730 t (28,310 to 47,150 t) for the 2016 fishery (Table 3; Fig. 15). A small pulse of adolescent males of sized between 11 and 23 mm was observed in the 2013 survey (Fig. 18). The abundance of males with a CW between 34 and 44 mm, which will reach the commercial size in 6 years, decreased in 2013 (Fig. 19). The surface area occupied by the prerecruits ≥ 56 mm CW in the 2013 survey was less spread out compared to 2012, and was mostly observed in Bradelle Bank, Shediac Valley, Orphan Bank, the southern part of the Magdalen Channel and the Cape Breton Corridor (Fig. 20).

The estimated abundances of immature and pubescent females in the population increased from 2001 to 2012 but decreased in 2013 (Figs. 12 and 21). The decrease in pubescent females observed in the 2013 trawl survey suggests that the abundance of mature females may decrease in the coming years. The abundance of mature females decreased in 2013 but remained high relative to the low values observed during 2006 to 2009 (Figs. 12 and 21).

# 6.0. UNCERTAINTIES

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

A number of survey protocol changes have weakened the assumption of homogeneity of the biomass time series.

Four different boats have been used to conduct the trawl survey: the “Emy-Serge” (1988-1998), a 65-foot side-trawling (375 HP) wooden boat, the “Den C. Martin” (1999-2002), a 65-foot stern-trawling (402 HP) steel boat, the “Marco-Michel’’ (2003-2012), a 65 feet stern-trawling (660 HP) fiberglass boat and the “Jean-Mathieu” in 2013, a 65-foot stern trawling (720 HP). Individual tows were standardized by trawl swept area using data from trawl acoustic monitoring sensors (Moriyasu et al. 2008). However, other factors may contribute varying catchability among boats, but no comparative fishing studies were performed. A preliminary statistical comparison between snow crab survey and September multispecies survey data suggests that the boats did have 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.

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

A Snow Crab Assessment Methods Framework Science Review conducted in November 2011 addressed these concerns as well as changes in survey design. Following the review, it was agreed that the time series from 1997 to the present was sufficiently coherent to be used in assessing stock status and providing catch advice (DFO 2012a). Further work is 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 for assessment purposes.

## 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, predation and population levels. In sGSL snow crab stocks, the biomass of commercial-sized adult male crab appears to fluctuate from periods of 3 to 4 years of high recruitment followed by 3 to 4 years of low recruitment (Sainte-Marie et al. 1995; Comeau et al. 1998a; Moriyasu et al. 1998). Since molting activity peaks in January for adolescent skip-molters and in March for normal molters, most postmolt males are potentially catchable as soon as the fishery starts (generally at the end of April). Soft-shelled males in the commercial catches are found from late April to August in the sGSL (Hébert et al. 2002).

The mechanism of molting to terminal phase is complex. Conan et al. (1988), and Comeau et al. (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 distribution of commercial-sized crabs is characterized by patchy concentrations of crab in the western and eastern portions of the sGSL which expand and contract through time.

Tagging studies have indicated exchanges of crab both within and between management areas of the sGSL (Biron et al. 2008). Interpretation of tagging study results is limited by: 1) the path between the release and recapture positions is unknown, 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 marginal habitat areas during the period of decreasing biomass (southern part of Magdalen Channel in 1999 and in Area 12E in 1997), generally moved towards core habitat areas: the center of Bradelle Bank (Biron et al. 2008). In Area 19, tag-recapture experiments were conducted during two stock phases: a decreasing biomass phase in 1993-1996 and an increasing phase in 1997-2001. During the decreasing phase, recaptured 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 adult crabs, between 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.). Quantitative estimates of commercial crab migration from the sGSL into western Cape Breton and adjacent areas are not available.

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

## 6.4. HIGHGRADING

Highgrading, the on-board selection of good commercial quality crabs, increases the proportion of discarded crab and can result in increased handling mortality or injury. Such injuries, such as leg loss, can have negative consequences for stock productivity. Stoner et al. (2008) reported that reflex impairment (even with no apparent physical damage) provided an excellent predictor of delayed mortality in fishes related to both physical (i.e. wounding) and physiological (e.g. thermal stress, air exposure) injury in *Chionoecetes opilio*. 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 a higher proportion 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 molting, reproductive dynamics and the movement of snow crab. Chassé and Pettipas (2009) reported that 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 12E and 12F 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 and 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 2013, near-bottom temperatures were normal in the southern portion of Area 12 and above normal in its northern portion as well as in Areas 12E and 12F. Temperatures in Area 19 were around normal except along the very-near coast where they were slightly lower than normal values. Most of the snow crab fishing grounds cooled down in 2013 compared to 2012, except for the Shediac Valley area where the water slightly warmed up. The warmer-than-average bottom waters of 2013 resulted in a below normal Southern Gulf snow crab habitat index (bottom area with temperatures from -1 to 3°C). In 2013, the habitat index was similar to 2012 and was 3.7% below the 1980-2010 average. The mean temperature (1.0°C) within the defined snow crab habitat area index (-1 to 3°C) in 2013 decreased compared to 2012 by about 0.4°C. During the previous year (2012), the mean temperature was the highest of the 42 year data series and the 2013 value is still significantly higher than the long term mean and is above the 1999-2002 and 2005-2007 warm periods. The mean temperature has been above normal over the last five years and for 12 of the last 15 years.

# 7.0. ACKNOWLEDGMENTS

The authors wish to thank J. Chassé (DFO Gulf Region) and B. Pettipas (DFO Maritimes Region) for providing information on oceanographic condition in 2013. The authors also wish to thank T. Surette (DFO Gulf Region) for reviewing the document.

# 8.0. REFERENCES CITED


Abello, P., Warman, C.G., Reid, D.G., and Naylor, E. 1994. Chela loss in the shore crab (*Carcinus maenas* Crustacea: Brachyura) and its effect on mating success. Mar. Biol. 121: 247-252.

Benhalima, K., Moriyasu, M., and Hébert, M. 1998. A technique for identifying the early-premolt stage in the male snow crab, *Chionoecetes opilio*, (Brachyura: Majidae) in Baie des Chaleurs, southern Gulf of St. Lawrence. Can. J. Zool. 76: 609-617.

Benoît, H.P., and Cadigan, N. 2014. Model-based estimation of commercial- sized snow crab (*Chionoecetes opilio*) abundance in the southern Gulf of St. Lawrence, 1980-2012, using data from two bottom trawl surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/114.

Biron, M., Ferron, C., and Moriyasu, M. 2008. Movement of adult male snow crab, *Chionoecetes opilio*, in the southern Gulf of St. Lawrence and eastern Nova-Scotia, Canada. Fish. Res. 91: 260-270.

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

Chiasson, Y., and Hébert, M. 1990. Literature review on stock delimitation pertaining to the Western Cape Breton Island snow crab (*Chionoecetes opilio*) and advice on a spring fishery in Area 18. DFO CAFSAC Res. Doc. 90/65.

Comeau, M., and Conan, G.Y. 1992. Morphometry and gonad maturity of male snow crab, *Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 49: 2460-2468.

Comeau, M., Conan, G.Y., Maynou, F., Robichaud, G., Therriault, J.-C., and Starr, M. 1998a. Growth, spatial distribution, and abundance of benthic stages of the snow crab (*Chionoecetes opilio*) in Bonne Bay, Newfoundland, Canada. Can. J. Fish. Aquat. Sci. 55: 262-279.

Comeau, M., Robichaud, G., Starr, M., Therriault, J.-C., and Conan, G.Y. 1998b. Mating of snow crab, *Chionoecetes opilio*, (O. Fabricius, 1788) (Decapoda, Majidae) in the fjord of Bonne Bay, Newfoundland. Crustaceana 71: 926-941.

Conan, G.Y., and Comeau, M. 1986. Functional maturity of male snow crab, (*Chionoecetes opilio*). Can. J. Fish. Aquat. Sci. 43: 1710-1719.

Conan, G.Y., Moriyasu, M., Comeau, M., Mallet, P., Cormier, R., Chiasson, Y., and Chiasson, H. 1988. Growth and maturation of snow crab (*Chionoecetes opilio*), p. 45-66. In G.S. Jamieson and W.D. McKone (eds.). Proceedings of the international workshop on snow crab biology, December 8-10, 1987, Montréal Québec. Can. MS Rep. Fish. Aquat. Sci. 2005.

DFO. 2006. Proceedings of the Assessment Framework Workshop on the southern Gulf of St. Lawrence snow crab (Areas 12, E, F and 19), Gulf Regional Advisory Process; 11-14 October 2005. DFO Can. Sci. Advis. Sec. Proc. Ser. 2006/042.

DFO. 2009. A fishery decision-making framework incorporating the Precautionary Approach.

DFO. 2010a. Reference points consistent with the precautionary approach for snow crab in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/014.

DFO. 2010b. Assessment of Nova Scotia (4VWX) snow crab. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/040.

DFO. 2011. Assessment of Nova Scotia (4VWX) snow crab. DFO. Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/045.

DFO. 2012a. Proceedings of the Gulf Region Science Peer Review Framework Meeting of Assessment Methods for the Snow Crab Stock of the southern Gulf of St. Lawrence; November 21 to 25, 2011. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2012/023.

DFO. 2012b. Revised reference points for snow crab to account for the change in estimation area of the southern Gulf of St. Lawrence biological unit. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/002.

Dufour, R., Bernier, D., and Brêthes, J.-C. 1997. Optimization of meat yield and mortality during snow crab (*Chionoecetes opilio*, O. Fabricius) fishing operations in Eastern Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2152.

Hébert, M., Gallant, C., Chiasson, Y., Mallet, P., DeGrâce, P., et Moriyasu, M. 1992. Le suivi du pourcentage de crabes mous dans les prises commerciales de crabe des neiges (*Chionoecetes opilio*) dans le sud-ouest du golfe du Saint-Laurent (zone 12) en 1990 et 1991. Rapp. Tech. Can. Sci. Halieut. Aquat. 1886.

Hébert, M., Wade, E., DeGrâce, P., Biron, M., and Moriyasu, M. 1996 assessment of snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 18, 19, 25/26 and zones E and F). DFO Can. Sci. Advis. Sec. Res. Doc. 1997/086.

Hébert, M., Benhalima, K., Miron, G., and Moriyasu, M. 2002. Molting and growth of male snow crab, *Chionoecetes opilio*, (O. Fabricius, 1788) (Crustacea: Majidae) in the southern Gulf of St. Lawrence. Crustaceana 75: 671-702.

Hébert, M., Wade, E., Surette, T., and Moriyasu, M. 2007. The 2006 assessment of snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, E and F). DFO Can. Sci. Advis. Sec. Res. Doc. 2007/028.

Hébert, M., Wade, DeGrâce, P., Bélanger, P., and Moriyasu, M. 2008. The 2007 assessment of snow crab (*Chionoecetes opilio*) stock in the southern Gulf of St. Lawrence (Areas 12, 19, E and F). DFO Can. Sci. Advis. Sec. Res. Doc. 2008/040.

Hébert, M., Wade, E., Biron, M., DeGrâce, P., Landry, J.-F., and Moriyasu, M. 2011. The 2010 assessment of snow crab, *Chionoecetes opilio*, stocks in the southern Gulf of St. Lawrence (Areas 12, 19, E and F). DFO Can. Sci. Advis. Sec. Res. Doc. 2011/082.

Keitt, T. H., Bivand, R., Pebesma, E., and Rowlingson, B. 2012. rgdal: Bindings for the Geospatial Data Abstraction Library. R package version 0.7-8.

Kuhn, P.S., and Choi, J.S. 2011. Influence of temperature on embryo developmental cycles and mortality of female *Chionoecetes opilio* (snow crab) on the Scotian Shelf, Canada. Fish. Res. 107: 245-252.

Landry, J.-F., Wade, E., Moriyasu, M., and Hébert, M. 2014. Summary of the 2013 multispecies trawl survey activities in the southern Gulf of St. Lawrence and preliminary results. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/087.

Mallet, P., Conan, G.Y., and Moriyasu, M. 1993. Periodicity of spawning and duration of incubation time for *Chionoecetes opilio*, in the Gulf of St. Lawrence. ICES CM/1993: K:26.

Moriyasu, M., and Conan, G.Y. 1988. Aquarium observation on mating behaviour of snow crab, *Chionoecetes opilio*. ICES C. M., 1988/K: 9.

Moriyasu, M., Conan, G.Y., Mallet, P., Chiasson, Y.J., and Chiasson, H. 1988. Growth at molt, molting season and mating of snow crab, *Chionoecetes opilio*, in relation to functional and morphometric maturity. ICES CM/1987 K:21.

Moriyasu, M., and Comeau, M. 1996. Grasping behavior of male snow crab, (*Chionoecetes opilio* O. Fabricius, 1788, Decapoda, Majidae). Crustaceana 69:,211-222.

Moriyasu, M., and Lanteigne, C. 1998. Embryo development and reproductive cycle in the snow crab, *Chionoecetes opilio* (Crustacea: Majidae), in the southern Gulf of St. Lawrence, Canada. Can. J. Zool. 76: 2040-2048.

Moriyasu, M., Wade, E., Sinclair, A., and Chiasson, Y. 1998. Snow crab, *Chionoecetes opilio*, stock assessment in the southwestern Gulf of St. Lawrence by bottom trawl survey. Can. Spec. Publ. Fish. Aquat. Sci. 125:29-40.

Moriyasu, M., Wade, E., Hébert, M., and Biron, M. 2008. Review of the survey and analytical protocols used for estimating abundance indices of southern Gulf of St. Lawrence snow crab from 1988 to 2006. DFO Can. Sci. Advis. Sec. Res. Doc. 2008/069.

Rondeau, A., and Sainte-Marie, B. 2001. Variable mate-guarding time and sperm allocation by male snow crab, *Chionoecetes opilio*, in response to sexual competition, and their impact on the mating success of females. Biol. Bull. 201: 204-217.

Sainte-Marie, B., and Hazel, F. 1992. Moulting and mating of snow crabs, *Chionoecetes opilio* (O. Fabricius), in shallow waters of the northwestern Gulf of Saint Lawrence. Can. J. Fish. Aquat. Sci. 49: 1282-1293.

Sainte-Marie, B., and Carrière, C. 1995. Fertilization of the second clutch of eggs of snow crab, *Chionoecetes opilio*, from females mated once or twice after their molt to maturity. Fish. Bull. 93: 759-764.

Sainte-Marie, B., Raymond, S., and Brêthes, J.-C. 1995. Growth and maturation of the benthic stages of male snow crab, *Chionoecetes opilio* (Brachyura: Majidae). Can. J. Fish. Aquat. Sci. 52: 903-924.

Sainte-Marie, B., Urbani, N., Sévigny, J.-M., Hazel, F., and Kuhnlein, U. 1999. Multiple choice criteria and the dynamics of assortative mating during the first breeding season of female snow crab *Chionoecetes opilio* (Brachyura, Majidae). Mar. Ecol. Prog. Ser. 181: 141-153.

Sainte-Marie, B., Gosselin, T., Sévigny, J.-M., and Urbani, N. 2008. The snow crab mating system: opportunity for natural and unnatural selection in a changing environment. Bull. Mar. Sci. 83: 131-161.

Stoner, A.W., Rose, C.S., Munk, J. E., Hammond, C.F. and Davis M.W. 2008. An assessment of discard mortality for two Alaskan crab species, Tanner crab (*Chionoecetes bairdi*) and snow crab (*C. opilio*), based on reflex impairment. Fish. Bull. 106: 337-347.

Surette, T., and Wade, E. 2006. Bayesian serial linear regression models for forecasting the short-term abundance of commercial snow crab (*Chionoecetes opilio*). Can. Tech. Rep. Fish. Aquat. Sci. 2672.

Surette, T., Marcotte, D., and Wade, E. 2007. Predicting snow crab (*Chionoecetes opilio*) abundance using kriging with external drift with depth as a covariate. DFO Can. Tech. Rep. Fish. Aquat. Sci. 2763.

Wade, E., Surette, T., Apaloo, J., and Moriyasu, M. 2003. Estimation of mean annual natural mortality for adult male snow crab, *Chionoecetes opilio*, in the southern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/017.

Wade, E., Moriyasu, M., and Hébert, M. 2014. Methods and models used in the 2012 assessment of the snow crab (*Chionoecetes opilio*), stock in the southern Gulf of St-Lawrence.DFO Can. Sci. Advis. Sec. Res. Doc. 2013/113.

Waiwood, K.G., and Elner, R.W. 1982. Cod predation of snow crab (*Chionoecetes opilio*) in the Gulf of St. Lawrence. In: Proceedings of the International Symposium on the genus Chionoecetes. p. 449-520. Lowell Wakefield Symposium Series, Alaska Sea Grant Report. 82:10. University of Alaska Fairbanks.

Watson, J. 1969. Biological investigation on the spider crab, *Chionoecetes opilio*, p. 23-47. In Pro. Meeting on Atlantic Crab Fishery Development. Can. Fish. Rep. 13.

Watson, J. 1972. Mating behavior in the Spider Crab, *Chionoecetes opilio*. J. Fish. Res. Board Can. 29: 447-449.

# 9.0. TABLES

*Table 1. Estimated biomass (t, mean and 95% confidence interval in parentheses) of commercial-sized adult male snow crab, Chionoecetes opilio, in the southern Gulf of St. Lawrence (all zones) by kriging in weight, 1997 to 2013. Recruitment refers to snow crab with carapace conditions 1 and 2 whereas residual biomass refers to snow crab with carapace conditions 3 to 5.*

| Survey year | Commercial biomass | Recruitment biomass | Residual biomass |
|---|---|---|---|
| 1997 | 65,310 (54,801-77,239) | 37,619 (26,376-52,064) | 27,690 (21,995-34,407) |
| 1998 | 57,595 (45,630-71,735) | 29,818 (17,580-47,435) | 27,775 (21,022-36,013) |
| 1999 | 57,051 (47,946-67,376) | 25,874 (15,918-39,818) | 31,177 (25,051-38,346) |
| 2000 | 49,823 (40,473-60,682) | 39,845 (30,543-51,093) | 9,977 (6,649-14,401) |
| 2001 | 59,150 (47,740-72,460) | 42,243 (31,198-55,942) | 16,905 (12,657-22,125) |
| 2002 | 79,559 (66,688-94,181) | 66,481 (53,434-81,746) | 13,075 (10,451-16,157) |
| 2003 | 84,423 (71,964-98,410) | 57,503 (44,809-72,679) | 26,919 (21,223-33,674) |
| 2004 | 103,429 (91,029-117,036) | 83,702 (70,955-98,069) | 19,726 (15,836-24,280) |
| 2005 | 82,537 (73,487-92,387) | 58,398 (48,417-69,824) | 24,140 (18,726-30,632) |
| 2006 | 74,285 (66,192-83,087) | 54,371 (46,124-63,660) | 19,914 (16,161-24,275) |
| 2007 | 66,660 (60,183-73,638) | 39,635 (33,089-47,092) | 27,025 (23,354-31,106) |
| 2008 | 52,564 (46,658-59,006) | 31,555 (25,181-39,048) | 21,010 (17,960-24,426) |
| 2009 | 30,920 (27,237-34,959) | 20,520 (16,848-24,754) | 10,399 (8,560-12,516) |
| 2010 | 35,795 (31,681-40,291) | 20,351 (15,360-26,450) | 15,444 (12,859-18,394) |
| 2011 | 63,162 (55,965-71,022) | 29,394 (20,909-40,190) | 33,768 (28,297-39,985) |
| 2012 | 74,997 (65,822-85,086) | 48,969 (38,667-61,173) | 26,028 (21,950-30,641) |
| 2013 | 65,868 (56,283-76,610) | 38,981 (28,969-51,346) | 26,886 (22,909-31,352) |

*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 2013.*

| Survey year | Carapace condition 1+2 | | | Carapace condition 3 | | | Carapace condition 4 | | | Carapace condition 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Confidence interval | | Mean | Confidence interval | | Mean | Confidence interval | | Mean | Confidence interval | |
| 1997 | 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 |
| 2013 | 62.875 | 54.251 | 72.471 | 30.204 | 25.895 | 35.020 | 18.560 | 14.744 | 23.060 | 0.695 | 0.338 | 1.273 |

*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 |
|---|---|---|---|---|---|---|---|---|
| | R – 4 | R - 3 | R - 2 | R - 1 | R-1 | Res | B | S |
| 1997 | 114.2 | 92.7 | 57.9 | 37,619 (26,376-52,064) | na | 27,690 (21,995-34,407) | 65,310 (54,801-77,239) | na |
| 1998 | 139.5 | 91.6 | 57.1 | 29,818 (17,580-47,435) | na | 27,775 (21,022-36,013) | 57,595 (45,630-71,735) | na |
| 1999 | 199.7 | 150.9 | 115.0 | 25,874 (15,918-39,818) | na | 31,177 (25,051-38,346) | 57,051 (47,946-67,376) | na |
| 2000 | 238.7 | 159.4 | 89.3 | 39,845 (30,543-51,093) | na | 9,977 (6,649-14,401) | 49,823 (40,473-60,682) | na |
| 2001 | 313.2 | 229.2 | 135.7 | 42,243 (31,198-55,942) | na | 16,905 (12,657-22,125) | 59,150 (47,740-72,460) | na |
| 2002 | 166.7 | 241.8 | 199.7 | 66,481 (53,434-81,746) | na | 13,075 (10,451-16,157) | 79,559 (66,688-94,181) | na |
| 2003 | 137.8 | 207.1 | 181.4 | 57,503 (44,809-72,679) | na | 26,919 (21,223-33,674) | 84,423 (71,964-98,410) | na |
| 2004 | 86.4 | 122.8 | 142.5 | 83,702 (70,955-98,069) | na | 19,726 (15,836-24,280) | 103,429 (91,029-117,036) | na |
| 2005 | 63.3 | 79.4 | 117.1 | 58,398 (48,417-69,824) | 60,500 (38,800-86,000) | 24,140 (18,726-30,632) | 82,537 (73,487-92,387) | na |
| 2006 | 55.0 | 49.8 | 65.3 | 54,371 (46,124-63,660) | 49,700 (33,200-73,000) | 19,914 (16,161-24,275) | 74,285 (66,192-83,087) | na |
| 2007 | 57.2 | 47.9 | 56.0 | 39,635 (33,089-47,092) | 35,200 (21,300-55,000) | 27,025 (23,354-31,106) | 66,660 (60,183-73,638) | na |
| 2008 | 80.4 | 54.3 | 45.8 | 31,555 (25,181-39,048) | 29,000 (18,500-42,000) | 21,010 (17,960-24,426) | 52,564 (46,658-59,006) | na |
| 2009 | 89.4 | 69.5 | 43.6 | 20,520 (16,848-24,754) | 27,700 (17,800-38,000) | 10,399 (8,560-12,516) | 30,920 (27,237-34,959) | na |
| 2010 | 140.4 | 109.1 | 71.8 | 20,351 (15,360-26,450) | 25,900 (17,100-37,000) | 15,444 (12,859-18,394) | 35,795 (31,681-40,291) | 0.65 |
| 2011 | 91.5 | 98.7 | 87.6 | 29,394 (20,909-40,190) | 33,700 (22,900-47,000) | 33,768 (28,297-39,985) | 63,162 (55,965-71,022) | 0.69 |
| 2012 | 96.0 | 86.8 | 80.4 | 48,969 (38,667-61,173) | 40,700 (31,300-52,400) | 26,028 (21,950-30,641) | 74,997 (65,822-85,086) | 0.69 |
| 2013 | 103.8 | 87.5 | 78.4 | 38,981 (28,969-51,346) | 40,380 (31,670-50,380) | 26,886 (22,909-31,352) | 65,868 (56,283-76,610) | 0.73 |
| 2014 | na | na | na | na | 37,893 (28,568-49,114) | na | na | 0.72 |
| 2015 | na | na | na | na | 37,730 (28,310-47,150) | na | na | 0.72 |

*Table 4. Estimated of snow crab commercial biomass (t, mean and 95% confidence interval) in 2013 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 | 65,868 | (56,283-76,610) |
| Area 12 | 48,028 | 50,867 | (42,594-60,273) |
| Area 19 | 3,833 | 9,795 | (8,175-11,640) |
| Area 12E | 2,443 | 409 | (19-2,083) |
| Area 12F | 2,438 | 4,064 | (2,793-5,718) |
| Sum of management areas | 56,742 | 65,135 | na |
| Unassigned zone above 12E **(A)** | 674 | 81 | (0-540) |
| Buffer zone 19/12F **(B)** | 112 | 299 | (187 – 454) |
| Buffer zone 12/ 19 **(C)** | 310 | 483 | (190-1,018) |
| Sum of total areas | 57,838 | 65,998 | na |

*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 2013.*

| Year of the fishery | Landings (t) | Southern Gulf of St. Lawrence | | |
|---|---|---|---|---|
| | | Estimated commercial biomass (t) from survey in year-1 | Estimated residual biomass (t) from survey in year-1 | Exploitation rate (%) (landings fishery year t / commercial biomass fishery year t-1) |
| 1998 | 13,575 | **65,310** (54,801-77,239) | **27,690** (21,995-34,407) | 20.8 |
| 1999 | 15,110 | **57,595** (45,630-71,735) | **27,775** (21,022-36,013) | 26.2 |
| 2000 | 18,712 | **57,051** (47,946-67,376) | **31,177** (25,051-38,346) | 32.8 |
| 2001 | 18,262 | **49,823** (40,473-60,682) | **9,977** (6,649-14,401) | 36.7 |
| 2002 | 25,691 | **59,150** (47,740-72,460) | **16,905** (12,657-22,125) | 43.4 |
| 2003 | 21,163 | **79,559** (66,688-94,181) | **13,075** (10,451-16,157) | 26.6 |
| 2004 | 31,675 | **84,423** (71,964-98,410) | **26,919** (21,223-33,674) | 37.5 |
| 2005 | 36,118 | **103,429** (91,029-117,036) | **19,726** (15,836-24,280) | 34.9 |
| 2006 | 29,121 | **82,537** (73,487-92,387) | **24,140** (18,726-30,632) | 35.3 |
| 2007 | 26,867 | **74,285** (66,192-83,087) | **19,914** (16,161-24,275) | 36.2 |
| 2008 | 24,458 | **66,660** (60,183-73,638) | **27,025** (23,354-31,106) | 36.7 |

| 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) |
| 2009 | 23,642 | **52,564** (46,658-59,006) | **21,010** (17,960-24,426) | 45.0 |
| 2010 | 9,549 | **30,920** (27,237-34,959) | **10,399** (8,560-12,516) | 30.9 |
| 2011 | 10,708 | **35,795** (31,681-40,291) | **15,444** (12,859-18,394) | 29.9 |
| 2012 | 21,956 | **63,162** (55,965-71,022) | **33,768** (28,297-39,985) | 34.8 |
| 2013 | 26,049 | **74,997** (65,822-85,086) | **26,028** (21,950-30,641) | 34.7 |
| 2014 | na | **65,868** (56,283-76,610) | **26,886** (22,909-31,352) | na |

*Table 6. Risk analyses for different catch options in 2014 (A) and 2015 (B) for the southern Gulf of St. Lawrence snow crab 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 2014 and 2015. The risk analysis for the 2015 fishery is based on a catch option of 22,790 t for the 2014 fishery, which is 50% of chance of exceeding $F_{lim}$ as used for the 2013 fishing season.*

| A) Catch option (t) for 2014 | Probability | | | Predicted commercial biomass for 2015 (t) |
|---|---|---|---|---|
| | > $F_{lim}$ (34.6%) | < $B_{lim}$ (10,000 t) | < $B_{usr}$ (41,400 t) | |
| 18,500 | 0.01 | 0 | 0 | 66,950 (56,388-77,443) |
| 19,000 | 0.02 | 0 | 0 | 66,450 (55,888-76,943) |
| 19,500 | 0.03 | 0 | 0 | 65,950 (55,388-76,443) |
| 20,000 | 0.06 | 0 | 0 | 65,450 (54,888-75,943) |
| 20,500 | 0.10 | 0 | 0 | 64,950 (54,388-75,443) |
| 21,000 | 0.16 | 0 | 0 | 64,450 (53,888-74,943) |
| 21,500 | 0.24 | 0 | 0 | 63,950 (53,388-74,443) |
| 22,000 | 0.33 | 0 | 0 | 63,450 (52,888-73,943) |
| 22,500 | 0.44 | 0 | 0 | 62,950 (52,388-73,443) |
| 22,790 | 0.50 | 0 | 0 | 62,660 (52,098-73,153) |
| 23,000 | 0.55 | 0 | 0 | 62,450 (51,888-72,943) |
| 24,000 | 0.75 | 0 | 0 | 61,450 (50,888-71,943) |
| 26,000 | 0.96 | 0 | 0 | 59,450 (48,888-69,943) |
| 28,000 | 1 | 0.007 | 0 | 57,450 (46,888-67,943) |
| 30,000 | 1 | 0.028 | 0.0138 | 55,450 (44,888-65,943) |

| B) Catch option (t) for 2015 | Probability | | | Predicted commercial biomass for 2016 (t) |
|---|---|---|---|---|
| | > $F_{lim}$ (34.6%) | < $B_{lim}$ (10,000 t) | < $B_{usr}$ (41,400 t) | |
| 17,500 | 0.03 | 0 | 0 | 65,507 (52,877-78,507) |
| 18,000 | 0.05 | 0 | 0 | 65,007 (52,377-78,007) |
| 18,500 | 0.08 | 0 | 0 | 64,507 (51,877-77,507) |
| 19,000 | 0.12 | 0 | 0 | 64,007 (51,377-77,007) |
| 19,500 | 0.16 | 0 | 0 | 63,507 (50,877-76,507) |
| 20,000 | 0.23 | 0 | 0 | 63,007 (50,377-76,007) |
| 20,500 | 0.30 | 0 | 0 | 62,507 (49,877-75,507) |
| 21,000 | 0.38 | 0 | 0 | 62,007 (49,377-75,007) |
| 21,500 | 0.47 | 0 | 0 | 61,507 (48,877-74,507) |
| 21,679 | 0.50 | 0 | 0 | 61,328 (48,698-74,328) |
| 22,000 | 0.56 | 0 | 0 | 61,007 (48,377-74,007) |
| 23,000 | 0.72 | 0.01 | 0 | 60,007 (47,377-73,007) |
| 25,000 | 0.93 | 0.02 | 0.01 | 58,007 (45,377-71,007) |
| 27,000 | 0.99 | 0.06 | 0.03 | 56,007 (43,377-69,007) |
| 29,000 | 1 | 0.11 | 0.05 | 54,007 (41,377-67,007) |

## 10.0. FIGURES

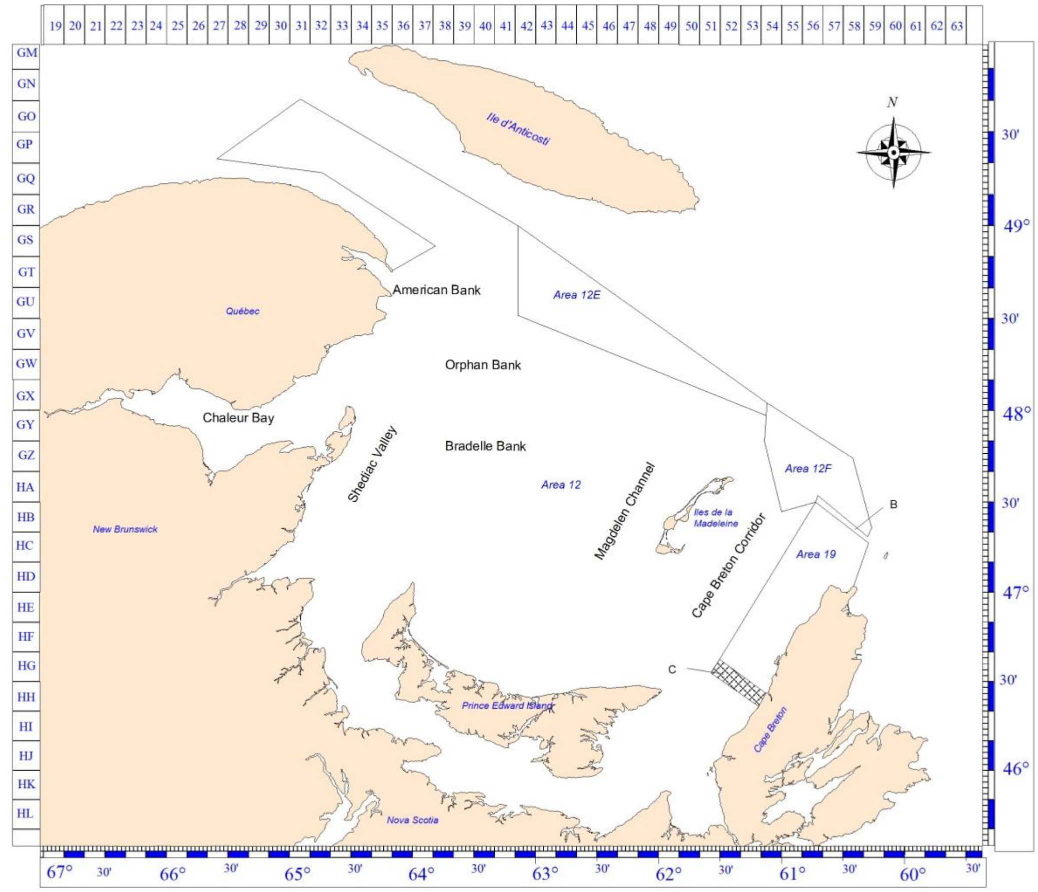


*Figure 1. Map of the southern Gulf of St. Lawrence showing the snow crab (Chionoecetes opilio) fishing areas, fishing grounds, and management buffer zones (labels B and C, shaded areas).*

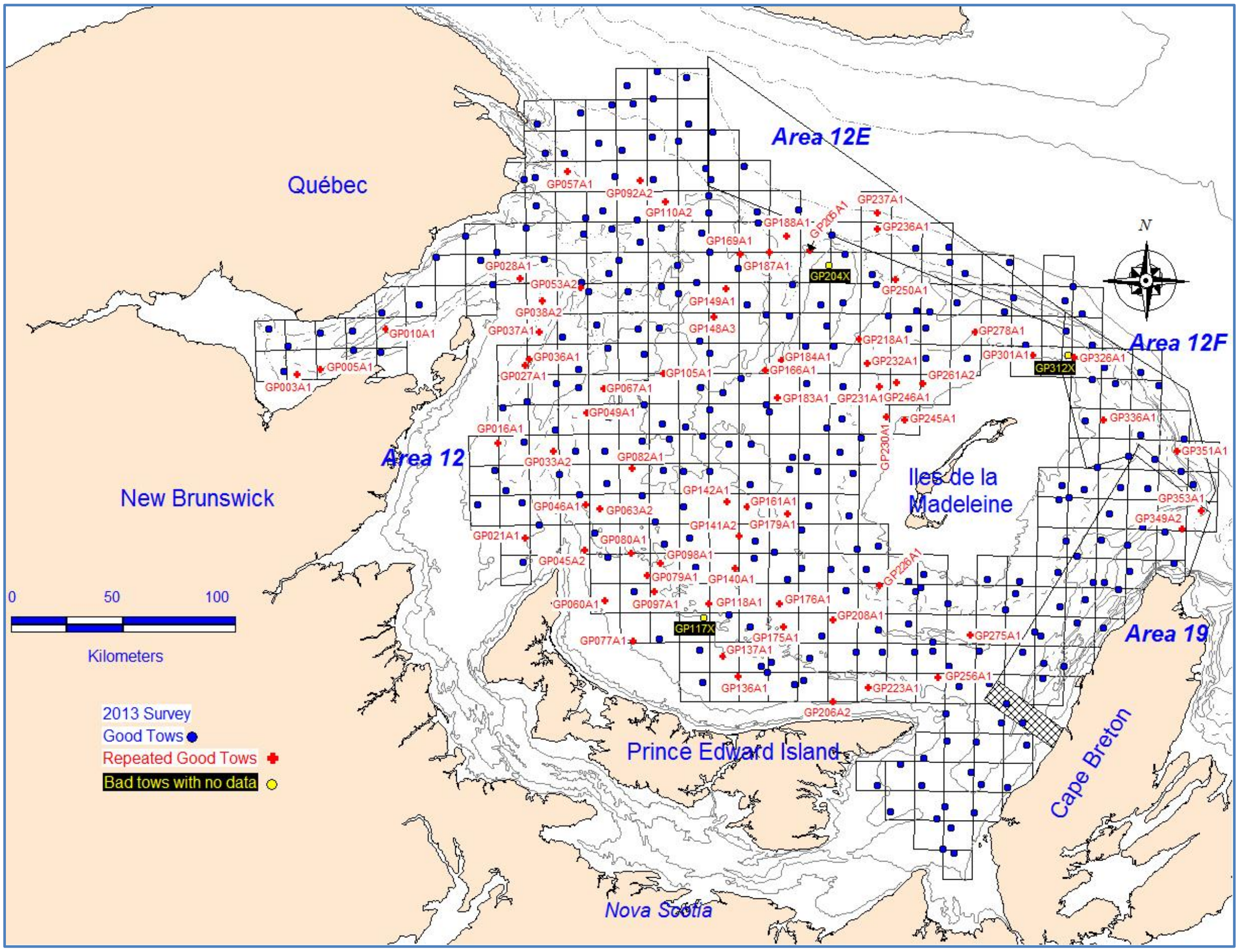


*Figure 2. Locations of the 2013 snow crab (Chionoecetes opilio) trawl survey stations within the revised estimation polygon of 57,840 km$^2$ in the southern Gulf of St. Lawrence. The blue points are successful tows, red points are successful repeat tows and yellow points are abandoned tows.*

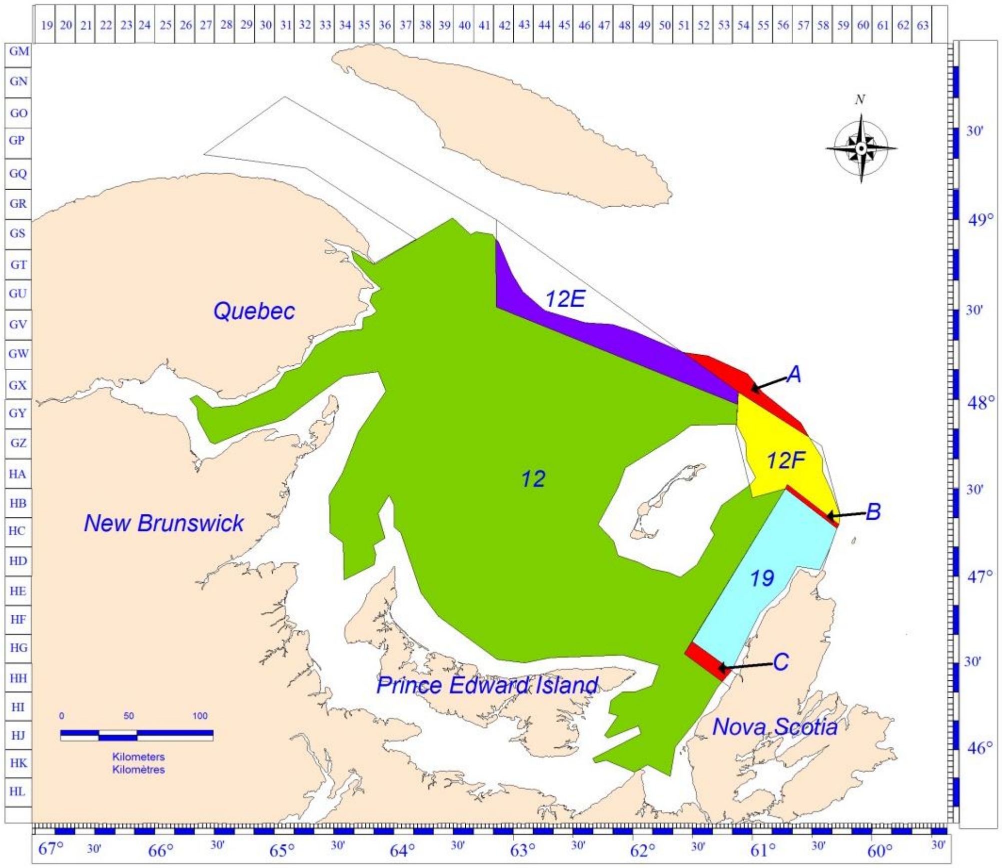


*Figure 3. The estimation polygon of 57,840 km$^2$ used for the 2013 snow crab (Chionoecetes opilio) stock assessment in the southern Gulf of St. Lawrence (all coloured areas) and corresponding estimation polygons for the four crab fishing areas (12, 12E, 12F and 19). The unsigned zone north of areas 12E and 12F (label A) and buffer zones (labels B and C) are also shown.*

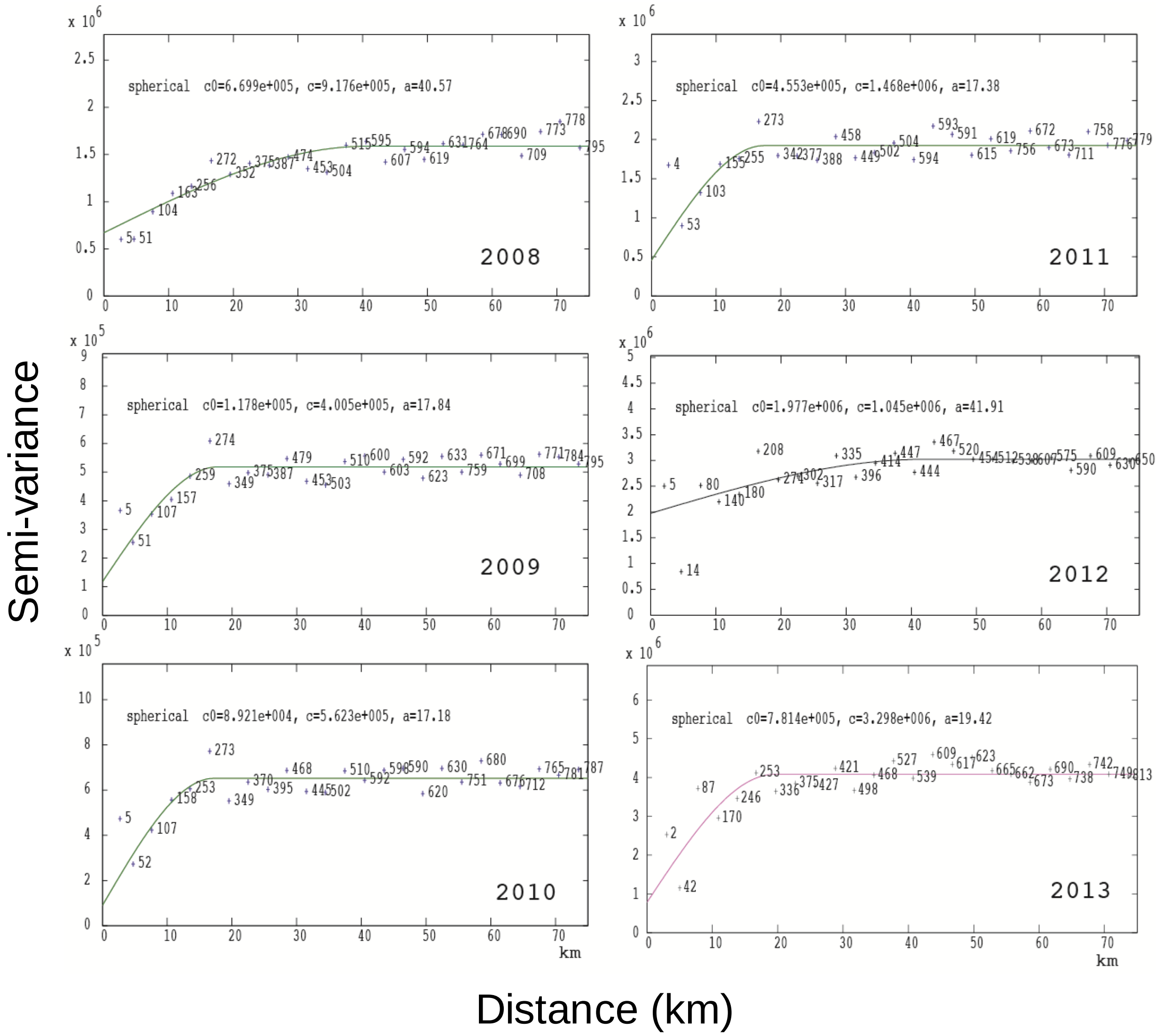


*Figure 4. Variogram models with 3 years moving average for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2008 to 2013. Indicated is the number of paired observations used per distance lag semi-variance calculation.*

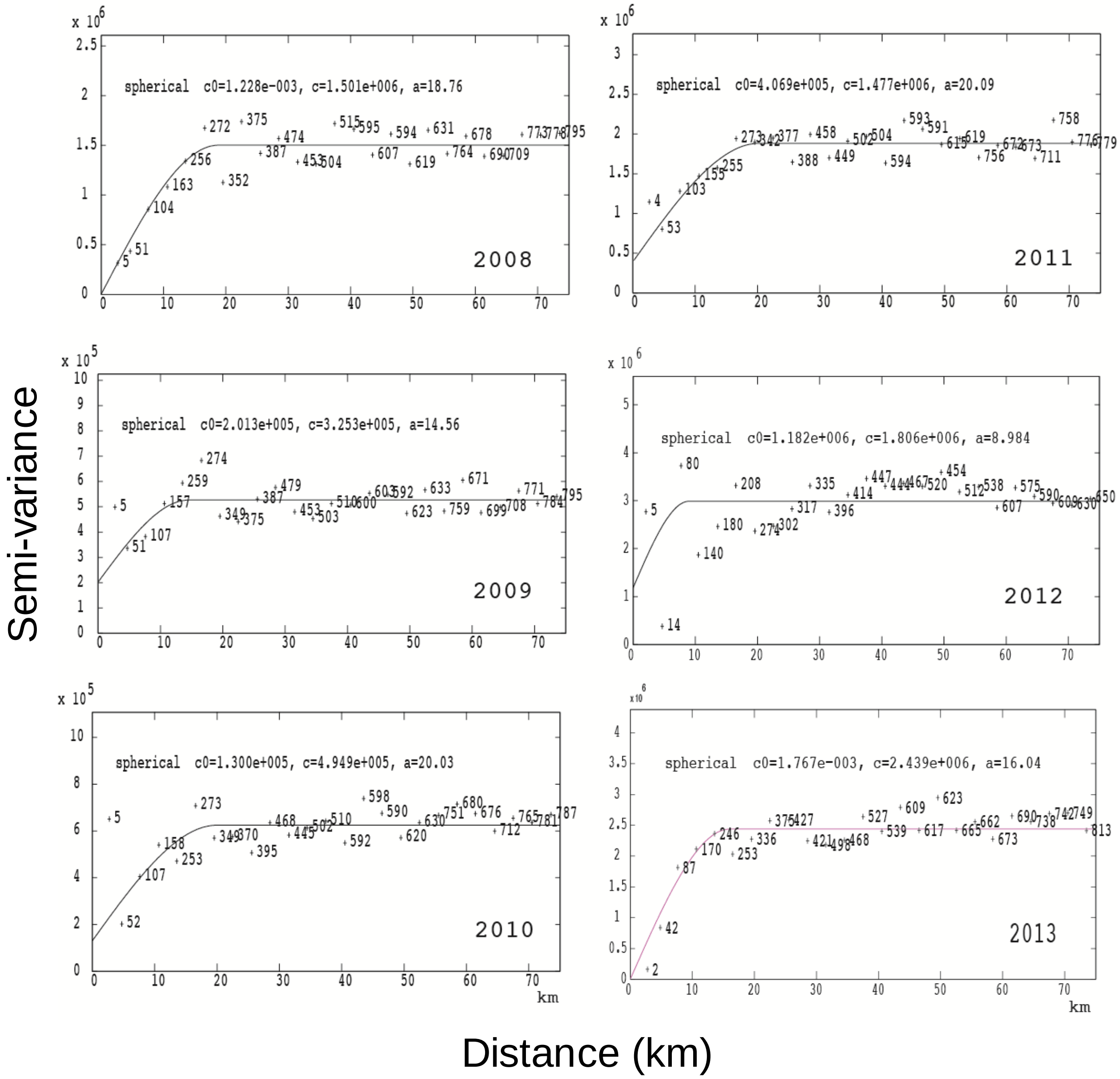


*Figure 5. Annual variogram models for commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 2008 to 2013. Indicated is the number of paired observations used per distance lag semi-variance calculation.*

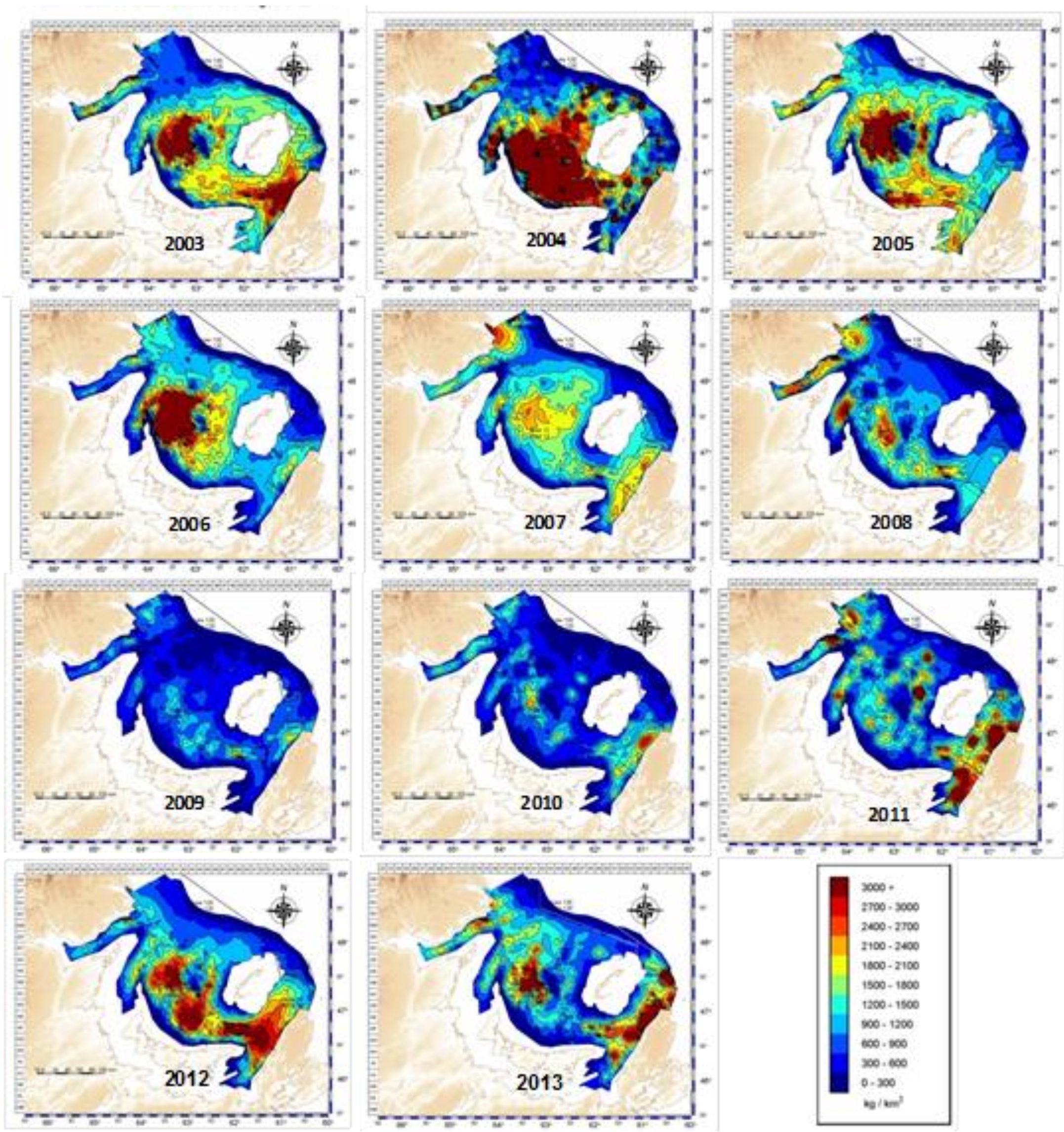


*Figure 6. Density (kg per km²) contours of commercial-sized (≥ 95 mm of carapace width) adult male snow crab (Chionoecetes opilio) based on trawl survey data in the southern Gulf of St. Lawrence, 2003 to 2013.*

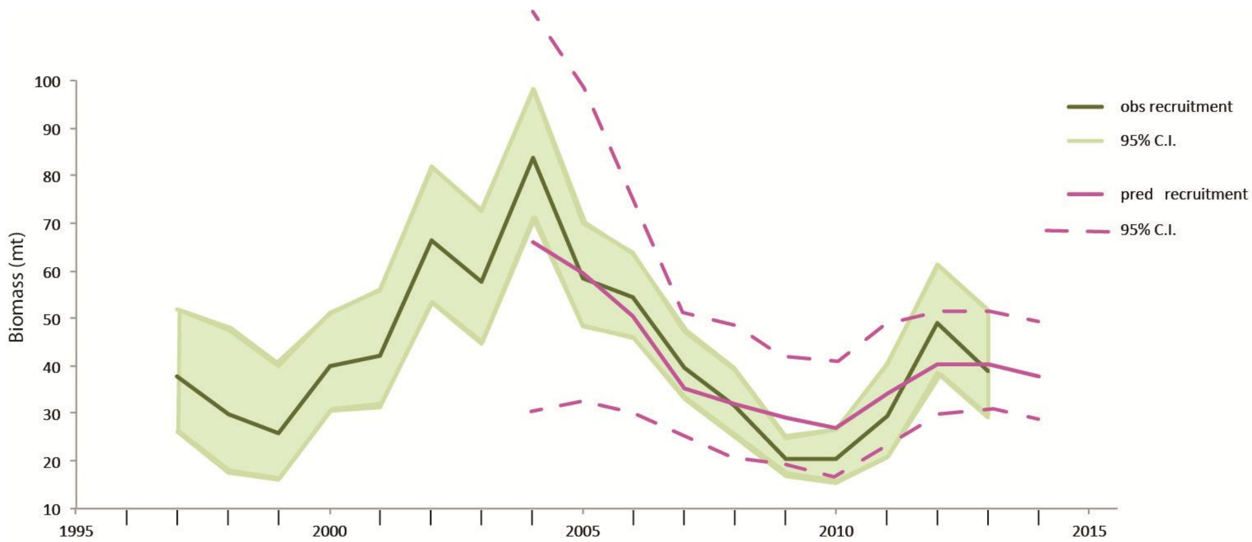


*Figure 7. Comparison between the observed (mean with 95% confidence intervals) and predicted (mean with 95% confidence intervals) recruitment (R-1) of male snow crab (Chionoecetes opilio) based on the Bayesian model on prerecruits (Surette and Wade 2006; Wade et al. 2014).*

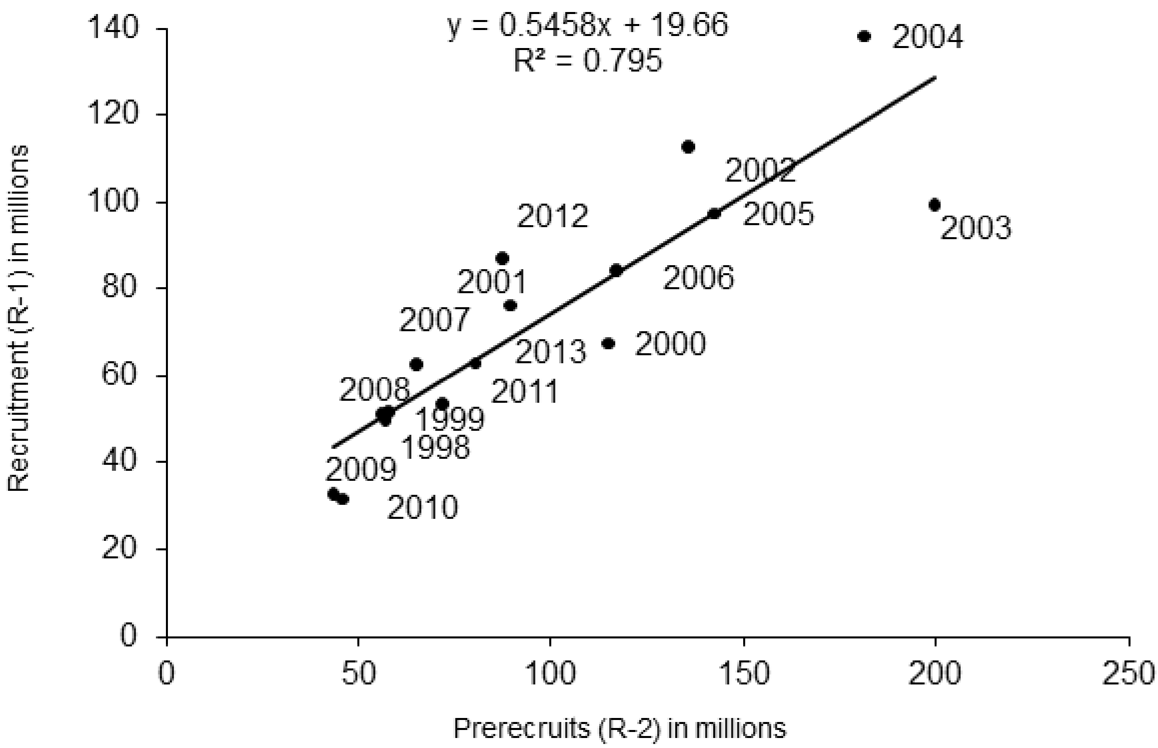


*Figure 8. Relationship between the estimated abundance of prerecruits R-2 in year t and the estimated abundance of the recruitment to the fishery (R-1) in year t + 1 from the trawl survey data for the snow crab (Chionoecetes opilio) assessment in the southern Gulf of St. Lawrence.*

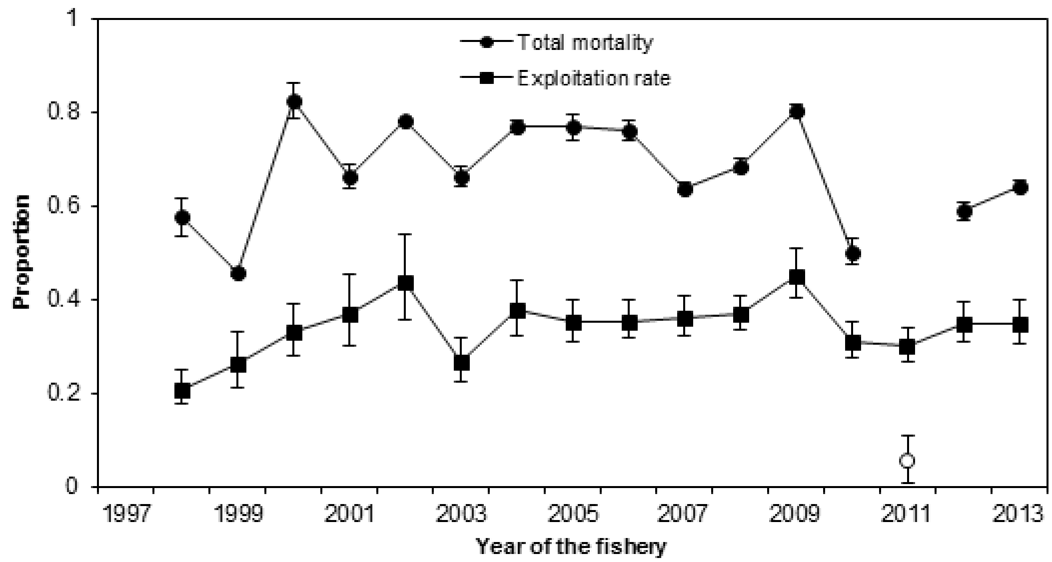


*Figure 9. Estimated annual rates of exploitation and total loss of commercial-sized adult male snow crab (Chionoecetes opilio) in the southern Gulf of St. Lawrence, 1997 to 2013. The 2011 total mortality value is not reliable (Hébert et al. 2012).*

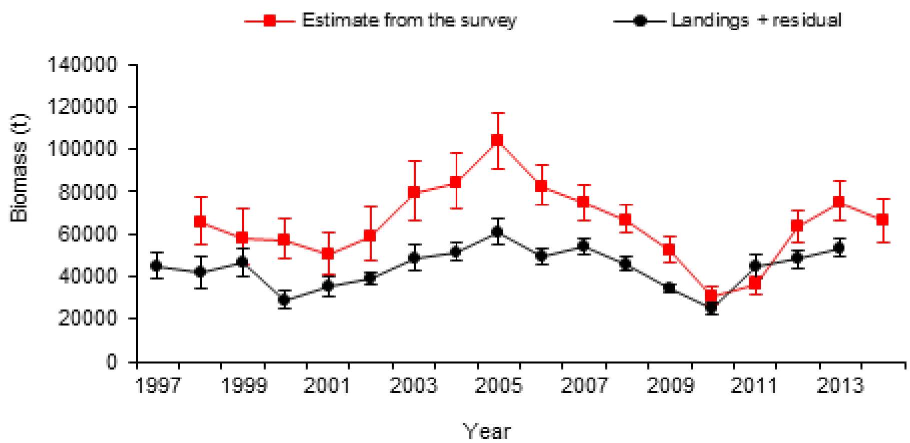


*Figure 10. Comparison of the post-fishery calculated biomass (t; residual biomass plus the landings in year t+1) and the pre-fishery commercial-sized adult male snow crab (Chionoecetes opilio) biomass (t; recruitment plus residual biomass in year t) estimated from the trawl survey in the southern Gulf of St. Lawrence.*

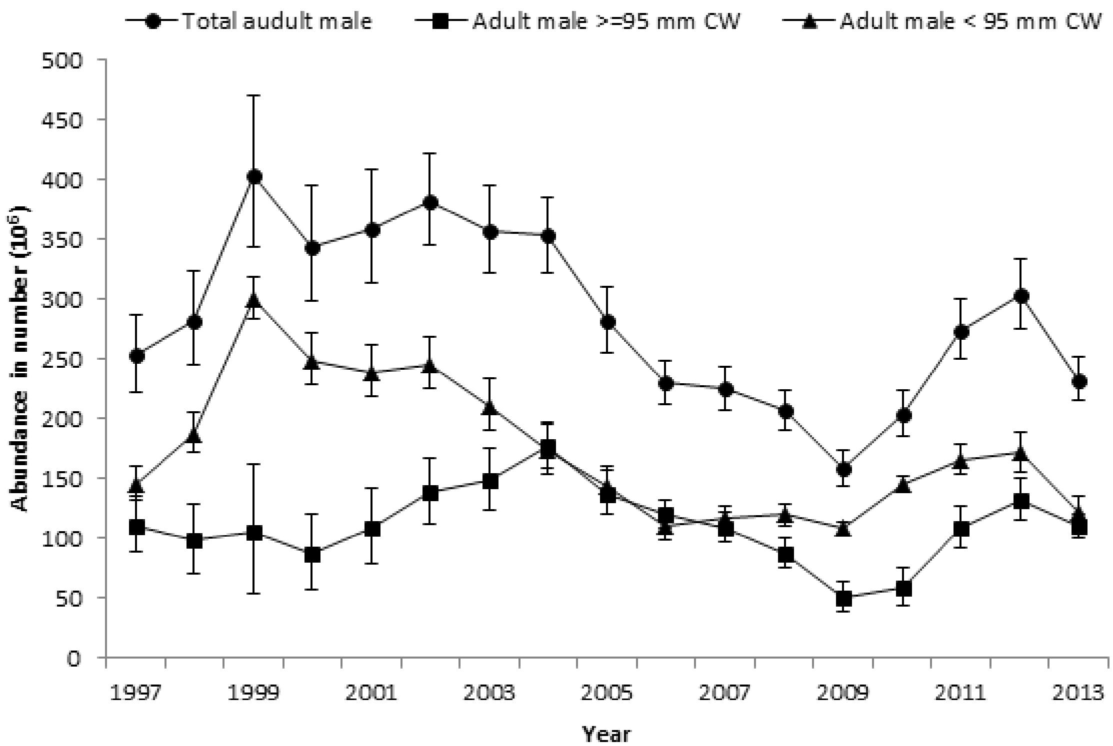


*Figure 11. Estimated abundance (number in millions) of snow crab (Chionoecetes opilio) adult males in the southern Gulf of St. Lawrence, 1997 to 2013. CW = Carapace width.*

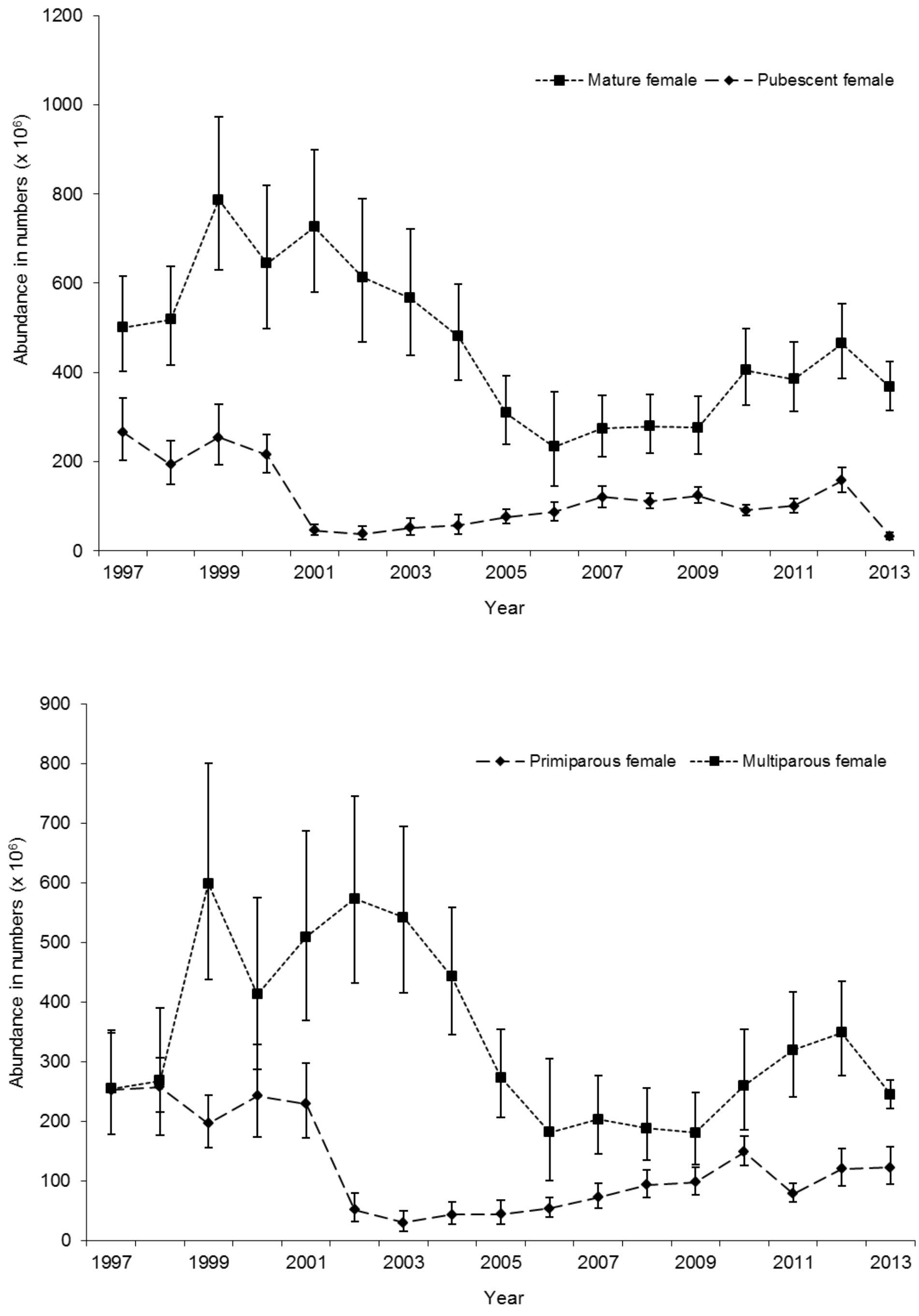


*Figure 12. Abundance (number in millions) of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females in the southern Gulf of St. Lawrence, 1997 to 2013.*

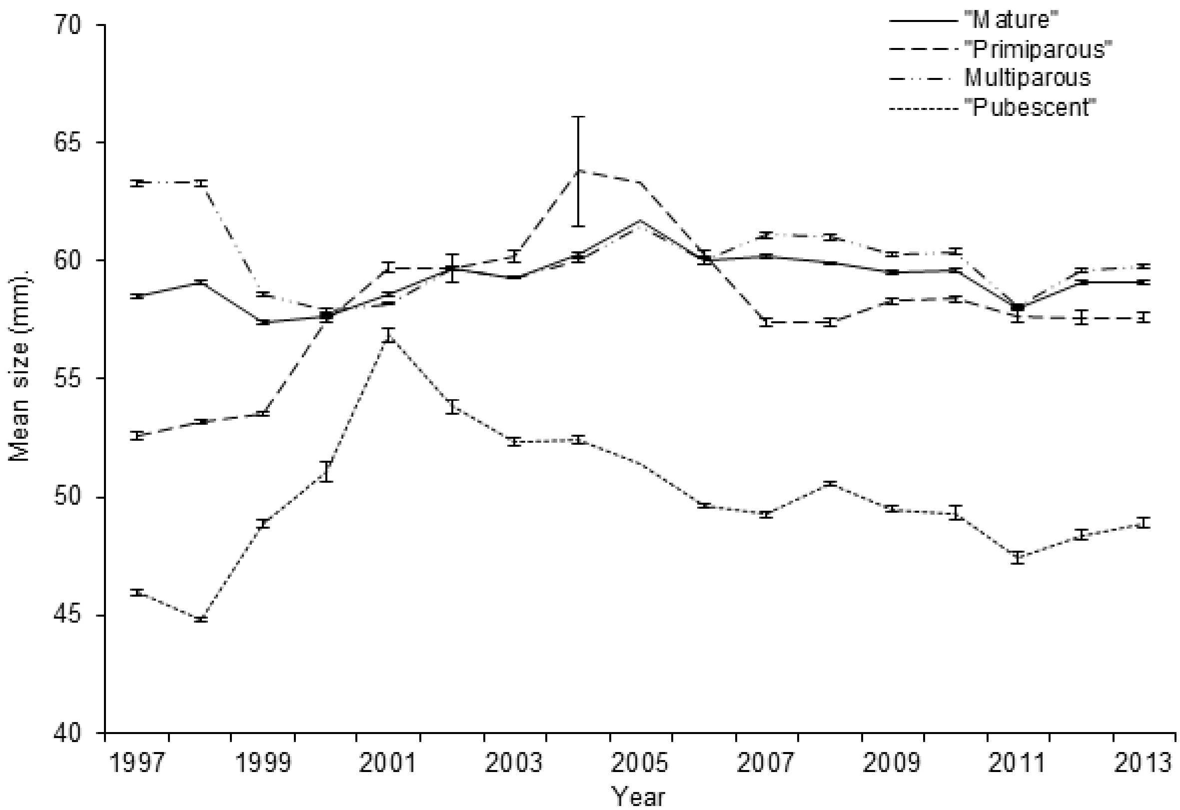


*Figure 13. Mean size (carapace width in mm) with standard errors of pubescent, primiparous, multiparous and mature snow crab (Chionoecetes opilio) females based on samples from the trawl surveys, 1997 to 2013.*

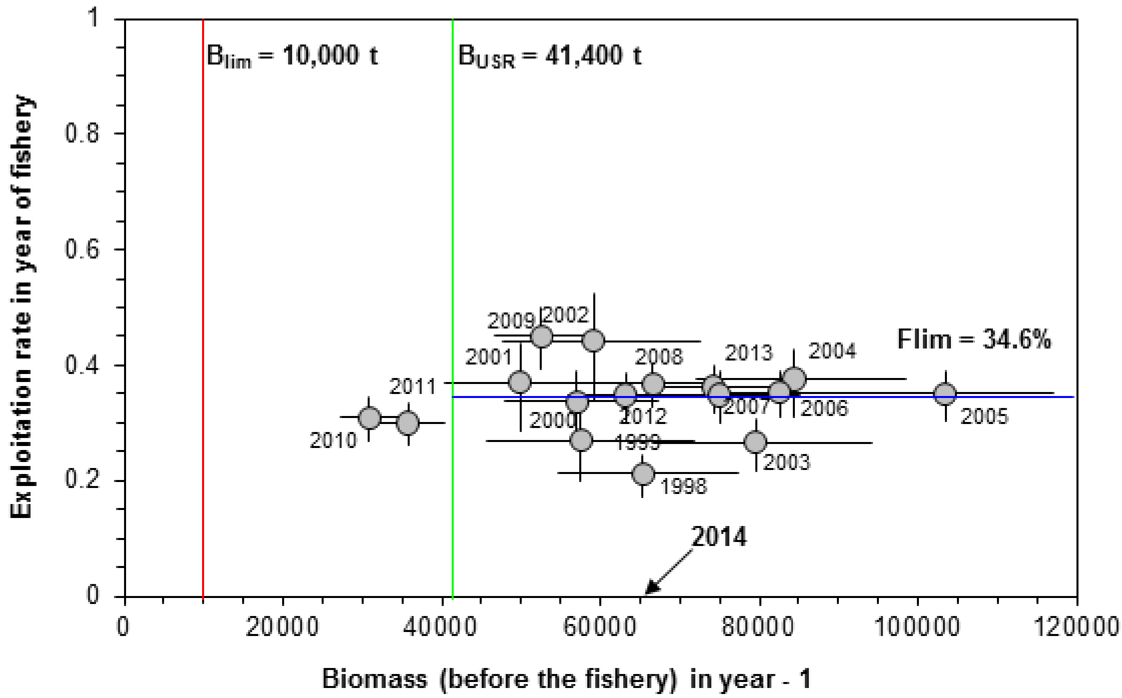


*Figure 14. Trajectory of stock abundance (biomass of commercial-sized adult male snow crab (Chionoecetes opilio) as estimated from the trawl survey in year t – 1 versus exploitation rate of this biomass in the fishery of year t. Year of the fishery is labelled on the figure. $B_{lim}$ = The limit reference point for biomass; Flim = Fishing removal rate limit reference point; $B_{USR}$ = The upper stock reference point.*

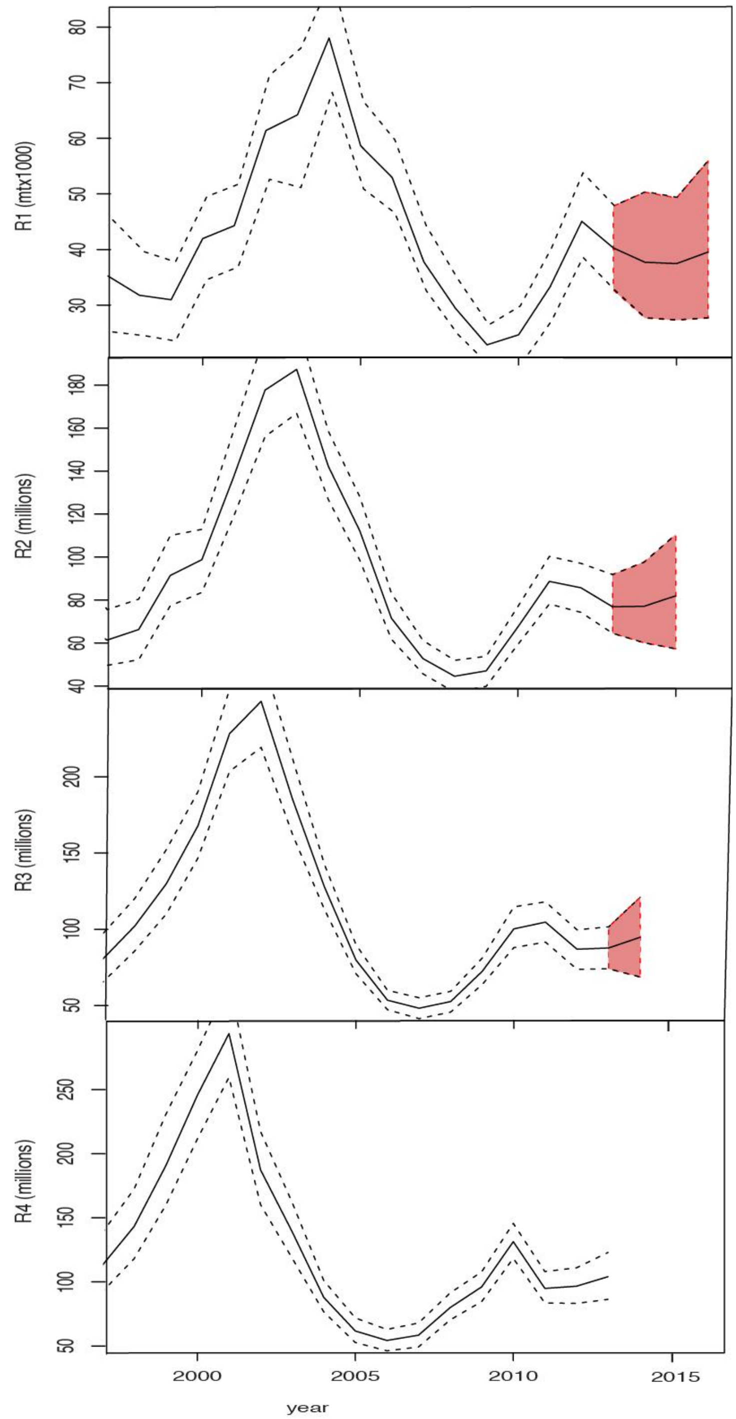


*Figure 15. Snow crab (Chionoecetes opilio) recruitment (R) abundance (mean with 95% confidence intervals) by pre-recruit stages (Rj), where j =1,…,4 years until recruitment to the fishery based on the survey data estimates. Shaded areas are forecasted abundance from the Bayesian model (Surette and Wade 2006).*

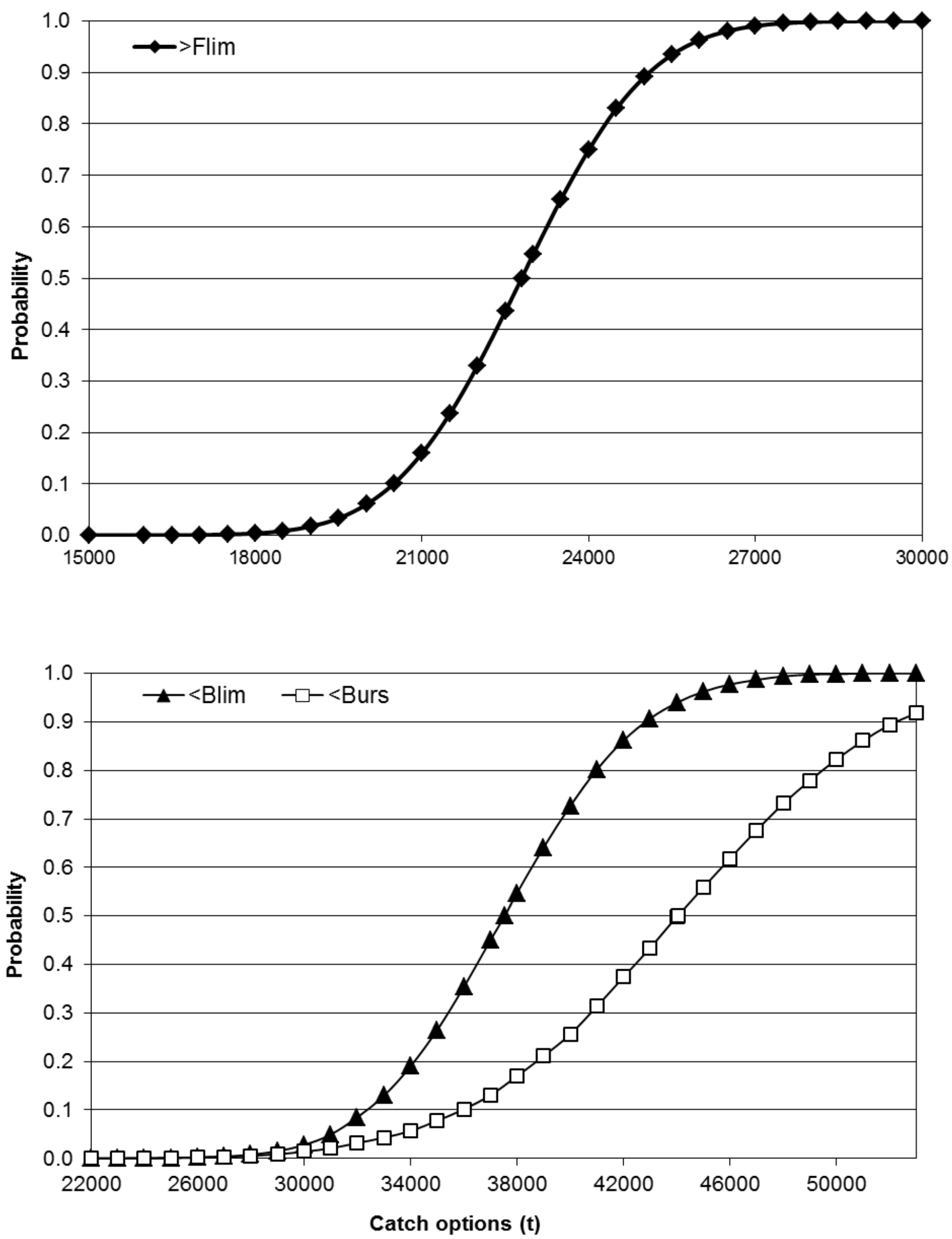


*Figure 16. Risk analysis of catch options (t) for the 2014 fishery based on the expanded polygon for the southern Gulf of St. Lawrence snow crab, Chionoecetes opilio, showing probabilities of exceeding the fishing removal rate limit reference point ($F_{lim}$), of the hard-shelled commercial-sized adult male remaining biomass in 2014 falling below the limit reference point for biomass ($B_{lim}$) and of the commercial-sized adult male biomass in 2014 will be below the upper reference point ($B_{USR}$) after the 2014 fishing season.*

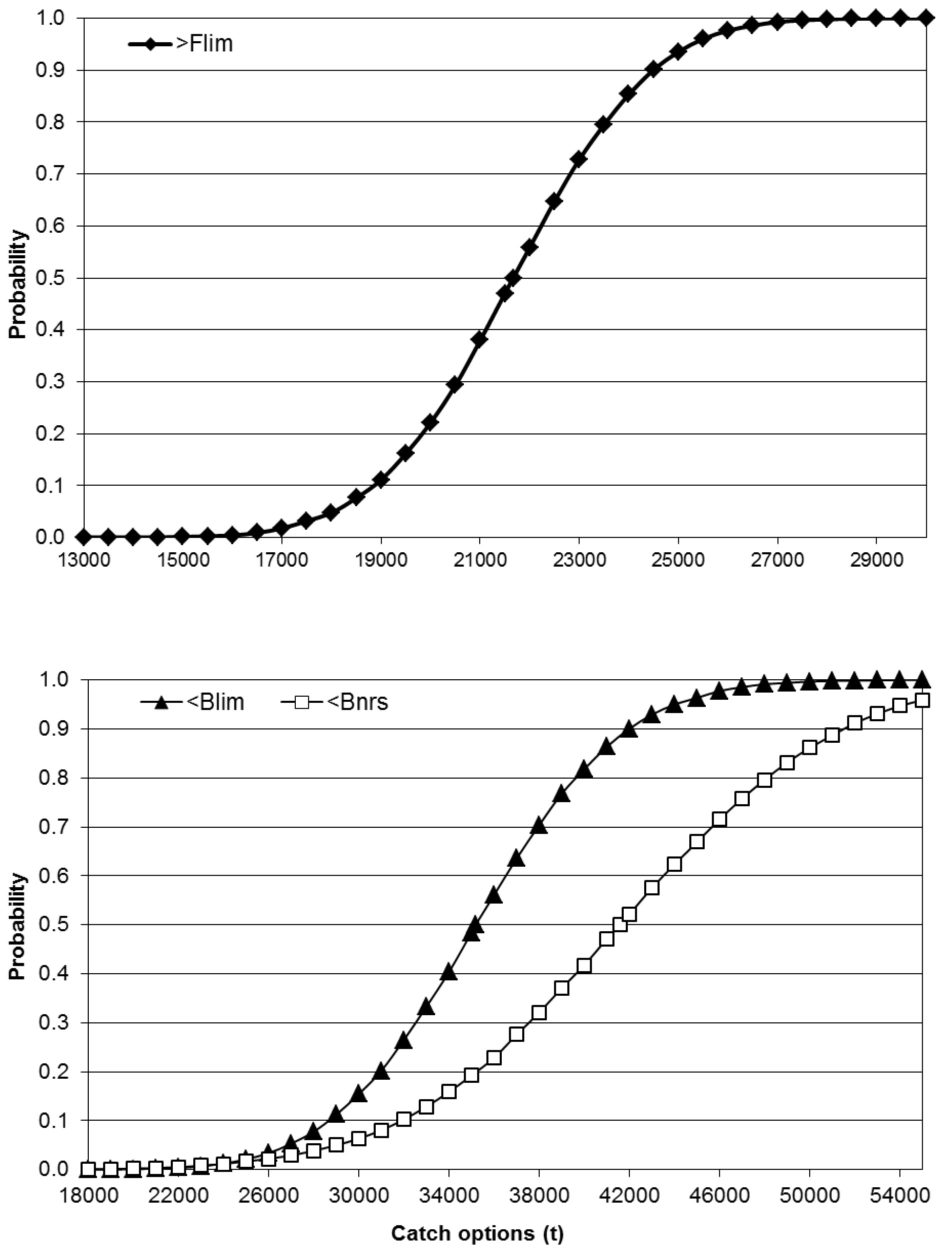


*Figure 17. Risk analysis of catch options (t) for the 2015 fishery based on the expanded polygon for the southern Gulf of St. Lawrence snow crab, Chionoecetes opilio, showing* probabilities of exceeding the fishing removal rate limit reference point (Flim), of the hard-shelled commercial-sized adult male remaining biomass in 2015 falling below the limit reference point for biomass (Blim) and of the commercial-sized adult male biomass in 2015 will be below the upper reference point (BUSR) after the 2015 fishing season.

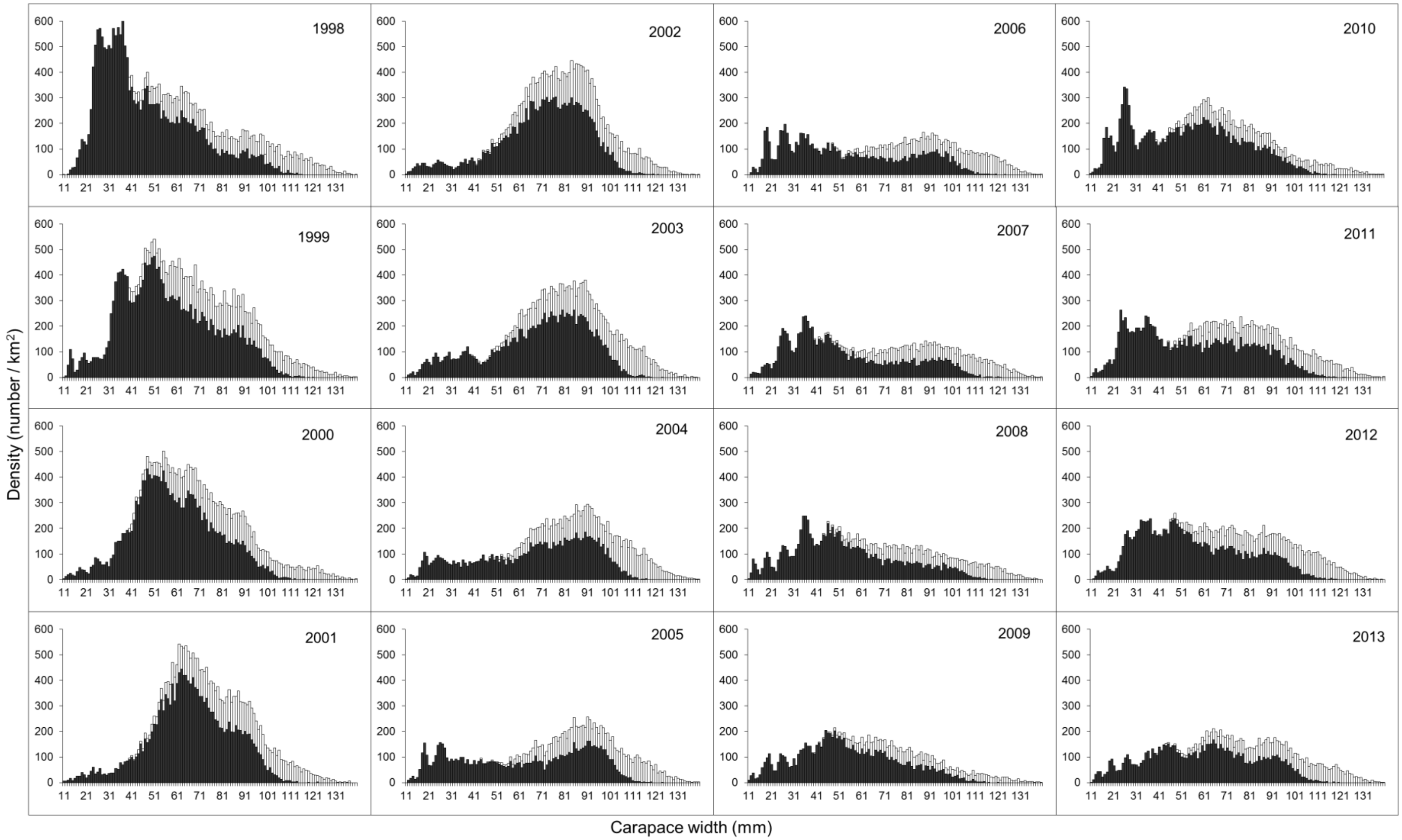


*Figure 18. Size frequency distributions (by 1 mm carapace width interval) for male snow crabs (white bars are adult males and black bars are adolescent males) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1997 to 2013. These size frequency distributions represent the mean number of male snow crab (Chionoecetes opilio) per km$^2$ based directly on samples in the trawl survey*.

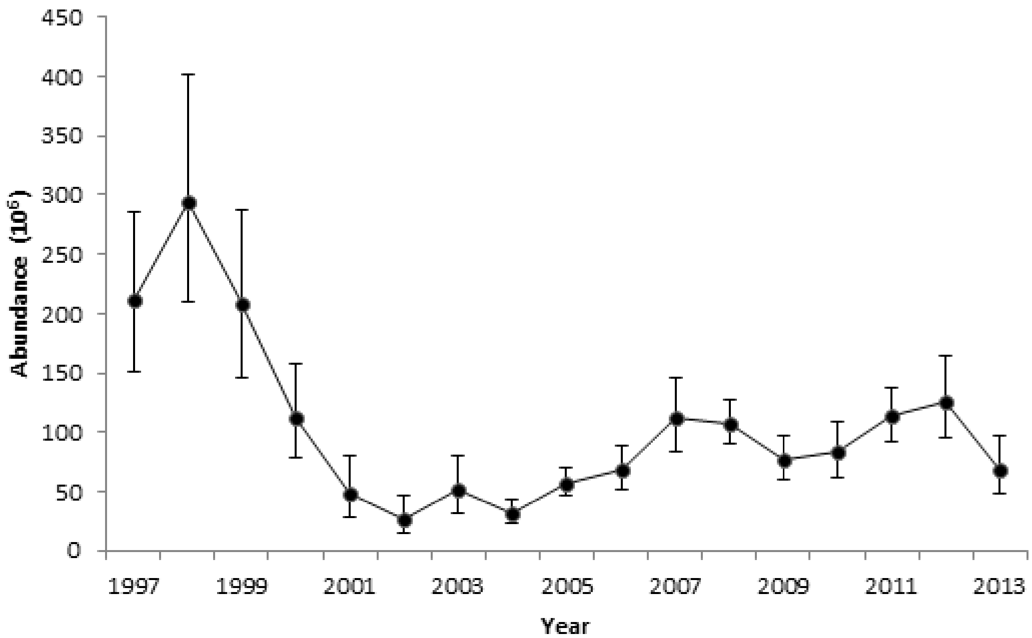


*Figure 19. Abundance indices of small adolescent male snow crab (Chionoecetes opilio) with carapace width between 34 to 44 mm estimated from the trawl survey data in the southern Gulf of St. Lawrence, 1997 to 2013. These are crabs which reach legal size in approximately 6 years.*

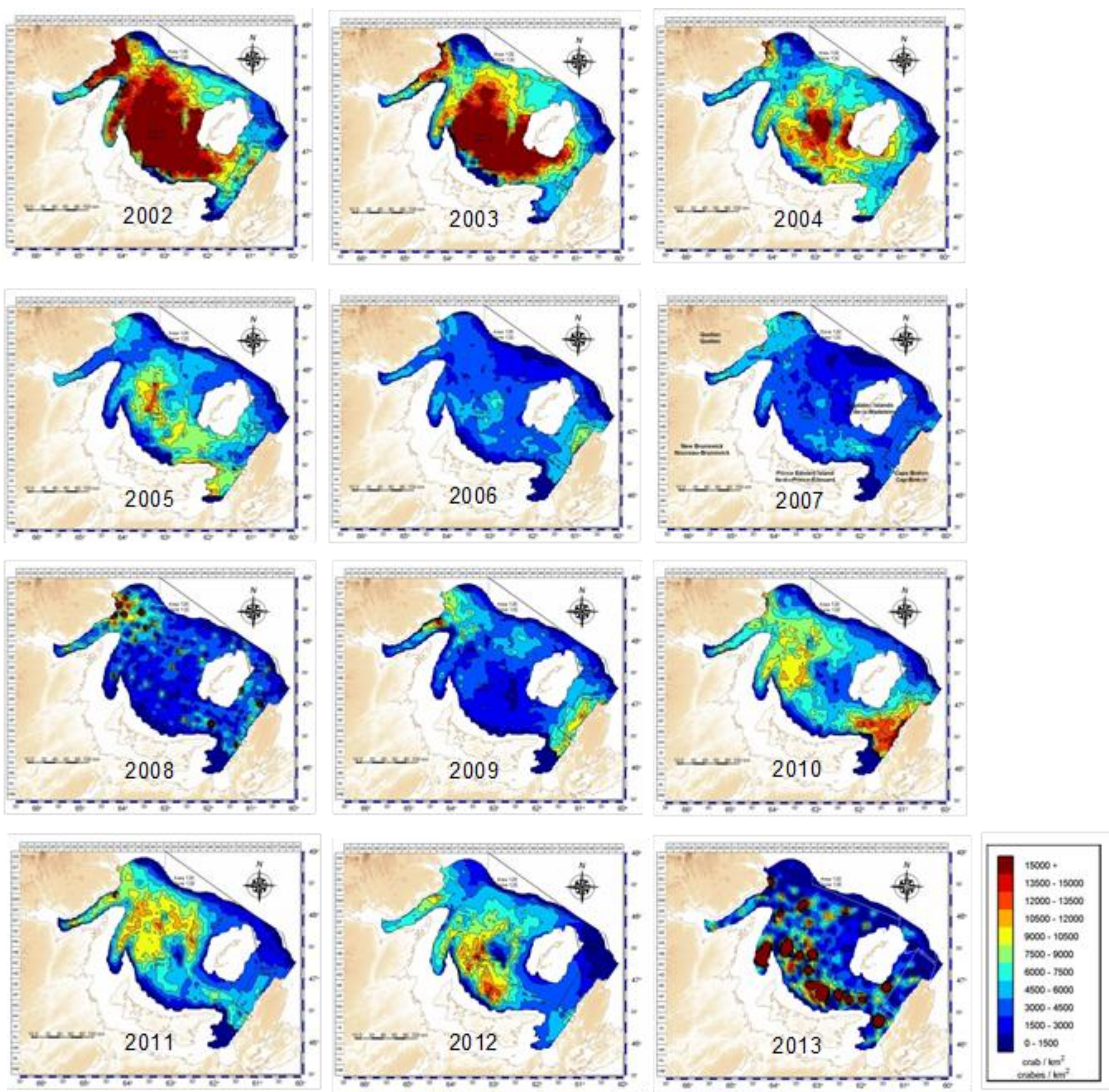


*Figure 20. Density (number per km²) contours of adolescent male snow crab, (Chionoecetes opilio), ≥ 56 mm of carapace width based on the trawl surveys conducted in the southern Gulf of St. Lawrence, 2002 to 2013.*

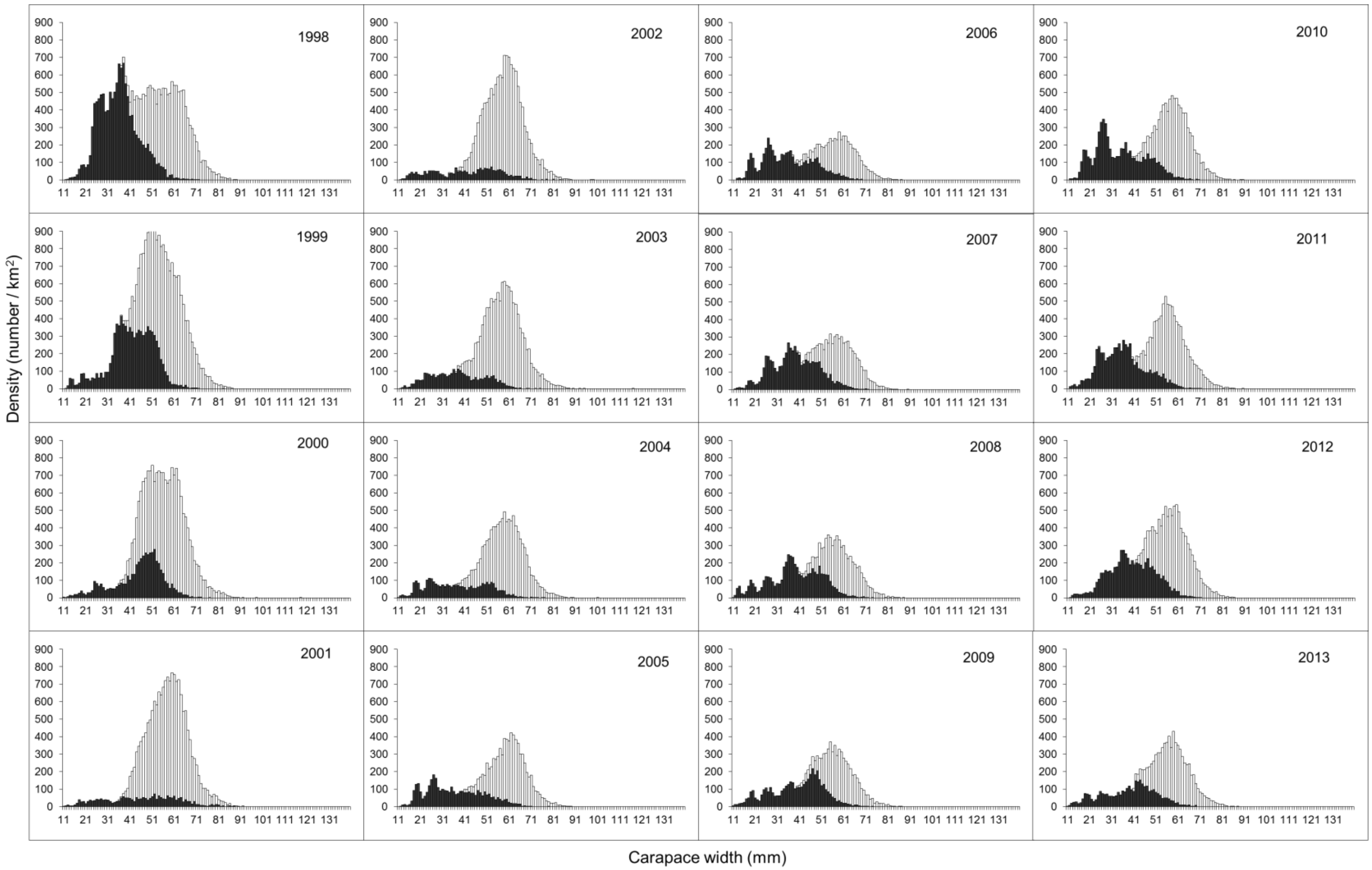


*Figure 21. Size frequency distributions (carapace width by 1 mm interval) for female (white bars are mature females and black bars are pubescent and immature females) snow crab (Chionoecetes opilio) based on samples from the post-fishery trawl surveys in the southern Gulf of St. Lawrence, 1997 to 2013. These size frequency distributions represent the mean number of female crab per km$^2$ directly based on samples in the trawl survey.*