Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2016/089

Gulf Region

Trends in the biomass, distribution, size composition and model-based estimates of commercial abundance of snow crab (*Chionoecetes opilio*) based on the multi-species bottom trawl survey of the southern Gulf of St. Lawrence, 1980-2015

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October 2016

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:

Benoît, H.P., and Cadigan, N. 2016. Trends in the biomass, distribution, size composition and model-based estimates of commercial abundance of snow crab (*Chionoecetes opilio*) based on the multi-species bottom trawl survey of the southern Gulf of St. Lawrence, 1980-2015. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/089. v + 20 p.

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ABSTRACT

The research vessel bottom-trawl survey of the southern Gulf of St. Lawrence undertaken each September (RV survey) provides reliable standardized indices of biomass, spatial distribution and habitat use of commercial-sized male snow crab (*Chionoecetes opilio*) for 2001 to the present and of all snow crab (aggregated index) for 1980 to the present. Furthermore, results from that survey have successfully been combined with data from a dedicated snow crab survey as part of model-based estimation of the abundance of commercial male snow crab. This document provides an update for biomass indices, spatial distribution, and size composition based on the results of the 2015 RV survey and an update of the model-based estimates of commercial crab abundance. This information was provided in support of the regional snow crab assessment process that took place in Moncton, NB on January 27-28, 2016. Of particular note, the RV survey confirmed a slight decline in the biomass of commercial-sized adult male snow crab from a recent high level, as was also estimated by the dedicated snow crab survey. Model-based estimates of commercial crab abundance in 2015 were above, yet close to, the long-term average. As in recent years, the 2015 RV survey captured an unusually high number of small crabs (≤15 mm) in several areas of the southern Gulf of St. Lawrence. This is seemingly part of a general increase in small crab abundance since the early 2000s.

Tendances de la biomasse, de la distribution, de la composition des tailles et des estimations de crabe des neiges (*Chionoecetes opilio*) de taille commerciale basées sur le relevé annuel multi-espèces au chalut de fond du sud du golfe du Saint-Laurent, 1980 à 2015

RÉSUMÉ

Le relevé annuel au chalut de fond effectué en septembre par un navire de recherche (NR) dans le sud du golfe du Saint-Laurent (ci-après nommé relevé par NR) produit des indices normalisés fiables de biomasse, de répartition et d'utilisation de l'habitat pour le crabe des neiges (*Chionoecetes opilio*) mâle de taille commerciale depuis 2001, et pour tous les crabes des neiges (indice agrégé) depuis 1980. De plus, les résultats provenant de ce relevé ont été intégrés avec succès aux résultats provenant d'un relevé visant principalement le crabe des neiges dans le cadre d'une estimation basée sur un modèle de l'abondance de crabes commerciaux. Dans le présent document de recherche, une mise-à-jour des indices de biomasse, de distribution et de répartition des tailles du relevé par NR sont présentés basés sur les résultats du relevé de 2015. De plus, une mise-à-jour est présentée pour l'estimation basée sur un modèle de l'abondance de crabes commerciaux. Ces informations sont fournies en appui au processus d'évaluation régionale du crabe des neiges, lequel a eu à Moncton, au N.-B., du 27 au 28 janvier 2016. En particulier, le relevé par NR confirme une légère baisse dans la biomasse de crabes adultes de taille commerciale du niveau élevé des années récentes, qui a aussi été observée dans le cadre du relevé dédié au crabe des neiges. L'estimation de l'abondance de crabes commerciaux basée sur un modèle suggère que l'abondance se trouvait au-delà mais près de la moyenne à long terme en 2015. Comme par les années récentes, en 2015 le relevé par NR a capturé un nombre anormalement élevé de petits crabs (≤15 mm) à plusieurs endroits dans le sud du golfe du Saint-Laurent. Ceci fait partie d'une tendance générale à la hausse qui a débutée au début des années 2000.

INTRODUCTION

There are two fishery-independent bottom-trawl surveys that provide relative abundance indices for snow crab in the southern Gulf of St. Lawrence (sGSL). One of the surveys is principally directed at snow crab and has been conducted annually since 1988 (henceforth called the crab survey, CS) (Hébert et al. 2014). The second is a multi-species research vessel bottom-trawl survey conducted annually since 1971 (henceforth called the research vessel survey, RVS), which was initially focused on demersal fish but which has provided information on snow crab in the catches since 1980 (Benoît 2014). Both surveys provide a coherent picture of the abundance, distribution, habitat preferences and demographic structure of sGSL snow crab (Benoît 2012).

This document provides an update for biomass indices, spatial distribution, and size composition of sGSL snow crab based on the results of the 2015 RVS. The document also provides an update for commercial snow crab abundance estimates derived from a model that integrates the data from the RVS and CS (Benoît and Cadigan 2014). This model addresses a number of shortcomings in the respective surveys to provide a standardized index of abundance for 1980 to 2015. These shortcomings include past changes in the sampling frame for the CS, uncalibrated changes in survey vessel and gear in the CS, and failure to disaggregate catches of snow crab in the RVS by sex and size prior to 2001 (details in Benoît and Cadigan 2013, 2014).

The information presented in this document was provided in support of the regional snow crab assessment process that took place in Moncton (NB) during January 27 and 28, 2016.

METHODS

BACKGROUND AND DATA

The September multi-species RV survey (RVS)

The RVS has been undertaken each September since 1971. It follows a random-stratified design, with strata defined on the basis of depth and area (Fig. 1) (see Hurlbut and Clay 1990 for details on the survey methodology). A common group of strata has been sampled annually since 1971, covering most of the southern Gulf of St. Lawrence (Northwest Atlantic Fishery Organization area 4T). Three inshore strata (strata 401, 402, and 403) were added to the survey in 1984. There are very few snow crab caught in these strata (Benoît and Cadigan 2013) and these strata and data are excluded from analyses that include years prior to 1984 so that the same set of strata are used in the time series analyzed. The target fishing procedure at each station during the survey is a 30 min. tow at a speed of 3.5 knots. The number of valid fishing sets completed annually has varied from approximately 70 during the early 1980s to 175 or more during much of the 1990s and 2000s. In 2015, 161 valid sets were completed (Table 1).

Catches of snow crab (numbers and mass per tow) have consistently been recorded in the survey since 1980 (Tremblay 1997). Prior to 1992, there was a small number of sets for which catch numbers were recorded but mass was not when the mass was <1 kg (Table 1). This was the consequence of the precision of the spring scales used at that time to weigh catches, and these cases were generally when catch per tow was ≤ 0.5 kg; amounts were generally rounded up to the nearest kg otherwise. For the calculation of an aggregated biomass index (kg/tow) the mass was assumed to be 0.5 kg in these cases, producing a very comparable result to that obtained using an estimated mean mass of crabs multiplied by the observed number in a set to estimate catch mass. For the model based estimates, such cases were assumed to reflect the absence of large snow crab (≥95 mm) in the catch (for an explanation see Benoît and Cadigan 2013). In most years prior to 2001 there was a small proportion of sets for which snow crab catch mass was recorded, but not catch numbers (Table 1). In these instances, the number caught was inferred using the stratum and year specific average catch mass per crab derived from sets with both catch and mass observations.

Since 2001, captured crabs have also been measured (carapace width) and sexed. Since 2012 all individual crabs were meant to be sexed, measured, weighed and their maturity determined based on the shape of the abdomen for females and based on measurements of chela height using the method of Conan and Comeau (1986) for males. In addition, any missing or regenerated appendages were meant to be noted. However, problems with the survey data entry system arising mid-way through the 2014 survey prevented the recording of chela height and appendage data. Consequently, the maturity of males could not be determined for the last 49 sets that caught males in 2014.

Fishing during the RV survey was carried out by the *E.E. Prince* from 1971 to 1985 using a Yankee-36 trawl. Since then, a number of different vessels have been used, each fishing a Western IIA trawl: the *Lady Hammond* (1985-1991), the *CCGS Alfred Needler* (1992-2002 and 2004-2005), the *CCGS Wilfred Templeman* (2003), and the *CCGS Teleost* (2004-present). Parameters for the trawls and vessels used in the RV survey are provided in Tables 2 and 3, respectively. Note that both trawls used in the survey are meant for fishing groundfish, though a liner is used in the codend to retain small animals.

Prior to the gear change and all but one of the vessel changes in the RVS (*CCGS Wilfred Templeman* used in 2003), paired tows involving the two vessels/gears at common sites were undertaken to estimate their relative catchabilities (Benoît and Swain 2003a; Benoît 2006). Based on these comparative fishing experiments, the *E.E. Prince* fishing the Yankee-36 was found to be less efficient at capturing snow crab compared to the *Lady Hammond* and *CCGS Alfred Needler*, and as a result corrections are applied to the *E.E. Prince* data prior to the calculation of indices for the RVS (Benoît and Swain 2003a; Benoît 2006). No corrections are applied for the CCGS Teleost (Benoît 2014). Note that in contrast to the approach used for the RVS indices, adjustments for differences in relative catchability between vessels are estimated and implemented directly in the model-based estimations (details below; Benoît and Cadigan 2014).

The absence of comparative fishing with the *CCGS Wilfred Templeman* used in 2003 precludes the direct estimation of catchability relative to other RVS vessels. Though the model of Benoît and Cadigan (2013, 2014) does provide an estimate for commercial-sized crabs (details below), it does not provide an estimate for size-aggregated catches and still needs to be validated with simulation testing. Consequently, results of the indices based exclusively on the RVS for 2003 are not presented in this report.

From 1971 to 1984, fishing in the RVS was restricted to daylight hours (07:00-19:00). Since 1985, fishing has been conducted 24 hours per day. Because fishing efficiency can vary by time of day, survey catches were standardized post-hoc for the calculation of indices from the RVS, based on the results of analyses of survey catches and comparative fishing over the diel cycle (Benoît and Swain 2003b; details in Benoît 2014). Note again that in contrast to the approach used for the RVS indices, adjustments for diel differences in relative catchability are estimated and implemented directly in the model-based estimations (details below; Benoît and Cadigan 2014).

The estimation model of Benoît and Cadigan (2014) is based in part on the abundance of commercial sized crabs (males ≥ 95 mm) in the RVS. Those values are directly available since 2001 but not for the 1980-2000 period. For the 1980-2000 time period, an empirical relationship between the mean mass of crabs in a survey set and the proportion of large males (*PLM*) in that set is used to predict the catches of commercial sized males based on length aggregated catches (details in Benoît and Cadigan 2013, 2016). Because the estimation of *PLM* is done with the model estimation process, uncertainty associated with inferring *PLM* is reflected in the uncertainty of the abundance estimates from the model.

The snow crab survey

The snow crab survey has been conducted annually since 1988, though survey coverage was very limited in 1996; details are available in Moriyasu et al. (2008). The survey has generally been conducted following the commercial fishery, generally beginning in July and ending in late September or early October, though the start and duration have varied between years. The survey follows a systematic random sampling design in which, for most years, stations were largely fixed once chosen. The survey gear is a Nephrops trawl (20 m Bigouden trawl net) and the target fishing procedure at each site is a 4 to 6 minute tow at an average speed of approximately 2 knots. Trawl mounted sensors are used to quantify the swept area of tows, which is used to standardize the catches. Each individual crab captured in the snow crab survey is sampled with respect to its biological characteristics. Here we consider only the catches of commercial sized-males. For 2015, there were 352 valid CS sets included in the analysis (Table 1).

Four chartered vessels have been used to conduct the survey since 1988: the side trawler Emy-Serge (1988 to 1998), and the stern trawlers, Den C Martin (1999 to 2002), Marco-Michel (2003 to 2012) and Jean-Mathieu (2013 to 2015). There has not been any comparative fishing between these vessels to estimate their relative fishing efficiency. In addition to the change in vessels, the survey gear was modified after 1990. Specifically, a chain that had been attached to the trawl footgear was subsequently wrapped around the footgear to increase gear-handling safety and fishing efficiency, based on the advice of experienced harvesters. There has been no comparative fishing with respect to the gear modification.

The snow crab survey sampling frame has changed considerably since the inception of the survey (Moriyasu et al. 2008; Benoît and Cadigan 2013). With the notable exception of 1996, the area covered generally increased over time though the area was largely constant from 1997 to 2005 and from 2006 to present. Survey data for 1988-1996 are not used in the stock assessment because of gaps in survey coverage with respect to the target sGSL snow crab assessment area (DFO 2012).

The approach of Benoît and Cadigan (2013, 2014, 2016) models the survey catches of commercial snow crab as a function of the RVS strata (Fig. 1). Stratum 417 was modified slightly to include a small area consistently sampled by the CS. Sets from the snow crab survey were attributed to the strata based on their respective geographic positions using the ‘point.in.polygon’ function in the ‘sp’ package for R (Bivand et al. 2008). The estimation domain for the model was strata 415 to 439, including the adjustment to stratum 417.

ANALYSIS

Multi-species RV survey indices

Trawlable biomass (kg) of commercial male snow crab in year t (RVt), was calculated as:

$$RV_t = Padult_t \sum_{l=1}^{L} \frac{U_l}{n_{l,t}} \sum_{i=1}^{n_{l,t}} \sum_{j=95}^{J} y_{i,j,t} \alpha j^{\beta} \quad (1)$$

for t = 2001 to 2015 (excluding 2003),

where $Padult_t$ is the proportion of snow crab ≥95mm that were adults in year t,

U_l is the number of trawlable units in stratum l (i.e., surface area / area swept by a standard tow),

$n_{l,t}$ is the number of survey tows in stratum l and year t,

$y_{i,j,t}$ is the standardized number of male crab of carapace width j caught in tow i in year t, and

α = 2.665E-7 and β = 3.089 are parameters for the relationship between carapace width (in mm) and mass (in g) (Hébert et al. 2014).

The values for $Padult_t$ were taken from the dedicated snow crab survey for all years for reasons of consistency (Hébert et al. 2014; Hébert pers. comm. for 2014 and 2015 value). Confidence intervals were calculated using the standard estimator for standard error based on stratified random sampling (Krebs 1989) and using a Satterthwaite approximation for the degrees of freedom for the t-value.

An aggregated biomass index for snow crab per standard 1.75 NM tow (mean kg/tow, B_t ; all sizes and sexes) was calculated as:

$$B_t = \sum_{l=1}^{L} \frac{U_l}{U \cdot n_{l,t}} \sum_{i=1}^{n_{l,t}} b_{i,t} \qquad (2)$$

for t = 1980 to 2013 (excluding 2003),

where U is the total number of trawlable units in the survey domain and

$b_{i,t}$ is the observed biomass (kg) of snow crab in set i of year t.

Analyses for B_t were undertaken for two geographic areas of inference: the current snow crab assessment area representing 57,840 km^2, and the RV survey area for strata 415-439 (Fig. 1) representing 70,061 km^2. To approximate the snow crab assessment area, strata 401-403, 420, 421, 428, 432, and 435 were excluded from the analysis. Analyses for RV_t were only undertaken for the geographic area equivalent to the current snow crab assessment area because the values of $Padult_t$ are pertinent to this area.

Annual survey-weighted proportions ($P_{j,s,t}$) of sGSL crab as a function of each mm carapace diameter j, and each sex (for 2001-2011) or sex and maturity stage (2012-2015) s, were calculated as:

$$P_{j,s,t} = \sum_{i} \left(w_{i,t} \cdot y_{i,j,s,t} \right) \Big/ \sum_{s} \sum_{j_s} \sum_{i} \left(w_{i,t} \cdot y_{i,j_s,s,t} \right) \qquad (3)$$

where $w_{i,t} = \dfrac{U_l}{U \cdot n_{l,t}}$.

These values were used to produce annual histograms for the RV survey catches.

Catch rates as numbers per tow of commercial-sized adult male snow crab in the RV survey were mapped using inverse distance weighted gradient interpolation. The contour levels for plotting were defined as the 10th, 25th, 50th, 75th, and 90th percentiles of non-zero catches over the period of interest, 2001-2015 (excluding 2003). Catch rates of small crab (≤15 mm) were likewise mapped to illustrate their spatial distribution given an observed high relative abundance since 2012.

Integrated abundance index estimation model

Here we provide a summary of the estimation model (see Benoît and Cadigan (2014, 2016) for additional details).

The basic model assumes that crab density is stochastically constant within strata, i.e., density varies randomly within a stratum with a constant mean. Density is assumed to be independent from site to site within strata, and crab densities are modeled separately for each stratum and for each year. The index of stock size is based on the strata size-weighted average of the strata densities. Trawl catches are basically assumed to be Negative Binomial (NB) random variables, which is considered suitable for modeling trawl catches (Cadigan 2011). Trawl catches are assumed to be a function of the underlying density, catchability of commercial snow crab to the surveys, and the area swept by survey tows.

The model contains parameters that account for factors that affect the catchability of crab within and between surveys. First, there is a parameter that accounts for different catchability between day (7:00-19:00) and night tows in the RVS. Information to estimate this parameter comes from the contrasts between day and night catches in the RVS within common strata and years and for repeated (paired) tows conducted day and night at the same sites, typically within 24 hrs. No diel adjustment is required for the CS (Benoît and Cadigan 2013).

Second, there is a suite of parameters to account for catchability differences between vessels used for the surveys (qv; see Figure 2 for a summary of which vessels were used in each year):

$$q_v = \begin{cases} 1, & v = Teleost, & 2004-2014, \\ q_{WT\rightarrow T}, & v = Wilfred\ Templeman, & 2003, \\ q_{AN\rightarrow T}, & v = Alfred\ Needler, & 1992-2005,\ not\ 2003, \\ q_{LH\rightarrow T} = q_{LH\rightarrow AN}\,q_{AN\rightarrow T}, & v = Lady\ Hammond, & 1985-1992, \\ q_{EP\rightarrow T} = q_{EP\rightarrow LH}\,q_{LH\rightarrow AN}\,q_{AN\rightarrow T}, & v = EE\ Prince, & 1980-1985, \\ q_{SCS1\rightarrow T}, & gear\ used\ in\ SCS1, & 1988-1990, \\ q_{SCS2\rightarrow T}, & gear\ used\ in\ SCS2, & 1991-1998, \\ q_{SCS3\rightarrow T}, & v\ in\ SCS3, & 1999-2002, \\ q_{SCS4\rightarrow T}, & v\ in\ SCS4, & 2003-2012. \\ q_{SCS5\rightarrow T}, & v\ in\ SCS5, & 2013-2015 \end{cases}$$

The notation $q_{a\rightarrow b}$ indicates the catchability of vessel a relative to vessel b. The catchability of the CCGS Teleost was fixed at one and CCGS Teleost was the reference vessel. Information to estimate the catchabilities for all RVS vessels except the Wilfred Templeman comes almost exclusively from the paired-tow comparative fishing data (within-pair catch contrast). Because there was no direct comparative fishing between the EE Prince or the Lady Hammond and the CCGS Teleost, these conversions were inferred stepwise, e.g. $q_{EP\rightarrow T} = q_{EP\rightarrow LH}\,q_{LH\rightarrow AN}\,q_{AN\rightarrow T}$. Information to estimate the catchabilities for the remaining vessels (Wilfred Templeman and the five CS vessels, SCS1-SCS5) comes from contrasts in catches between surveys, within strata and years.

Third, there are two parameters that determine the NB over-dispersion; one for between-site variability of crab density (k) and one for within pair over-dispersion (kp).

The model was implemented in Template Model Builder (TMB; Kristensen 2013), a new model fitting environment that provides considerably efficient and rapid estimation of random effects, as are used here to model the NB over-dispersion and to address within pair correlations.

RESULTS AND DISCUSSION

MULTI-SPECIES RV SURVEY INDICES

The biomass of commercial-sized adult male snow crab increased from a relatively low level in 2001, to a relatively high level mid-decade, declining to the lowest levels of the 2000s in 2010 (Fig. 3). Since then, the index has increased, reaching a level in 2013 and 2014 that is comparable to that of the mid-2000s, before declining a little in 2015.

The RV survey aggregated biomass index (all sizes, both sexes) provides a longer-term perspective of snow crab population dynamics in the sGSL (Fig. 4). Trends in this index during the 2000s generally match those observed for large male crab (Fig. 3) because the large males typically comprise the bulk of the biomass in the catches. The exception was in 2013, when the aggregated index reached its highest value since the early 1990s (Fig. 4). The value for 2015 was above the long-term average of around 6.0 kg/tow.

The size-frequency distributions of crabs in the RV survey are shown in Figure 5. Generally, the late 2000s were characterized by a higher proportion of snow crab < 30 mm, relative to the early 2000s. In particular, a very high proportion of small crab (≤ 15 mm) was observed in the 2012 to 2015 surveys. Crabs of this size were captured at higher abundances and in more locations in 2013 to 2015 compared to surveys in 2001 to 2011 (Fig. 6). In fact, high densities of small crabs were caught throughout most of the survey area. These crabs may represent a very early signal of strong incoming recruitment that will hopefully be tracked over the coming years.

The relative composition of commercial-sized adult male crab in 2015 was comparable to the levels seen in 2007, 2008 and 2011 to 2014 (Fig. 5). As in 2012 to 2014, the proportion of crab larger than 110 mm remained small and at a level comparable to that observed during the relatively low abundance years of 2001 and 2009. Densities of commercial-sized adult male snow crab over the Magdalen shallows and the west of Cape Breton Island in the 2015 RV survey were similar to those observed in 2013 to 2014 (Fig. 7).

INTEGRATED ABUNDANCE INDEX ESTIMATION MODEL

The model-based index of commercial crab abundance has generally followed a cyclic pattern with a period of roughly 10 years (Fig.8; Table 4). For the most recent period, the index peaked in 2013 and 2014 and declined a little in 2015. The value for the index in 2015 is just above the long-term (1980 to 2015) mean level. Residuals from the model do not indicate any problems with model fit with the addition of the 2015 data (Fig. 9).

The annual CS was undertaken by the vessel Jean-Matthieu (SCS5) for the third year and the relative catchability of that vessel is still estimated to be one of the lowest of the five vessel/gear combinations used for the survey since 1988 (Table 5). While its catchability is significantly different from that of the CS vessel that was in operation from 1999 to 2003, the confidence intervals for the relative catchability parameters for SCS5 and SCS4 (2004 to 2012) overlap slightly.

Overall, the conclusions of Benoît and Cadigan (2013, 2014) remain valid with the addition of the 2015 values. The model provides a useful method for integrating the available data on snow crab abundance in the sGSL, making the best use of available data. The model draws strength from both the RV and crab surveys to estimate relative catchability parameters that would otherwise be difficult to estimate (SCS1-SCS5 and $q_{WT \rightarrow T}$). Furthermore, the model provides a useful framework in which to efficiently estimate relative catchability coefficients for the RV survey vessels and for a diel effect by drawing simultaneously on information from samples that are grouped at the site level and at the stratum. By estimating these parameters within a common modeling framework, their associated uncertainties are reflected in the estimated abundance index. Simulation testing of the model to ensure its statistical reliability has begun and should be complete in time for the next sGSL snow crab assessment.

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TABLES

Table 1. Annual summary of the number of sets from the research vessel (RVS) and snow crab (CS) surveys used to estimate the abundance index. The summary for the RVS sets is further broken down to indicate the number of sets for which both catch mass and numbers were recorded and sets for which values of only one of the two variables was recorded.

Year	RVS total valid sets	RVS sets with numbers and mass	RVS sets with numbers only	RVS sets with mass only	CS valid sets
1980	70	47	2	21	na
1981	70	57	13	0	na
1982	65	47	17	1	na
1983	67	48	14	5	na
1984	102	85	12	5	na
1985	209	162	41	6	na
1986	164	156	0	8	na
1987	152	128	13	11	na
1988	147	121	19	7	154
1989	166	143	14	9	155
1990	141	134	6	1	212
1991	188	184	0	4	215
1992	162	154	0	8	233
1993	183	176	0	7	208
1994	154	150	0	4	259
1995	175	168	0	7	260
1996	194	189	0	5	72
1997	202	185	0	17	259
1998	192	145	0	47	261
1999	180	175	0	5	277
2000	182	181	0	1	280
2001	141	141	0	0	290
2002	173	173	0	0	319
2003	78	78	0	0	317
2004	212	212	0	0	347
2005	231	231	0	0	355
2006	165	165	0	0	354
2007	163	163	0	0	355
2008	177	177	0	0	355
2009	148	148	0	0	355
2010	137	137	0	0	354
2011	126	126	0	0	353
2012	142	142	0	0	321
2013	122	122	0	0	351
2014	156	156	0	0	353
2015	161	161	0	0	352

Table 2. Parameters for the two trawls used in the RV survey of the southern Gulf of St. Lawrence.

Characteristics	Yankee 36	Western IIA
Years in operation	1971 to 1984	1985 to present
Footrope	7 inch (outer sections) and 14 inch (inner sections) rubber disc spacers + 17 lb. iron spacers	21 inch (outer) and 18 inch (inner) rubber bobbins and 6.75 inch diameter 7 inch long rubber spacers
Footrope length (feet)	80	106
Headline length (feet)	60	75
Headline height (feet)	9	15
Wingspread (feet)	35	41
Door type	Steel bound wood	Portuguese (all steel)
Door weight (lb)	1,000	1,800
Lengthening piece liner (inches)	1.25	1.25
Codend liner (inches)	0.25	0.75

Table 3. Parameters for the vessels used in the RV survey of the southern Gulf of St. Lawrence for the years presented in this report.

Characteristics	*E.E. Prince*	*Lady Hammond*	*CCGS Alfred Needler*	*CCGS Teleost*
Vessel type	Stern trawler	Stern trawler	Stern trawler	Stern trawler
Tonnage	406	897	959	2,405
Length	40 m	58 m	50 m	63 m

Table 4. Model-based estimates of annual density (number per km^2; mean, coefficient of variation (CV) and 95% confidence intervals) of sGSL snow crab abundance.

Year	Estimate	CV	Lower 95%	Upper 95%
1980	107.654	0.36	53.104	218.237
1981	81.655	0.43	35.002	190.493
1982	135.091	0.39	62.876	290.251
1983	149.177	0.40	68.175	326.421
1984	70.425	0.32	37.384	132.669
1985	46.972	0.23	29.688	74.319
1986	56.318	0.23	35.922	88.294
1987	64.429	0.24	39.907	104.021
1988	80.449	0.26	48.213	134.238
1989	79.560	0.19	54.589	115.955
1990	221.800	0.18	154.474	318.470
1991	130.532	0.15	98.093	173.699
1992	150.259	0.14	115.225	195.945
1993	184.288	0.14	138.935	244.444
1994	205.403	0.14	155.936	270.562
1995	146.613	0.14	111.704	192.431
1996	63.664	0.16	46.263	87.609
1997	85.500	0.13	65.825	111.055
1998	95.086	0.13	73.068	123.738
1999	72.547	0.14	55.456	94.905
2000	65.442	0.14	50.134	85.426
2001	65.873	0.14	49.638	87.417
2002	80.786	0.14	61.530	106.068
2003	129.603	0.11	105.254	159.585
2004	136.658	0.09	114.517	163.078
2005	123.947	0.09	104.455	147.076
2006	104.942	0.09	88.489	124.453
2007	88.040	0.08	75.148	103.143
2008	74.822	0.08	63.899	87.611
2009	47.247	0.09	39.604	56.365
2010	47.923	0.09	40.357	56.907
2011	91.125	0.08	77.196	107.566
2012	99.626	0.09	83.889	118.316
2013	119.812	0.10	98.165	146.233
2014	121.238	0.10	100.386	146.420
2015	108.892	0.10	90.041	131.689

Table 5. Estimates (mean, CV, and 95% confidence interval) of some snow crab model parameter estimates.

Parameter	Estimate	CV	Lower 95%	Upper 95%
δ diel	1.582	0.04	1.454	1.721
k	2.772	0.07	2.431	3.161
k_p	0.995	0.04	0.925	1.069
$q_{AN \rightarrow T}$	0.963	0.10	0.786	1.180
$q_{LH \rightarrow AN}$	1.310	0.11	1.061	1.617
$q_{PR \rightarrow LH}$	0.445	0.16	0.327	0.606
$q_{WT \rightarrow T}$	0.615	0.21	0.408	0.926
$q_{SCS1 \rightarrow T}$	10.437	0.19	7.223	15.081
$q_{SCS2 \rightarrow T}$	21.140	0.12	16.666	26.815
$q_{SCS3 \rightarrow T}$	25.378	0.13	19.627	32.814
$q_{SCS4 \rightarrow T}$	19.345	0.06	17.297	21.636
$q_{SCS5 \rightarrow T}$	14.678	0.09	12.272	17.557

FIGURES

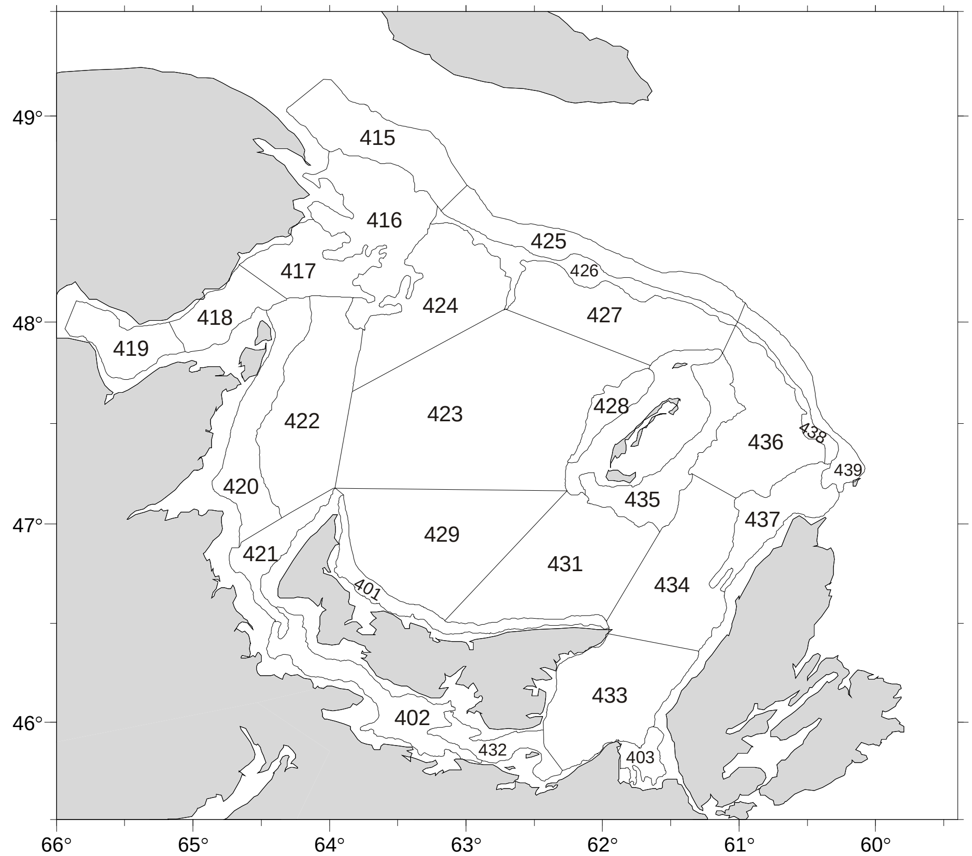

Figure. 1. Stratum boundaries for the southern Gulf of St. Lawrence September RV survey.

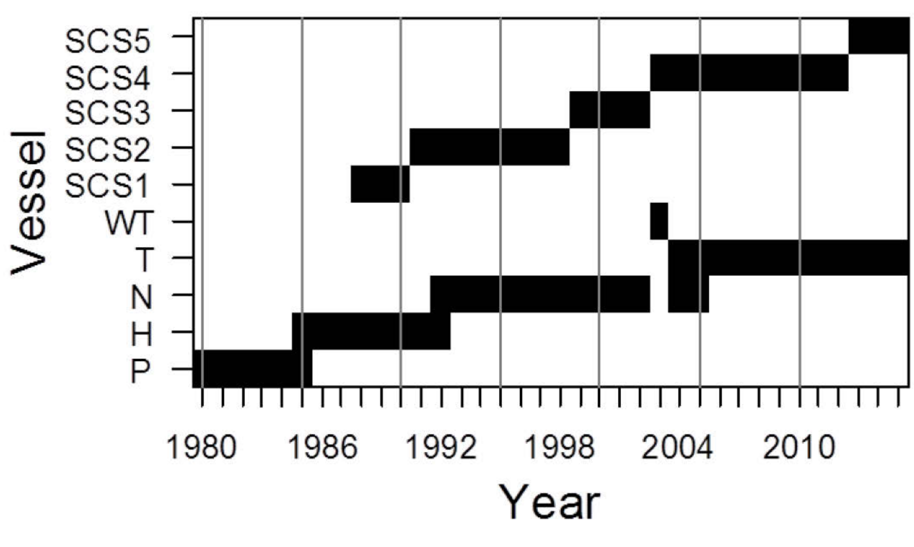

Figure 2. Summary of the survey vessels used in the snow crab surveys (SC) and research vessel survey (RVS) as a function of year for 1980-2015

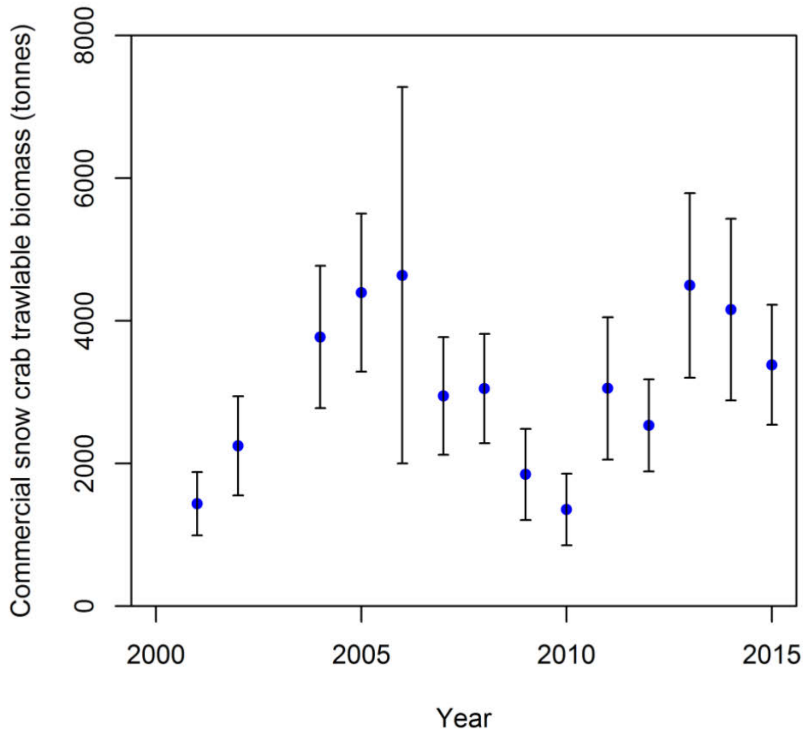

Figure 3. Estimated trawlable biomass (tonnes; mean ± 95% confidence interval) of commercial-sized adult male snow crab in the RV survey, 2001-2015, for a geographic area comparable to that used for the current snow crab assessment.

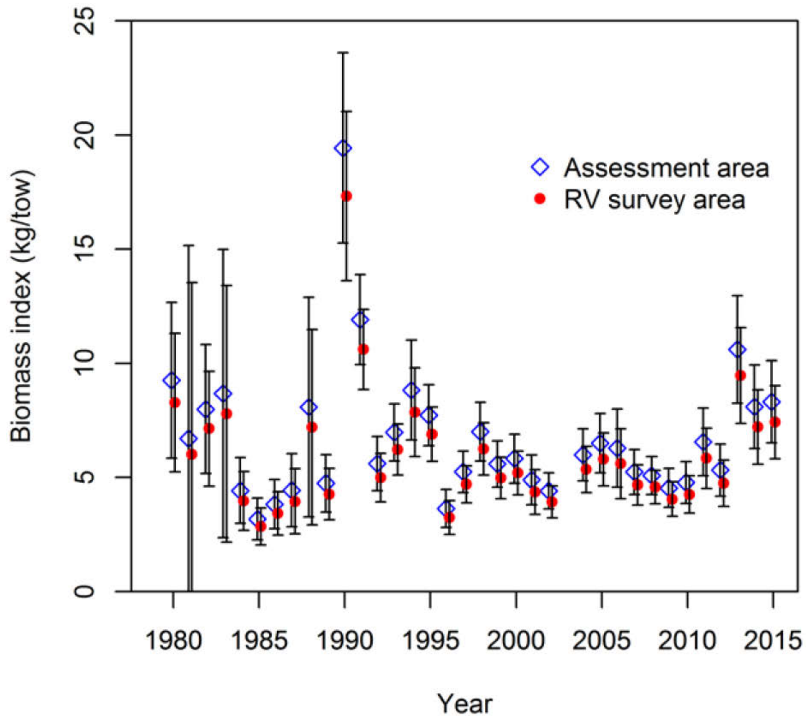

Figure 4. Biomass index (kg/tow; mean ± 95% confidence interval) for all snow crab (male and female) in the RV survey, 1980-2015, for a geographic area comparable to that used for the current snow crab assessment (open blue diamond) and for the entire RV survey area (solid red circle).

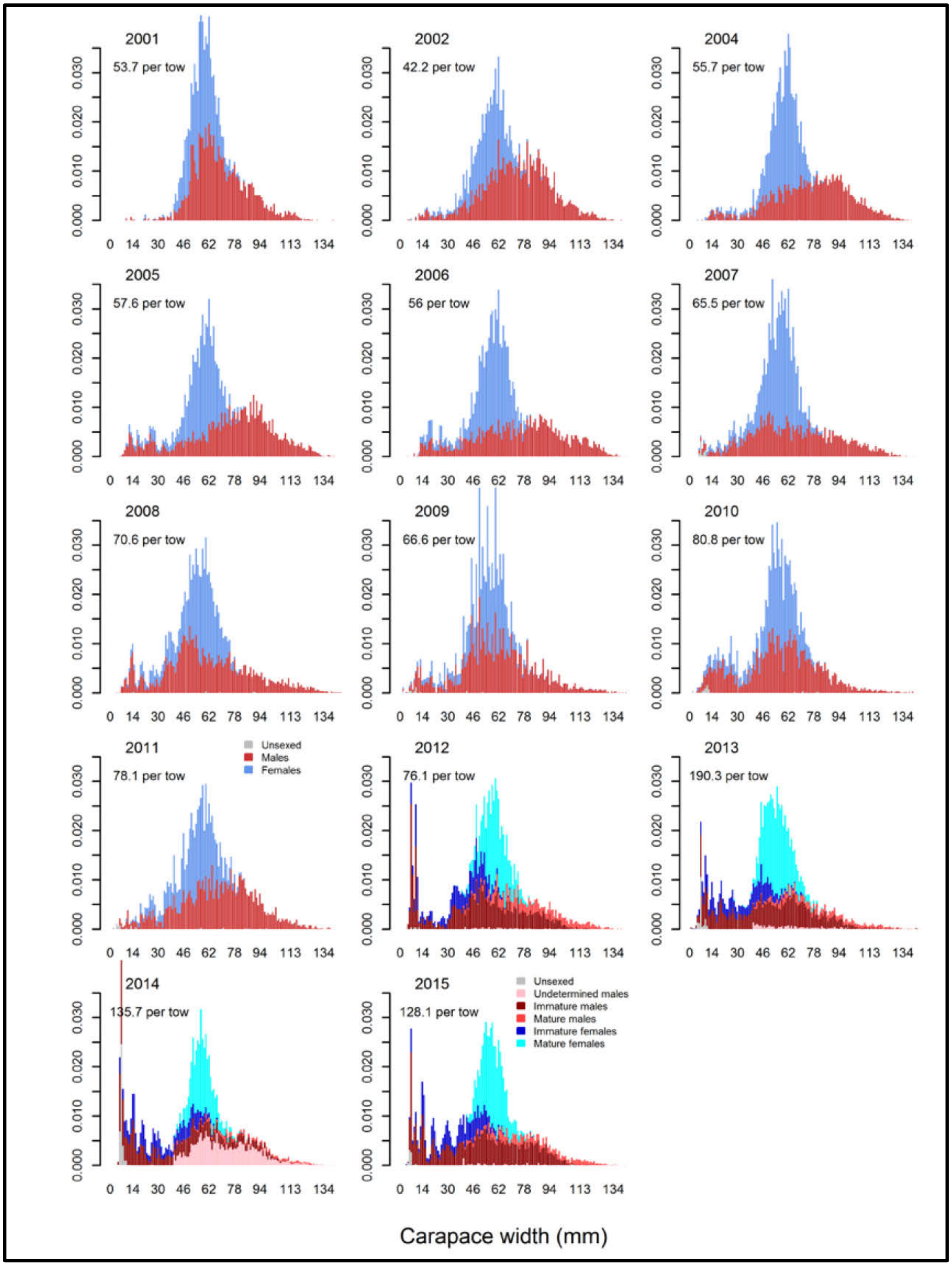

Figure 5. Annual survey-weighted relative frequency distributions (expressed as proportions) of snow crab by carapace width (mm) as a function of sex (for 2001 to 2011) or sex and maturity stage (2012 to 2015). The numbers in each panel indicate the value of the annual abundance index (numbers per tow) for snow crab (all sizes and sexes). The data for 2003 are not shown because that survey was incomplete.

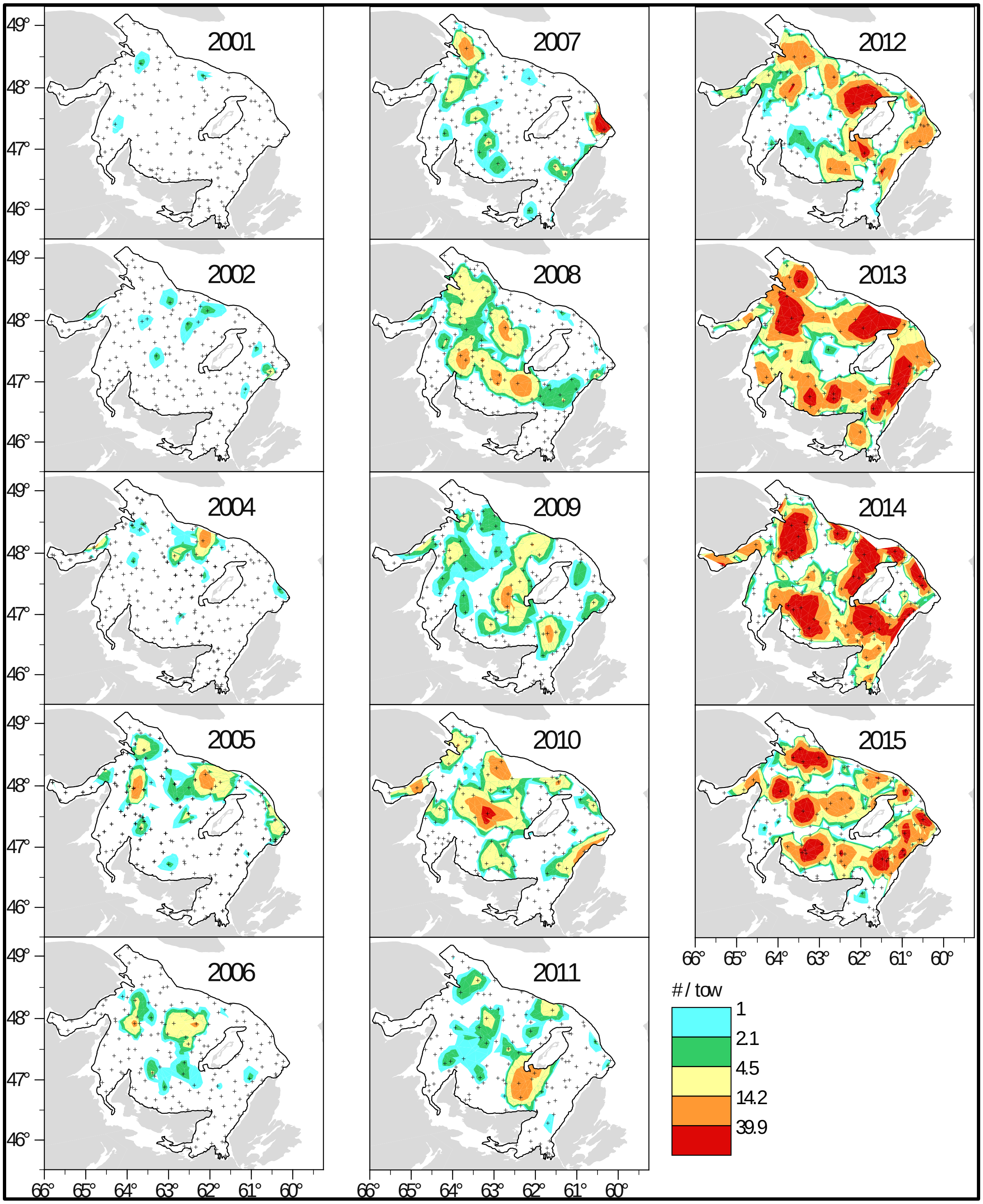

Figure 6. Annual geographic distribution of catch rates (number of crabs per tow) of small snow crab (≤15 mm) in the September RV survey, 2001 to 2015 (excluding 2003). The small crosses indicate the set locations. The contour levels represent the 10th, 25th, 50th, 75th and 90th percentiles of non-zero catches for the entire period.

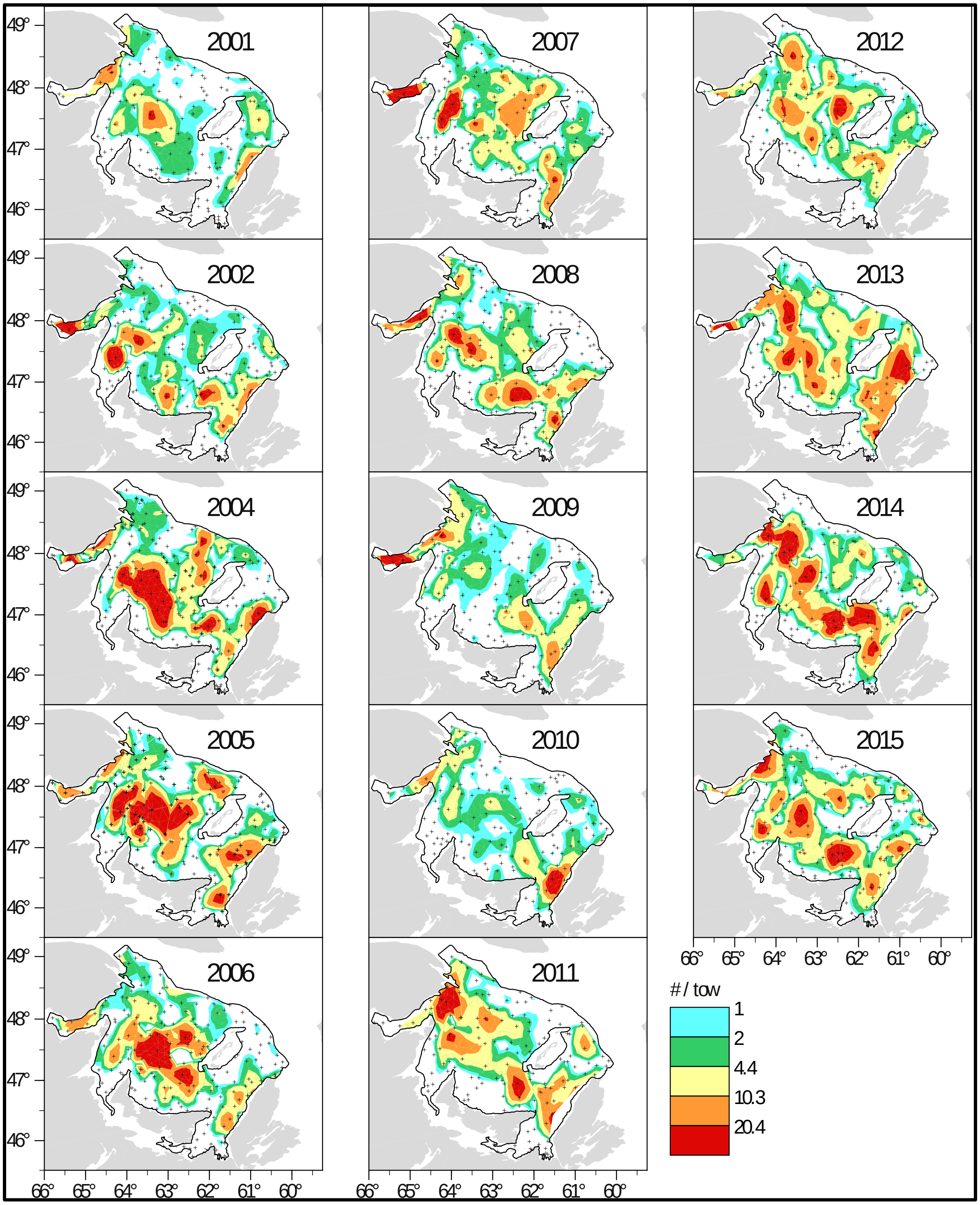

Figure 7. Annual geographic distribution of snow crab catch rates (number of crabs per tow; males ≥95 mm) in the September RV survey, 2001 to 2015 (excluding 2003). The small crosses indicate the set locations. The contour levels represent the 10th, 25th, 50th, 75th and 90th percentiles of non-zero catches for the entire period.

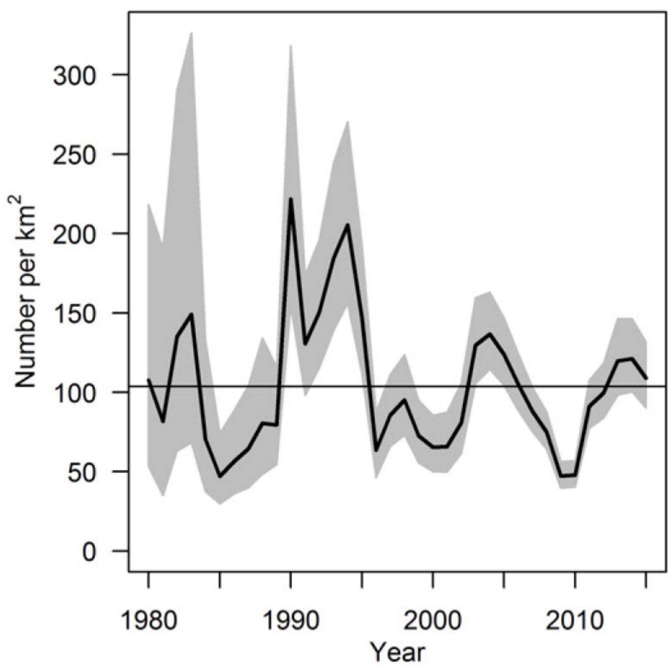

Figure 8. Annual estimated densities (number per km²) of southern Gulf commercial male snow crab, 1980 to 2015. The horizontal lines indicate the series average and the shaded region indicates the 95% confidence interval ranges.

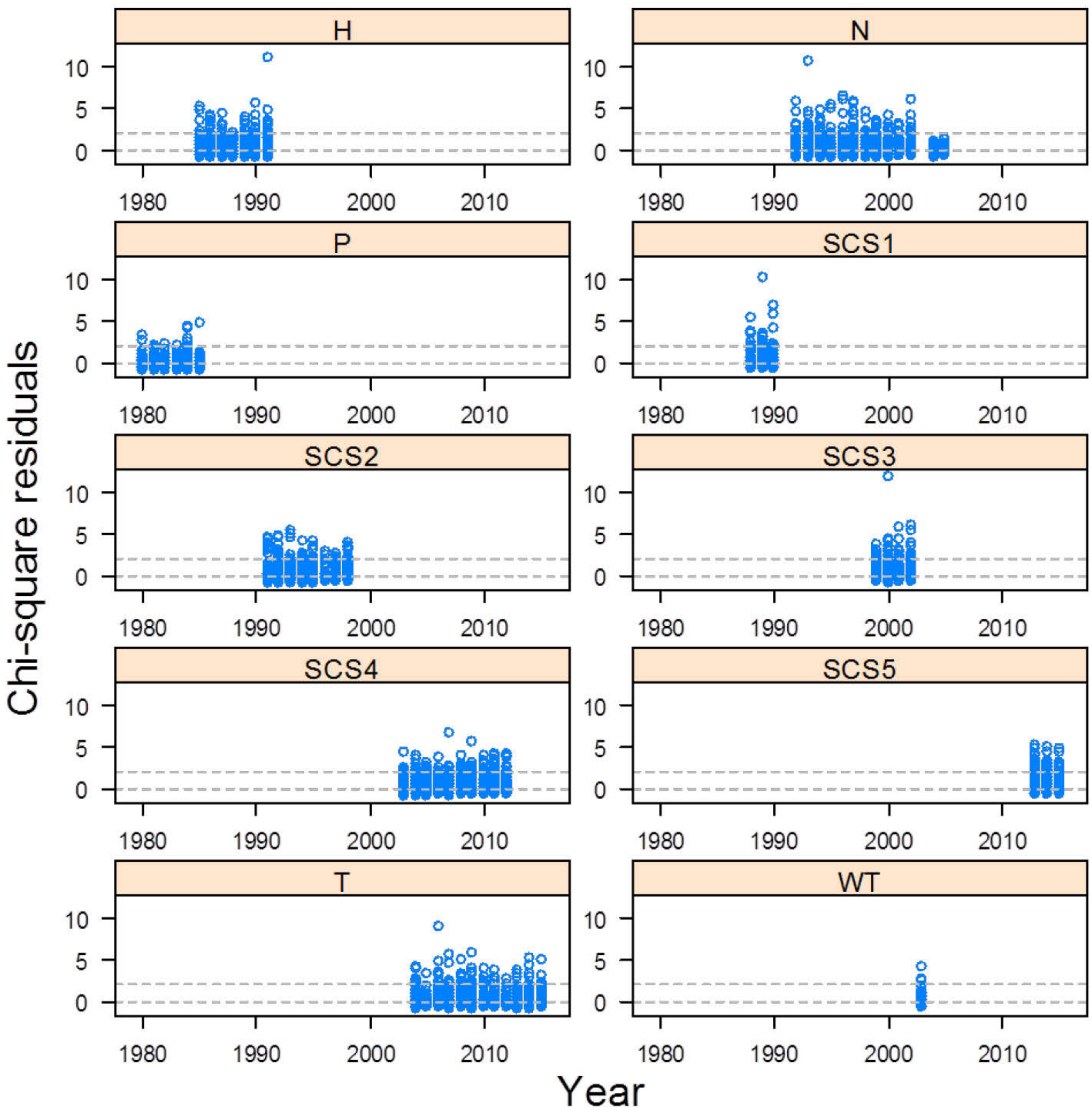

Figure 9. Standardized model residuals by year (x-axes) and vessel (panels).