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A comparison of the abundance, size composition, geographic distribution and habitat associations of snow crab (*Chionoecetes opilio*) in two bottom trawl surveys in the southern Gulf of St. Lawrence

Comparaison de l'abondance, de la composition selon la taille, de la répartition géographique et des associations d'habitat du crabe des neiges (*Chionoecetes opilio*) dans deux relevés au chalut de fond réalisés au sud du golfe du Saint-Laurent

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ABSTRACT

A framework review of the assessment methods for the southern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) stock took place in Moncton (NB) from November 19-23, 2011. The objectives of the meeting included reviewing the current sampling design and inference zone for the bottom-trawl survey used to assess crab abundance and distribution, and reviewing the methods for reconstructing a homogenous time series of biomasses and abundances from 1989 to present. To date, the snow crab assessment has been founded in large part on a dedicated bottom-trawl survey, undertaken annually since 1988, to provide a fishery-independent index of stock status. A standardized research vessel (RV) bottom-trawl survey of the southern Gulf has also been undertaken each September since 1971 and has principally been used for assessments and scientific research dedicated to marine fish. Though snow crab catches have been quantified in the RV survey since 1980, this information has yet to be incorporated into the assessment of southern Gulf snow crab. This document presents the first formal evaluation of the utility of the RV survey data for the assessment of southern Gulf snow crab, while addressing three aspects of the terms of reference (ToR) for the framework review. First, based on the broader geographic scope of the RV survey compared to the crab survey, it is shown that the snow crab survey presently covers the majority of the areas inhabited by snow crab in the southern Gulf, with the exception of deeper waters where low and temporally stable densities of crab are found. Second, based on the broader spatial and longer temporal scopes for the RV survey, it is shown that crab densities vary with both depth and bottom-temperature, though the relationship with depth is temporally more stable. Depth is therefore an appropriate environmental variable for defining the crab survey area and a valid auxiliary variable for the model used to estimate biomass in the assessment (kriging with external drift). Third, using the RV survey as a baseline, possible differences in catchability between the vessel used to undertake the crab survey from 1999-2002 and the one used since 2003 were examined. The analysis revealed evidence that the former vessel may have been more efficient at catching snow crab, particularly small but also large individuals, though the two vessels are presently assumed to be equivalent in the assessment. Overall, the RV survey was found to produce a picture of southern Gulf snow crab abundance, distribution and size composition that is very comparable to that obtained from the dedicated snow crab survey. The information from the standardized RV survey has a strong potential for helping to address key problems with the snow crab survey related geographic areas that were unsampled in the past, as well as in addressing possible changes in catchability that resulted from uncalibrated vessel changes. Furthermore, the RV survey has the potential to enhance understanding of stock productivity and dynamics by extending abundance indices back to 1980.

RÉSUMÉ

Un examen du cadre des méthodes d'évaluation du stock de crabes des neiges (*Chionoecetes opilio*) du sud du golfe du Saint-Laurent a été réalisé à Moncton (N.-B.) du 19 au 23 novembre 2011. Les objectifs de la réunion étaient d'évaluer le plan d'échantillonnage actuel et la zone d'inférences du relevé au chalut qui a servi à évaluer l'abondance et la répartition du crabe, et d'examiner les méthodes de reconstitution d'une série chronologique homogène de la biomasse et de l'abondance de 1989 jusqu'à présent. À ce jour, l'évaluation du crabe des neiges s'est fondée en grande partie sur un relevé au chalut focalisé sur le crabe, réalisé chaque année depuis 1988 afin d'obtenir un indice de l'état du stock indépendant de la pêche. Chaque mois de septembre depuis 1971, un relevé normalisé au chalut de fond est également effectué à bord d'un navire de recherche au sud du golfe du Saint-Laurent, essentiellement à des fins d'évaluations et de recherches scientifiques sur les poissons marins. Bien que les prises de crabe des neiges aient été chiffrées dans le relevé du navire de recherche depuis 1980, l'information n'a pas encore été intégrée à l'évaluation du crabe des neiges du sud du golfe. Le présent document expose la première évaluation officielle de l'utilité des données des relevés du navire de recherche pour l'évaluation du crabe des neiges du sud du golfe et traite de trois aspects du cadre de référence pour l'examen de cadre. Premièrement, selon la portée géographique plus étendue du relevé du navire de recherche par rapport à celle du relevé du crabe, il a été démontré que ce dernier couvre actuellement la majorité des zones habitées par le crabe des neiges dans le sud du golfe, à l'exception des eaux profondes qui contiennent des densités de crabe faibles et stables dans le temps. Deuxièmement, concernant la plus grande portée temporelle et spatiale du relevé du navire de recherche, il a été constaté que les densités de crabe varient en fonction de la profondeur et de la température du fond. La relation avec le facteur de profondeur est toutefois plus stable. Par conséquent, la profondeur est une variable environnementale pertinente pour définir la zone de relevé du crabe et une variable auxiliaire valide pour le modèle d'estimation de la biomasse utilisé dans l'évaluation (krigeage avec dérive externe). Troisièmement, en prenant le relevé du navire de recherche comme référence, on a examiné les différences potentielles de capturabilité entre le navire ayant servi au relevé du crabe de 1999 à 2002 et celui utilisé depuis 2003. L'analyse a démontré que le précédent navire pourrait s'être montré plus efficace dans la capture du crabe des neiges, particulièrement des petits individus, mais également des plus grands, alors que les deux navires sont actuellement considérés comme équivalents dans l'évaluation. Dans l'ensemble, le relevé du navire de recherche a produit un tableau de l'abondance, de la répartition et de la composition selon la taille du crabe des neiges très comparable à celui obtenu par le relevé étudiant exclusivement le crabe des neiges. L'information du relevé normalisé du navire de recherche pourrait fortement contribuer à régler les principaux problèmes du relevé du crabe des neiges, liés aux zones géographiques qui n'ont pas été échantillonnées auparavant, et à résoudre les questions de modifications potentielles de la capturabilité causées par des remplacements de navire non calibrées. De plus, le relevé du navire de recherche peut améliorer la compréhension de la productivité et de la dynamique du stock au moyen d'indices d'abondance remontant jusqu'à 1980.

INTRODUCTION

A framework review of the assessment methods for the southern Gulf of St. Lawrence snow crab (*Chionoecetes opilio*) stock took place in Moncton (NB) from November 19-23, 2011. The objectives of the framework science meeting included reviewing the current sampling design and inference zone for the bottom-trawl survey used to assess crab abundance and distribution, and reviewing the methods for reconstructing a homogenous time series of biomasses and abundances from 1989 to present.

The snow crab assessment has been founded in large part on a dedicated bottom-trawl survey (henceforth, the crab survey), undertaken annually since 1988 (except in 1996), to provide a fishery-independent index of stock status (Hébert et al. 2011). Another standardized research vessel (RV) bottom-trawl survey of the southern Gulf (henceforth the RV survey) has been undertaken each September since 1971 and has principally been used for assessments and scientific research dedicated to marine fish (e.g., Hurlbut et al. 2010; Benoît and Swain 2008). Though this survey routinely captures snow crab, there has been no formal evaluation of the utility of this information for the assessment of southern Gulf snow crab. The present document aims to provide such an initial evaluation, while addressing three aspects of the terms of reference (ToR) for the framework review.

The first aspect of the ToR that is addressed is an examination of the relevance of the present geographic polygon used to infer crab abundance, by considering the geographic distribution of crab catches in the RV survey (ToR 2b.i). Because the RV survey extends to both shallower and deeper waters compared to the crab survey, it is possible to evaluate whether the crab survey adequately covers the geographic distribution of southern Gulf snow crab.

The second aspect of the ToR that is addressed is an examination of whether water depth or bottom temperature can be used to refine the sampling polygon, and whether they are valid candidates as auxiliary variables for the assessment's abundance spatial-interpolation model (e.g., kriging with external drift; Surette et al. 2007) (ToRs 1b.i and 2a). Because the RV survey has a broader geographic extent compared to the crab survey and because of its longer history, data from the RV survey can provide information on the stability of crab distribution with respect to depth and temperature, thereby validating the use of these environmental variables in informing the assessment.

The third aspect is an examination of whether an uncalibrated change in the vessel used to undertake the crab survey after 2002 resulted in a systematic change of catchability of snow crab in that survey (ToR 3a.i). Because the RV survey time series data are standardized for all years from 1971-2011 (except 2003; see Methods for explanation), they constitute a benchmark against with to examine the relative catchabilities of snow crab of various sizes in the snow crab survey before and following the vessel change. Another change in vessel in 1999 and a change in gear configuration in 1990 represent two other instances in which the catchability of snow crab to the crab survey may have changed. While these too could be evaluated using the data from the RV survey, this was not attempted here because prior to 2001 information on the size composition of snow crabs was not collected in the RV survey, making the analysis more complex and not feasible in time for the meeting. Perspectives on how this could be done subsequent to the framework meeting are provided in the Discussion.

METHODS

THE SURVEYS

The snow crab survey

The snow crab survey has been undertaken during the summer and early autumn each year since 1988, except in 1996. The survey follows a fixed station design, with stations chosen initially within individual 10 minute by 10 minute grids cells. The survey uses a Bigouden Nephrops trawl, which digs into soft sediment and is efficient at catching crab (details in Moriyasu et al 2008). Though an uncalibrated change in the configuration of the trawl was made in 1990, the configuration has remained the same since. The vessel used to undertake the survey changed after the 1998 survey and again after the 2002 survey (Moriyasu et al 2008). There have been no assessments to date of possible differences in catchability between the vessels. Fishing in the snow crab survey takes place only during daylight hours, minimizing the introduction to the survey data of an effect of diel changes in catchability.

Since its inception the snow crab survey has always covered snow crab management area 12, though the total survey area further expanded from 1988 to 2006. The number of stations sampled increased concomitantly with the survey area, from 155 in 1988-1989 to 355 in recent years. Details on the changes in the crab survey are provided in Moriyasu et al. (2008).

During each tow, the depth and bottom-temperature of the station are recorded, though there are missing values in the present database. All captured crabs are counted, measured, sexed and the maturity and shell condition is obtained for certain sizes of crab. Crab catches are standardized by the swept area of the trawl and are expressed as densities, number/km^2 (details in Hébert et al. 2011).

The RV survey

The RV survey 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 in 1984 (Fig. 1). The target fishing procedure at each station is a 30-min. tow at 3.5 knots. Catches of snow crab (numbers and mass per tow) have consistently been recorded in the survey since 1980 (Tremblay 1997). Since 2001, captured crabs have also been measured and sexed, though maturity is not determined. Here, catches are standardized for the distance towed in the set and are expressed as a mean per standard tow of 1.75 nm, except where noted for particular analyses. Bottom temperature and depth are recorded at each survey station.

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 1 and 2 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. Though snow crab are routinely captured in the RV survey, the configuration of the footrope is such that catchability is expected to be much lower than in the crab survey.

The gear change and all of the vessel changes in the RV survey, except for the use of the CCGS *Wilfred Templeman* in 2003, involved comparative fishing to estimate the relative catchability of the vessels/gears when capturing various species of fish or macroinvertebrates (see Benoît and Swain 2003b; Benoît 2006). During the years in which the comparative fishing experiments between the CCGS *Alfred Needler* and the CCGS *Teleost* took place (2004 and 2005), both vessels were used to complete the surveys. Based on all of the 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 corrections are applied to the data as a result (Benoît and Swain 2003b; Benoît 2006). Comparative fishing results also suggest that the *CCGS Teleost* may be more efficient at catching snow crab relative to the *CCGS Alfred Needler* and the *Lady Hammond*, though the statistical significance of the effect was very weak despite having a large number of set pairs (n=85) in which crab were caught. As a result, many of the analyses presented here were undertaken separately either assuming that there was or there was not a difference in fishing efficiency between those vessels. Because the survey area was not completely covered in 2003 and the relative fishing efficiency of the vessel used that year (*CCGS W. Templeman*) is not known, data from 2003 have been omitted from the present analyses.

Fishing in the RV survey was restricted to daylight hours (07:00-19:00) from 1971 to 1984 but has been conducted 24 hours per day since 1985. Because fishing efficiency can vary by time of day as a result of species-specific diel behaviours such as hiding and trawl avoidance, survey catches are standardized post-hoc based on the results of analyses of survey catches and comparative fishing over the diel cycle (Benoît and Swain 2003a). Overall, from a size aggregated basis, snow crab are more catchable at night in the survey. However the diel effect is size dependent, with small crabs (<100 mm carapace width) being more catchable during the day, and larger crabs (≥100 mm) more catchable at night. For those years in which only snow crab numbers and biomass were recorded in the survey, a size-aggregated correction is applied. For subsequent years, the correction is size-specific (Benoît and Swain 2003b).

ANALYSIS

The spatio-temporal distribution of snow crab abundance in the RV survey (numbers/tow) and snow crab survey (numbers/km^2) was compared using maps of catches interpolated using inverse distance weighted gradient interpolation. The contour levels for plotting were defined by survey, as the 10th, 25th, 50th, 75th and 90th percentiles of non-zero catches over the period of interest: 1988-2010 for all crabs (i.e., size-aggregated), and 2001-2010 for males ≥95 mm (excluding 2003 in both cases). No other standardization was applied to the catches to make the surveys more comparable.

Following Perry and Smith (1994), cumulative distribution functions (cdfs) were used to describe the association of snow crab with the hydrographic variables depth (m) and temperature (^{o}C). Analyses were carried out by survey, and either by year or for groups of years. The available habitat (depth or temperature) for a given survey and time block was characterized using the following cdf (expressed as a proportion):

$$f(t) = \sum_{i=1}^{n} w_i I \quad \text{where} \quad I = \begin{cases} 1 & \text{if } x_i \le t \\ 0 & \text{otherwise} \end{cases} \qquad 1)$$

where t is a level of the hydrographic variable of interest, w_i is a weighting factor for tow i, n is the total number of tows, and x_i is the hydrographic measurement. For the RV survey, w_i is defined as the proportion of the survey area in the stratum fished by tow i, divided by the number of tows made in that stratum and also divided by the number of years included in the calculation. For the crab survey, w_i is defined as the proportion of the survey area in the grid cell fished by tow *i*, divided by the number of tows made in that grid cell and the number of years. The cdf for snow crab catch in relation to temperature or depth was characterized using the following cdf:

$$g(t) = \sum_{i=1}^{n} w_i I \frac{y_i}{\overline{Y}} \text{ where } I = \begin{cases} 1 & \text{if } x_i \leq t \\ 0 & \text{otherwise} \end{cases} \qquad 2)$$

where y_i is the standardized number of crab caught in tow *i* and $\overline{Y}$ is the mean catch per tow.

The depth distribution of male snow crab ≥95 mm in the RV survey was also examined using generalized additive models (GAMs; Hastie and Tibshirani, 1990). A Poisson error distribution was assumed in the GAMs, allowing for overdispersion. Models were of the form:

$$\mathrm{E}[y_i] = \mu_i = \exp(\beta_0 + s(x_i)) \qquad 3)$$

$$\mathrm{Var}[y_i] = \phi\mu_i \qquad 4)$$

where y_i is the catch of male snow crab ≥95 mm in tow *i*, β_0 is a common intercept, $s(x_i)$ is a cubic spline function of depth and ϕ is the overdispersion parameter. The degree of smoothing for the depth term was specified by setting its degrees of freedom to 4. The analysis was carried out for the years 2001-2010 (excluding 2003), in aggregate and in blocks of two or three years.

The size composition of snow crab captured in the two surveys was compared to evaluate the relative size-dependent catchability of crabs to the surveys. Analyses were limited to the years 2001, 2002 and 2004-2010. To keep the comparisons relevant, certain strata in the RV survey were excluded from the analysis to produce a similar survey area to the crab survey (strata 401-403, 415, 420, 421, 425, 432 and 439). Comparisons were based on the survey area mean density of crabs (numbers/km^2) in 3-mm bins of carapace width. The size-dependent relative catchability was assessed using the following GAM, which assumed a Normal error distribution:

$$\mathrm{E}\left[CS_j / RV_j\right] = \beta_1 + s(D_j) \qquad 5)$$

where CS_j is the mean number of crabs in carapace-width bin *j* from the crab survey, RV_j is the mean number of crabs in bin *j* from the RV survey, β_1 is a common intercept and $s(D_j)$ is a cubic spline function of carapace width (mm). Analyses were carried out for the entire size distribution as well as for crabs limited to ≥95 mm (including both mature and immature males). For the former, the degree of smoothing for the carapace width term was specified by setting its degrees of freedom to 8, while for the latter more restricted size group, the degrees of freedom were set to 4. An analysis was carried out including all the years listed above, as well as a second one for which the model was fit for two time periods in which different vessels were used in the crab survey, 2001-2002 and 2004-2010. This latter analysis aimed to provide an initial evaluation of whether or not the crab survey vessels differed in their relative fishing efficiency. All of the analyses involving eqn 5 were undertaken separately for RV survey data that were corrected and that were uncorrected for a possible difference in fishing efficiency between the *CCGS Alfred Needler* and *CCGS Teleost* (Benoît 2006).

For all of these analyses, the ability of eqn 5 to properly characterize the relative fishing efficiency of the crab and RV surveys was evaluated in two manners. In the first, RV survey crab catches at length were converted to crab survey equivalents using eqn 5 and were then compared to the length frequency distribution observed in the crab survey. In the second, the trawlable abundance of mature male snow crab ≥95 mm in RV survey data, converted into crab survey equivalents, was compared to the estimated abundance of large mature snow crabs from the snow crab assessment (Hébert et al. 2011). The trawlable abundance of mature male snow crab ≥95 mm in year *t*, A_t, was estimated as:

$$A_t = U \cdot p_t \cdot \sum_i \left(w_{i,t} \cdot \sum_{j=95}^{J\max} y_{i,j,t} \cdot \mathrm{E}\left[CS_j / RV_j\right]_t \right) \quad 6)$$

where *U* is the number of trawlable units in the inference area (i.e., surface area / area swept by a standard tow) and p_t is the proportion of male crabs ≥95 mm that were mature in the summer of year *t* (taken from the snow crab assessment). Confidence intervals were calculated using the standard estimator for standard error based on stratified random sampling (Krebs 1989).

Finally, abundance indices straight from the RV survey were also produced to consider trends in the snow crab stock as perceived by that survey. In this case, the trawlable abundance of mature male snow crab ≥95 mm in year *t*, RV_t, was calculated as:

$$RV_t = U \cdot p_t \cdot \sum_i \left(w_{i,t} \cdot \sum_{j=95}^{J\max} y_{i,j,t} \right) \quad 7)$$

for *t*=2001,…,2010 (excluding 2003). Similarly, the length-aggregated biomass index for snow crab (mean kg/tow), B_t, was calculated as:

$$B_t = \sum_i w_{i,t} \cdot b_{i,t} \quad 8)$$

for *t*=1980,…,2010 (excluding 2003) and where $b_{i,t}$ is the biomass (kg) of snow crab in set *i* of year *t*. Analyses for RV_t and B_t were undertaken separately for catches by the *CCGS Teleost* that were and that weren't corrected for a possible difference in fishing efficiency compared to the *CCGS A. Needler*. Furthermore the analyses were undertaken for two geographic areas of inference: the snow crab assessment area, representing 44302 km^2, and the RV survey area exclusive of strata 401-403 (Fig. 1), representing 70061 km^2.

RESULTS

Generally speaking, the snow crab and RV surveys provide comparable depictions of the abundance and distribution of snow crab (all sizes combined) in the southern Gulf of St. Lawrence (Fig. 2). The two surveys generally identify similar areas of both high and low abundance, and the surveys appear to pick up similar years of overall low and high abundance (e.g., in Fig. 2 compare 1989-1990 and 2001-2002). However, with a lower density of stations, interpolation of catches in the RV survey is more sensitive to occasional large catches. This might explain certain areas of high density identified in the RV survey but not the crab survey (e.g., 2004, west of the Magdalen Islands). Furthermore, because the relative efficiencies of the RV and crab surveys differ as a function of crab carapace diameter (presented later), the size composition of the indices differs between surveys. This too may explain some of the discrepancies between surveys.

There is also a reasonable concordance between surveys specifically for catches of male crab ≥95 mm (Fig. 3). Again, areas of both high and low abundance are generally consistently identified by both surveys, as are years of relatively higher (e.g., 2006) and lower (e.g., 2009) abundance. Note however that in this comparison, the data for the snow crab survey are restricted to mature males whereas those for the RV survey are not. Furthermore, note that distribution plots are for individual years, making the interpolation even more sensitive to lower sampling density in the RV survey compared to Fig. 2.

The geographic limits of the RV survey are plotted for the 2006-2010 panels for crab survey catches in Fig. 3 to highlight present differences in survey coverage. The area northeast of the Gaspé peninsula (northwestern portion of the RV survey area) is sampled by the RV survey but not the crab survey. Snow crab are captured in low densities in this area (Figs. 2 and 3). The RV survey also covers areas that are inshore of the crab survey. Snow crab are generally not caught in the RV survey in the areas that are inshore of the crab survey polygon employed since 2006.

Based on its present survey boundaries, the crab survey covers a narrower range of both depths and temperatures compared to the RV survey (Fig. 4, dotted lines). Despite the difference in the available habitat sampled by the two surveys, the habitat occupancy of snow crab is very comparable between the surveys for both temperature and depth (Fig. 4, solid lines). The small difference between surveys is in the upper portion of the cdfs of occupied habitat. For example, while the snow crab survey predicts that all crabs occur in waters <175 m, the RV survey predicts that small densities can be found nearly 100 m deeper.

The two surveys generally pick-up similar interannual differences in the habitat occupancy cdfs (Fig. 5). For example, both surveys indicate that male crab ≥95 mm occupied relatively colder waters in 2008 (orange line) and relatively warm waters in 2010 (red line). Likewise, there is an indication that crab occupied slightly deeper waters in 2010. (Note that the cdfs for the RV survey are less smooth that those for the crab survey likely in large part because of the difference in survey sampling intensity). Generally speaking, the cdfs of occupied depths show less interannual variation that the cdfs of occupied temperature.

The cdfs for temperature and depth were estimated for 5-year blocks using the RV size-aggregated survey data to further examine the temporal stability of the distributions. The data were aggregated in 5-yr blocks to minimize stochasticity. The cdfs for both habitat variables were quite stable over time, though the cdf for temperature in 1991-1995 indicates that crab occupied colder waters in those years (Fig. 6), a time of particularly cold bottom-water temperatures throughout much of the southern Gulf (Fig. 7). Despite the colder ambient temperature in 1991-1995 (Fig. 6c), the depth distribution of snow crab did not change, suggesting that the colder occupied temperatures in those years was a passive result of temperature change rather than a change in temperature preference. This inference is supported by similar observations for the annual cdfs in Fig 5.

In the RV survey during the 2000s, the predicted local density of male crab ≥95 mm increased rapidly as a function of depth, peaking at a value of around 9 crabs per tow on average at depths of 80-90 m (Fig. 8). With increases in depth from 90 m to around 140 m, local density decreased rapidly. Beyond depths of around 150 m, density decreased more gradually as a function of depth. Crab were still captured in the survey at the maximum depth sampled (around 375 m), though the predicted density is low (<1 crab per tow on average). Note however that depths beyond 300 m constitute only a very small fraction of the area of the southern Gulf (e.g., Fig 4.), so the number of large male crabs present is likely very small.

During the 2000s, adult male snow crab ≥95 mm underwent pronounced changes in abundance, with low levels around 1999-2001 and especially in 2009, and high levels in 2003-2005 (Hébert et al. 2011). During these periods of contrasting abundance, the density distribution of male snow crab ≥95 mm in both shallow areas (<50 m) and deep areas (>200 m changed very little (Fig. 9). The most pronounced changes occurred at the depths most favoured by large male snow crab, between roughly 50-150 m, but especially around 80-100 m. Waters of this depth in the southern Gulf of St. Lawrence are sampled well by both the RV and crab surveys. The fact that density changes are most pronounced over a narrow range of depths with high crab densities explains the temporal stability of the cdfs of occupied depths (Figs. 5 and 6).

The crab survey catches roughly two orders of magnitude more crabs per km^2 compared to the RV survey at all crab sizes (Fig. 10). The relative catchabilities of the two surveys depend on crab size, with the crab survey catching particularly more crabs with a carapace width of 20-30 mm. The level of the relative catchability functions also depends on whether a correction is applied to the RV data for a possible difference in relative fishing efficiency between the CCGS *Needler* and *Teleost*. When *Needler* catches are corrected (Fig 10b), the magnitude of the relative efficiency of the crab and RV surveys is smaller than when no correction is applied (Fig 10a). In both cases, there is a large difference between the relative efficiency functions estimated for 2001-2002 (red lines) and those estimated for 2004-2010 (blue lines). This difference does not appear to be a function of a more limited number of years used to estimate the former, since relative efficiency functions estimated for two-year blocks for the period 2004-2010 are quite similar (Fig. 11). Using the RV survey as the benchmark, the crab survey vessel used from 1999-2002 (Fig. 10, red lines) appears to have been more efficient at catching crab of most sizes compared to the current vessel (blue line). (Note however that the confidence intervals for the size-dependent relative catchability function are large for the former vessel and the difference is not statistically significant for most crab sizes >40 mm). The former vessel appears to have been particularly more efficient at capturing crab 15-35 mm, but also larger crab around 125 mm (Fig. 10).

When a single size-dependent relative catchability function is estimated for the years 2001-2010 (black lines in Fig. 10) and is used to predict the size-frequency distribution of crab in the crab survey using data from the RV survey, there is a mismatch between observations and predictions in all years (Figs. 12 and 13). For 2001 and 2002, the predictions (green lines) fall below the observations (blue lines) for most crab sizes, while for the other years, the predicted densities fall above those observed. When size-dependent relative catchability functions specific to 2001-2002 and to 2004-2010 (i.e., the periods in which different vessels were used in the crab survey) are estimated and applied to the RV survey catches, the predicted size-frequency distributions (red lines) more closely match those observed in the crab survey (blue lines) for most sizes and years (Figs. 12 and 13). This is true whether or not a correction is applied to the *Needler* catches for a possible difference in efficiency with the *Teleost*, and suggests that to the extent that the RV survey series is adequately standardized, the two vessels used in the crab survey during the 2000s differed in fishing efficiency, at least for certain sizes of crab (Fig. 10).

The above analyses were repeated, focusing on male crab ≥95 mm. Here too, there was a significant difference between the relative size-dependent catchability function for the crab-survey vessel used from 1999-2002 and the present vessel (Fig. 14). The former vessel tended to catch more crab, especially crab 120-133 mm. As in the analysis for the entire size-frequency of crab, the use of a single relative catchability function for 2001-2010 tended to underestimate the abundance of male crab ≥95 mm in 2001-2002 and overestimate it in most years since 2003 (Figs. 15 and 16). For the most part, using size-dependent relative catchability functions specific to 2001-2002 and to 2004-2010 results in a slightly closer correspondence between the densities observed in the crab survey (blue lines) and those predicted based on observations in the RV survey (red lines).

Estimates of large mature male crab abundance based on catches in the RV survey converted using the size-dependent relative catchability functions (squares) correspond well with the abundance estimates from the snow crab assessment (blue diamonds), though the relative error of the estimates is greater (Fig. 17). RV survey estimates based on size-dependent relative catchability functions specific to 2001-2002 and to 2004-2010 (red squares) closely match those from the assessment, and the respective confidence intervals overlap in all years. In contrast, RV survey estimates based on a single relative catchability function for 2001-2010 (green squares) tend to be further from the assessed abundances in most years and confidence intervals for the crab and RV survey fail to overlap in certain years (2001 and 2002).

The effect on the estimated abundance of large mature male snow crab of a possible difference in fishing efficiency between the vessels used to conduct the crab survey in 1999-2002 and in the period since then is apparent in the trend in trawlable abundance from the RV survey (eqn 7)(Fig. 18). Based on the RV survey, abundance appears to have increased during the early 2000s from a low level in 2001, peaking around 2005 and then declining to a low level in 2010 that was comparable to the one in 2001. In contrast the current snow crab assessment suggests that abundance in 2001 was at an intermediate level, increasing until 2004 and then declining to low levels in 2009 and 2010 (Fig. 17, blue diamonds) (Hébert et al, 2011). Trends in the RV survey estimates of trawlable abundance are not very sensitive to whether a correction is applied to *Teleost* catches, though abundances are higher by approximately 20% for the period 2004-2010 when a correction is applied (compare open and filled squares in Fig. 17). Trawlable abundance in the 70061 km^2 RV survey area that excludes strata 401-403 is estimated to be between 20-40% greater than the abundance estimated for the current snow crab assessment area of 44302 km^2 (compare blue and red squares in Fig. 17).

The RV survey size-aggregated biomass index provides a longer-term perspective of snow crab population dynamics in the southern Gulf (Fig. 19). This index suggests that crab biomass since the mid-1990s has been low relative to levels observed in the early 1980s and in 1991, and in particular relative to the high level observed in 1990. The magnitude of the changes since 1980 is such that a correction for a possible difference in catchability between the *CCGS Needler* and *Teleost* changes little the perceived dynamics of the stock over the entire series. Trends in the biomass index for the current snow crab assessment area of 44302 km^2 are nearly identical to those for the 70061 km^2 RV survey area that excludes strata only 401-403.

The trends in the RV size-aggregated biomass index for the 1992-2010 period (Fig. 19) match remarkably well the trends estimated by Cadigan (2012) for the same period using the snow crab survey data and a generalized linear model (GzLM) to account for changes over time in the spatial coverage of the snow crab survey (Fig. 20). However the two sets of estimates diverge considerably for 1988-1991. During this period, snow crab in the RV survey were disproportionately caught in and just outside the Baie de Chaleurs (Figs. 21), an area of geographically-restricted sampling in the crab survey until the mid 2000s (Fig. 2). While the GzLM used by Cadigan (2012) can accommodate random interannual changes in crab spatial distribution, it cannot deal adequately with systematic shifts in distribution as appear to have occurred during the early 1990s in the southwestern Gulf. Cadigan's abundance estimates for poorly sampled areas in and around the Baie des Chaleurs prior to this shift are therefore very likely to be biased low. An additional explanation for the discrepancy between the RV survey results and those of Cadigan (2012) is the substantial change in the configuration of the crab survey trawl that occurred in 1990 (Moriyasu et al. 2008) that may have resulted in a change in fishing efficiency in that survey that is not accounted for in Cadigan's analysis.

DISCUSSION

The analyses presented here confirm the utility of the September RV survey in providing an additional fishery-independent indicator of the relative abundance, distribution and demographic composition of snow crab in the southern Gulf of St. Lawrence. The RV survey provides a very similar picture, relative to the crab survey, of the distribution, habitat associations, and when properly adjusted, the abundance and size composition of snow crab. This provides support for the reliability of the crab survey in providing an unbiased estimate of these features. Furthermore, given the RV survey's broader geographic area, longer history of standardized catch information and synoptic nature, data from this survey can be used to support and enhance the present southern Gulf snow crab assessment. Here, I begin by discussing the results this study in light of the ToR for the framework meeting. I then provide some perspectives for further analyses that could be undertaken to further bolster the assessment.

The results presented here confirm that the snow crab survey presently covers most of the area occupied by southern Gulf snow crab within the RV survey boundaries. The snow crab survey appears to cover all areas inshore of the distribution of crab, and only misses some deeper areas in which crab densities appear to be low and which constitute only a very small proportion of the geographic area of the southern Gulf. Though snow crab appear to extend beyond the deepwater boundaries of the RV survey, the projected densities there are expected to be very low (Fig. 8).

Crab distribution changes predictably with both depth and bottom temperature. The relationship between density and depth based on cumulative distribution functions shows less interannual variability compared to the relationship with temperature. Furthermore the changes in distribution with temperature appear to reflect a passive change in the thermal conditions of the depth habitat occupied by crabs rather than an active change in temperature preference. Based on the results presented here, depth appears to be the environmental variable most suited for delimiting the area (polygon) for the crab survey. Depth also appears as a reasonable covariate for interpolation and perhaps extrapolation of crab densities (especially at shallower and deeper depths), as is presently done in the assessment (Surette et al. 2007; Hébert et al. 2011). Alternatively, given the strong concordance of crab abundance and distribution between the RV and crab surveys, co-kriging of the data from both surveys could be used to estimate crab abundance for 1988 to the present (section 3.2.3, Cressie 1993). This would be particularly beneficial for the years prior to 2006, when areas of the present crab survey polygon were not sampled.

Using the RV survey mean crab catches as a function of crab carapace diameter, it appears that the vessel used in the crab survey from 1999-2002 was more efficient at catching snow crab compared to the present vessel. From the perspective of relative abundance, this would mean that the abundance of crab prior to 2003 was lower than is presently perceived, assuming equal catchability among vessels. However, prior to concluding that this is the case, a more rigorous analysis of relative catchability should be undertaken. Notably, the analysis should be based on geographically local patterns (i.e., set-level) of relative catchability between the RV and crab surveys so as to better capture the uncertainty in the relationship. Furthermore, uncertainty in the relative efficiencies of the *CCGS Alfred Needler* and the *CCGS Teleost* should be included in the estimation process to better reflect the overall level of variability.

Using the RV survey data as a benchmark, it should also be possible to examine the size-aggregated relative catchability of snow crab for the vessel used in the crab survey from 1988-1998 and the two recent ones. Given the absence of length information in the RV survey prior to 2001, the estimates will necessarily apply to all crab lengths. The analysis would begin by applying the size-dependent relative catchability relationship for the vessel used from 1999-2002, such as estimated here (Fig. 10), to the data from the crab survey to create a size-aggregated index comparable to the catches from the RV survey. This index could then be compared to local catches from the RV survey to test for a difference in relative catchability for the years prior to and following 1999, indicating an effect of the vessel change. Such an approach might also be used to test for a difference in relative catchability resulting from the gear-configuration change that occurred in 1990. In both cases, care will be required in properly defining the geographic scope for the data from the RV survey, given the reduced size of the crab survey area in the 1990s.

Concerns have been raised about the possible effect of within-survey movements of crabs during the crab survey, which extends over a two, sometimes three, month period. These movements, if important, could result in biased estimates of abundance due to double counting and missed crabs. Because the RV survey is relatively synoptic, being carried out in 3 to 4 weeks, the importance of crab movement to the assessment could be evaluated by carefully comparing the results of the two surveys.

Finally, perhaps the biggest contribution of the RV survey to the snow crab assessment is in providing a considerably longer term perspective on stock dynamics and productivity. Size aggregated dynamics estimated from the RV survey correspond generally to the inferred dynamics of large mature male snow crab in the RV survey (compare the 2000s period in Figs 18 and 19). This is because the large males typically comprise the bulk of the biomass in the catches. To the extent that this was also true prior to 2001, the size-aggregated index provides a reasonable proxy for the abundance of commercial-sized male crabs back to 1980. This suggests that the stock may have been at least 40-50% larger in certain years during the period prior to 1997, compared to the apparently high abundance years in the period following. This result could have ramifications for the application of the precautionary approach for snow crab in the southern Gulf of St. Lawrence, which is currently based on stock productivity characteristics over the period 1997-2008 (DFO 2010).

ACKNOWLEDGEMENTS

Thanks to Doug Swain for undertaking the GAM analyses of snow crab depth distribution.

REFERENCES

Benoît, H.P. 2006. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: results of the 2004-2005 comparative fishing experiments and other recommendations for the analysis of the survey data. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/008.

Benoît, H.P., and Swain, D.P. 2003*a*. Accounting for length- and depth-dependent diel variation in catchability of fish and invertebrates in an annual bottom-trawl survey. ICES J. Mar. Sci. 60: 1298-1317.

Benoît, H.P., and Swain, D.P. 2003*b*. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: adjusting for changes in research vessel, gear and survey protocol. Can. Tech. Rep. Fish. Aquat. Sci. no. 2505: iv + 95 pp.

Benoît H.P., and Swain, D.P. 2008. Impacts of environmental change and direct and indirect harvesting effects on the dynamics of a marine fish community. Can. J. Fish. Aquat. Sci. 65: 2088-2104.

Cadigan, N.G. 2012. Preliminary investigations into standardizing the 4T snow crab (*Chionoecetes opilio*) bottom-trawl survey index. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/016. iv + 48 p.

Cressie, N.A.C. 1993. Statistics for spatial data, revised edition. Wiley-Interscience, N.Y.

DFO. 2010. 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.

Hastie, T. and Tibshirani, R. 1990. Generalized Additive Models, Chapman and Hall.

Hébert, M., Wade, E., Biron, M., DeGrâce, P., Landry, J.-F., and Moriyasu, M. 2011. The 2010 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. 2011/082. vi+ 73 p.

Hurlbut, T., and Clay, D. 1990. Protocols for research vessel cruises within the Gulf Region (demersal fish) (1970-1987). Can. Manuscr. Rep. of Fish. Aquat. Sci., 2082: 143 p.

Hurlbut, T., Morin, R., Surette, T., Swain, D.P., Benoît, H.P., and LeBlanc, C. 2010. Preliminary results from the September 2009 bottom-trawl survey of the southern Gulf of St. Lawrence. DFO Can. Sci. Adv. Sec. Res. Doc. 2010/044. iv + 50 p.

Krebs, C.J. 1989. Ecological methodology. Harper Collins Publishers, N.Y.

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. iii + 36 p.

Perry, R.I., and Smith, S.J. 1994. Identifying habitat associations of marine fishes using survey data: an application to the NW Atlantic. Can. J. Fish. Aquat. Sci. 51: 589-602.

Surette, T.J., Marcotte, D., and Wade, E. 2007. Predicting snow crab (*Chionoecetes opilio*) abundance using kriging with external drift with depth as a covariate. Can. Tech. Rep. Fish. Aquat. Sci. 2763: vi + 33 p.

Tremblay, M.J. 1997. Snow crab (*Chionoecetes opilio*) distribution limits and abundance trends on the Scotian shelf. J. Northw. Atl. Fish. Sci. 21: 7-22

Table 1. Parameters for the two trawls used in the RV survey of the southern Gulf of St. Lawrence.

	Yankee 36	*Western IIA*
Years in operation	1971-1984	1985-present
Footrope	7'' (outer sections) and 14'' (inner sections) rubber disc spacers + 17 lb. iron spacers	21'' (outer) and 18'' (inner) rubber bobbins and 6.75'' diameter 7'' long rubber spacers
Footrope length	80'	106'
Headline length	60'	75'
Headline height	9'	15'
Wingspread	41'	41'
Door type	Steel bound wood	Portuguese (all steel)
Door weight	1000 lb	1800 lb
Lengthening piece liner	1.25''	1.25''
Codend liner	0.25''	0.75''

Table 2. Parameters for the vessels used in the RV survey of the southern Gulf of St. Lawrence for the years presented in this report.

	E.E. Prince	*Lady Hammond*	*CCGS Alfred Needler*	*CCGS Teleost*
Vessel type	Stern trawler	Stern trawler	Stern trawler	Stern trawler
Tonnage	406	897	925	2405
Length	40 m	58 m	50 m	63 m

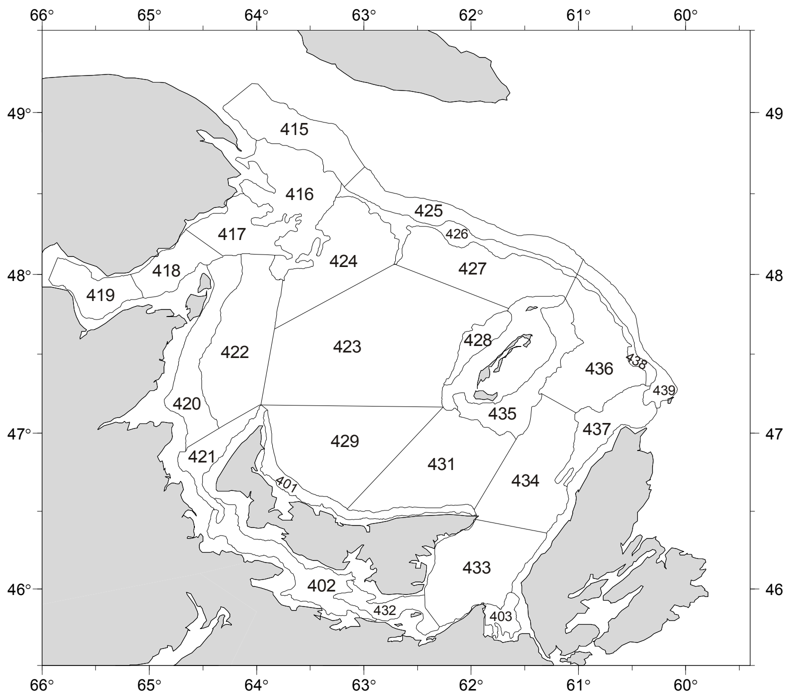


Figure. 1. Stratum boundaries for the southern Gulf of St. Lawrence September RV survey.

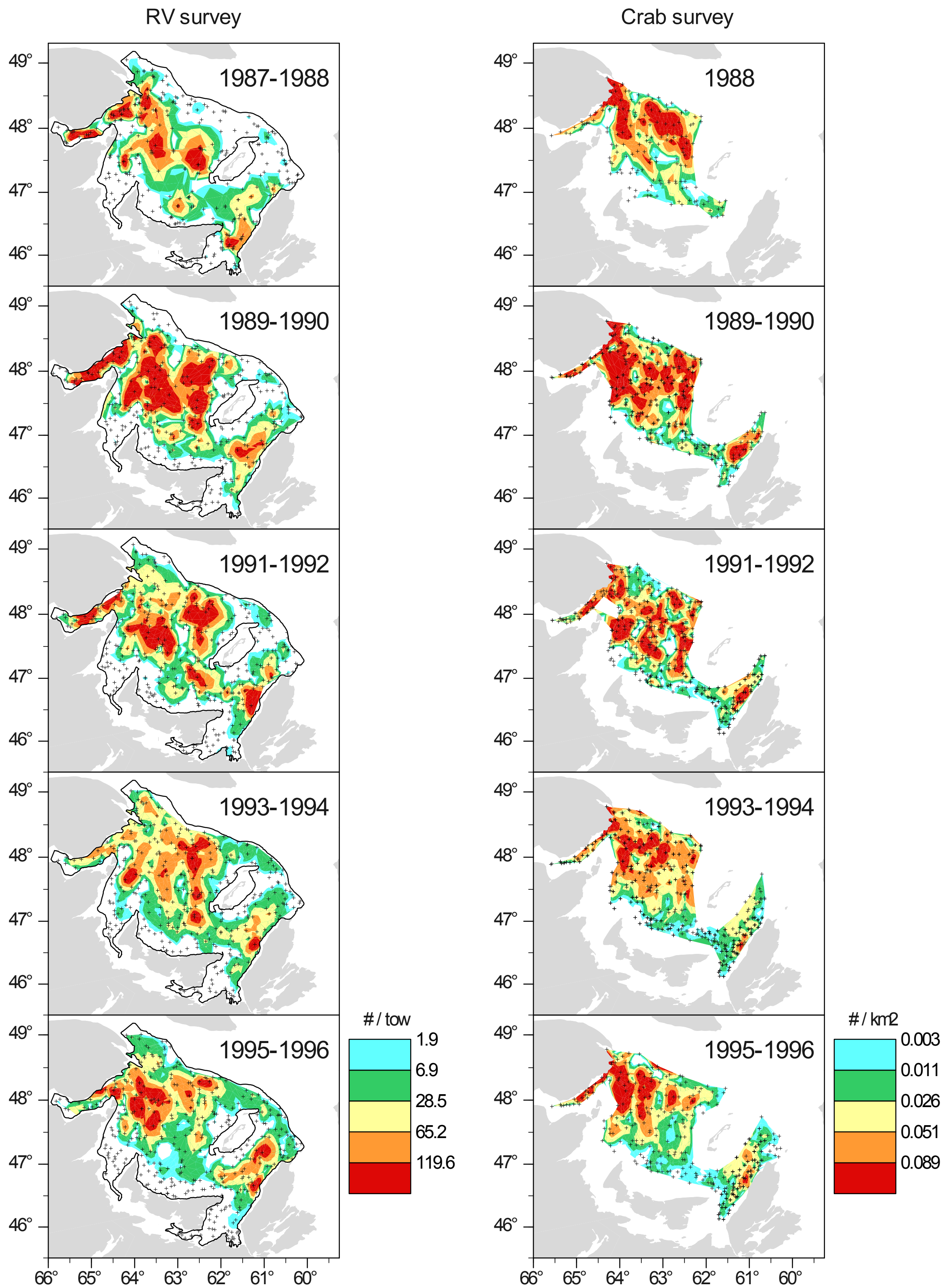
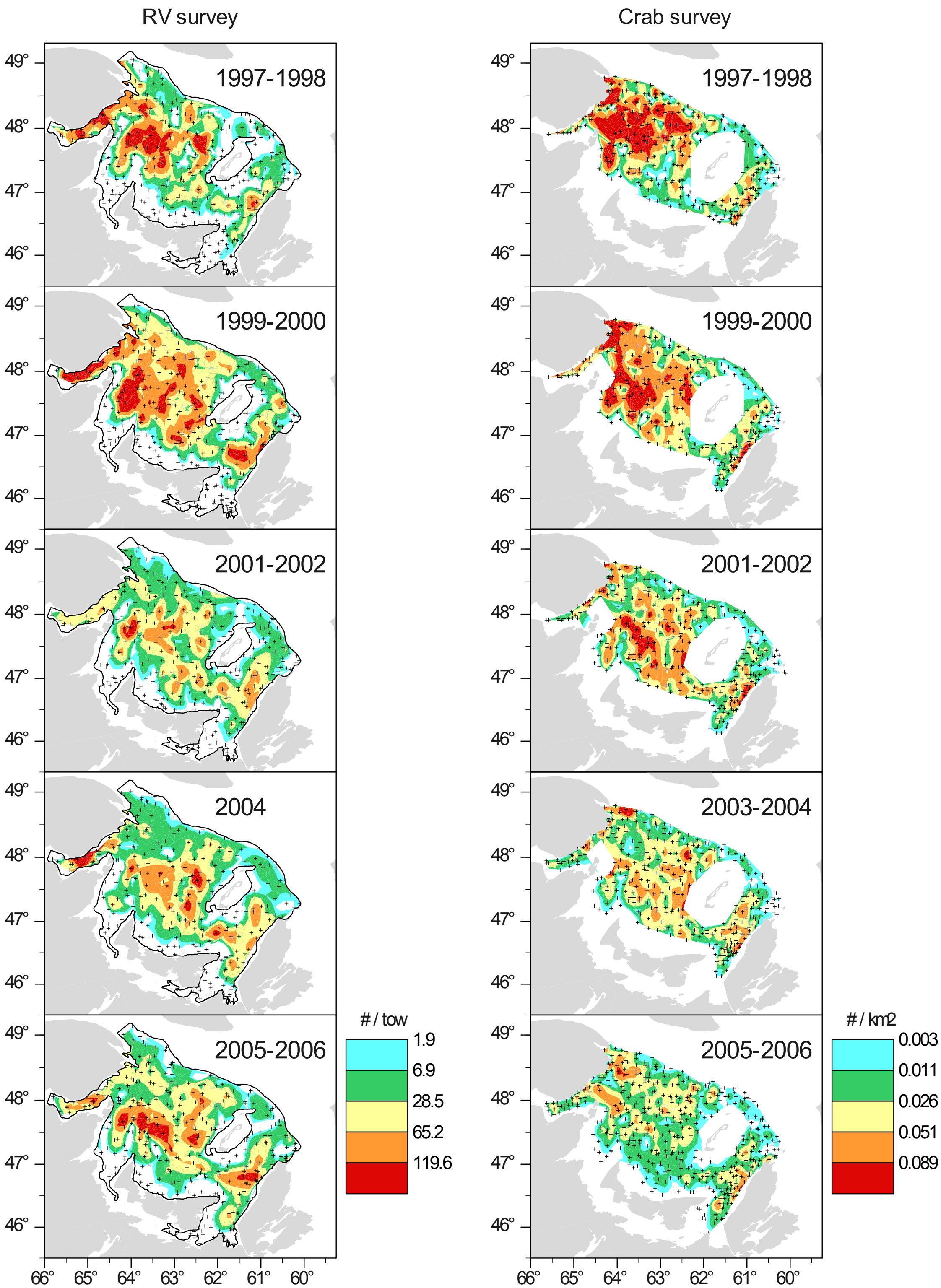


Figure 2. Geographic distribution of snow crab catches in two-year blocks in the September RV survey (left column, in numbers per tow) and in the snow crab survey (right column, in numbers/km²). The small crosses indicate the set locations. Note that the levels for the contours differ between the two surveys.



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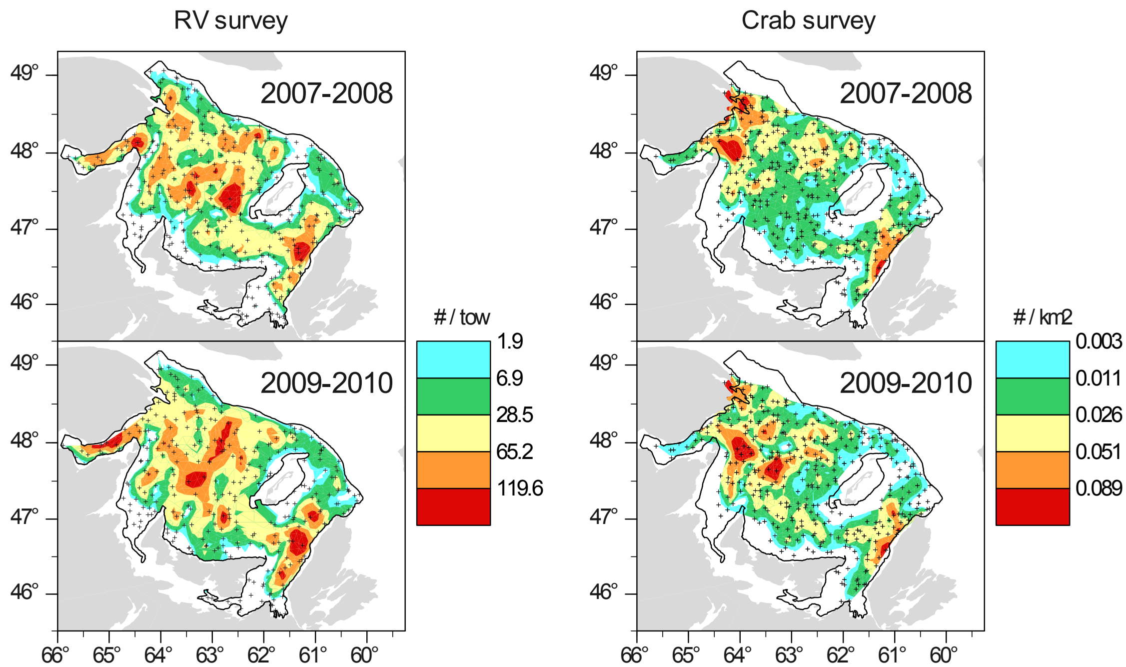

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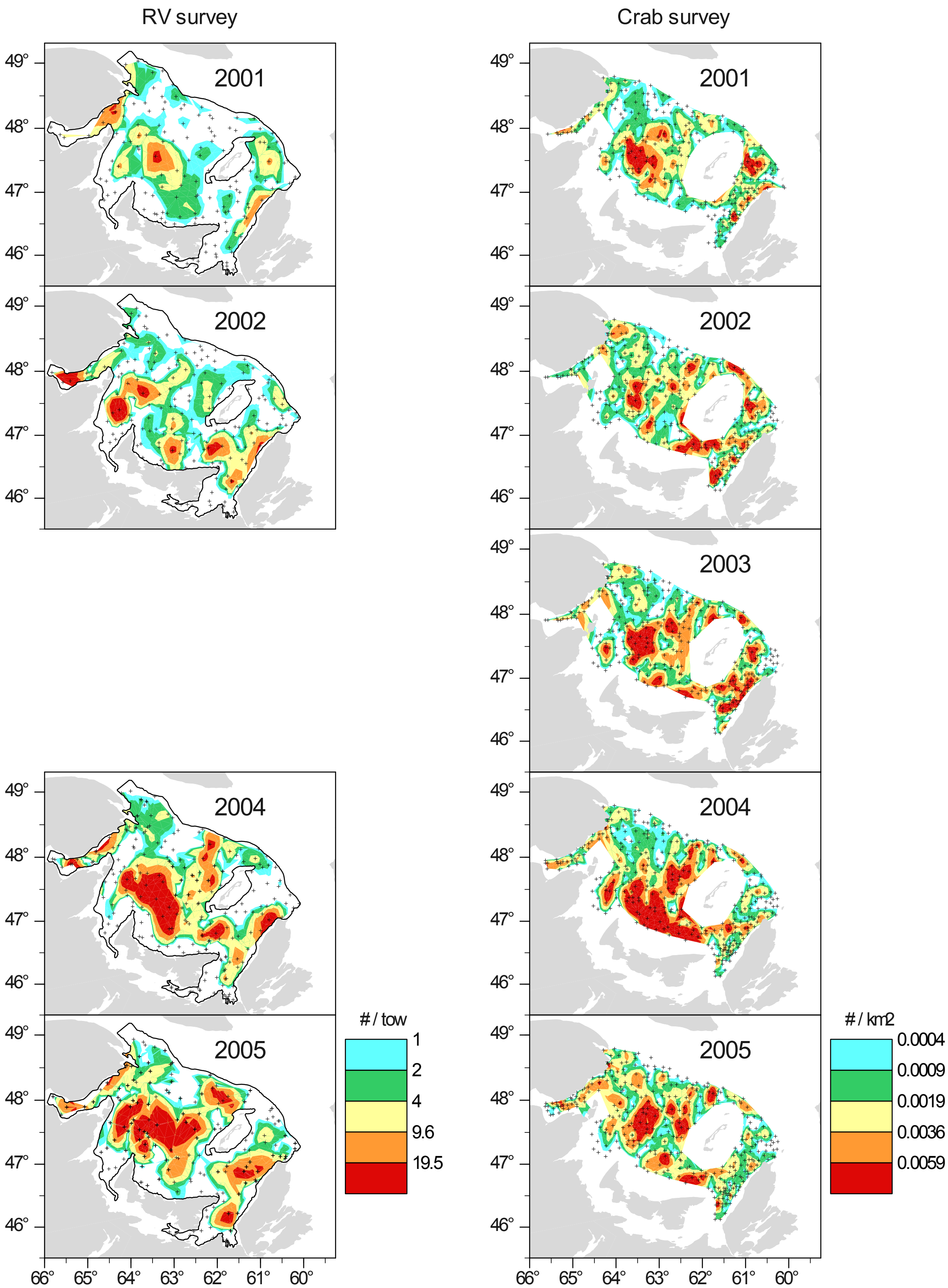
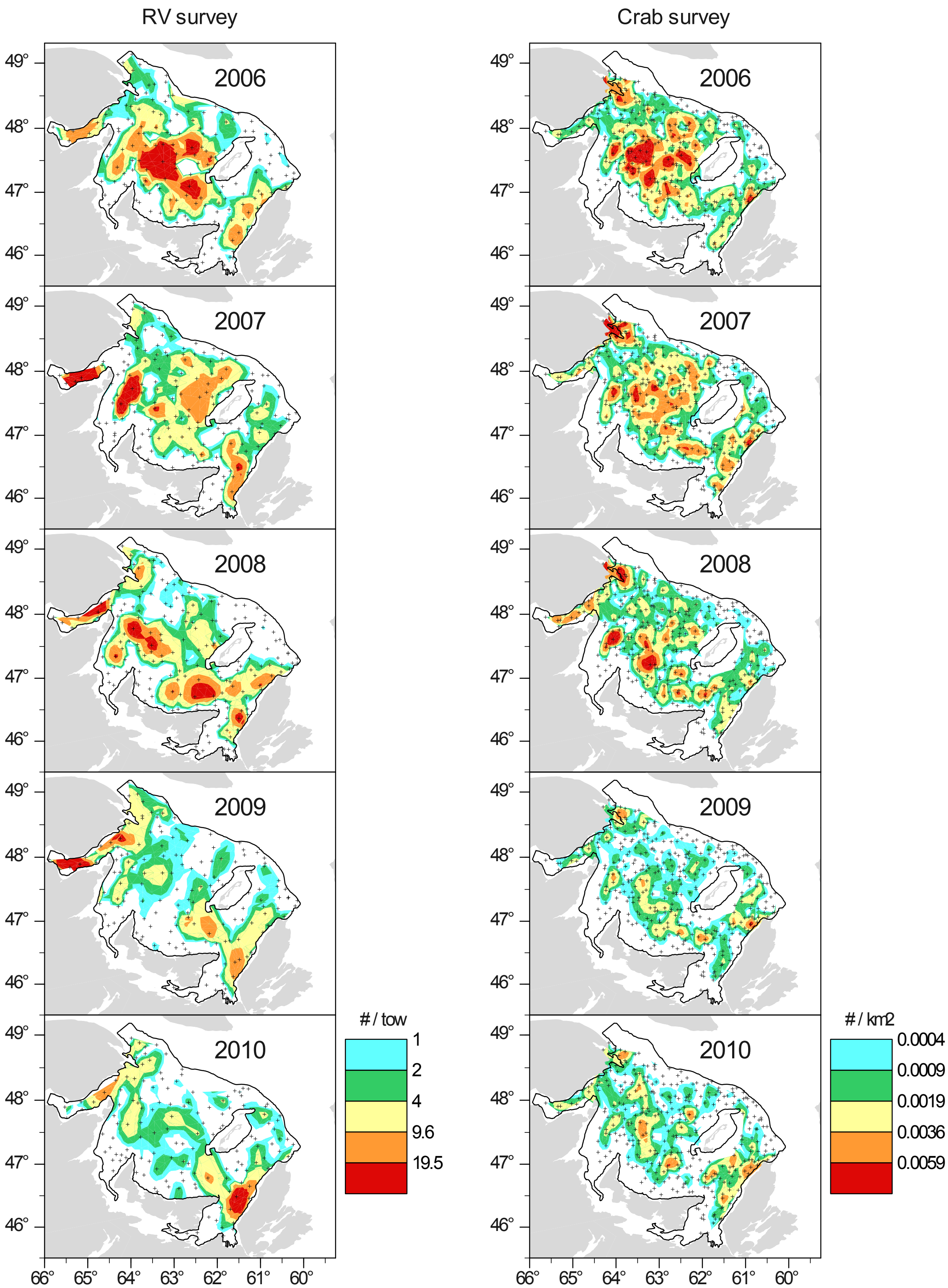


Figure 3. Annual geographic distribution of snow crab catches (males ≥95 mm) in the September RV survey (left column, in numbers per tow) and in the snow crab survey (right column, in numbers/km^2). The small crosses indicate the set locations. Note that the RV survey includes all males whereas the snow crab survey includes only mature males. Note also that the levels for the contours differ between the two surveys.



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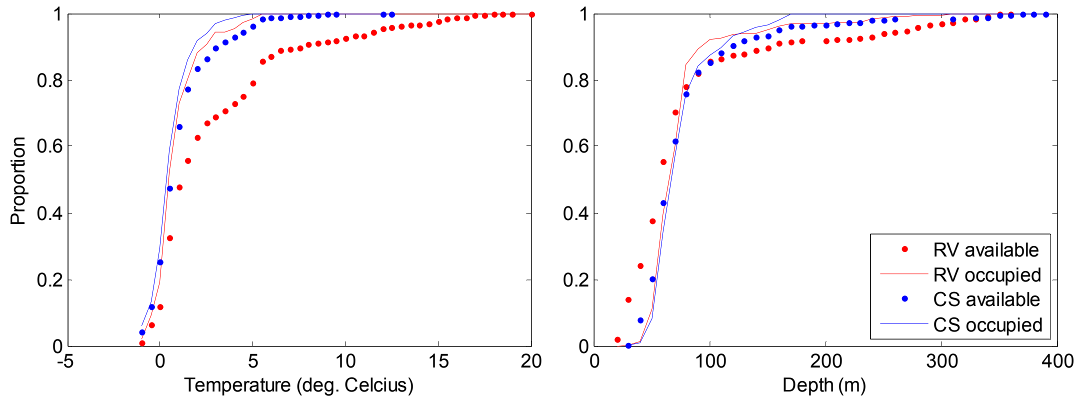


Figure 4.Cumulative distribution functions of the habitat (temperature, left panel, or depth, right) available in the southern Gulf of St. Lawrence (dotted lines) and occupied by southern Gulf male snow crab ≥95 mm (solid lines) as perceived by the RV surveys (red) and the crab surveys (CS; blue) for the years 2006-2010. Note that the data for the snow crab survey are limited to mature males only whereas the data for the RV survey include mature and immature males.

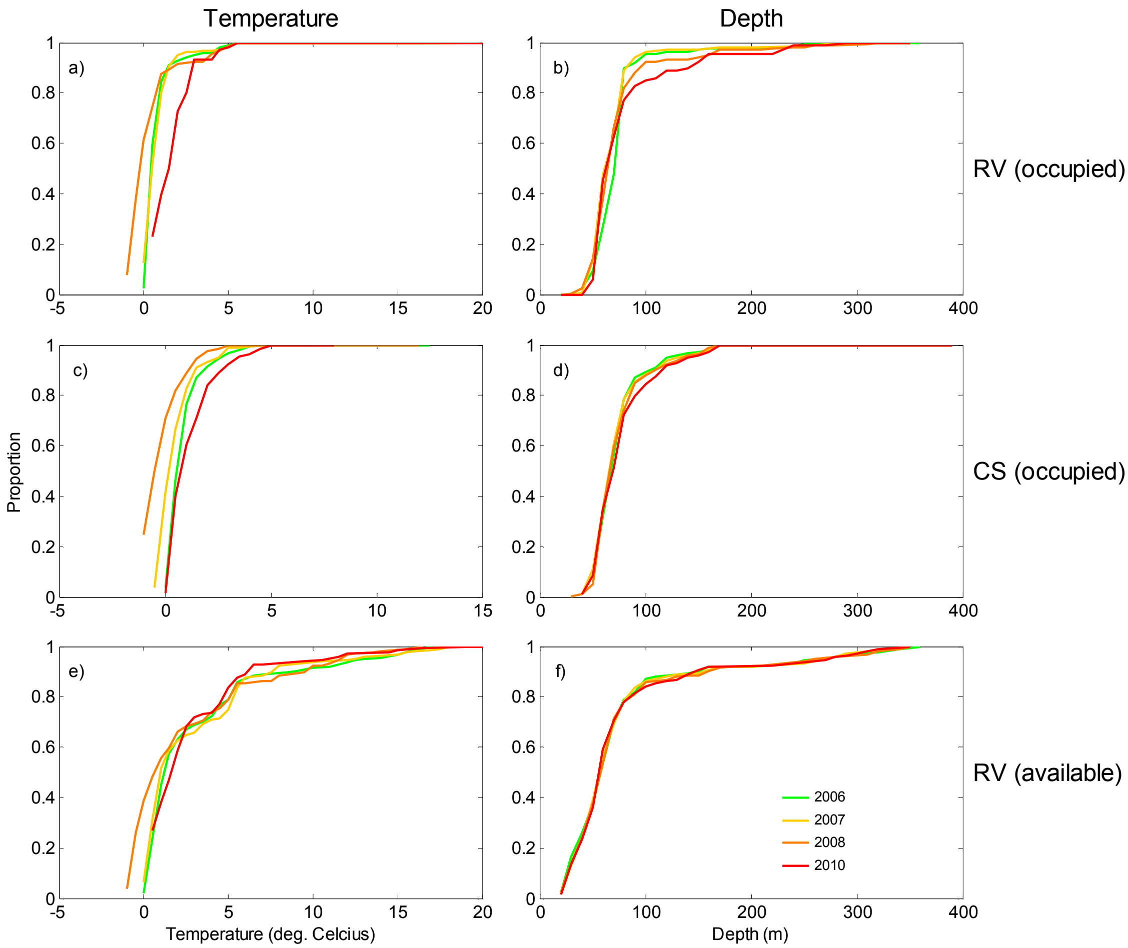


Figure 5.Annual cumulative distribution functions (cdfs) of the habitat (temperature, left panels, or depth, right) occupied by male snow crabs ≥95 mm in the RV survey (first row), occupied by mature male snow crab ≥95 mm in the snow crab survey (second row), and available in the ecosystem based on the RV survey (third row). In each panel, cdfs for individual years are distinguished using different colours. Only the years 2006-2010 are plotted because these are the years for which the entire area covered by present crab survey polygon was sampled. Note that 2009 was omitted because of missing temperature values for the crab survey.

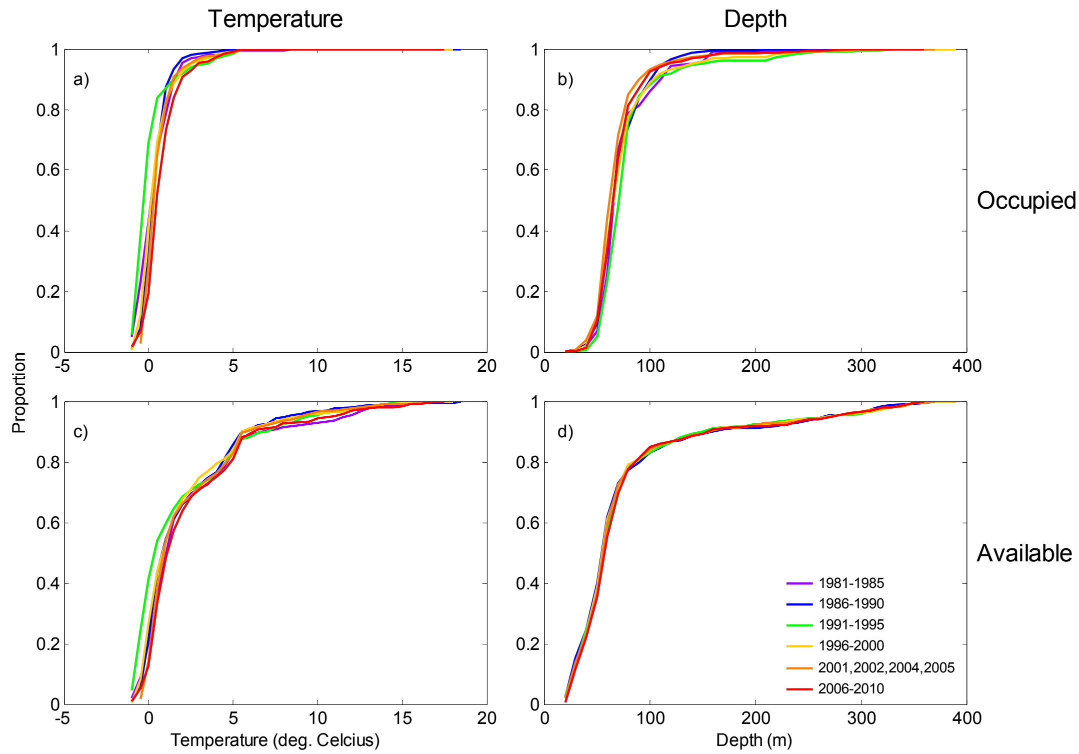


Figure 6.Cumulative distribution functions (cdfs) of the habitat (temperature, left panels, or depth, right) occupied by snow crab of all sizes (first row) and the habitat available in the southern Gulf (second row) based on the RV survey, for 5-year blocks (except for 2001-2005), indicated using different colours.

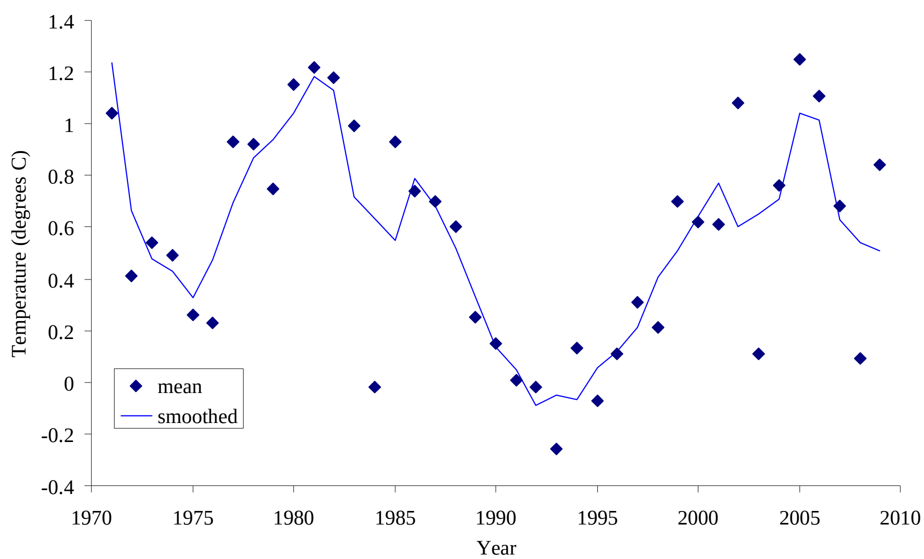


Figure 7.Trend in the mean bottom temperature of the waters between 60-120 m depth in the southern Gulf of St. Lawrence.

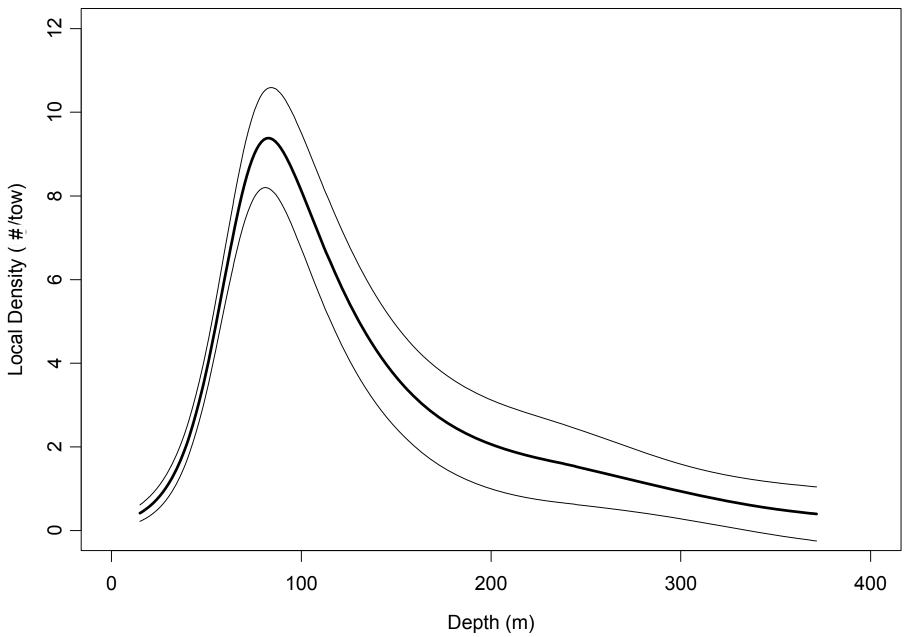


Figure 8.Predicted local density (and 95% confidence interval) of male snow crab ≥95 mm, as a function of depth in the RV survey (2001-2010, excluding 2003), based on the GAM analysis using eqns.3 & 4.

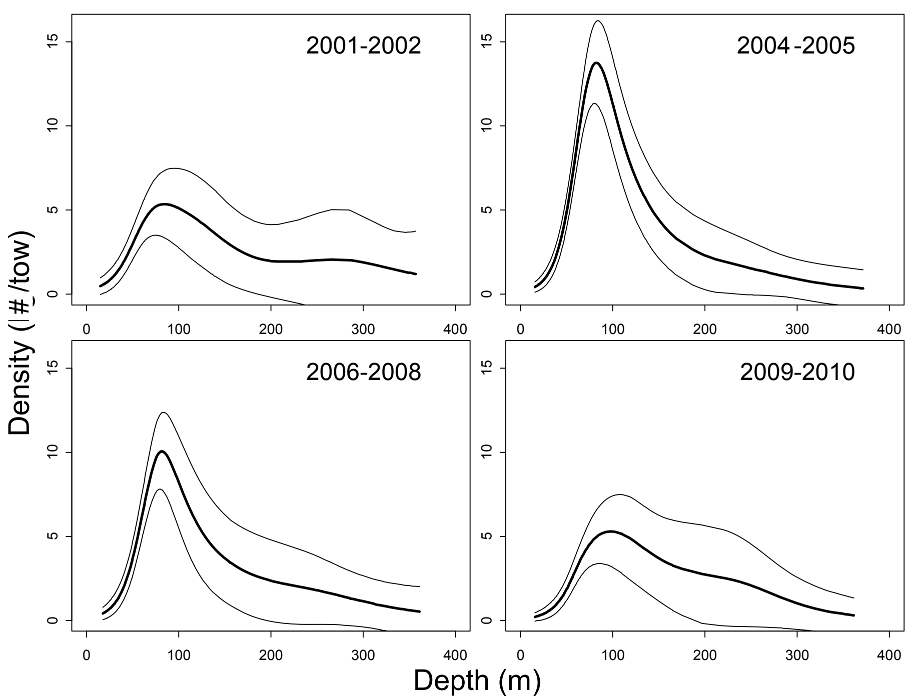
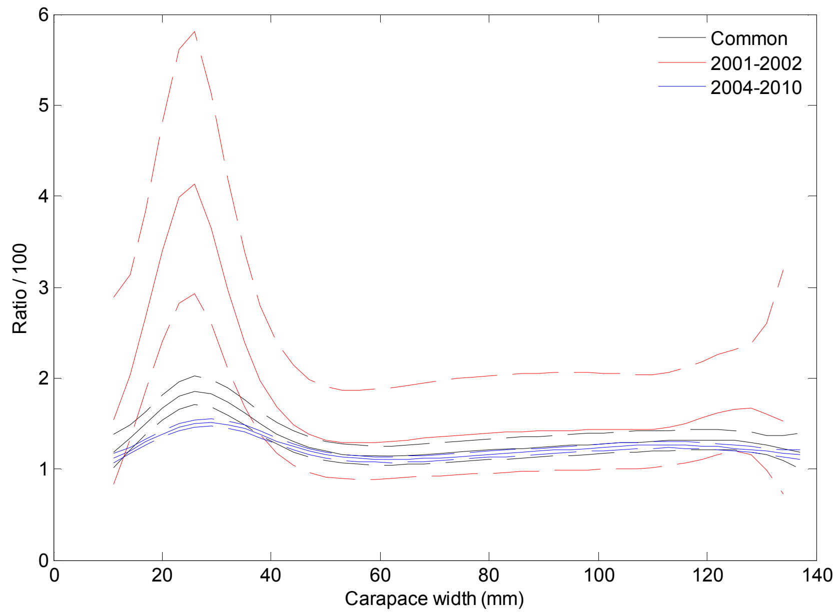


Figure 9. Predicted local density (and 95% confidence interval) of male snow crab ≥95 mm, as a function of depth in the RV survey in two- or three-year blocks, based on the GAM analysis using eqns.3 & 4.

a)



b)

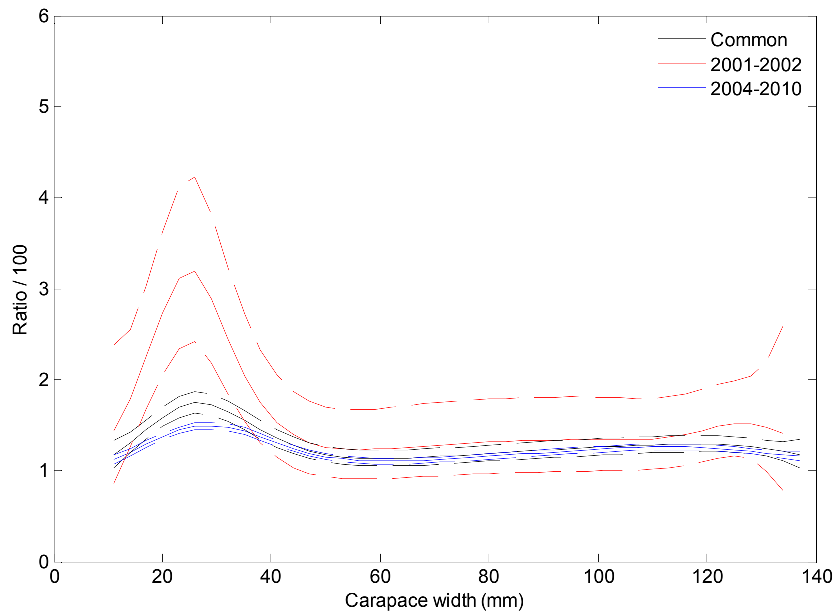


Figure 10. Predicted ratio (with 95% confidence interval indicated using dashed lines) of snow crab catches in the snow crab survey and in the RV survey as a function of carapace width, based on GAM analyses for 2001-2002 (red), 2004-2010 (blue) and all years combined (black). Results are presented for analyses based on RV survey data that were either uncorrected (panel a) or corrected (panel b) for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

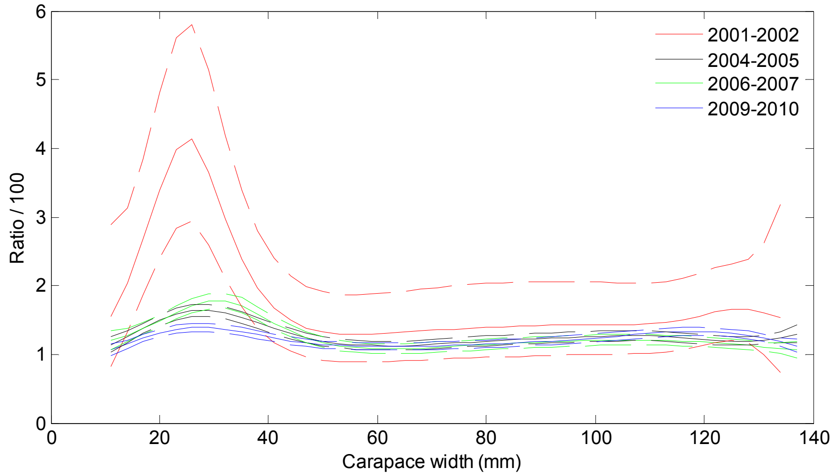


Figure 11. Predicted ratio (with 95% confidence interval indicated using dashed lines) of catches of male snow crab ≥95 mm in the snow crab survey and in the RV survey as a function of carapace width, based on GAM analyses for four two-year blocks. For both surveys, both mature and immature males are included. The results are for analyses based on RV survey data that were not corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

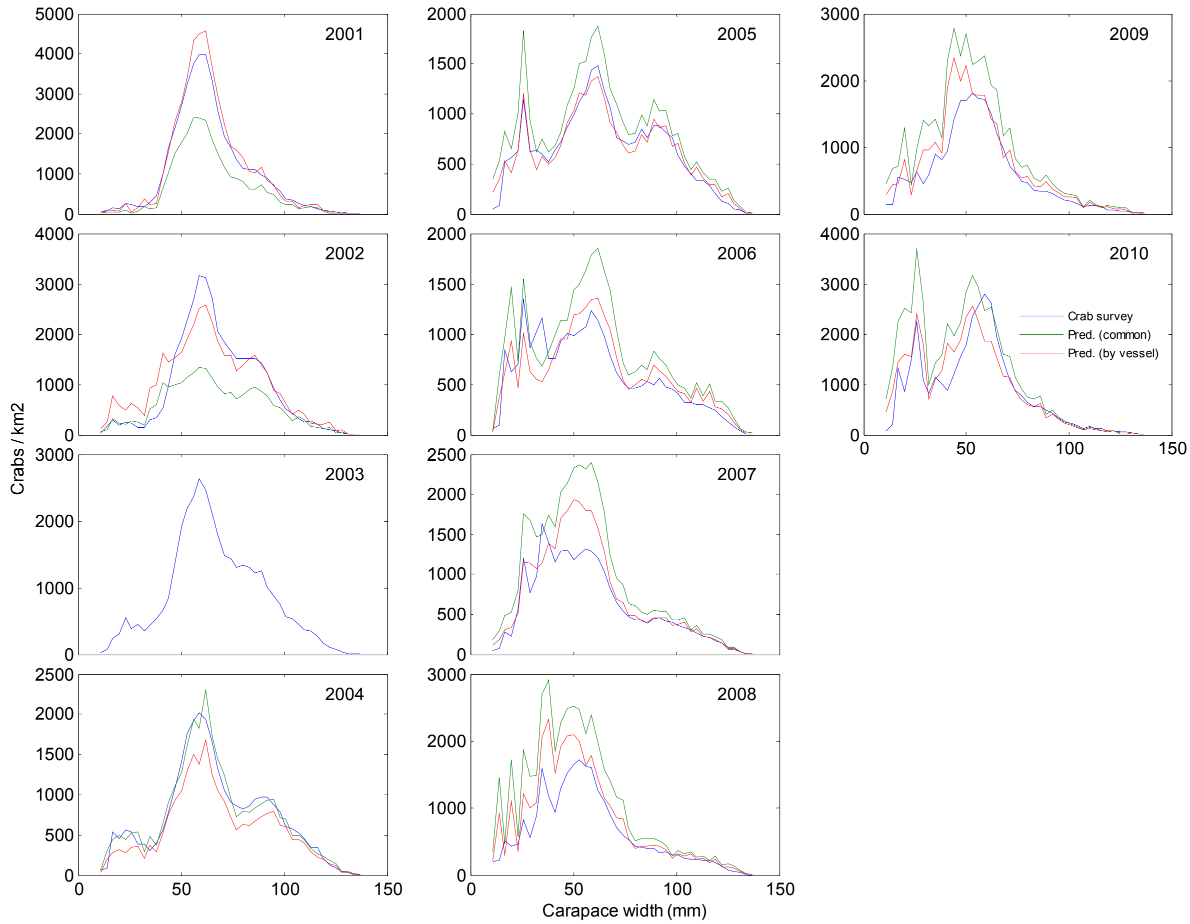


Figure 12. Observed annual length frequency distributions of snow crab in the crab survey (blue line), and predicted length frequencies based on observations from the RV survey and the size-dependent relative efficiency of the two surveys (eqn.5) estimated using data for all years combined (green lines) or estimated by groups of years for which different vessels were used in the crab survey (2001-2002 and 2004-2010; red lines). The RV survey data used in this analysis were not corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

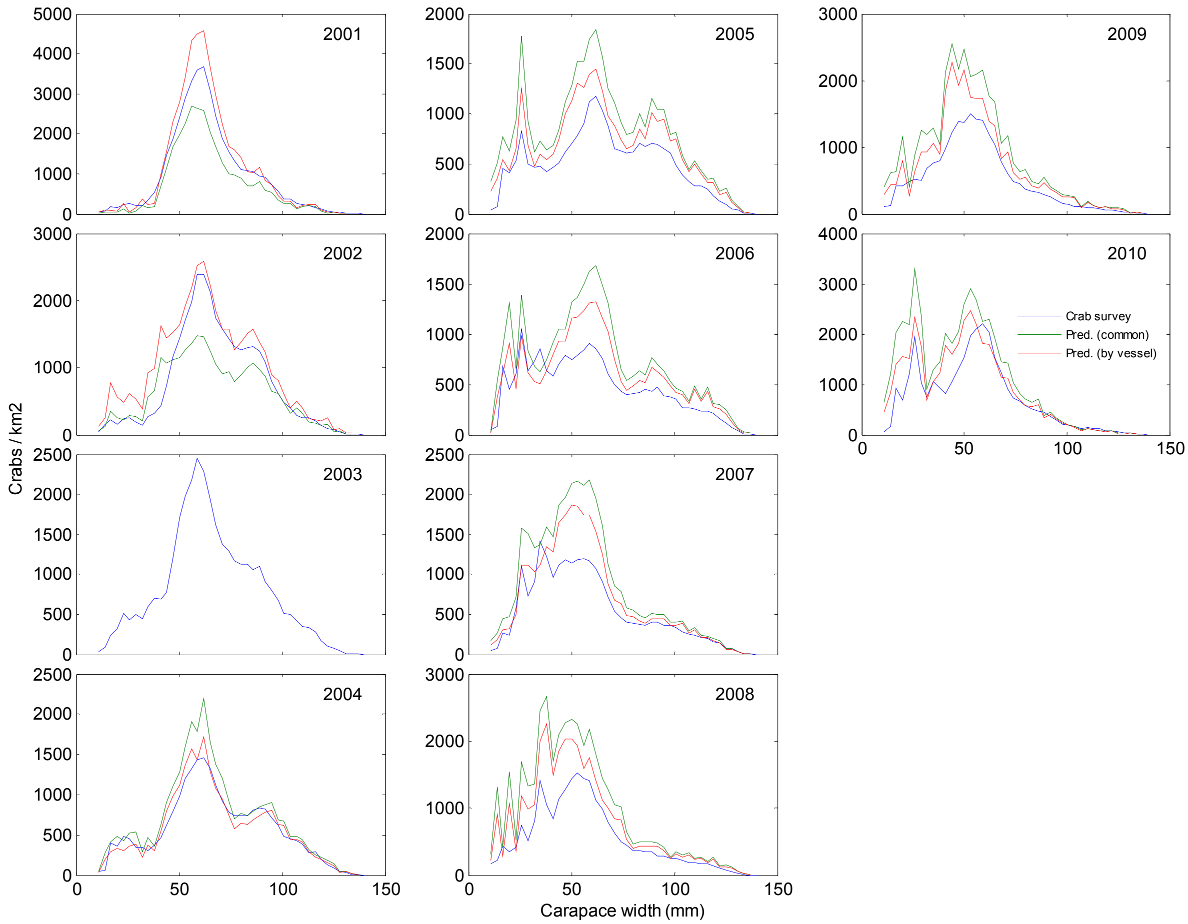
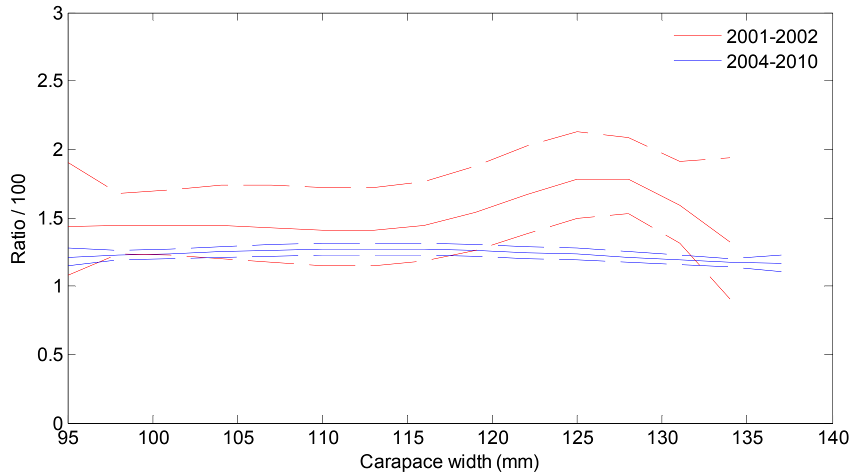


Figure 13. Observed annual length frequency distributions of snow crab in the crab survey (blue line), and predicted length frequencies based on observations from the RV survey and the size-dependent relative efficiency of the two surveys (eqn.5) estimated using data for all years combined (green lines) or estimated by groups of years for which different vessels were used in the crab survey (2001-2002 and 2004-2010; red lines). The RV survey data used in this analysis were corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

a)



b)

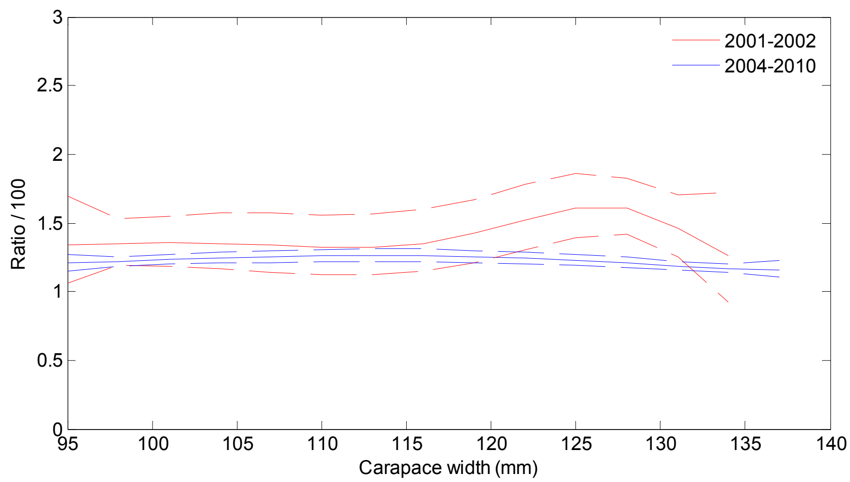


Figure 14. Predicted ratio (with 95% confidence interval indicated using dashed lines) of catches of male snow crab ≥95 mm (mature and immature) in the snow crab survey and in the RV survey as a function of carapace width, based on GAM analyses for 2001-2002 (red) and for 2004-2010 (blue). Results are presented for analyses based on RV survey data that were either uncorrected (panel a) or corrected (panel b) for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

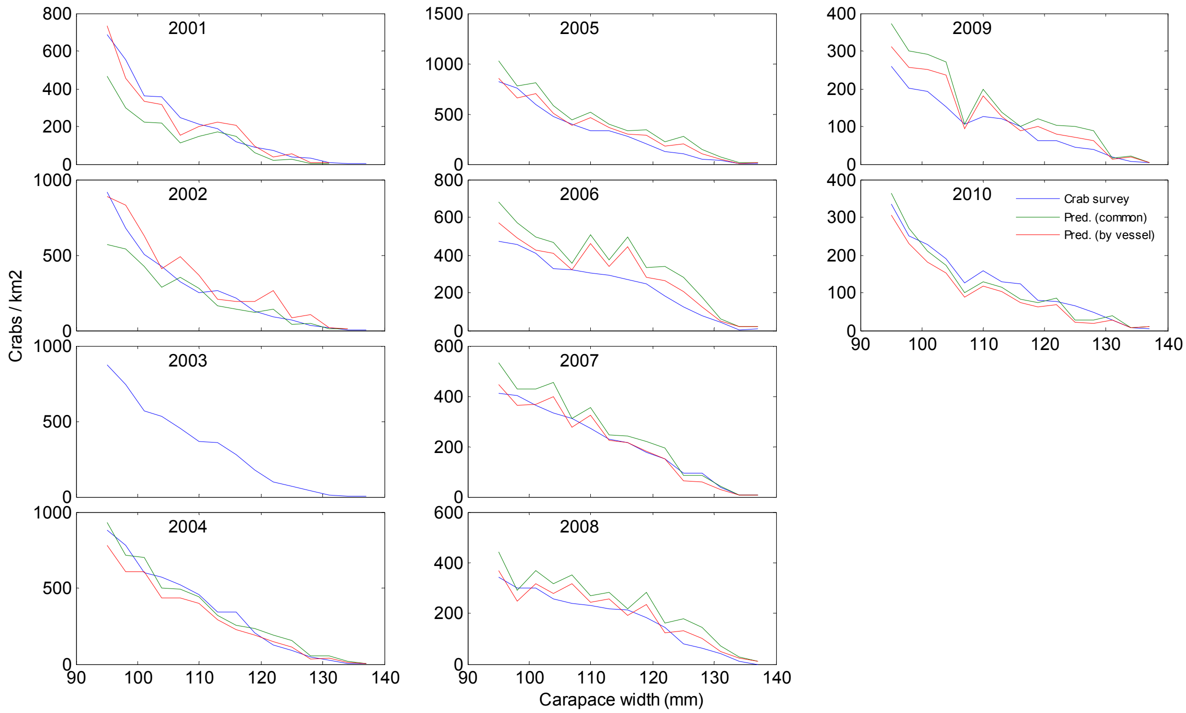


Figure 15. Observed annual length frequency distributions of male snow crab ≥95 mm (mature and immature) in the crab survey (blue line), and predicted length frequencies based on observations from the RV survey and the size-dependent relative efficiency of the two surveys (eqn.5) estimated using data for all years combined (green lines) or estimated by groups of years for which different vessels were used in the crab survey (2001-2002 and 2004-2010; red lines). The RV survey data used in this analysis were not corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

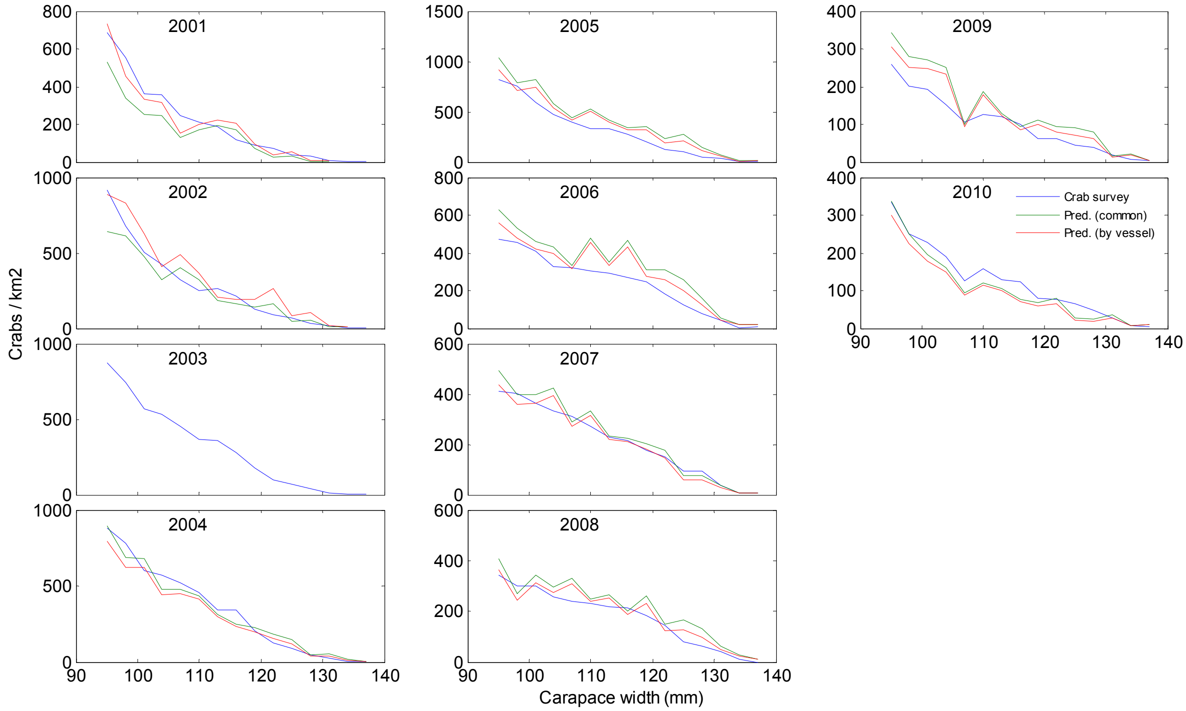


Figure 16. Observed annual length frequency distributions of male snow crab ≥95 mm (mature and immature) in the crab survey (blue line), and predicted length frequencies based on observations from the RV survey and the size-dependent relative efficiency of the two surveys (eqn.5) estimated using data for all years combined (green lines) or estimated by groups of years for which different vessels were used in the crab survey (2001-2002 and 2004-2010; red lines). The RV survey data used in this analysis were corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

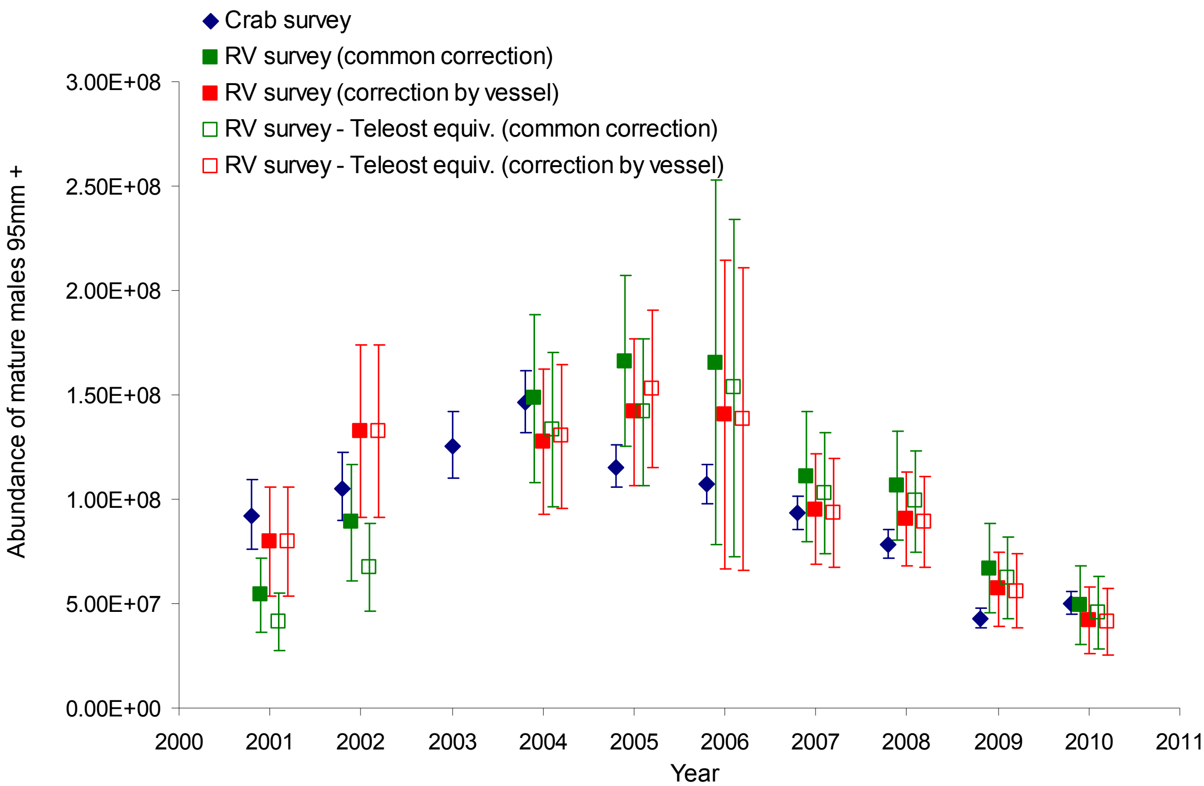


Figure 17. Estimated annual abundance of mature male snow crab ≥95 mm (± 95% confidence interval) occurring in the crab assessment polygon (2001-2010), based on the snow crab survey (blue diamonds) and the RV survey (squares). The estimates for the RV survey were transformed to be equivalent to those from the crab survey using the estimated GAM functions for the relative efficiency of the surveys: common function for 2001-2010 (green squares) and crab survey vessel-specific functions (red squares), for RV survey data that were (open squares) and weren't (filled squares) corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

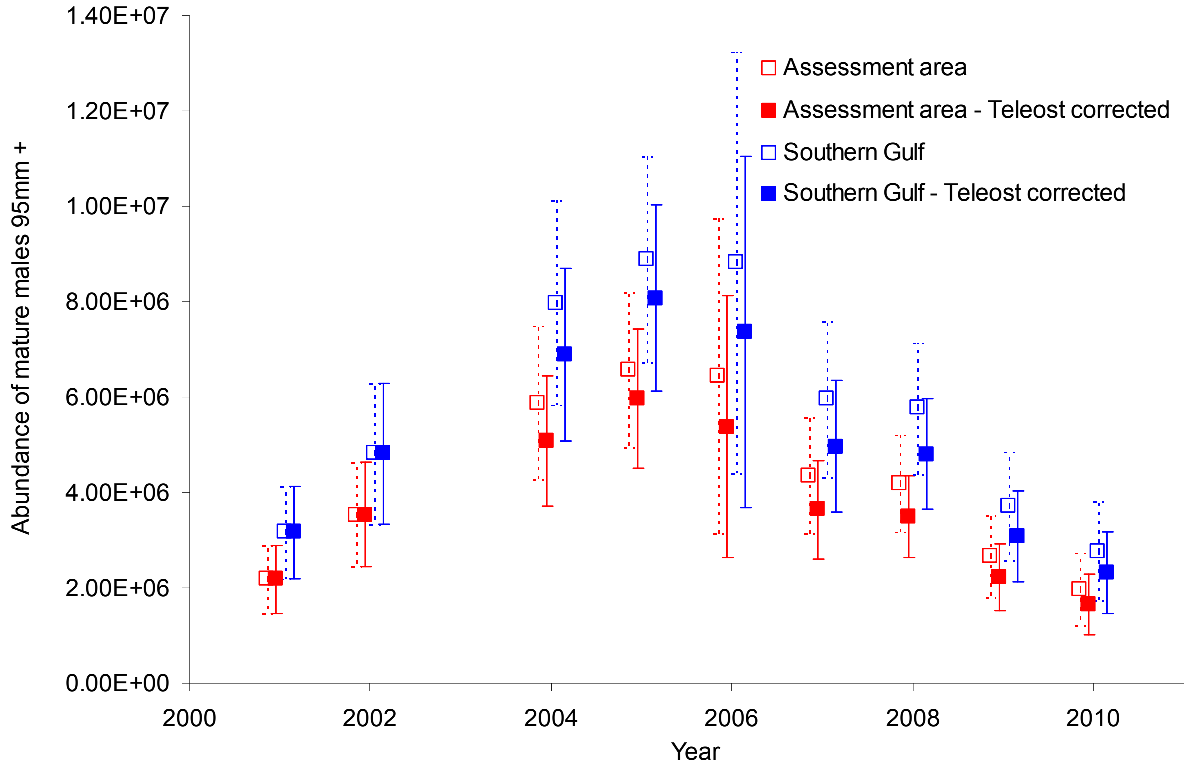


Figure 18. Trawlable abundance (± 95% confidence interval) of mature male snow crab ≥95 mm in the RV survey 2001-2010, based on a geographic area comparable to that used for the current snow crab assessment (red) and for the entire RV survey area (blue). In each case, series are presented for Teleost catches that were (closed symbols) and weren't (open symbols) corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

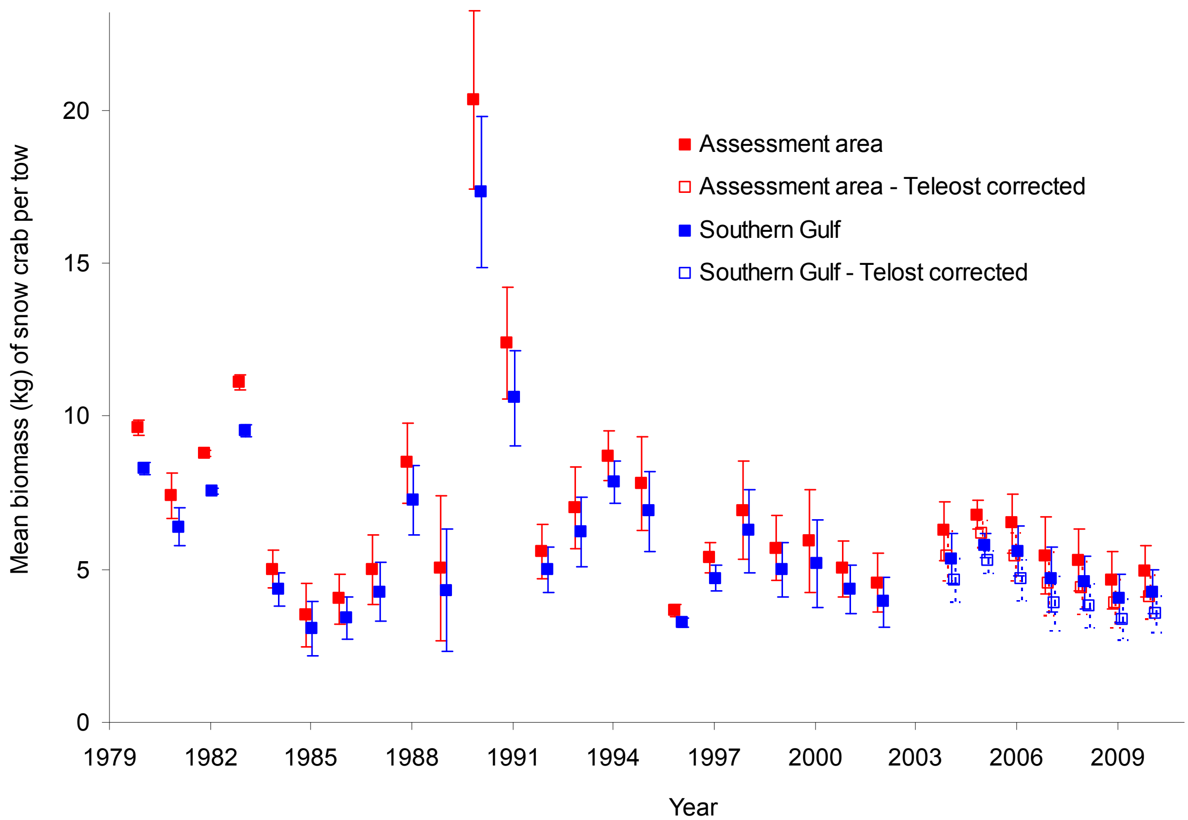


Figure 19. Biomass index (mean kg/tow ± 95% confidence interval) for snow crab in the RV survey 1980-2010, based on a geographic area comparable to that used for the current snow crab assessment (red) and for the entire RV survey area (blue). In each case, series are presented for Teleost catches that were (closed symbols) and weren't (open symbols) corrected for a possible difference in fishing efficiency between the CCGS Alfred Needler and the CCGS Teleost.

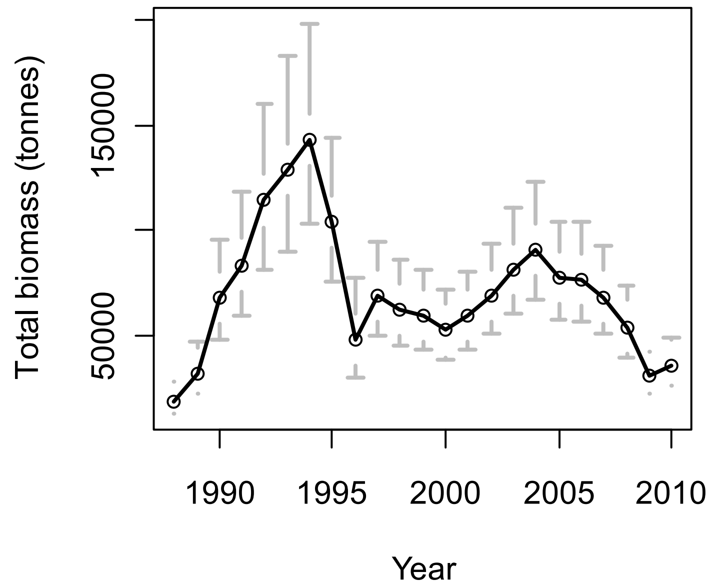


Figure 20. Estimates of total survey biomass for 4T snow crab (from Cadigan 2012). Grey vertical lines indicate 95% confidence intervals.

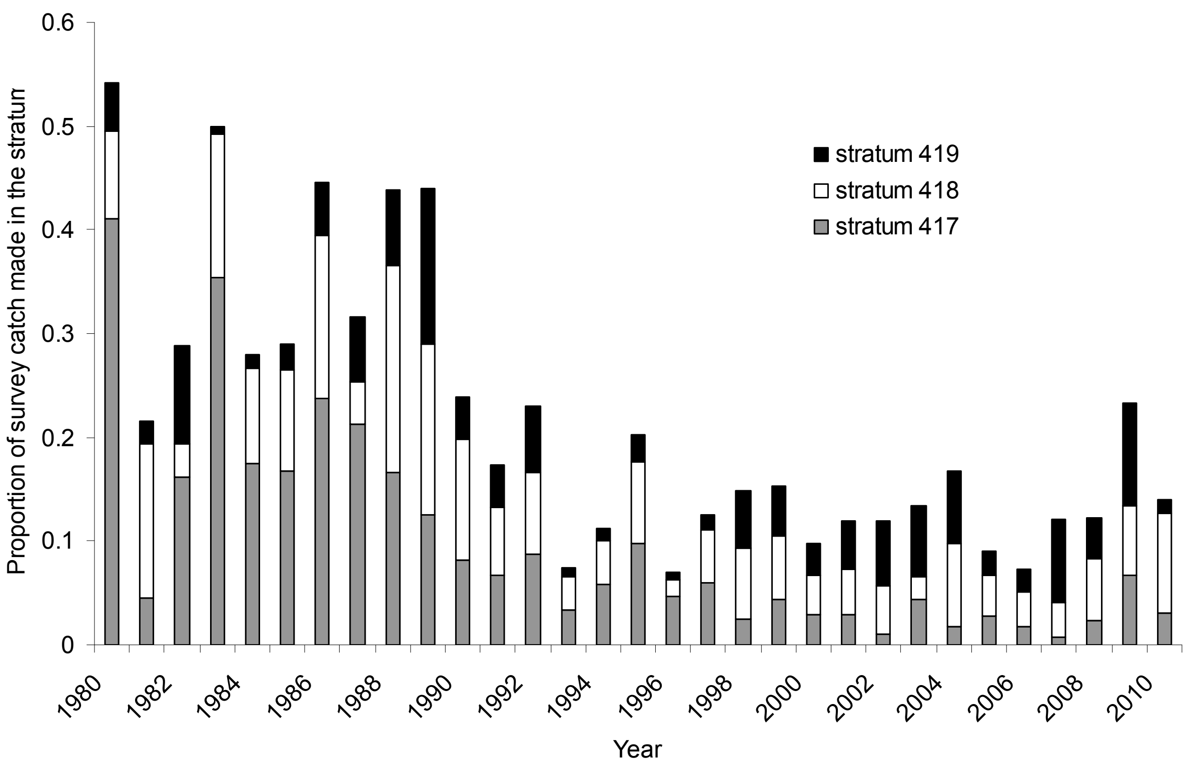


Figure 21. Annual proportion of total RV survey catches made in the three strata of in and immediately outside of Baie de Chaleurs (Fig. 1): stratum 419 (head of the bay), stratum 418 (mouth of the bay), and stratum 417 (north east of the mouth of the bay).