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Environmental conditions in the southern Gulf of St. Lawrence relevant to snow crab

J. Chassé[1], P.S. Galbraith[2], N. Lambert[2], M. Moriyasu[1], E. Wade[1], J.Marcil[1] and R.G. Pettipas[3]

[1] Fisheries and Oceans Canada
Gulf Fisheries Centre
P.O. Box 5030
Moncton, N.B., E1C 9B6

[2] Pêches et Océans Canada
Institut Maurice-Lamontagne
C.P. 1000, Mont-Joli, Québec, G5H 3Z4

[3] Fisheries and Oceans Canada
Bedford Institute of Oceanography
P.O. Box 1006
1 Challenger Drive, Dartmouth, Nova Scotia, B2Y 4A2

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Foreword

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

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ABSTRACT

Near-bottom temperatures and salinities in the southern Gulf of St. Lawrence (sGSL; Magdalen Shallows) were examined using data primarily collected during the snow crab and multi-species surveys. Annual data are presented relative to normal conditions (average of 1971-2000). The cold intermediate layer (CIL) volume time series clearly shows a greater quantity of cold water in the 1990's in the sGSL with a return to more normal conditions towards the end of the time series (2010). The analysis shows that the inter-annual variability of September bottom temperatures is larger in shallow waters (e.g. Northumberland Strait) and along steeper slopes (e.g. Laurentian Channel) than over the relatively flat bottom of the Magdalen Shallows. The five-year running means of bottom temperature anomalies for snow crab fishing areas 12, 19, 12E and 12F show a continuously decreasing temperature from the last maxima in the early 1980s to the minima in the early 1990s followed by a general warming trend since that time. The area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the September multi-species survey has shown a general decrease since the beginning of the 90's. Although there is a lot of inter-annual variability, the annual mean temperature within the snow crab habitat area increased significantly over the same period. The value in 2010 is significantly higher than the long-term mean and represents the highest value since 1982 when the maximum (1.31°C) of the time series was reached. The sGSL is covered with salinities < 34 psu with low inter-annual variability. The analysis of the commercial snow crab thermal distribution revealed that the occurrence of commercial crab in areas with temperatures above 3°C is very rare, with only 5.2% of the catches in bottom waters above 3°C. The results suggest that commercial male crab favoured habitat between -1.2 to 1.2°C. The depth distribution suggested that commercial crab favoured habitat between 65 to 100 m. The analysis of the temperature coverage of the old and new polygons used for the estimation of the biomass reveals that the new polygon has a better coverage of the snow crab thermal habitat than the previous polygon. The appropriateness of the polygon coverage also increases when bottom temperature thresholds of 3ºC to 5°C are considered. Since 95% of the crabs are caught below 3°C, the new polygon covers the commercial snow crab habitat relatively well.

Conditions environnementales dans le sud du golfe du Saint-Laurent en lien avec le crabe des neiges

RÉSUMÉ

Les températures et les salinités près du fond dans le sud du Golfe du Saint-Laurent (sGSL; plateau madelinien) ont été examinées à l'aide de données principalement recueillies au cours des relevés plurispécifiques et des relevés visant le crabe des neiges. Les données annuelles sont présentées en fonction des conditions normales (moyenne de 1971-2000). La série chronologique du volume de la couche intermédiaire froide montre clairement une plus grande quantité d'eau froide dans les années 1990 dans le sGSL, avec un retour à des conditions plus normales vers la fin de la série chronologique (2010). L'analyse indique que la variabilité interannuelle des températures près du fond en septembre est plus importante dans les eaux peu profondes (p. ex., dans le détroit de Northumberland) et le long des pentes plus fortes (p. ex., dans le chenal Laurentien) qu'au-dessus du fond relativement plat du plateau madelinien. Les moyennes mobiles sur cinq ans des anomalies de température au fond pour les zones de pêche au crabe des neiges 12, 19, 12E et 12F montrent une baisse constante de la température, allant du dernier maximum au début des années 1980 jusqu'au minimum au début des années 1990; depuis, la tendance indique un réchauffement général. La surface du fond du plateau madelinien, comprise entre -1 °C et 3 °C au cours du relevé plurispécifique de septembre, a subi une baisse générale depuis le début des années 1990. Malgré sa forte variabilité interannuelle, la température moyenne annuelle de la zone d'habitat du crabe des neiges a augmenté significativement au cours de cette même période. La valeur en 2010 est significativement plus élevée que la moyenne à long terme et représente en fait la valeur la plus élevée depuis 1982, année durant laquelle on a enregistré la température la plus haute (1,31 °C) de la série chronologique. Dans le sGSL, les salinités sont inférieures à 34 psu avec une faible variabilité interannuelle. L'analyse de la répartition thermique du crabe des neiges visé par la pêche commerciale a révélé que les crabes se trouvent très rarement dans les zones où la température de l'eau est supérieure à 3 °C, avec seulement 5,2 % des prises provenant de telles zones. Les résultats suggèrent que les crabes mâles ciblés par la pêche commerciale préfèrent un habitat dont la température se situe entre -1,2 °C et 1,2 °C. La répartition de la profondeur permet de penser que les crabes ciblés par la pêche commerciale préfèrent un habitat situé à une profondeur allant de 65 m à 100 m. L'analyse de la couverture thermique des ancien et nouveau polygones servant à estimer la biomasse révèle que le nouveau polygone couvre mieux l'habitat thermique du crabe des neiges que l'ancien. L'exactitude de la couverture du polygone augmente également lorsque l'on prend en compte les seuils de température au fond de 3 °C à 5 °C. Puisque 95 % des crabes sont capturés dans des eaux en dessous de 3 °C, le nouveau polygone couvre relativement bien l'habitat du crabe des neiges ciblé par la pêche commerciale.

INTRODUCTION

Snow crab (*Chionoecetes opilio*) is a cold-water stenothermic species typically inhabiting bottom depths of 20-310 m (Squires 1990). It can be found in areas with water temperatures as low as negative 1.5°C (Lovrich et al. 1995). An active and lucrative fishery presently exists in the southern Gulf of St. Lawrence (sGSL) (Figs. 1 to 3). Annual assessments of the stock abundance, fishing effort, biological characteristics and the environment of the snow crab are undertaken by the combined efforts of the Fisheries and Oceans Gulf Region (DFO) and the snow crab fishing industry (some fishing areas) (Hébert et al. 2012).

The purpose of this research document is to provide information on sea temperature and salinity for the period of 1981 to 2010 in the southern Gulf of St. Lawrence, including snow crab fishing areas (12, 19, 12E and 12F;Fig. 2). Information about the amplitude and phase of the bottom temperature seasonal cycle is also provided, as well as areal indices of the ocean bottom covered by summer water temperatures between -1°C and 3°C. The catch of snow crab during the snow crab survey as a function of temperature is presented and yearly changes are documented. The coverage of the snow crab habitat by the polygon used for the estimation of the biomass is investigated. We also investigate the coverage of a newly introduced polygon for the 2011 snow crab stock assessment (DFO 2012; Hébert et al. 2012). The research document begins with a description of the temperature and salinity data, and provides details of the methods used to analyze the temperature fields and finally present the results.

DATA

Temperature and salinity data in the known snow crab habitat and main fishing ground were available from two surveys conducted in the sGSL; the first is the snow crab survey conducted annually from July to September (355 stations in 2010), and the second the annual multi-species survey (formerly the groundfish survey) carried out in September (145 stations were sampled in 2010; Fig. 4). The snow crab survey obtained near-bottom temperatures with a thermistor recorder attached to the trawl. Temperature and salinity profile data were typically collected with a conductivity-temperature-depth (CTD) instrument. Other temperature data for the sGSL were obtained from the Integrated Science Data Management (ISDM) in Ottawa (Canada’s national oceanographic data archive) and from additional fisheries surveys, research surveys and measurements from ships of opportunity. The catch information, i.e. the number of crabs per tow, is maintained by DFO at the Gulf Fisheries Centre (GFC) in Moncton, New Brunswick.

METHODS

The results of two different interpolation methods of historical temperature and salinity data from CTD profiles, already produced for other purposes, were used within the current study. In the first method, from Galbraith et al. (2011), August and September vertical profile data are first interpolated for every meter depth on approximately a 2 km square resolution grid of the Gulf of St. Lawrence. The interpolation uses a weighted nearest neighbour method based on data from 1971 to 2010. The interpolated bottom temperature for every grid cell is used to construct a bottom temperature field that respects bathymetry-driven changes between sample stations. There were a few years when there were not enough data to obtain complete temperature and/or salinity fields, and for these cases, the annual data were excluded from the analysis. This approach allows for the estimation of mean properties of 3D fields as well as statistics of inter-annual variability. The interpolated-grid data set can then be contoured and specific polygon definitions and areas (e.g. 4°C) can be extracted.

We used a second interpolation method to generate a gridded field to estimate the average intra-annual properties of bottom temperature, i.e. to calculate the mean, the amplitude and phase of the seasonal cycle. This method projects all the available temperature and salinity data onto a grid with a mesh size of 0.1° by 0.1° (latitude, longitude) using an objective analysis procedure known as optimal estimation (Bretherton et al. 1976). This is a four-dimensional interpolation technique; i.e. three space dimensions, two horizontal and one vertical, and the time dimension. Then, a harmonic analysis (e.g. Ouellet et al. 2003) was performed to extract the mean and amplitude-phase of the seasonal cycle.

Using the second interpolation method, the snow crab habitat index, defined by Drinkwater et al. (1998) as the area of the bottom covered by temperatures between -1°C and 3°C (favorable temperature range for the adult snow crab), was calculated from the gridded temperature fields. The temperature at each grid point was assigned the area of bottom associated with that particular grid point. The areas with temperatures between -1°C and 3°C, inclusive, were then summed. The mean temperature within this area was also estimated. The 2010 indices were compared to those derived from earlier surveys. The time series of the indices begins in 1971 for the sGSL.

The catch of snow crab as a function of temperature and depth was also examined. The temperatures at which the crabs were caught were partitioned into 0.5°C bins and the depths into 5 m bins. The frequency distribution of the crab temperatures was expressed in percentages within each of the bins. These were then compared with the frequency distribution of the available temperatures at all of the stations sampled.

For each interpolated temperature field using the first method, the surface defined within the polygon used to estimate the commercial male biomass was calculated for the 3°C, 4°C, and 5 °C temperature thresholds and a time series of these is presented. We also, estimated the surface that is below a specific temperature threshold but not inside the polygon as well as the surface that is inside the polygon, but above the same threshold. These calculations were completed for the historical survey polygon for snow crab and the newly introduced polygon (Hebert et al. 2012).

To quantify the appropriateness of a polygon in covering bottom waters below a temperature threshold in the sGSL, we defined a score (Sc)' as:

$$Sc = Pc \cdot Pt$$

Where Pc is the percentage (in terms of area) of the polygon that is covered by temperatures less than or equal to a particular threshold and Pt is the percentage of the total surface in the sGSL that is covered by temperatures below the same threshold. The higher the Sc value the more appropriate is the polygon definition relative to the total bottom area with water temperatures below that threshold. A score of 100% is interpreted as a perfect match of a polygon to encompass the temperatures below that threshold in the sGSL.

RESULTS AND DISCUSSION

BOTTOM TEMPERATURES

September average temperature and salinity profiles are shown in Figure 5 for the sGSL. The September water column in the sGSL shows three separate layers: the surface layer, the cold intermediate layer (CIL), and the deeper water layer (see also Galbraith et al. 2011 for more details on vertical temperature and salinity structure in the GSL). At typical depths of the sGSL (~70m) the bottom is covered with CIL waters and therefore temperatures are usually < 1°C over a large portion of the Magdalen Shallows (Fig. 5). An estimation of the water volume < 1°C is shown in Figure 6. It can be clearly seen that there was a greater quantity of cold water in the 1990's in the sGSL with a return to more normal conditions towards the end of the time series.

The September 1971-2010 average bottom temperature field is shown in Figure 7 using the frrst interpolation method. Bottom temperatures ranged from <1°C to over 17°C and most of the bottom was covered by waters <3°C with the largest portion of the Magdalen Shallows (50-80 m) covered by waters <1°C. Bottom waters with temperature <1°C can also be seen in Chaleur Bay. There was also an area covered with sub-zero waters over the Magdalen Shallows. Bottom temperatures tended to increase from the center of the Magdalen Shallows towards the shallower, nearshore regions and towards the deeper Laurentian Channel. This is because in the Gulf of St. Lawrence during summer, cold temperatures are found at intermediate depths (50-150 m), sandwiched between warm solar-heated upper layer waters and the relatively warm, salty deep waters in the Laurentian Channel. The latter originate from the slope water region off the continental shelf and are transported up the Channel. Although the deeper waters are warmer than the CIL, their density is greater because of higher salinities. In winter, the CIL merges with the upper layer as the latter cools. The primary origin of the waters in the CIL is from atmospheric cooling of the water within the Gulf of St. Lawrence in winter with additional input through advection of cold Labrador Shelf water through the Strait of Belle Isle. The latter varies inter-annually with a mean of approximately 15% of the total volume of the winter cold surface layer, and influencing conditions mostly in the northeast Gulf of St. Lawrence (Galbraith, 2006). On average, the warmest near-bottom temperatures in the southern Gulf are found in Northumberland Strait which can exceed 23°C.

The inter-annual standard deviation (SD) of September bottom temperatures is below 1°C over most of Shallows with the central portion having a SD less than 0.5 °C (Fig. 8). The SD is larger in shallow waters (e.g. Northumberland Strait) and along steeper slopes (e.g. Laurentian Channel). Other large values of SD can be seen along the coast of New-Brunswick, northeast coast of Prince Edward Island (PEI), and around the Magdalen Islands. However, SDs in shallow water areas must be viewed with caution since the largest uncertainties in the interpolated temperature fields are in the nearshore regions. There are two main reasons for this. First, there tends to be greater temporal variability at shallower depths because they lie close to the strong vertical gradient in temperature, called the thermocline. Indeed, in these regions the mixed layer may at times extend to the bottom in response to wind storms producing large variability in the near-bottom temperatures. Second, the second interpolation method may extrapolate the temperatures horizontally to the coast if there are no data inshore. This can lead to fictitious data, especially in regions of strong horizontal temperature gradients.

A harmonic analysis of the annual temperature cycle was performed to extract the amplitude and phase. The mean annual temperature obtained from the harmonic analysis is shown in Figure 9. Compared to the 1971-2010 September average, there is a large portion of the Magdalen shallows that exhibits sub-zero bottom temperatures indicating that September is a warmer month than the annual mean. The amplitude of the annual cycle (Fig. 10) varies between 0.5 to 1.5 °C over a large portion of the sGSL which means that the range (twice the amplitude) between the minimum and maximum values is 1 to 3 °C. The maximum temperature (phase) is reached during the months of October and November over the largest portion of the sGSL (Fig. 11). Shallow waters are more exposed to direct warming from the surface and maximum temperatures are reached in August and September.

A time series of the bottom area covered by various temperature intervals (1°C bins) was estimated from the gridded temperature data (Fig. 12) using the first interpolation method. Prominent in the series is the large area covered by cold water (below 0°C) in the 1990's and the return to more normal conditions since.

The general trends in the temperature anomalies in the near-bottom waters throughout the Magdalen Shallows are similar. This is highlighted in Figure 13 that shows the five-year running means of the temperature anomalies for snow crab fishing areas 12, 19, 12E and 12F. These show the continuously decreasing temperature between the last maxima observed in the early 1980s and the minima in the early 1990s, followed by a generally warming trend since then.

BOTTOM SALINITY

The 1971-2010 September average bottom salinity field, interpolated using the first method, is shown in Figure 14. The entire sGSL is characterized by salinities less than 34 psu with the largest portion comprised between 31 and 33 psu. Inter-annual variability of salinity is low with a standard deviation between 0.2 and 0.4 over most of the sGSL (Fig. 15).

SNOW CRAB HABITAT INDEX

From the September multi-species survey, a time series of the snow crab habitat index (area of bottom with water temperatures between -1°C and 3°C,) based upon optimally estimated bottom temperatures is available from 1971 to 2010. The southern Gulf grid contains a total area of 70,039 km^2 (847 grid points). Similarly to Drinkwater et al. (1998), we also estimated the average temperature within the area covered by temperatures in the range -1°C to 3°C and correlated these with the habitat index.

In 2010, the area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the September multi-species survey increased compared to 2009. It was 50,177 km^2 in 2010 and was closer to the long-term mean (1971-2000) of approximately 51,969 km^2 than in 2009 (Fig. 16). The 2010 value represents 72% of the total Shallows area, and was 5% larger than in 2009, but is comparable to the areas during 2006 and 2008. In terms of area, this represents a return to almost normal conditions compared to 2009; the snow crab habitat index in 2009 was the third lowest value over the 40-year record, with 1980 and 1981 being the lowest values of the whole time series. The highest values were reached in 1976, 1984 and 1992. Note, however, that the variability in the habitat index for the Shallows tends to be small. The index only varied between 65% and 84% of the total area available over all years.

The mean temperature within the habitat area in 2010 (1.25°C) increased greatly compared to 2009 (by 0.5°C) and was the highest since 1982 when the maximum (1.31°C) of the time series was reached (Fig. 16, lower panel). The second highest value of the time series occurred in 2010. Other high values were estimated in 1971, 1977, 1981 and 1983. The 2010 value is sharply different from the low values observed during the 1990’s cold period and is also well above the 1999-2002 and 2005-2007 warm periods. The 2010 index also showed an increase of 1°C since 2008 and is the largest positive gradient (over a two-year period) of the time series. For recent years, the 2006 mean temperature within the habitat had been the highest of the previous 24 years. The correlation between the habitat index and the mean temperature over the years 1971-2010 is low and not statistically significant (-0.46).

TEMPERATURE AND DEPTH OCCUPIED BY SNOW CRAB

From 1988 to 2008, the temperature occupied by commercial adult male snow crab (i.e. terminally molted males larger than 95mm in carapace width, called “snow crab” hereafter) corresponded with the available temperature. However, looking at the difference between the mean temperature occupied by snow crab and the mean sampled temperature, slight fluctuations are apparent among years (Fig. 17). Snow crab occupied slightly colder temperatures than what was available in the sGSL since 2001, and this gap has been increasing since 2001. The mean depth occupied by snow crab was slightly higher than that available for most years (Fig. 18). However, as with the temperature distribution, there has been a slight general shift insnow crab depth distribution since 2001, i.e. the mean depth occupied by snow crab tended to be deeper than the mean sampled depth in the survey.

The habitat association of snow crab with bottom temperature shows infrequent statistical significance with only 8 years out of 20 having a p-value less than 0.05. The habitat limit for snow crab, i.e. where 95% of the crab were caught, ranged from -1.2 to 3.1 °C in 2008 to -0.5 to 5.6 °C in 1994. However, the occurrence of snow crab above 3°C was very rare (Fig. 19) even when looking at each year separately. Only 5.2% of the tows where snow crab were caught were at bottom temperatures above 3°C. When taking account the available area at each temperature interval (% of snow crab - % of area), the distribution suggested that snow crab favoured habitat between -1.2 to 1.2 °C (Fig. 20). The range of depth varied from 41.7 to 167.5 m for snow crab in 2005 (all years combined together in Figure 21). The Cumulative Density Function (CDF) for temperature occupied by snow crab generally follows that of the sampled temperature (Fig. 22), but with a slightly faster progression indicating the preference of snow crab for the cooler waters of the habitat.

The CDF for depth occupied by snow crab also followed closely that of available depth (Fig. 23), but the difference between occupied and available depth was significant ($p < 0.01$) over all years combined. When taking into account the available area at each depth interval (% of snow crab - % of area), the distribution suggested that snow crab favoured habitat between 65 to 100 m (Fig. 24).

TEMPERATURE RANGES WITHIN THE POLYGON USED TO ESTIMATE THE BIOMASS

A polygon with an inner surface of 44,316 km^2 (Fig. 25) was used in the DFO stock assessment process to estimate the biomass of commercial snow crab in the sGSL (DFO 2012; Hébert et al. 2012). To evaluate the adequateness of its coverage, the portion of the bottom surface in and out of the polygon was calculated for different temperature thresholds. Figure 26 shows the surface area that is covered by average (1971-2010) September bottom temperatures less than 3°C, less than 4°C, and less than 5 °C and Table 1 shows the statistics associated with each polygon and temperature threshold. For the surface defined by bottom temperatures less than 3°C, the total bottom area is 39,767 km^2. The polygon misses some areas, on the north side of PEI and around the Magdalen Island, with an area of 11,366 km^2 not included in the polygon and representing 22% of the total bottom area with temperatures less than 3°C (51,132 km^2). However, the polygon includes a bottom area of 4,550 km^2 that is above 3°C. The September average bottom area coverage increases to 41,447 km^2 for the surface defined by bottom water temperatures less than 4°C. A surface encompassing <4°C bottom water temperatures of 13,440 km^2 is excluded by the snow crab assessment polygon, representing 25% of the total area of water temperatures less than 4ºC (54,887 km^2). The area characterized by bottom water temperatures above 4°C that is included in the polygon shrinks to 2,869 km^2. The area defined by bottom water temperatures less than 5°C is 42,704 km^2. The area outside the snow crab assessment polygon is 15,910 km^2 and represents 27% of the total bottom area below 5°C (58,614 km^2). The polygon includes a surface of 1,613 km^2 that is above 5°C. On average the scores (Sc) are 70%, 71%, 70% for the 3°C, 4°C, and 5°C temperature thresholds, respectively. The polygon coverage is quite stable but does show a small decrease over time (Fig. 27). The surface covered by the polygon increases from the 3°C to the 5°C temperature thresholds.

TEMPERATURE RANGES WITHIN THE NEW PROPOSED POLYGON FOR THE ESTIMATION OF THE BIOMASS

In November 2011, a new polygon (Fig. 28) was recommended for the estimation of the biomass of commercial snow crab in the sGSL (DFO 2012; Hébert et al. 2012). The same analysis as in the previous section was applied to the new recommended polygon. The new polygon has a total inner surface area of 57,846 km^2. Figure 29 shows the bottom area covered by average September bottom temperatures less than 3°C, 4°C, and 5 °C and the statistics are summarized in Table 1. For the surface defined by bottom temperatures less than 3°C inside the polygon, the coverage is 49,350 km^2 which is 85% of the total area encompassed by the polygon. For the whole sGSL, the polygon misses only small areas with bottom temperatures less than 3°C, located off Gaspé Bay and northeastern Cape-Breton; this area totals 1,782 km^2 representing 3% of the total area of bottom water temperatures less than 3°C (51,132 km^2). The recommended polygon includes areas of 8,496 km^2 that are characterized by bottom water temperatures above 3°C; these are located at both entrances of Northumberland Strait and in the deep Laurentian channel. The September average bottom area coverage increases to 52,025 km^2 (90% of the polygon area) for the surface defined by bottom temperatures less than 4°C. The area of bottom water temperatures less than 4°C missed by the polygon is 2,862 km^2, representing 5% of the total area for this temperature (54,887 km^2). The surface that is above 4°C and included in the polygon shrinks to 5,821 km^2. The area defined by bottom temperatures less than 5°C is 54,155 km^2. The area outside the polygon that is below 5°C is 4,460 km^2, representing 8% of the total area below 5°C (58,614 km^2). The polygon includes an area of 3,692 km^2 that is above 5°C located in the deep Laurentian channel. The scores (Sc) are 82%, 85%, 86% for the 3°C, 4°C, and 5°C temperature thresholds, respectively, and constitute a significant increase in corresponding coverage relative to the previous polygon.

The new polygon area shows a small decrease in time that is more pronounced than in the case of the old polygon (Fig. 30). Since the new polygon is larger, it encompasses a greater portion of the bottom waters that have warmed up in the last 15 years. The surface covered by the polygon does increase when changing from the 3°C to the 5°C temperature thresholds. Considering that 95% of snow crabs are caught below 3°C and the new polygon misses only small surfaces with mean bottom water temperatures less than < 3°C, the new polygon is a better representation of the commercial snow crab distribution.

SUMMARY

Near-bottom temperatures and salinities in the sGSL (Magdalen Shallows) were examined using data primarily collected during the snow crab and multi-species surveys. Data were compared to normal conditions defined as the average conditions for the period 1971 to 2000. The CIL volume time series clearly show that there was a greater quantity of cold water in the 1990’s in the sGSL with a return to more normal conditions towards the end of the time series (2010). The analysis shows that the inter-annual variability of September bottom temperatures is larger in shallow waters (e.g. Northumberland Strait) and along steeper slopes (e.g. Laurentian Channel) than over the relatively flat bottom of the Magdalen Shallows. The five-year running means of bottom temperature anomalies for snow crab fishing areas 12, 19, 12E, and 12F show a continuously decreasing temperature from the last maxima in the early 1980s to the minima in the early 1990s followed by a general warming trend since. The area of the bottom of the Magdalen Shallows covered by waters between -1°C and 3°C during the September multi-species survey has shown a general decrease since the beginning of the 90’s.

Although there is a lot of inter-annual variability, the mean temperature within the snow crab habitat area increased significantly over the same period. The 2010 value is significantly higher than the long-term mean and represents the highest value since 1982 when the maximum

(1.31°C) of the time series was reached. The sGSL is characterized by waters with salinities less than 34 and with low inter-annual variability.

The analysis of the commercial snow crab thermal distribution revealed that the occurrence of commercial crab above 3°C is very rare with only 5.2% of the catches in bottom waters above 3°C. The results suggest that commercial male crab favoured habitat between -1.2 to 1.2°C and a depth distribution between 65 and 100 m.

The analysis of the temperature coverage of the previous and recommended snow crab assessment polygons indicates that the recommended polygon has a better coverage of the snow crab thermal habitat. The appropriateness of the recommended polygon coverage also increases when bottom temperature thresholds of 3°C to 5°C are considered. Since 95% of the crabs are caught below 3°C, the recommended polygon covers the commercial snow crab habitat relatively well.

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TABLE

Table 1. Statistics of the area of the southern Gulf of St. Lawrence with bottom temperature (T) below three temperature thresholds (Tt) covered by the two polygons for the snow crab assessment.

Characteristics	Old polygon ($44,316\ km^2$)			Recommended polygon ($57,846\ km^2$)		
Temperature threshold (Tt)	3°C	4°C	5°C	3°C	4°C	5°C
Area (km^2) with T<= Tt inside the polygon	39,767	41,447	42,704	49,350	52,025	54,155
Area (km^2) with T <= Tt outside the polygon	11,366	13,440	15,910	1,782	2,862	4,460
Total area (km^2) with T <= Tt in sGSL	51,132	54,887	58,614	51,132	54,887	58,614
Area (km^2) with T > Tt inside the polygon	4,550	2,869	1,613	8,496	5,821	3,692
% of polygon area covered by Tt	90%	94%	96%	85%	90%	94%
% of total area <= Tt outside the polygon	22%	24%	27%	3%	5%	8%
% of total area in the polygon	78%	76%	73%	97%	95%	92%

FIGURES

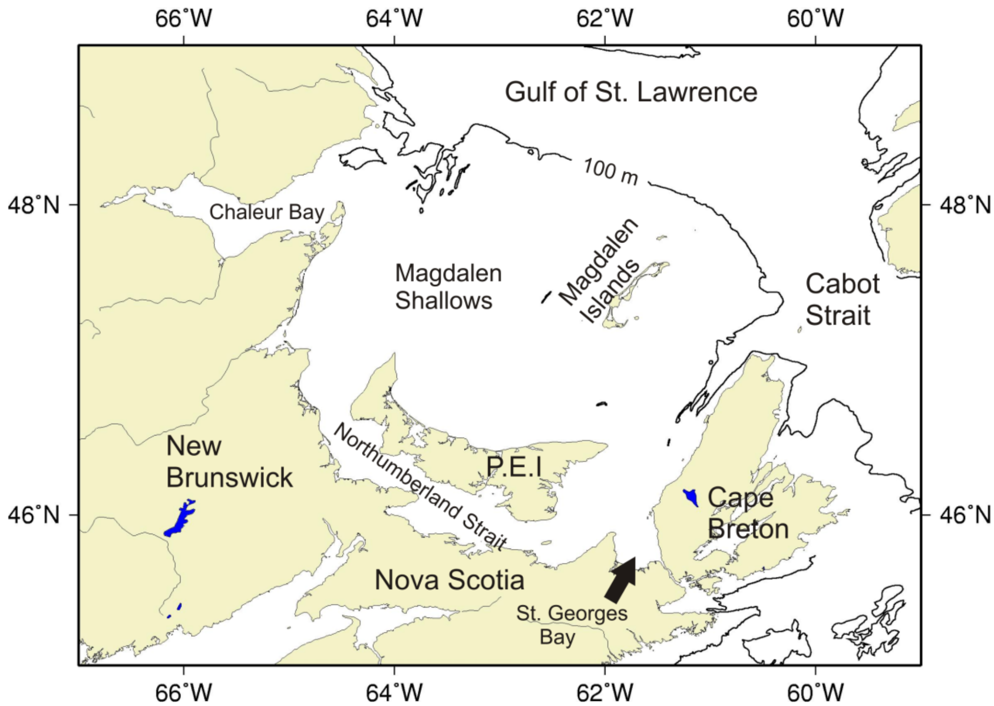

Figure 1. Chart of the southern Gulf of St. Lawrence showing geographic and topographic features.

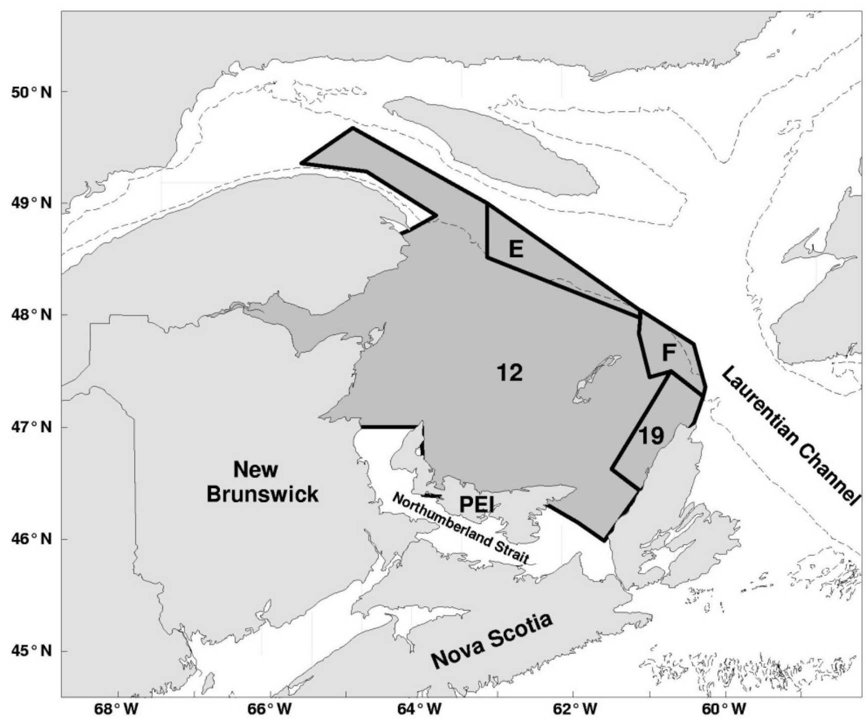

Figure 2. The southern Gulf of St. Lawrence showing the boundaries of snow crab fishing areas 12, 19, 12E, and 12F.

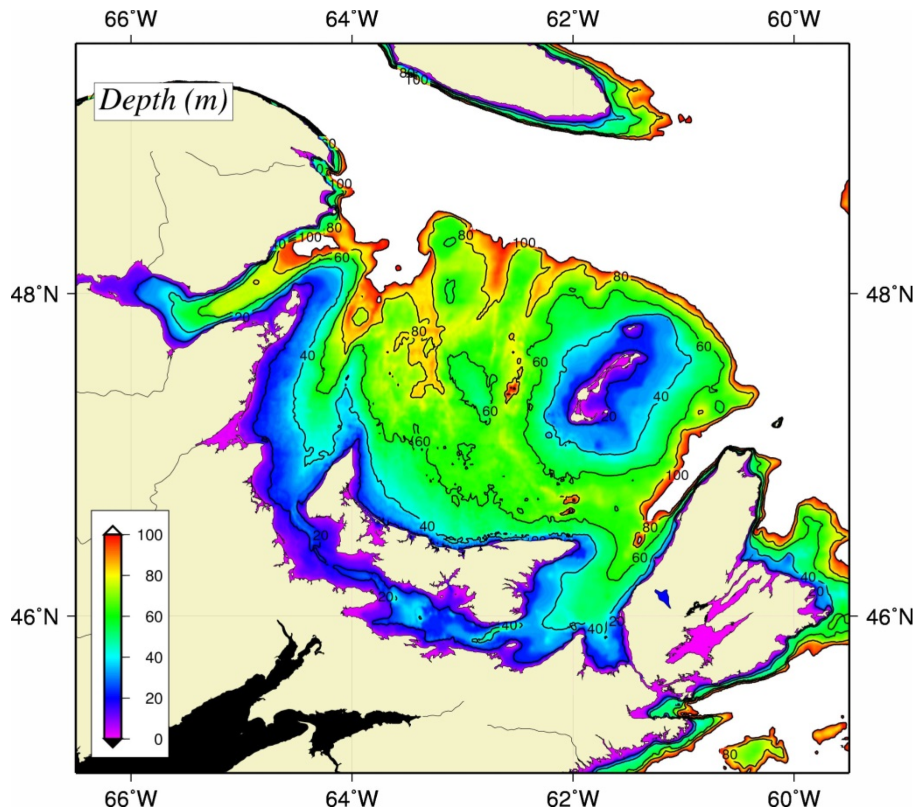

Figure 3. Bathymetry (m) of the Southern Gulf of St. Lawrence.

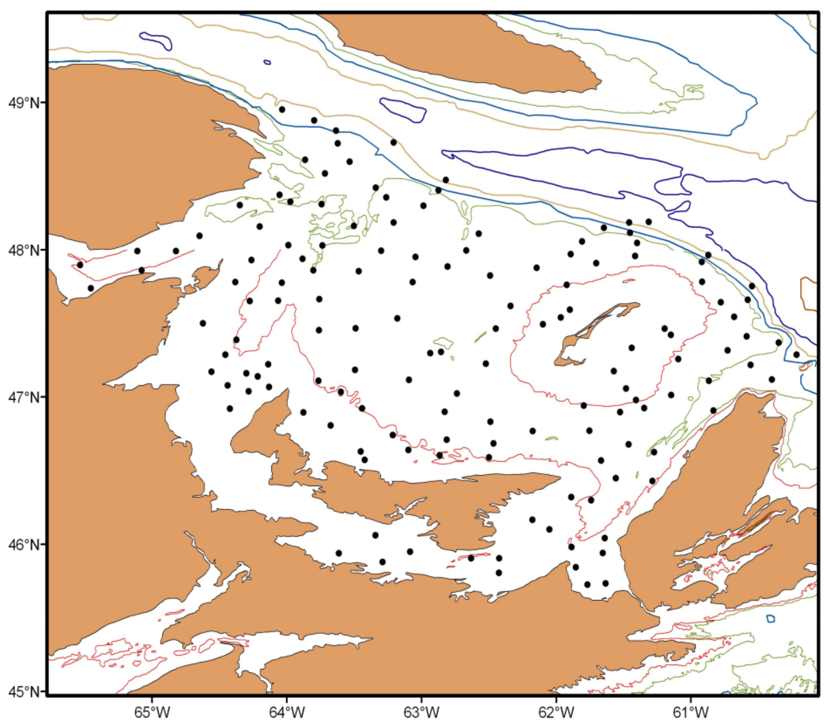

Figure 4. Typical coverage of CTD stations during the September multi-species survey (2010 shown as an example).

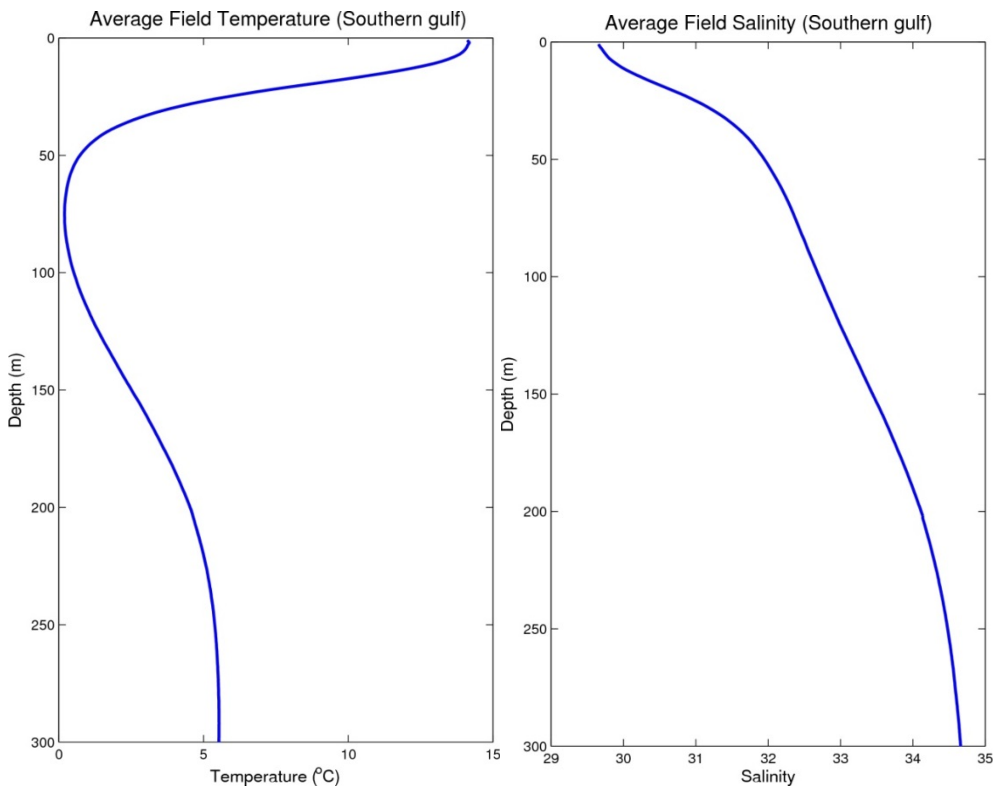

Figure 5. The 1971-2010 average temperature (left) and salinity (right) profiles in September in the southern Gulf of St. Lawrence.

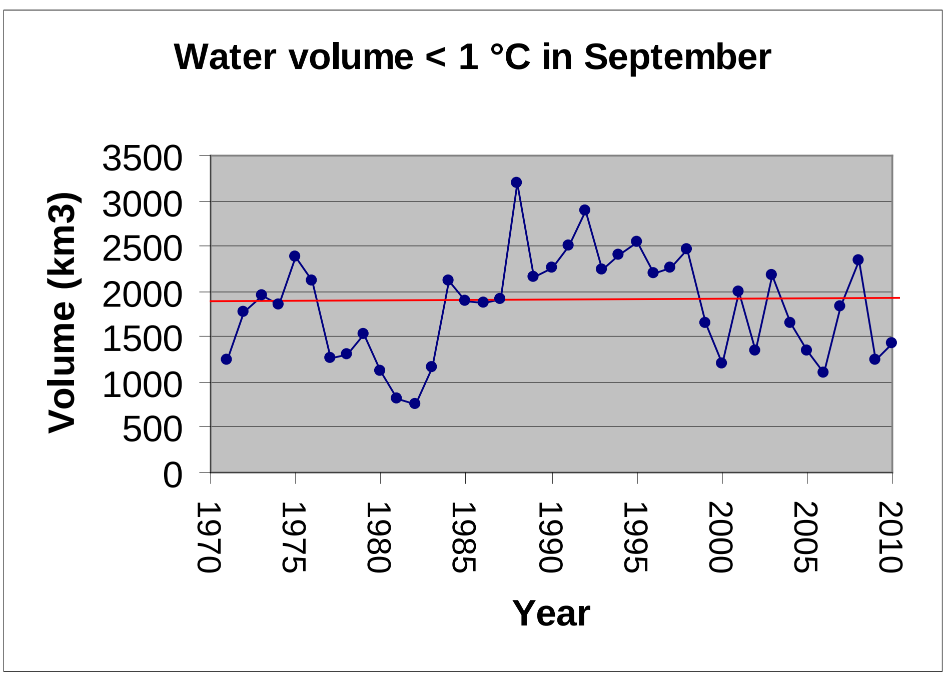

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Figure 6. Annual estimated volume (km^3) of the cold intermediate layer (CIL), defined as water temperatures less than 1ºC, over the southern Gulf of St. Lawrence during 1971 to 2010.

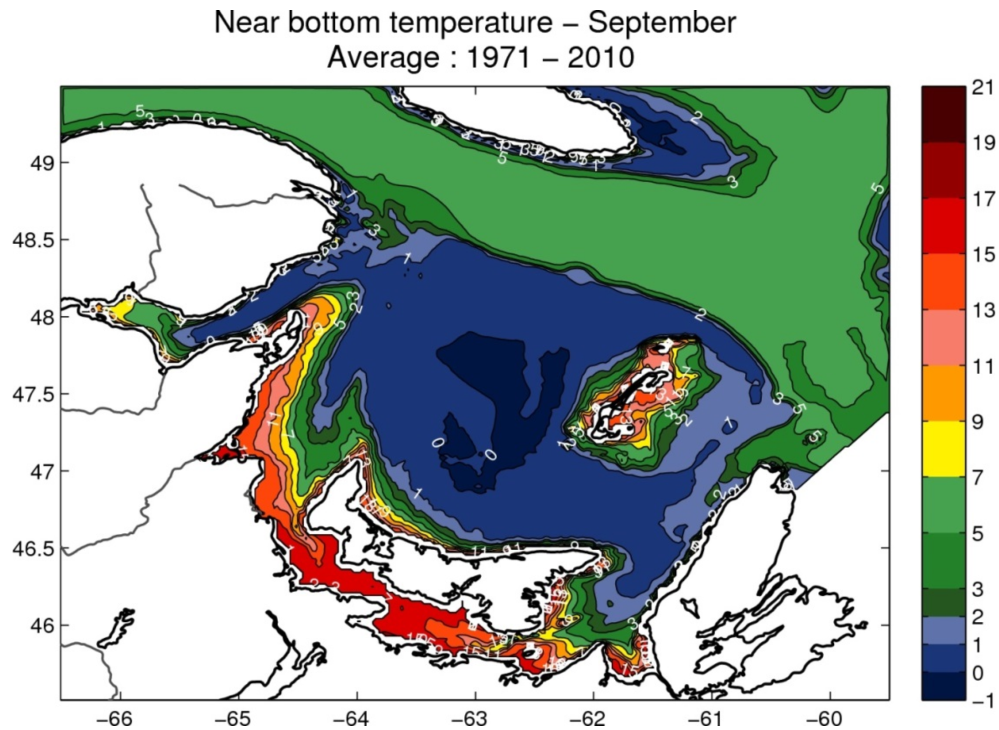

Figure 7. The 1971 to 2010 average bottom water temperature (°C) contours during September for the southern Gulf of St. Lawrence.

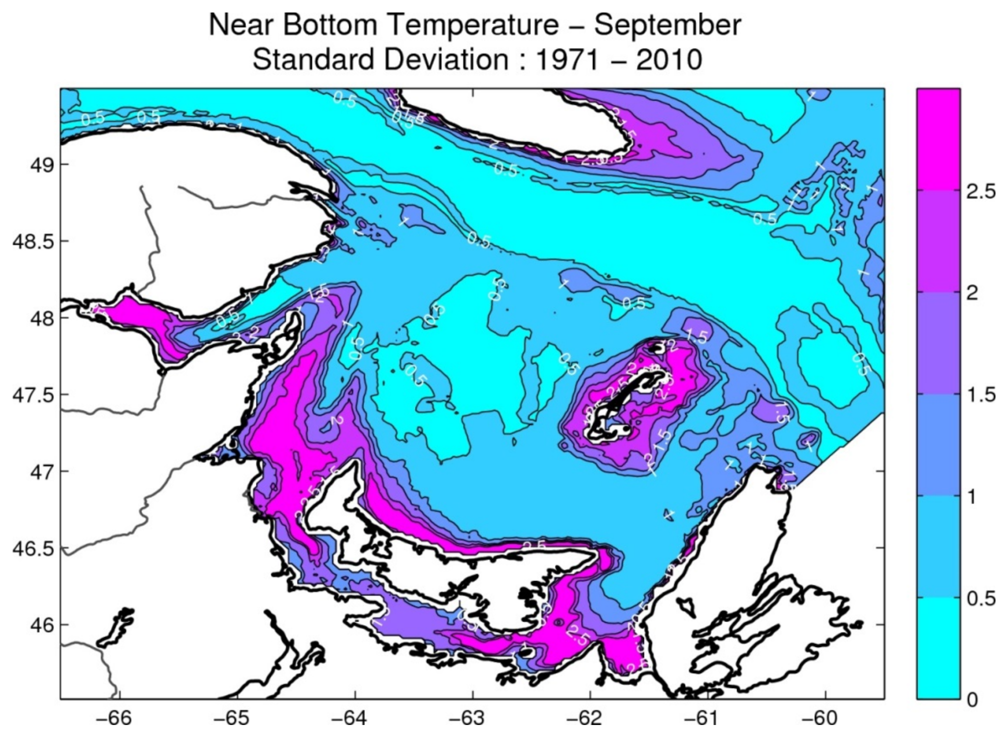

Figure 8. Standard deviation contours of the 1971 to 2010 September bottom water temperatures in the southern Gulf of St. Lawrence.

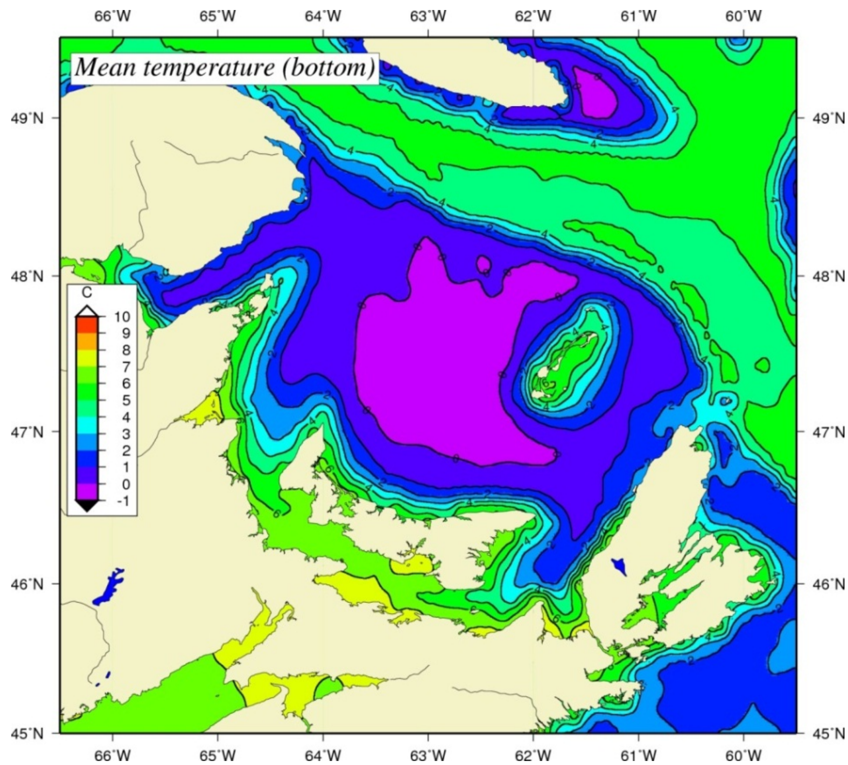

Figure 9. Mean annual bottom water temperature contours in the Southern Gulf of St. Lawrence obtained from the harmonic analysis.

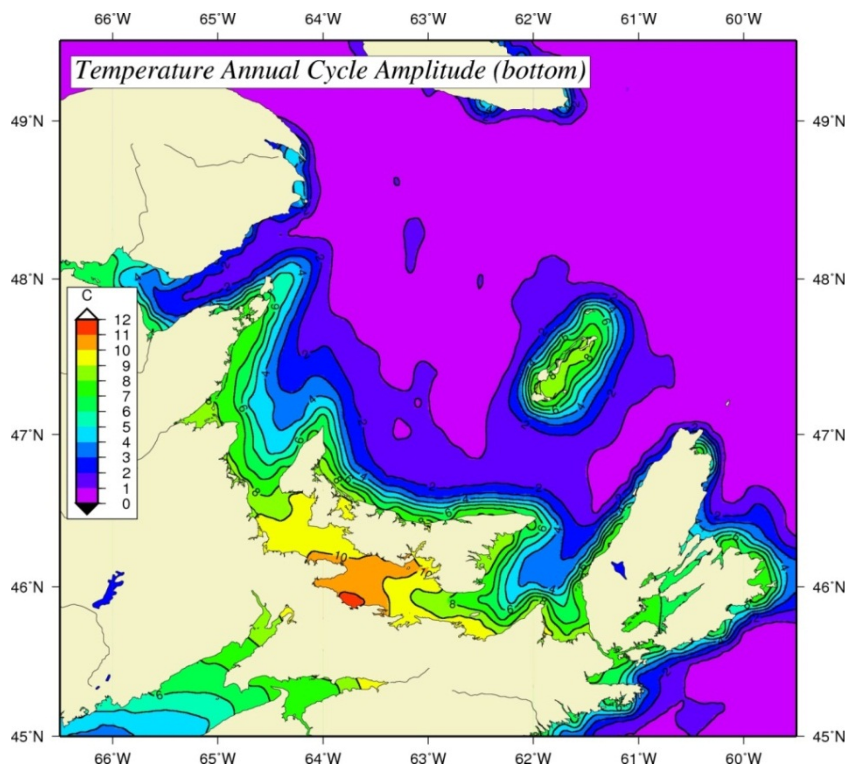

Figure 10. Amplitude (°C) contours of the bottom water temperature annual cycle in the southern Gulf of St. Lawrence.

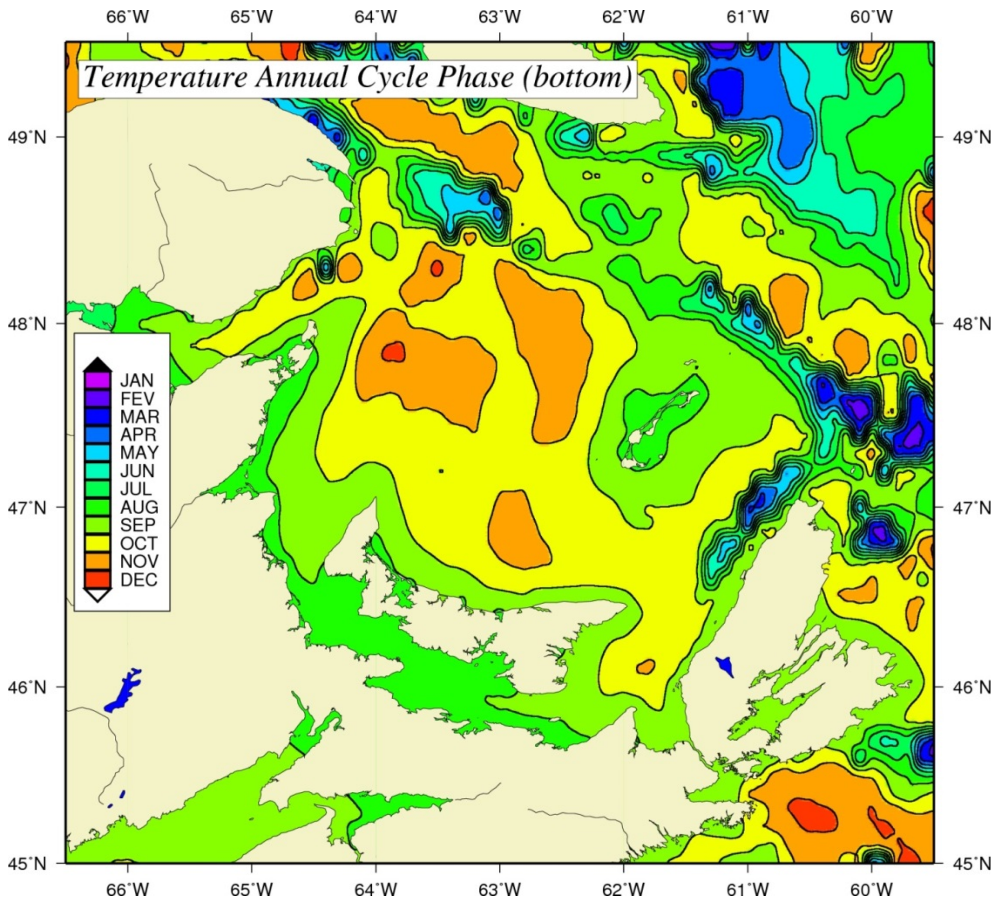

Figure 11. Phase (month of warmest temperature) contours of the bottom water temperature annual cycle in the southern Gulf of St. Lawrence.

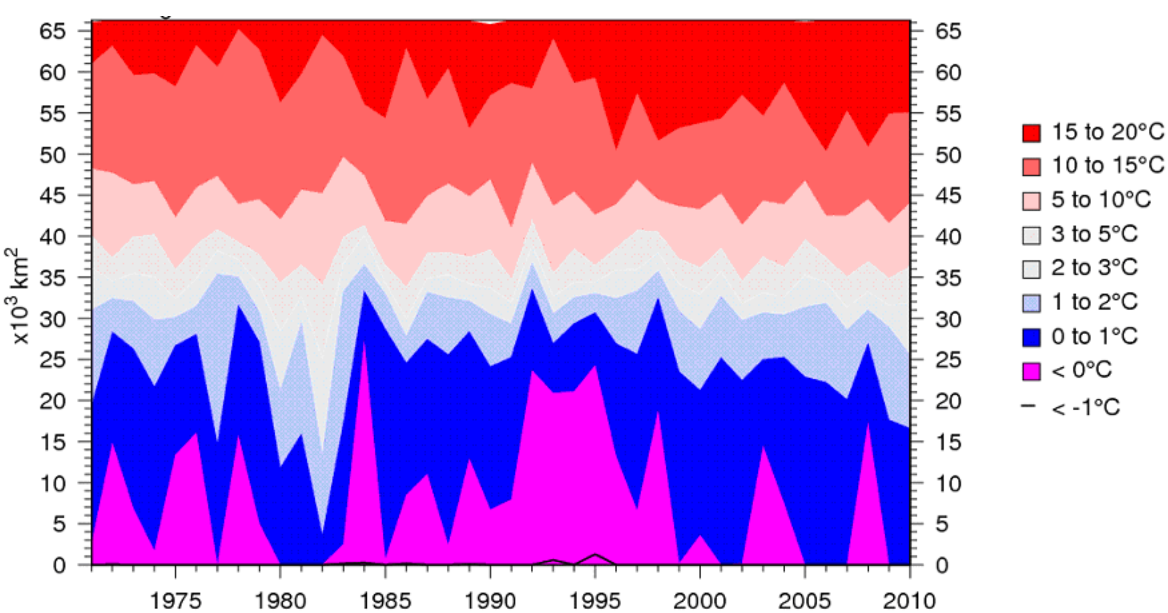

Figure 12. Time series of the areas (1000 km²) covered by different bottom water temperature bins during September over the southern Gulf of St. Lawrence during 1971 to 2010.

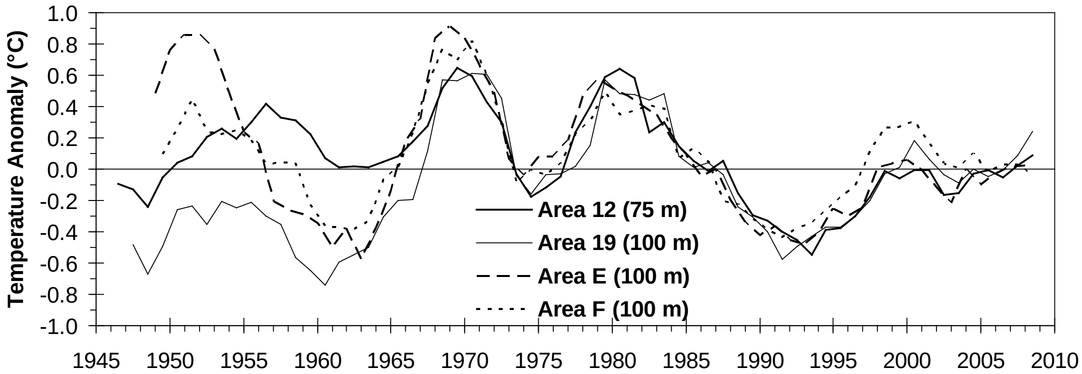

Figure 13. The five-year running means of the near bottom temperature anomalies for snow crab fishing areas 12, 19, 12E, and 12F, 1946 to 2009.

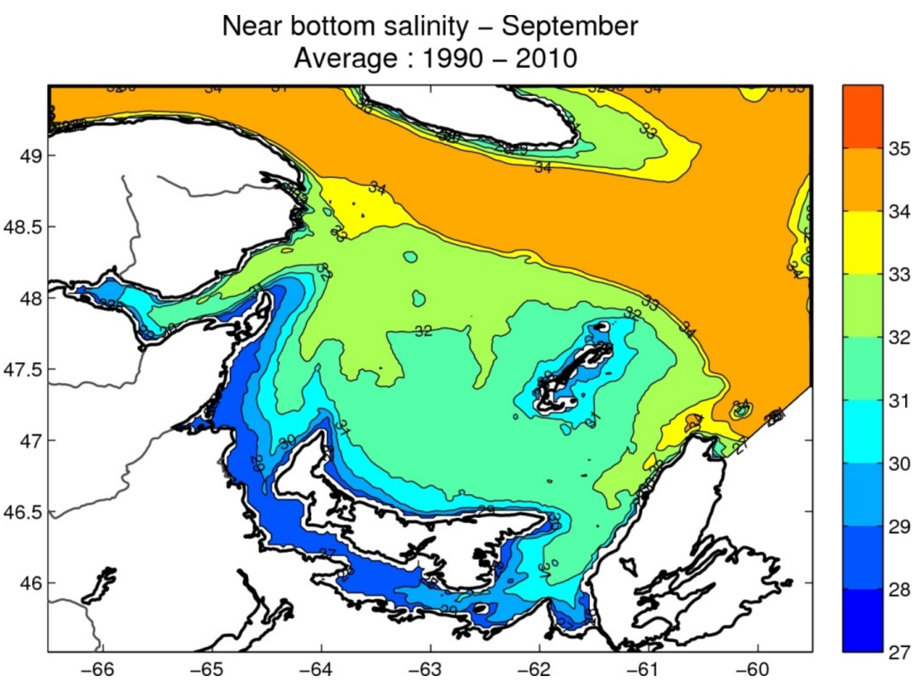

Figure 14. The 1990 to 2010 average bottom salinity (psu) contours in September for the southern Gulf of St. Lawrence.

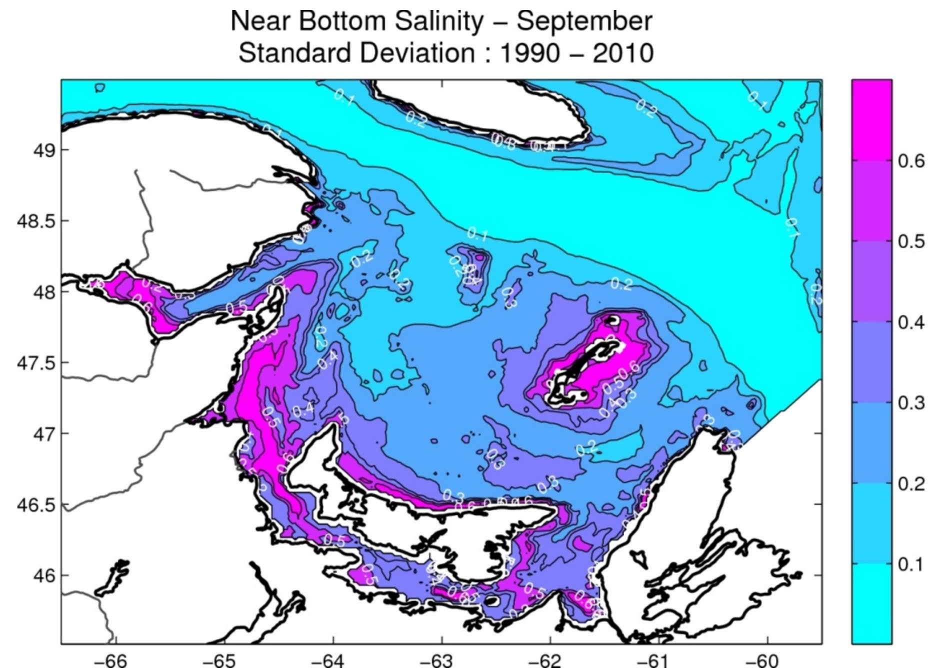

Figure 15. Standard deviation contours of the 1990 to 2010 September bottom salinities (psu) in the southern Gulf of St. Lawrence.

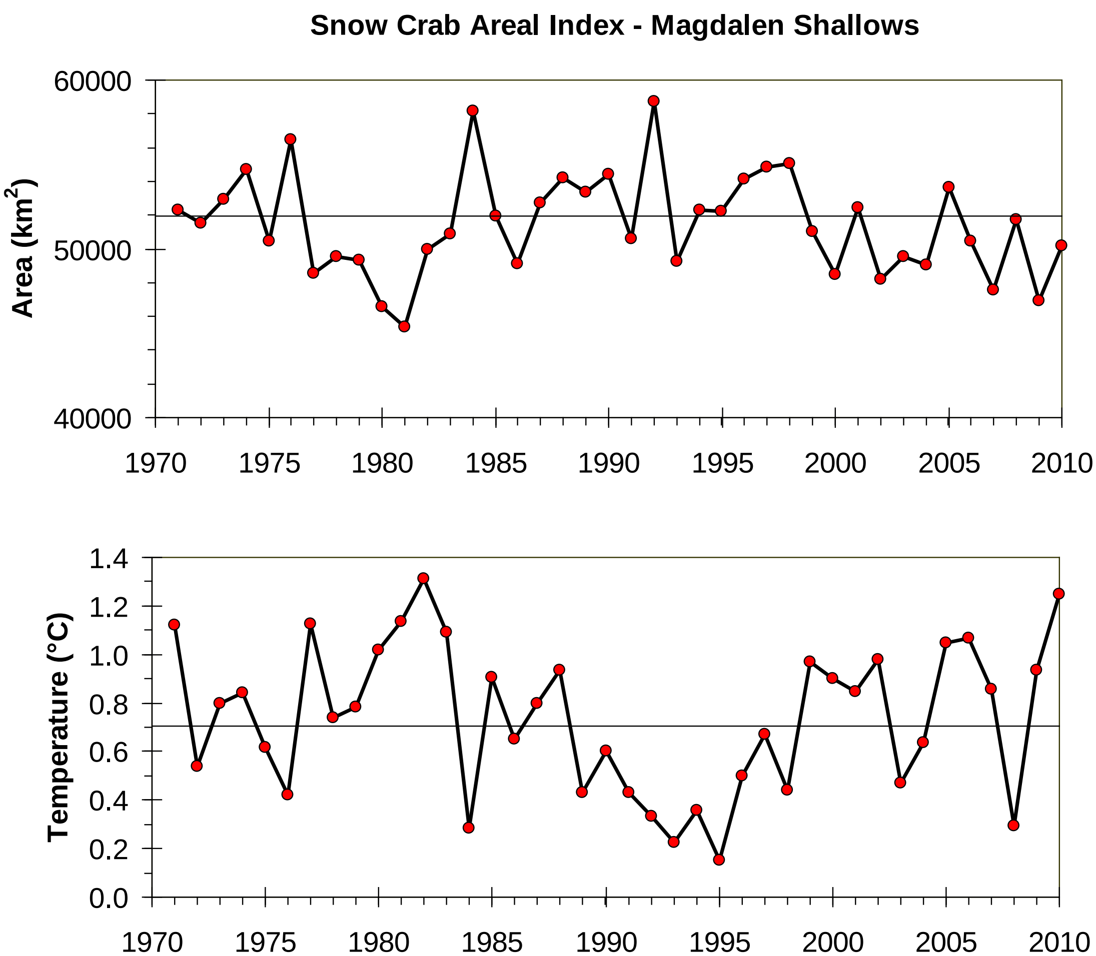

Figure 16. Time series of the area of Magdalen Shallows covered by bottom temperatures between -1° and 3°C in September (top panel) and the mean temperature within that area (bottom panel), 1971 to 2010.

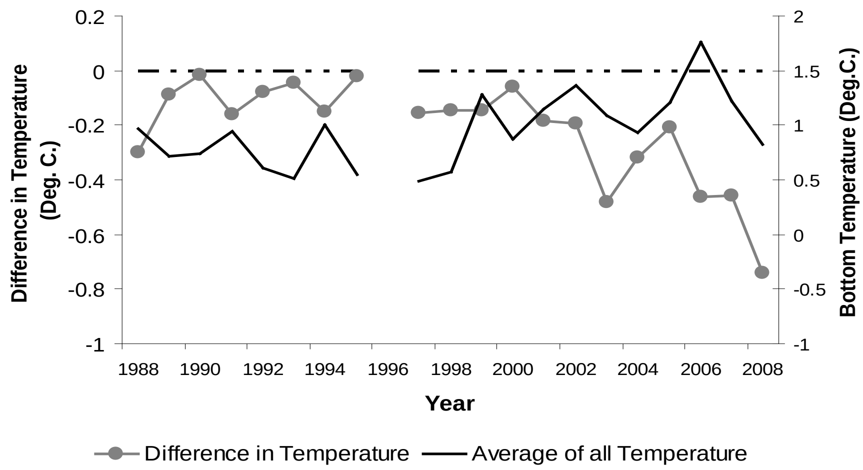

Figure 17. Difference between the mean temperature occupied by snow crab and the mean temperature over all samples, 1988 to 2008. Also shown is the mean bottom temperature sampled for each year during the survey.

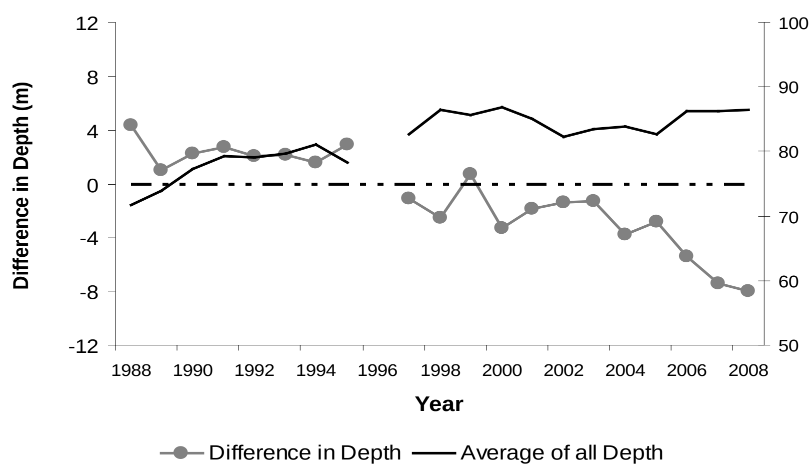

Figure 18. Difference between the mean depth occupied by snow crab and the mean depth over all samples, 1988 to 2008. Also shown is the mean depth sampled for each year during the survey.

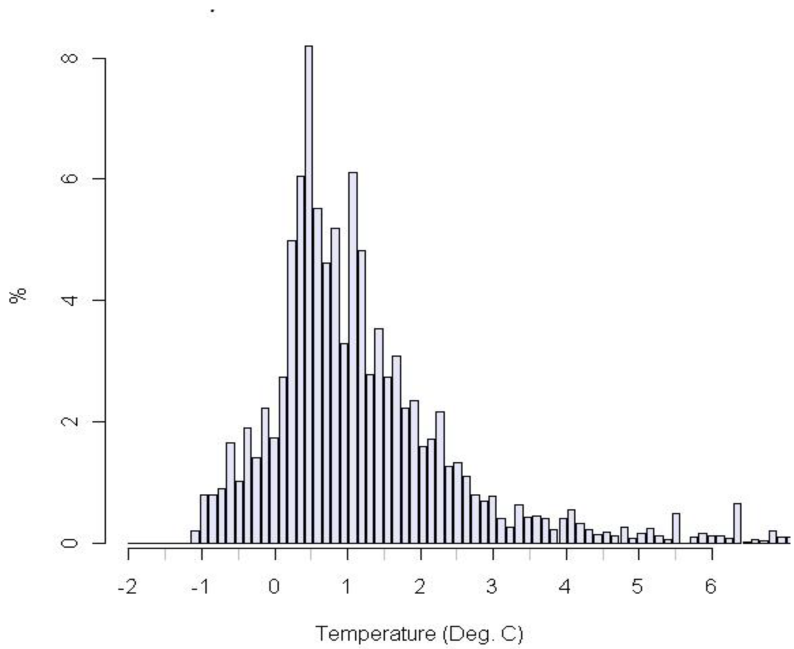

Figure 19. Percentage of commercially exploitable snow crab (adult male crab with carapace width greater than or equal to 95 mm) found by temperature bins of 0.1 °C, all years combined.

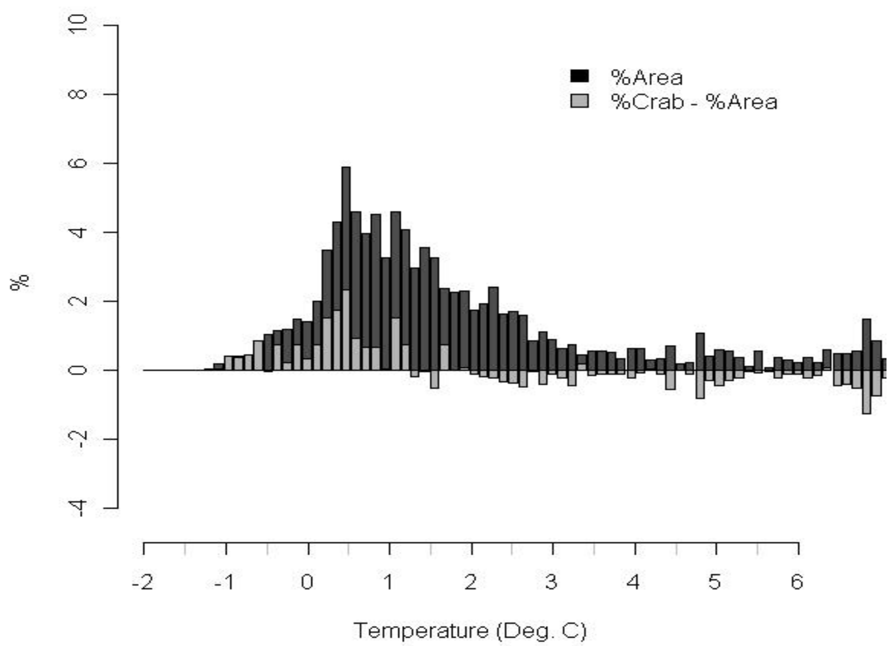

Figure 20. Habitat preference, expressed as % of commercially exploitable snow crab minus % of area, by water temperature bins of 0.1ºC.

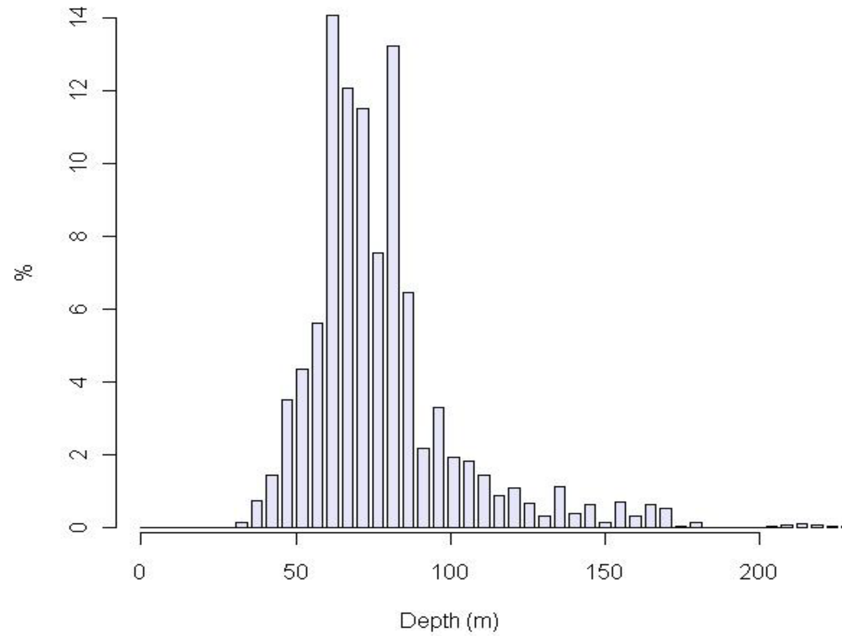

Figure 21. Percentage of commercially exploitable snow crab found by depth bins of 5 m, all years combined.

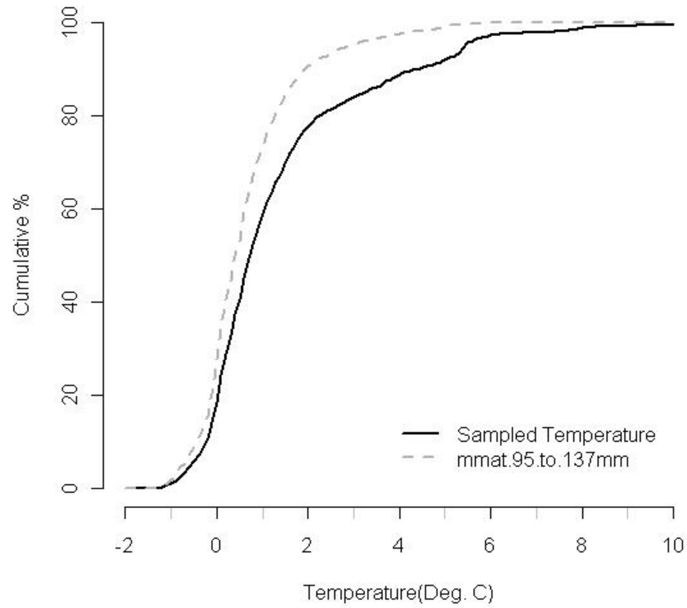

Figure 22. Cumulative density functions of sampled bottom water temperature over all samples (solid line) and of bottom water temperature occupied by commercially exploitable crab (dashed line), all years combined.

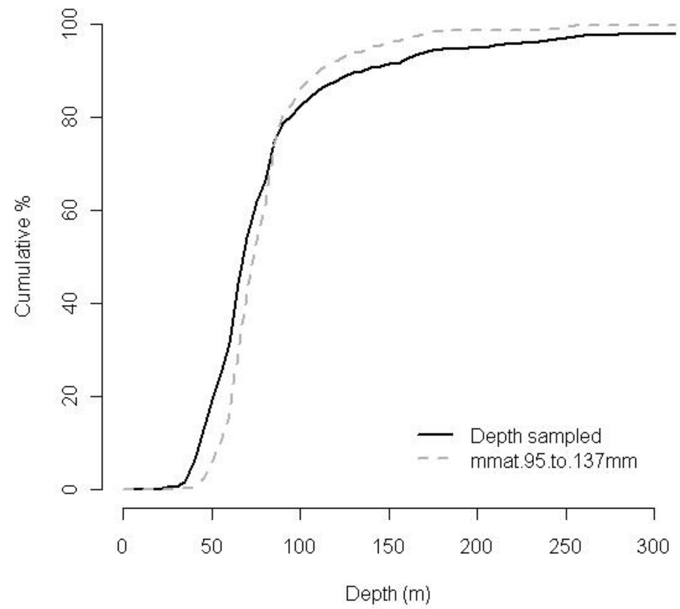

Figure 23. Cumulative density functions of sampled depth over all samples (solid line) and of depths occupied by commercially exploitable crab (dashed line), all years combined.

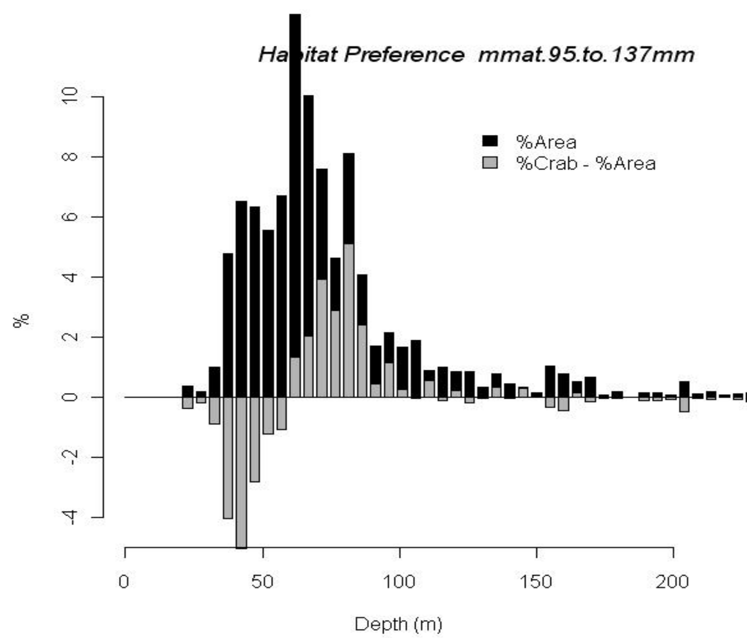

Figure 24. Habitat preference, expressed as % of commercially exploitable snow crab minus % of area, by depth bins of 5 m, all years combined.

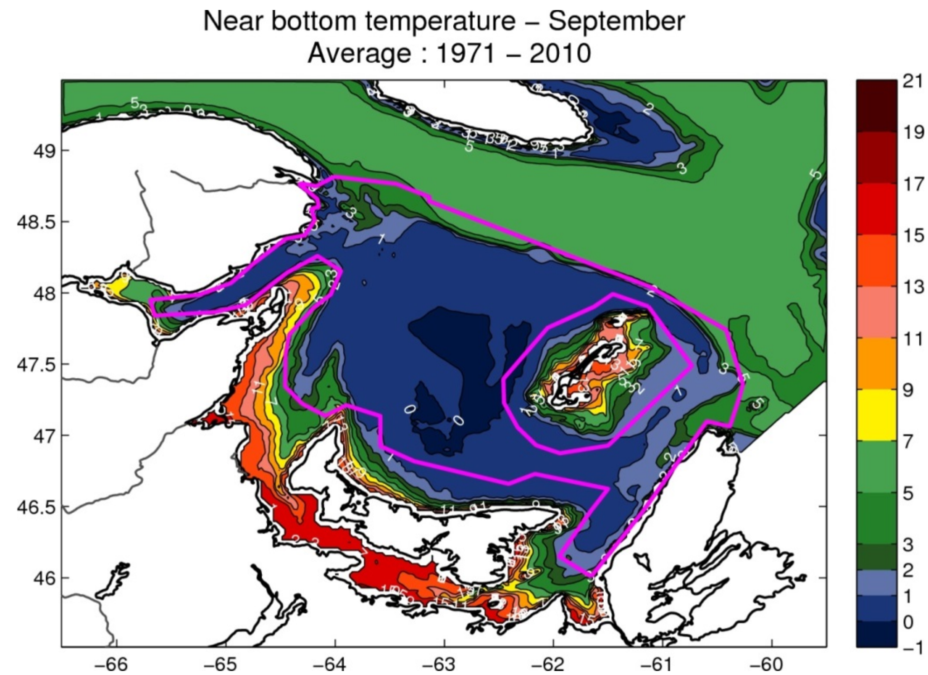

Figure 25. The 1971 to 2010 average bottom water temperature (°C) contours during September for the southern Gulf of St. Lawrence with the previous snow crab assessment polygon, highlighted as a purple line, used for the estimation of the snow crab biomass (Hébert et al. 2012). The polygon has an inner surface area of 44,316 km^2.

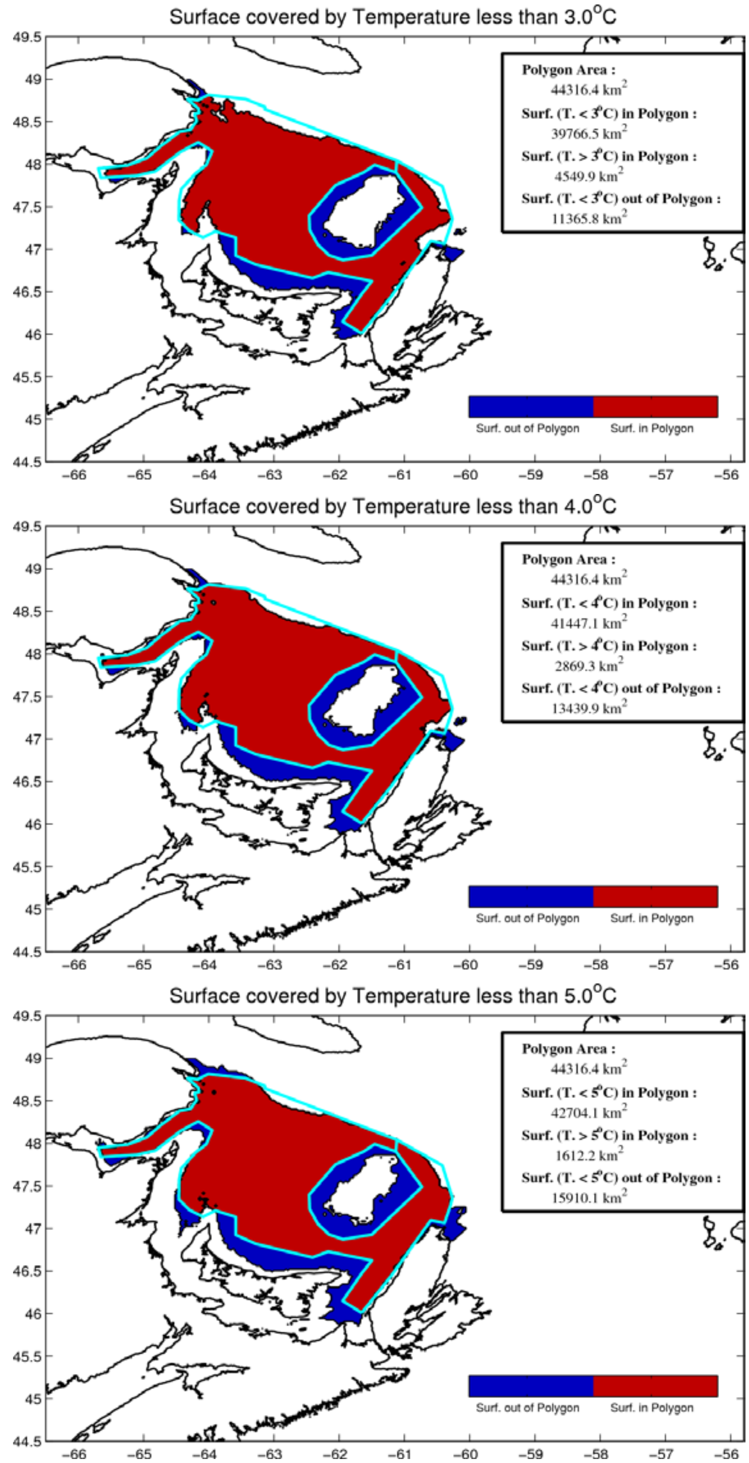

Figure 26. Total area (red plus blue) of average bottom temperatures less than 3°C (upper panel), less than 4ºC (middle panel) and less than 5ºC (lower panel). The light blue line represents the polygon area used for the estimation of the snow crab commercial male biomass. The blue colour represents area of bottom temperatures less than 3°C, 4ºC, and 5ºC, respectively, located outside the biomass estimation polygon. The red represents bottom temperatures less than 3°C, 4ºC, and 5ºC, respectively, located inside the biomass estimation polygon.

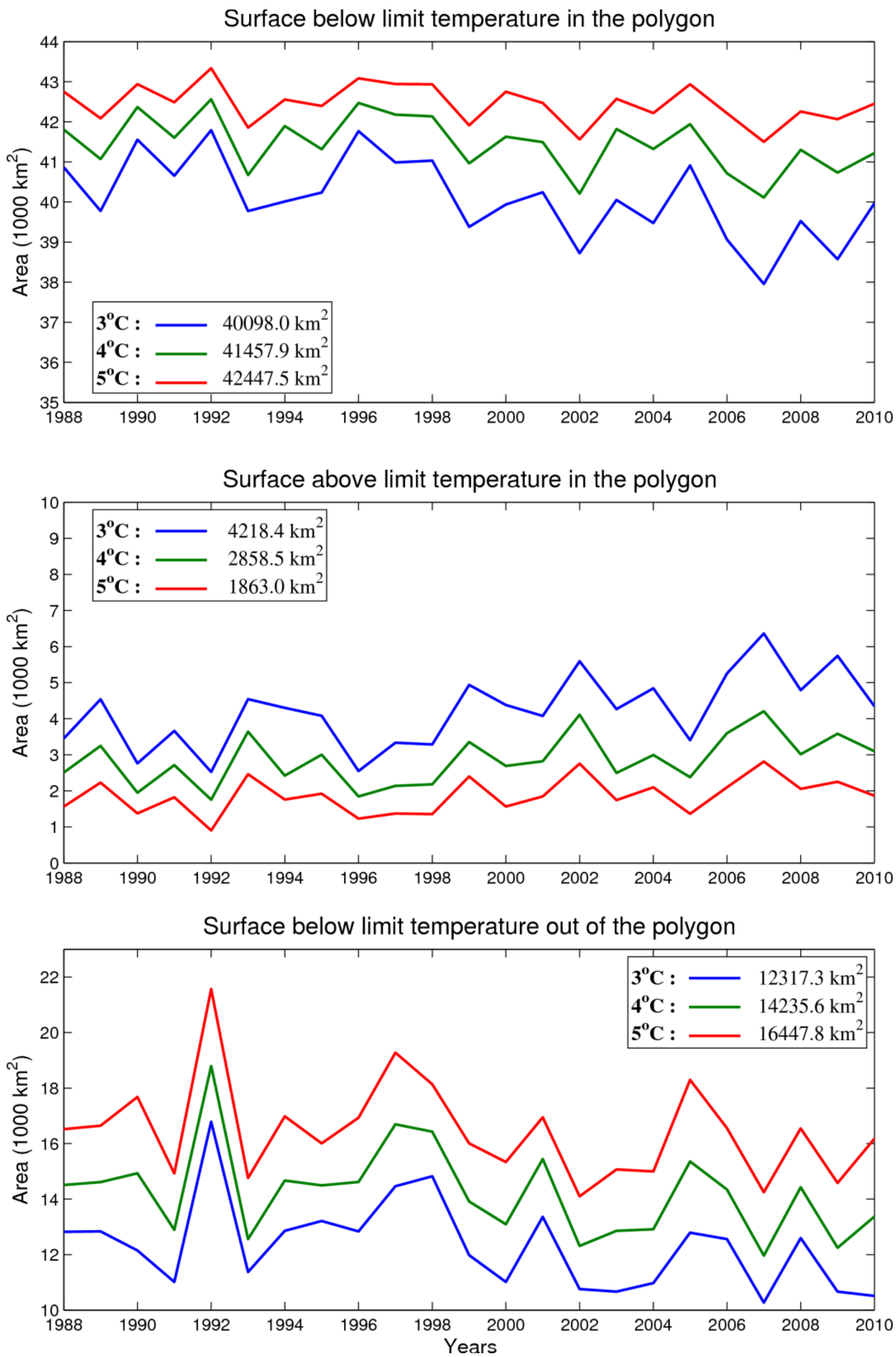

Figure 27. Time series of the area covered by temperatures less than 3ºC, less than 4ºC, and less than 5ºC located inside the polygon used for estimation of the biomass (top panel), time series of the area inside the polygon that is greater than 3ºC, greater than 4ºC, and greater than 5ºC (middle panel), and time series of the area with temperatures less than 3ºC, less than 4ºC, and less than 5ºC, respectively, not included in the polygon (lower panel).

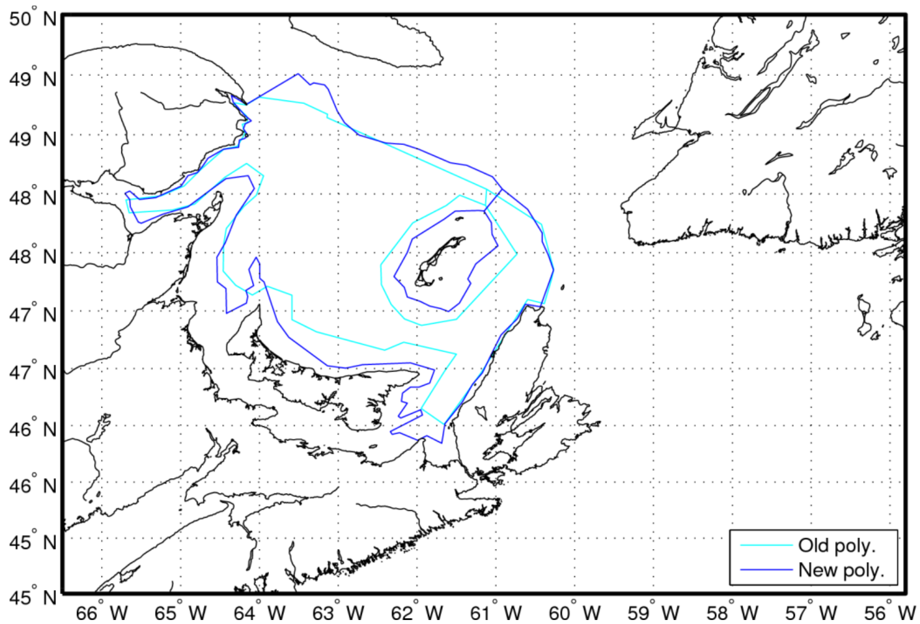

Figure 28. New proposed polygon (dark blue line) for the estimation of the snow crab biomass (Hébert et al. 2012) in the sGSL. The new polygon has an inner surface of 57,846 km^2. For comparison, the previous polygon used for snow crab stock assessment prior to the 2012 season is also shown (light blue line).

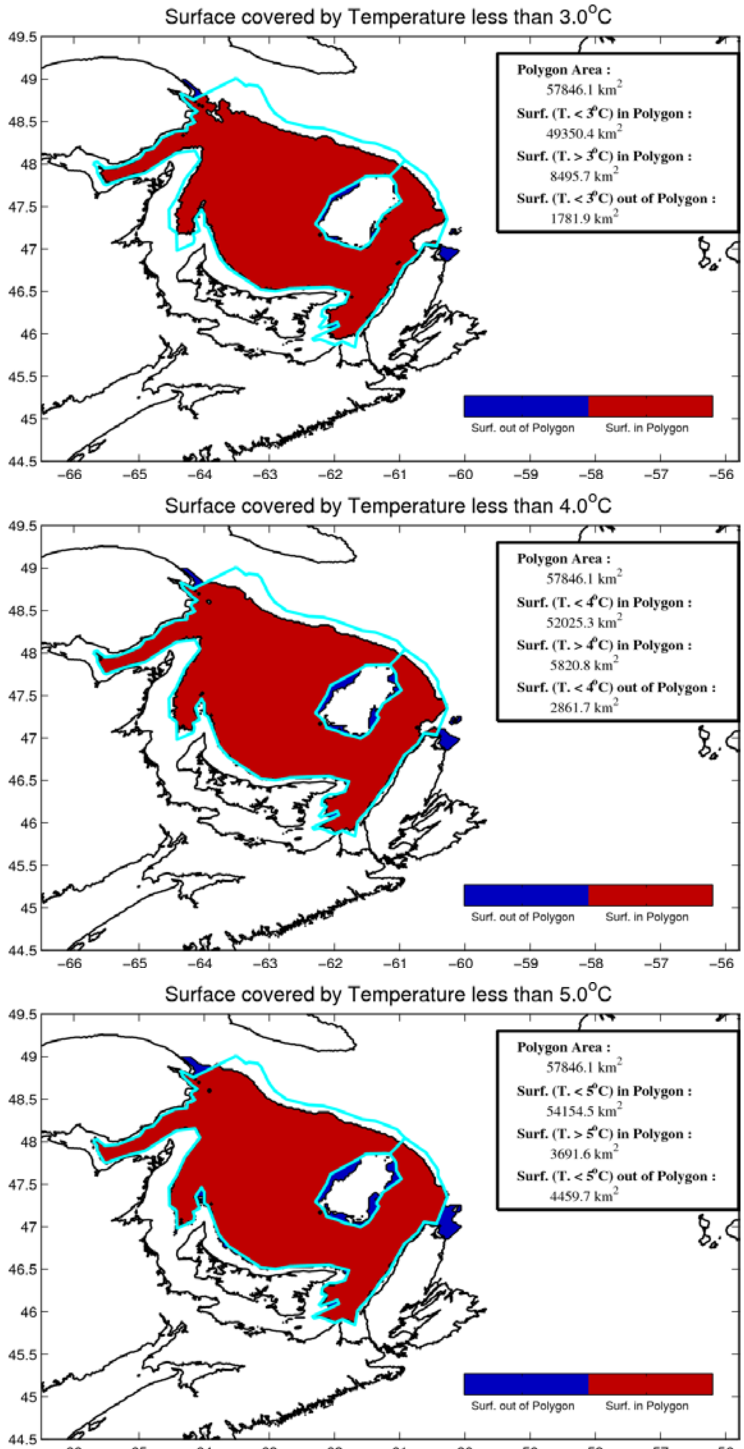

Figure 29. Total area (red plus blue) of average bottom temperatures less than 3°C (upper panel), less than 4ºC (middle panel) and less than 5ºC (lower panel). The new polygon proposed for the estimation of the snow crab commercial male biomass is show in light blue outline. The blue colour represents area of bottom temperatures less than 3°C, 4ºC, and 5ºC, respectively, located outside the biomass estimation polygon. The red represents bottom temperatures less than 3°C, 4ºC, and 5ºC, respectively, located inside the biomass estimation polygon.

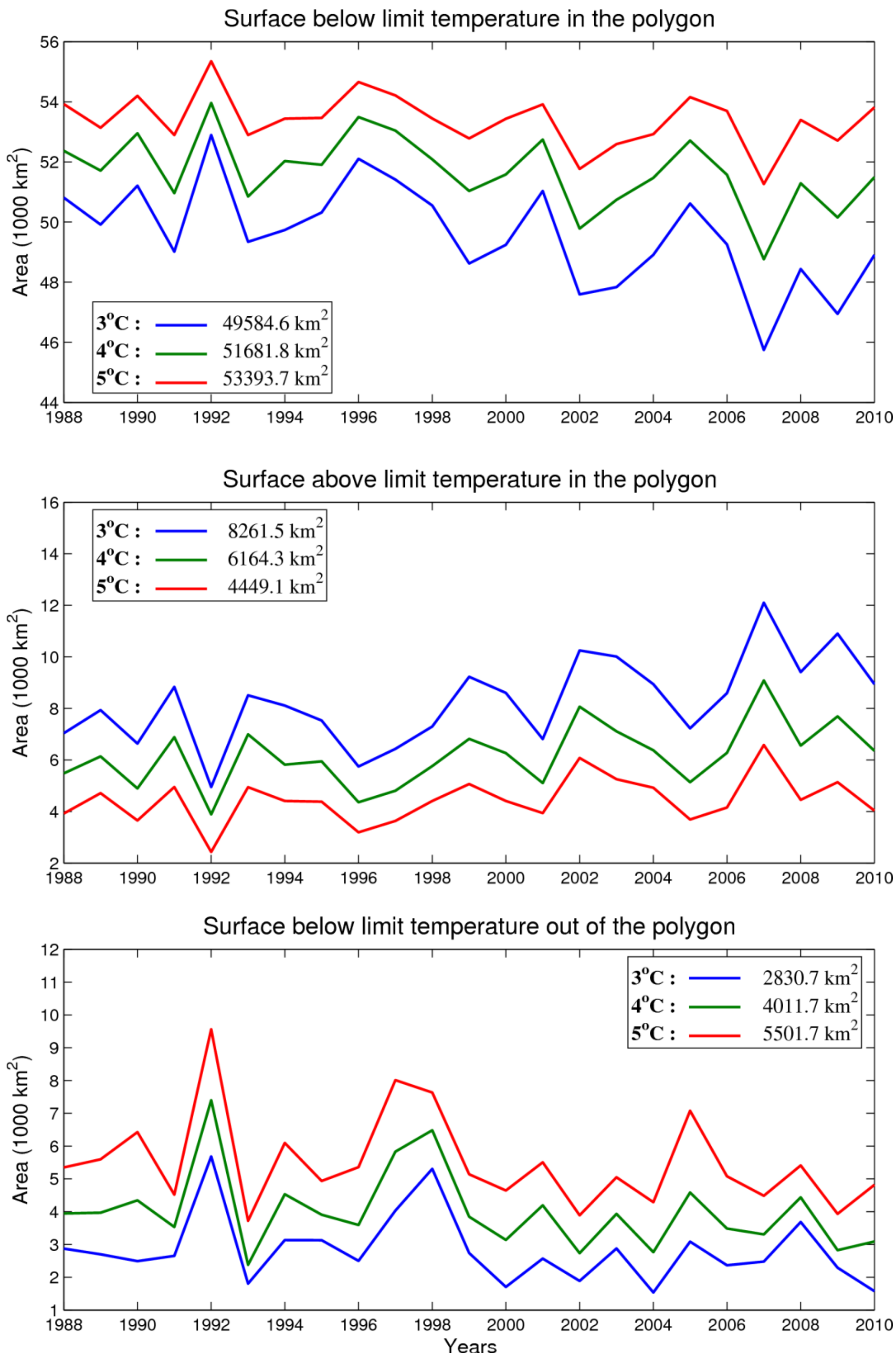

Figure 30. Time series of the area covered by temperatures less than 3ºC, less than 4ºC, and less than 5ºC located inside the recommended polygon used for estimation of the biomass (top panel), time series of the area inside the recommended polygon that is greater than 3ºC, greater than 4ºC, and greater than 5ºC (middle panel), and time series of the area with temperatures less than 3ºC, less than 4ºC, and less than 5ºC, respectively, not included in the recommended polygon (lower panel).