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Integrated assessment of the snow crab resident on the Scotian Shelf in 2008

Évaluation intégrée du stock de crabes des neiges résidant sur le plateau néo-écossais en 2008

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ABSTRACT

Landings in 2008 were 238 and 8,253 t for northern and southern areas of Eastern Nova Scotia (ENS), respectively, and 230 t for Crab Fishing Area (CFA) 4X in 2007/2008. The associated Total Allowable Catches (TACs) were 244, 8,316 and of 230 t, respectively. Average, non-standardised catch rates were 33.7, 96.1 and 29.1 kg trap^{-1}, respectively. These catch rates represent a 43% increase for N-ENS (though still well below the 12 year mean of 53.8 kg trap$^{-1)}$, a marginal decrease in S-ENS, and a 61% increase in CFA 4X, relative to 2007. Soft-shelled crab incidence in the commercial catch continued to be high in N-ENS at 49%. In contrast, S-ENS maintained a lower rate of incidence at 13%, even with the influx of recruitment to the area. CFA 4X had virtually no soft-shell incidence due to their offset season. Soft-shell incidence will continue to be an issue in N-ENS and S-ENS in 2009. Bycatch of non-target species is estimated to be less than 0.005% and 0.5% of total snow crab landings in ENS and CFA 4X, respectively.

In the short-term, recruitment is expected to continue for the next 4-5 years in all areas, with the exception of CFA 4X. Pre-recruits near the 80 mm carapace width (CW) modal group (instars 11-13) have been found in large numbers. The leading edge of this modal group began recruiting to the fishable biomass in 2007 in S-ENS and in 2008 in N-ENS. Full entry is expected in 2010/2011. In the long-term, as the reproductive potential of the Scotian Shelf population peaked in 2007 and is now on a declining trend, larval production should continue for another 3-4 years. However, potential predators of immature and soft-shelled snow crab have been found concentrated in areas with high densities of immature snow crab. Increasing bottom temperatures on the Scotian Shelf and an associated reduction of potential snow crab habitat may have negative consequences, especially in CFA 4X and parts of S-ENS. In addition to these factors, the signs of a gradual return of ecological, social and economic indicators of system state, in the direction of a low invertebrate dominated system adds, uncertainty to the medium- to long-term sustainability of the snow crab population.

The post-fishery fishable biomass of snow crab was estimated to be 3,200 t (with a 95% confidence range of: 2,500 t to 4,000 t) – an increase of approximately 200% relative to 2007 (1,070 t). This increase was most evident in the northern basin of N-ENS. In S-ENS, the post-fishery fishable biomass declined marginally to 54.3×10^3 t (with a 95% confidence range of: 41.4 to 71.4×10^3 t) – a decrease of 0.3% from 54.5×10^3 t in 2007. The majority of the increases were evident in all core areas of S-ENS. In CFA 4X, the pre-fishery fishable biomass was 360 t (with a 95% confidence range of 200 to 570 t) – an increase of 12.5% from 320 t in 2007.

Relative exploitation rates (by biomass) in N-ENS were 7% in 2008. Projections suggest that an exploitation rate between 10 and 20% may be suitable for long-term sustainability in N-ENS. Good recruitment suggests a positive outlook although soft-shell handling remains an issue. A moderate increase in TAC is recommended.

Relative exploitation rates in S-ENS were 13% in 2008. Maintaining exploitation rates between 10% and 30% may provide the greatest longevity to this fishery. Good recruitment and good

control of soft-shell crab capture suggests a positive outlook. A moderate increase in TAC is recommended.

Relative exploitation rates in CFA 4X were 38% in 2008/2009. The region is currently exploiting crab at the highest rates on the Scotian Shelf even though environmental conditions are the least favourable. Exploitation rates between 10% and 30% may provide the greatest longevity to this fishery. A status-quo TAC is recommended until the strength of recovery can be verified.

RÉSUMÉ

En 2008, les débarquements ont respectivement atteint 238 t et 8 253 t dans le nord-est et sud-est de la Nouvelle-Écosse, et 230 t dans la zone de pêche du crabe (ZPC) 4X en 2007-2008. Les totaux autorisés des captures (TAC) ont quant à eux été de 244 t, 8 316 t et 230 t, respectivement. Les taux de prises moyens non normalisés ont atteint respectivement 33,7, 96,1 et 29,1 kg/casier levé[1]. Ces taux de prises représentent une augmentation de 43 % pour le nord-est de la Nouvelle-Écosse. (encore bien inférieure à la moyenne de 53,8 kg/casier levé sur douze ans^{-1}), une diminution négligeable dans le sud-est de la Nouvelle-Écosse et une hausse de 61 % dans la ZPC 4X par rapport à 2007. La présence de crabes à carapace molle dans les prises commerciales (49 %) est demeurée élevée dans le nord-est de la Nouvelle-Écosse. À l'opposé, ce taux est resté plus bas (13 %) dans le sud-est de la Nouvelle-Écosse malgré le recrutement accru observé dans la zone. On n'a pour ainsi dire pas remarqué de crabes à carapace molle dans la ZPC 4X en raison du décalage de la saison de pêche. La présence de crabes à carapace molle continuera de poser un problème dans le nord-est de la Nouvelle-Écosse et le sud-est de la Nouvelle-Écosse en 2009. On estime que les prises accessoires d'espèces non ciblées représentent moins de 0,005 % et de 0,5 % du total des débarquements de crabe des neiges dans l'est de la Nouvelle-Écosse et dans la ZPC 4X respectivement.

À court terme, on s'attend à ce qu'au cours des quatre à cinq prochaines années, le recrutement se poursuive dans toutes les zones, à l'exception de la ZPC 4X. On a trouvé un grand nombre de prérecrues situées dans le groupe modal de 80 mm de LC (stades 11-13). Les premières recrues de ce groupe modal ont commencé à s'intégrer à la biomasse exploitable en 2007 dans le sud-est de la Nouvelle-Écosse et en 2008 dans le nord-est de la Nouvelle-Écosse. La pleine intégration de la vague de recrutement devrait se produire en 2010-2011. À long terme, la production de larves devrait se poursuivre pendant encore trois à quatre ans puisque le potentiel reproducteur de la population du plateau néo-écossais a connu un sommet en 2007 et a aujourd'hui tendance à diminuer. On a toutefois trouvé une concentration de prédateurs possibles des crabes immatures et des crabes des neiges à carapace molle dans les zones où se trouvent de fortes densités de crabes des neiges immatures. La hausse des températures dans les fonds du plateau néo-écossais et la réduction connexe de l'habitat possible du crabe des neiges pourraient avoir un impact négatif, en particulier dans la ZPC 4X et dans certaines parties du sud-est de la Nouvelle-Écosse. Outre ces facteurs, les signes d'un retour progressif des indicateurs écologiques, sociaux et économiques de l'état du système vers un système légèrement dominé par les invertébrés accroît l'incertitude quant à la viabilité à moyen et long termes de la population de crabes des neiges.

La biomasse exploitable de crabe des neiges après la pêche a été estimée à 3200 t (intervalle de confiance de 95 % : 2 500 t à 4 000 t), soit une augmentation d'environ 200 % par rapport à 2007 (1070 t). C'est dans le bassin nord du nord-est de la Nouvelle-Écosse que cette augmentation a été la plus marquée. Dans le sud-est de la Nouvelle-Écosse, la biomasse exploitable de crabe des neiges après la pêche a connu une baisse négligeable à $54,3 \times 10^3$ t (intervalle de confiance de 95 % : 41,4 à $71,4 \times 10^3$ t), soit une diminution de 0,3 % par rapport à $54,5 \times 10^3$ t en 2007. La majeure partie des augmentations ont été constatées dans toutes les zones principales du sud-est de la Nouvelle-Écosse. Dans la ZPC 4X, la biomasse exploitable de crabe des neiges avant la pêche a été de 360 t (intervalle de confiance de 95 % : 200 à 570 t), ce qui représente une augmentation de 12,5 % par rapport à 320 t en 2007.

Dans le nord-est de la Nouvelle-Écosse, le taux d'exploitation relatif (par rapport à la biomasse) a atteint 7 % en 2008. Les projections laissent entendre qu'un taux d'exploitation situé entre 10 et 20 % pourrait convenir à la viabilité à long terme de la pêche dans le nord-est de la

Nouvelle-Écosse. Le bon recrutement laisse présager une perspective favorable même si la manipulation du crabe à carapace molle demeure un problème. On recommande une très légère augmentation du TAC.

Dans le sud-est de la Nouvelle-Écosse, le taux d'exploitation relatif a été de 13 % en 2008. Le maintien du taux d'exploitation entre 10 et 30 % pourrait assurer une longévité optimale de cette pêche. Le recrutement sélectif et la bonne gestion de la pêche des crabes à carapace molle permettent d'envisager une perspective favorable. Une augmentation du TAC est recommandée.

En 2008-2009, le taux d'exploitation relatif s'est élevé à 38 % dans la ZPC 4X. Même si les conditions environnementales y sont les moins favorables, c'est dans cette zone que l'exploitation du crabe atteint actuellement les taux les plus élevés sur le plateau néo-écossais. Des taux d'exploitation de 10 à 30 % pourraient assurer une longévité optimale à cette pêche. On recommande de maintenir le TAC au niveau actuel jusqu'à ce que l'ampleur du rétablissement puisse être vérifiée.

INTRODUCTION

In keeping with the *Oceans Act* (1996) and the Department of Fisheries and Oceans' (DFO's) mandate to manage ocean resources in a precautionary, integrated, ecosystem-based manner, we attempt to delineate and assess the basic structural and functional roles of snow crab and their associated fishery in the Scotian Shelf Ecosystem (SSE). Due to the intrinsic complexities of ecosystems, this attempt at developing an ecosystem-based assessment is necessarily incomplete.

MANAGEMENT

The SSE snow crab fishery is managed as 3 main areas: Northern-Eastern Nova Scotia (N-ENS), Southern-Eastern Nova Scotia (S-ENS) and Crab Fishing Area (CFA) 4X (Figure 1, Table 1; where ENS is Eastern Nova Scotia and CFA is Crab Fishing Area). There is no biological basis for these spatial divisions; they represent *ad hoc* divisions based upon political, social, economic and historical convenience. In 2005, many areas and subareas were merged, except for CFAs 23A, 23 and 24. Fishing seasons have evolved for economic, safety and conservation considerations: severe weather conditions; catch of soft-shell and white crab; disruption of mating periods; and overlap with other fisheries, especially lobster. For example, the fishing season in CFA 4X (November to May) is disjoint from that of ENS (June to September) as it allows avoidance of soft-shelled crab and overlap with the lobster fishing season (Table 1).

From 1982 to 1993, the management of the ENS fisheries was based on effort controls (size, sex, shell-hardness, season, license, trap limits). Additional management measures were introduced from 1994 to 1999: Individual Boat Quotas (IBQs), Total Allowable Catches (TACs), 100% dockside monitoring, mandatory logbooks and at-sea monitoring by certified observers (currently, 5%, 10% and 10% in N-ENS, S-ENS and CFA 4X, respectively). Vessel Monitoring Systems (VMS) have been implemented in S-ENS and voluntary management measures requested by fishers were also introduced in some areas, such as a shortened fishing season and reduced numbers of traps. The designation of a "temporary licence" holder was dropped in 2005.

In 2006, an updated soft-shell protocol was adopted in S-ENS due to the expectation of an increased incidence of soft-shelled snow crab and the potential harm associated with handling mortality. Soft-shelled crab incidence observed by at-sea-observers was relayed to DFO within 24 hours of landing, plotted on a 2-minute grid and re-broadcast to all members of industry. Fishers were requested to voluntarily avoid fishing within 1.5 nautical miles of the locations that had greater than 20% soft crab in the observed catch. This voluntary adaptive fishing protocol allowed fishers to rapidly move fishing gear away from or altogether avoid potentially problematic areas (helping also to save their time and fuel). This approach was not adopted in CFA 4X due to the low incidence of soft crab in the catch. In N-ENS, extremely high soft crab landings in 2007 required more substantial management measures: an experimental early fishing season, in addition to the standard summer season; and closure of sub-areas based on observer reports of high soft crab incidence. Finally, the voluntary return to the sea of immature, legal sized crab ("pencil-clawed" crab) was implemented in 2006 for all areas on the SSE to allow these crab to moult to maturity and so maximise the total yield per crab captured and simultaneously the total lifetime reproductive success of these large-sized males.

The snow crab fishery in eastern Canada is one of the largest fisheries in Canada (Dufour and Dallaire 2003). The SSE snow crab fishery has been in existence since the late 1970s

(Figure 2). The earliest records of landings were at levels of < 1,000 t, mostly in the near-shore areas of ENS (Figure 3). By 1979, landings rose to 1,500 t subsequent to which the fishery declined substantially in the mid-1980s and was considered a collapsed fishery. Recruitment to the fishery was observed in 1986 and, since that time, landings have increased considerably (Figure 3). In 1994, directed fishing for snow crab began in CFA 4X, the southern-most range of distribution which continues at low levels.

In 1996, DFO (Gulf Fisheries Centre, Moncton, New Brunswick) and SSE snow crab fishers initiated a Joint Project Agreement (JPA) to assess SSE snow crab using a fisheries-independent trawl survey (Biron et al. 1997). It was officially accepted for use as an assessment tool in 1999. These surveys demonstrated the presence of unexploited crab in the southeastern shelf area, which subsequently led to large increases in TACs (Tables 2-4), catch rates and fishing effort (Figures 2, 4) and the addition of new participants. Trawl surveys were formally extended to CFA 4X in 2004.

Annual TACs continued to increase to a maximum in 2002/2003 at 9,113 t in S-ENS and 1,500 t in N-ENS. Approximately 10,000 t of snow crab were landed each year between 2000 to 2004. Thus, the post-1998 period was one of rapid expansion of both the economic importance of the crab fishery and also the spatial extent of their exploitation. In 2004, with persistent low levels of recruitment and a steady decline in fishable biomass estimates since the early-2000s, a more precautionary exploitation strategy was adopted throughout the SSE. TACs increased substantially in 2008 in S-ENS due to signs of increased recruitment, whereas TACs were maintained at low levels in CFAs 4X and N-ENS due to continued signs of low recruitment and high exploitation (Tables 2-4).

METHODS

The analytical approaches used for assessment have evolved to accommodate the high inter-annual variability in spatial distributions of SSE snow crab, existing on the southern-most extreme of their distributional range in the northwest Atlantic.

General Analytical Tools

All data analyses were implemented in the statistical computing language and environment R (R Development Core Team 2008, version 2.8.1) to allow migration and documentation of methods into the future. The complete analytical suite, coded in R, is posted to:

http://sites.google.com/site/autocatalysis/snowcrabanalysis

Spatial interpolation of biological data is conducted in 2 ways: geo-statistical kriging for abundance estimation and simple thin-plate-spline for visualization of data not associated with abundance estimation. Thin-plate-splines were computed with Generic Mapping Tools (Wessel and Smith 1998, version 4.1) with a tension parameter T=0.4 and a spatial extent of interpolation of 20 km radius from every datum, a range comparable with that observed in the empirical variograms of many variables (see below). This interpolation method was used only when data were inappropriate for kriging (i.e., due to unstable variogram solutions and/or sparse spatial data coverage). Kriging was conducted with the R package, GSTAT (Pebesma 2004, version 0.9-35). Conversions between cartographic and Cartesian co-ordinate systems for analytical purposes were computed with PROJ (Evenden 1995, version 4.4.9) onto the Universal Transverse Mercator grid system (UTM region 20).

Fisheries Data

Catch rates are biased indicators of crab abundance. The spatial and temporal distribution of both crabs and the fishing effort are not uniform, varying strongly with season, bottom temperatures, food availability, timing of spring plankton blooms, reproductive behaviour, substrate/shelter availability, relative occurrence of soft and immature crab and associated discards, fisher experience, bait type and soak time and ambient currents. These numerous but important factors have not been modelled, rendering the interpretation of catch rates as an index of abundance an uninformative tool. They are presented here only to maintain continuity with historical records.

Mandatory logbooks provide information on location, effort (number of trap hauls) and landings (verified by dockside monitoring). The data are stored in the MARFIS database (Maritimes Region, Policy and Economics Branch, Commercial Data Division). Data were quality checked.

At-sea-observed data provide information about the size structure and the carapace condition of the commercially exploited stock (Table 5). The data are stored in the Observer Database System. At-sea-observers are deployed randomly (Figure 5) with the coverage being as evenly distributed as possible between areas. The target coverage (by quota) was 5% for N-ENS and 10% (by quota for S-ENS and 4X. This information was also used to compute the potential bycatch of other non-snow crab species by the snow crab fishery. Bycatch estimates of each species *i*, was extrapolated from the biomass of species *i* observed in the catch and the relative observer coverage in 2 ways:

By Landings:

$$Bycatch_i\ [kg] = Observed\ catch_i\ [kg] \times Total\ snow\ crab\ landings\ [kg] / Observed\ catch_{snow\ crab}\ [kg]$$

By Effort:

$$Bycatch_i\ [kg] = Observed\ catch_i\ [kg\ ] \times Total\ snow\ crab\ effort\ [th]\ ] / Observed\ effort\ [th]$$

Research Survey Data

Spatial coverage in the survey is (1) **extensive**, going well beyond all known commercial fishing grounds, and (2) **intensive**, with a minimum of 1 survey station located pseudo-randomly in every 10 × 10 minute area (Figure 6). This sampling design was developed to facilitate geostatistical estimation techniques (i.e., *kriging*; Cressie 1993; Legendre and Legendre 1998; Kern and Coyle 2000). Since 2004, approximately 400 stations have been sampled annually on the fishing vessel, *The Gentle Lady* (a 65 foot) with the same captain. In the 2008 survey, 405 stations were sampled.

The extensiveness of the sampling design allows the objective determination of the spatial bounds of the snow crab population, information that must be known if reliable estimates of biomass and population structure (e.g., size, sex, maturity) are to be made. The spatial distribution of snow crab is quite dynamic and so can rapidly shift to areas where they are not "traditionally" found. For the purposes of monitoring such changes in spatial distribution, sampling is required in areas where crab have not been previously observed. In addition, the distributional patterns of immature, soft-shelled, very old and female crabs do not correspond to those of legal size males. The former are considered to be less competitive and more susceptible to predation (Hooper 1986) and usually observed in more marginal environments or substrates with greater cover (gravel, rocks; Comeau et al. 1998). Focusing upon only those areas where large hard-shelled males occur in high frequency would preclude the reliable estimation of the relative abundance of these other important segments of the crab population.

Due to the gradual evolution of the aerial extent and alterations in the intensity and timing of surveys since the mid-1990s, direct inter-annual comparisons of the data are made difficult. Currently, surveys are conducted in the autumn (September to November; i.e., post-fishing season in ENS and just prior to the fishing season in CFA 4X). The timing of the surveys have stabilised to this latter period only since 2002. Prior to 2002, surveys were conducted during the spring/summer (April to July; i.e., prior to the fishing season in ENS). As a consequence, temporal trends are most reliable for the post-2001 period. In the southern-most area of snow crab distribution (CFA 4X) trawl survey coverage has been historically sporadic, but have stabilised since 2004.

A *Bigouden Nephrops* trawl, a net originally designed to dig into soft sediments for the capture of lobsters in Europe was used to sample the substrate (headline of 20 m, 27.3 m foot rope mounted with a 3.2 m long 8 mm chain, with a mesh size of 80 mm in the wings and 60 mm in the belly and 40 mm in the cod-end). Net configuration was recorded with Netmind sensors; depth and temperature were recorded with Minilog sensors; and positional information as recorded with a global positioning system. Tows were conducted for approximately 5 minutes in duration. Actual duration of bottom contact was assessed from Netmind and Minilog data streams. The ship speed was maintained at approximately 2 knots. The warp length was approximately 3 × the depth. Swept area of the net was computed from swept distance and net width.

All crab were enumerated; measured with callipers; shell condition determined (Table 5); claw hardness measured with a durometer; and weighed with motion-compensated scales. The latter allowed direct biomass measurement rather than estimates relying upon allometric relationships between body parts (the approach in 2003 and earlier; see below). Data entry and quality control was provided by JaviTech and migrated onto the Observer Database System, held at DFO, BIO (Bedford Institute of Oceanography, Dartmouth, Nova Scotia).

Snow crab biomass estimates prior to 2004 were approximated from CW measurements by applying an allometric relationship developed for SSE adult hard shelled snow crab (Biron et al. 1999; $R^2 = 0.98$, n = 750):

$$mass\ [g] = 1.543 \times 10^{-4} \times CW\ [mm]^{3.206}$$

The maturity status of males was determined from a combination of biological staging (carapace condition) and morphometric analysis. While physiological maturity is not directly co-incident with the onset of morphometric maturity (morphometrically immature male crabs are more than capable of mating in the absence of competition from terminally moulted males; Sainte-Marie 1993), the latter is more readily quantified. In the terminal moult of male snow crab, a disproportionate increase of chela height (CH) relative to CW is generally observed, a factor which may be associated with increased mating and/or reproductive success. Such morphometrically mature males can be discriminated from those that have not undergone the rapid chela growth via the following equation (E. Wade, personal communication, GFC):

$$M_{(male)} = -25.324 \times \ln(CW[mm]) + 19.776 \times \ln(CH[mm]) + 56.650$$

where an individual is considered mature if $M_{(male)} > 0$.

The maturity status of females is assessed from direct visual inspection of eggs or gonad development. Where maturity status was ambiguous, maturity was determined morphometrically, as the width of abdomen (measured by the width of the fifth abdominal segment, AW) increases rapidly relative to CW at the onset of morphometric maturity, facilitating the brooding of eggs. This onset of morphometric maturity can be delineated via the following equation (E. Wade, personal communication, GFC):

$$M_{(female)} = -16.423 \times \ln(CW[mm]) + 14.756 \times \ln(CH[mm]) + 14.900$$

where an individual is considered mature if $M_{(female)} > 0$.

Sex ratios were calculated from kriged numerical abundance estimates N as:

$$Sex\ ratio = N_{(female)} \,/\, (N_{(male)} + N_{(female)})$$

Size-frequency histograms were expressed as number per unit area swept in each size interval (No · km^{-2}; i.e., the arithmetic mean numerical density per unit area). Modes and the bounds of the each modal group were identified from size frequency distributions. Each instar (I) was determined after an analysis of size-frequency distributions to have a lower bound of carapace width (mm) approximated by (see also Figures 7, 8):

$$CW_{(I,\ male)}[mm] = \exp(1.918 + 0.299 \times (I - 3))$$

$$CW_{(I,\ female)}[mm] = \exp(2.199 + 0.315 \times (I - 4))$$

"*Viable habitat*" for fishable snow crab was modelled from trawl surveys via logistic regression of survey locations where fishable snow crab were found or not found. Specifically, a binomial Generalised Additive Model with a logit link function was used with smoothed (thin-plate-spline) covariate functions (R-library "mgcv"; Wood 2006). Statistically significant covariates were determined to be year, northing and easting, depth bottom slope, bottom curvature, bottom temperature, annual amplitude of temperature fluctuations, the week number at which temperature minima were observed and substrate grain size (Figures 9, 10; Table 23). These modelled relationships were used to predict SSE snow crab habitat after discretising covariate information to a spatial resolution of 1 × 1 km grids (Figure 9). Potential snow crab habitat was identified as those locations where the predicted probability of finding snow crab was > 0.5 (Figure 11). The habitat surface of fishable crab was used as a first approximation for females and immature crab; more appropriate habitat bounds will be determined in the future. As such, abundance estimates of females and immature crab are likely to be biased (underestimated) because habitat use is known to be more varied than that of large fishable crab. The advantage of this approach is that it deviates from the more ad-hoc and contentious approaches towards defining viable snow crab habitat used in the past.

The biomass and numerical densities of crab was predicted upon this dynamically changing habitat surface using geostatistical methods: modelling of variograms (the behaviour of variance as a function of distance) for each of the individual variables, in each year. The variogram, $2\hat{\gamma}(\cdot)$ or alternately the quantity, $\hat{\gamma}(\cdot)$ known as the semi-variance or semi-variogram, is classically determined by the method of moments (Cressie 1993) for some random process, $Z(\cdot)$, such as biomass or number of crab. In the simple case of an isotropic random process, $Z(\cdot) \approx Z(\Delta x)$, where $\Delta x = x_i - x_j$, the distance between all pairwise sampling positions x. For such a processes, the method of moments estimator of the variogram is:

$$
\begin{aligned}
2\hat{\gamma}(\triangle x) &= Var(Z(x_i) - Z(x_j)) \\
&= \frac{1}{|N_{\triangle x}|} \sum_{N_{\triangle x}} [Z(x_i + \triangle x) - Z(x_i)]^2
\end{aligned}
$$

where Var is the variance, and $N_{\Delta x}$ is the number of pairwise cases.

Empirical variograms standardised to unit variance were constructed using a moving, time-averaged approach. Specifically, a weighted average of the semivariance of 3 years +/- the focal year was obtained where the annual weights decayed exponentially with time (year). The final solution was re-scaled to the local variance of the region and year of interest. Variograms were modelled using a number of functional forms (bessel, spherical, exponential, circular, gaussian or generalised Matern) via weighted nonlinear least-squares within GSTAT (Levenberg-Marquart algorithm). A simple least-squares criterion was used to select the best fitting model (examples are provided in Figure 12).

Spatially explicit means and variances were then obtained using trans-gaussian, Universal (block) Kriging with External Drift (UKED). UKED is a technique that linearly accounts for variations in external (drift) parameters under the kriging formalism (i.e., a variogram constraint). The same covariates that entered the habitat model were used as external drift terms as they were found to be significant factors from preliminary analysis of the abundance density via GLM. To help further delineate core fishing grounds, the average historical fishery catch rates (domain of fishing core areas), all discretised to 2 × 2 km^2 was also included as an external drift term. Confidence intervals (95%) were established by (Sequential) Conditional Gaussian Simulation. This deviates from past approaches where universal block kriging had been used to estimate confidence bounds. However, the high spatial resolution of the data resulted in unrealistically small variance estimates. Conditional Gaussian Simulation is a randomisation approach that more robustly captures the real variability in the data.

Growth stanzas of male snow crab were determined from size-frequency analysis (Tables 6, 7) and the numerical abundance of each of these nominal growth stanzas (Figure 13) were also determined via kriging (where possible).

An index of relative exploitation rate (*ER*) at time *t* is calculated as:

$$ER_t = Landings_t / (Landings_t + Mature\ fishable\ biomass_t)$$

where *t* is time, $Landings_t$ is the total landed snow crab in year *t*, and $Mature\ fishable\ biomass_t$ is the total mature and legally fishable biomass (mature male snow crab ≥ 95 mm CW) estimated from kriging for year *t*. This definition is used as there is agreement to focus exploitation upon mature individuals and to return immature crab (pencil-clawed) to the water.

An index of relative numerical exploitation rates of each growth stanza was also estimated from at-sea-observed catches for each major area with the assumption of 100% catchability for each growth stanza and constant natural and handling mortality:

$$ER_{(t,i)} = Number\ landed_{(t,i)} / (Number\ landings_{(t,i)} + Number\ surveyed_{(t,i)})$$

where *t* is time, *i* is growth stanza, $Number\ landed_{t,i}$ are the total number of snow crab estimated to have been landed from at-sea-observed proportions of each growth stanza *i* in the catches of year *t*, and *Number surveyed*$_{t,i}$ is the total number of snow crab estimated from kriged numerical abundance of each growth stanza *i*, in year *t*.

Markov-type transition matrices (Tables 8-10) were determined for each nominal growth stanza of male snow crab based upon historical data from 2003 to the present. Data prior to 2003 could not be used to compute the transition matrix due to the very different timing of the surveys (spring) and differences in the spatial extent of the research surveys. Due to gear and sampling bias and the bi-annual moulting of snow crab instars 1 to 5, numerical abundance and transition matrix estimates were limited to instars 5 and greater. There is no information on reproduction and early pelagic and benthic survival; nor is there information on any stock-recruitment relationships. As the full life cycle is not being modelled, these transition matrices are referred to as *pseudo-transition matrices*. Further, the relative differences in catchability of the various size and maturity classes (i.e., "Observation error") were not separated from survivorship resulting in transfer functions that can be greater than 1. The catchability of the commercially exploitable population was assumed to be 100%. These pseudo-transition matrices were developed for each major region separately (N-ENS, S-ENS, CFA 4X) whenever possible and used for forward projection under varying scenarios of exploitation rates.

Forward projection scenarios were derived from fishing patterns in the most recent year of at-sea-observed estimates of relative exploitation for each of the above growth stanzas and the most recent year of abundance estimates from trawl surveys. Errors (Δx) from all potential sources were propagated assuming all *n* variables (x_n) were independent of each other:

$$\begin{aligned} z &= f(x_1, x_2, \ldots, x_n) \\ (\Delta z)^2 &= (\frac{\partial f}{\partial x_1}\Delta x_1)^2 + (\frac{\partial f}{\partial x_2}\Delta x_2)^2 + \ldots + (\frac{\partial f}{\partial x_n}\Delta x_n)^2 \end{aligned}$$

Synthetic Analysis of Indicators

An approach similar to the traffic light framework used in some stock assessments (Brodziak and Link 2002; Koeller et al. 2000, 2006) in combination with a multivariate data simplification method known as ordination (see methods in Choi et al. 2005b) were used to describe systemic patterns in temporal data series. Indicators were made directly comparable to one another by expression as anomalies in standard deviation units and then colour-coded. Missing values were coded as white. The metrics were then ordered in the sequence of the primary gradient (first eigenvector) obtained from a multivariate ordination. This allowed the visualisation of any coherence in the manner in which suites of these indicators changed over time. The sequence of the indicators reflects the degree of similarity in their temporal dynamics. Specifically, a variant of Principal Components Analysis (PCA) was used that involved an eigenanalysis of the correlation matrices of the indicators, following data-normalisation of those that were not normally distributed ($\log_{10}(x+1)$ transformations). In classical PCA, it is customary to delete all such cases (years), but this would have eliminated much of the data series from the analysis. Instead, Pearson correlation coefficients were computed for all possible pair-wise combinations with the implicit assumption that it represents a first-order approximation of the "true" correlational structure.

LIFE HISTORY

The snow crab (*Chionoecetes opilio*, Brachyura, Majidae, O. Fabricius) is a subarctic species resident along the east coast of North America from northern Labrador to the Gulf of Maine. In the SSE, commercially fished snow crab are generally observed between depths of 60 to 280 m and between temperatures of -1 to 6 ^{o}C (Figures 9, 10). Near 7 ^{o}C, metabolic costs are thought to match metabolic gains (Foyle et al. 1989). Snow crab are generally observed on soft mud bottoms although small-bodied and moulting crabs are also found on more complex (boulder, cobble) substrates (Sainte-Marie and Hazel 1992; Comeau et al. 1998).

Snow crab eggs are brooded by their mothers for up 2 years, depending upon ambient temperatures, food availability and the maturity status of the mother (up to 27 months in primiparous females – first breeding event; and up to 24 months in multiparous females – second or possibly third breeding events; Sainte-Marie 1993). More rapid development of eggs (from 12 to 18 months) has been observed in other systems (Elner and Beninger 1995; Webb et al., 2007). A primiparous female of approximately 57.4 mm CW would produce between 35,000 to 46,000 eggs which are extruded between February and April (in the Baie Sainte-Marguerite; Sainte-Marie 1993). The actual range of fecundity is however quite large, especially as multiparous females are thought to be more fecund with more than 100,000 eggs being produced by each female. Eggs are hatched from April to June when the larvae become pelagic, feeding upon the plankton for 3 to 5 months (zoea stages 1 and 2 and then the megalopea stage). The larvae settle to the bottom in autumn to winter (September to October in the Gulf area). In the SSE, pelagic stages seem to have highest abundance in October and so may begin settling as late as January. Very little is known of survival rates at these early life stages.

Once settled to the bottom (benthic phase), snow crab grow rapidly, moulting approximately twice a year (Sainte-Marie et al. 1995; Comeau et al. 1998). The first inter-moult stage (instar 1) is approximately 3 mm CW. After the 5th instar (15 mm CW), the frequency of moults decline; moulting occurring once a year in the spring until they reach a terminal maturity moult. Growth is allometric with weight increasing approximately 250% with each moult (Figure 8; Tables 6, 7). Terminal moult has been observed to occur between the 9th to the 13th instar in males and the 9th to 10th instar in females (see Results). Just prior to the terminal moult, male crab may skip a moult in 1 year to moult in the next (Conan et al. 1992**)**. Male snow crab generally reach legal size (≥ 95 mm CW) by the 12th instar; however, a variable fraction of instar 11 snow crab are also within legal size. Male instar 12 snow crab represent an age of approximately 9 years since settlement to the bottom and 11 years since egg extrusion. Thereafter, the life expectancy of a male is approximately 5 to 6 years. Up to 10 months are required for the shell to harden (carapace conditions 1 and early 2; Table 5) and up to 1 year for meat yields to be commercially viable. After hardening of the carapace (carapace conditions 3 to 4) the male is able to mate. Near the end of the lifespan of a snow crab (carapace condition 5), the shell decalcifies and softens, often with heavy epibiont growth. In some warm-water environments (e.g., continental slope areas), epibiont growth occurs at an accelerated rate creating some uncertainty in the classification of carapace condition 5 crab.

Females reproducing for the first time (primiparous females) generally begin their moult to maturity at an average size of 60 mm CW and mate while their carapace is still soft (early spring: prior to the fishing season in ENS, and during the fishing season in CFA 4X). A second mating period later in the year (May to June) has also been observed for multiparous females (Hooper 1986). Complex behavioural patterns have also been observed: the male helps the primiparous female moult, protects her from other males and predators and even feeds her (indirectly; Hooper 1986). Pair formation (a mating embrace where the male holds the female) may occur up to 3 weeks prior to the mating event (Hooper 1986). Upon larval release, males have been seen to wave the females about to help disperse the larvae (i.e., prior to a multiparous mating). Females are selective in their mate choice, as is often the case in sexually dimorphic species, and have been seen to die in the process of resisting mating attempts from unsolicited males (Watson 1972; Hooper 1986). Males compete heavily for females and often injure themselves (losing appendages) while contesting over a female. Larger males with larger chela are generally more successful in mating and protecting females from harm.

ECOSYSTEM CONTEXT

Overview

An overview of some relevant social, economic and ecological factors are here provided to form a basis for discussion of the place of snow crab in its ecosystem. Utilizing the same multivariate approach to the statistical summary and synthesis of indicators as in Choi et al. (2005b), key environmental (climatic), social, economic and fishery-related indicators were identified and summarised as standardised residuals in Figure 14. Appendix 1 provides a list of these indicators and their sources.

The first axis of variation accounted for 15.9% of the total variation in the data (Figure 15), and was dominated by the influence of socio-economic indicators of ocean use by humans and associated changes in their relative abundance: landings and landed values of groundfish (declining), invertebrates (increasing) and Oil and Gas exploration and development (increasing). Gross Domestic Product (GDP) associated with the Oil and Gas sector, as well as total Nova Scotia GDP were also influential factors that have also been increasing. Further, PCB levels in Atlantic puffins and grey seals have been declining, as has the physiological condition of many groups of fish. However, the total number of shellfish closures have increased with time, as has the amount of seismic activity. Increasing ocean colour and abundance of, diatoms and dinoflagellates and declining abundance of *Calanus finmarchicus* were also influential to the first axis of variation. The temporal differences along this axis of variation indicates that coherent systemic changes of socio-economic and ecological indicators occurred in the early 1990s with no real return to historical states evident (Figure 15).

Importantly, temperature-related changes were generally orthogonal (independent) to the above axis of variation: the second (orthogonal) axis of variation, accounting for 9% of the total variation (Figure 16) was strongly associated with the Cold Intermediate Layer (CIL) temperature and volume, bottom temperatures and variability in bottom temperatures, bottom oxygen concentrations and sea ice coverage. The temporal variations of this axis (Figure 16) indicate that the current ocean-climate has returned to its average state after a decade-long divergence from the late 1980s to the late 1990s.

Anecdotal information from fishers and fishery-based catch rates (Figures 4, 14) suggests that the abundance of snow crab was quite low in the near-shore areas of the SSE, prior to 1980. Increases in catch rates were observed throughout the shelf in the mid-1980s and 1990s in N- and S-ENS, respectively. As commercially exploitable snow crabs require 9 years or more from the time of settlement to reach the legal size of 95 mm CW, their increasing dominance on the shelf must have had their origins as early as the late-1970s and 1980s (N- and S-ENS, respectively). For S-ENS, these time-lines are confounded by the expansion of the fishing grounds towards increasingly offshore areas and the exploitation of previously unexploited crab populations. However, most of this expansion was observed in the post-2000 period when TACs and the closely associated landings increased up to 6 fold relative to the TACs and landings of the 1990s and a doubling of fishing effort (Figures 2, 3). The catch rate increases observed in the 1980s and 1990s were, therefore, likely reflecting real increases in snow crab abundance.

The possible causes of this change in abundance can be simplistically broken down into the following categories of explanation: connectivity (metapopulation dynamics), environment (habitat), top-down (predation), bottom-up (resource limitation), lateral (competition) and human (complex perturbations). These will be discussed below, in brief.

Connectivity

Connectivity refers to the manner in which various populations are connected to each other via immigration and emigration, also known as metapopulation dynamics. In the case of snow crab, connectivity between populations exists due to 2 main processes: larval dispersion in the planktonic stages and directed movement during the benthic stage.

1. Larval dispersion:

The potential for hydrodynamic transport of snow crab larvae from the southern Gulf of St. Lawrence to the SSE has been studied by J. Chassé (Ocean Sciences Division, BIO, DFO; pers. comm.). Treating larvae as passive particles, simulations suggest that a large numbers of larvae can be transported onto the SSE (especially near Sable Bank and in the shallows further west). While pelagic organisms can maintain their position in a single location in even very strong advective conditions via control of vertical migrations, the possibility of snow crab larvae entering the SSE from the Gulf of St. Lawrence region cannot be ignored. While the biological importance of this flow has not been quantified nor studied empirically, the following observations indicate that the SSE population is currently acting as an autonomously reproducing system:

- The temporal dynamics of the SSE snow crab population is generally out-of-phase with the cycles seen thus far in the Southern Gulf of St. Lawrence. If the SSE was dependent upon the larval drift from the Gulf region, the temporal dynamics of the populations would be in-phase.
- The spatial distribution of Brachyuran larvae (Ichthyoplankton Sampling program in the 1980s; see summary in Choi et al. 2005a, page 14) have been observed to be quite pervasive throughout the SSE with no spatial clines (i.e., no declines in abundance with distance from the Gulf of St. Lawrence area) as one might expect if the source of larvae were solely from the Gulf region.
- A pulse of larval abundance was observed from 1997 to 1999 with peak levels in 1998 (Choi et al. 2005a, page 14). The timing of this pulse is concordant with the growth schedules of the currently expected ‘local’ recruitment. Approximately 9 years would be required to grow from the zoea stages to instar 11/12, the stages in which snow crab begin to moult to maturity in 2007, the same time difference between 1998 and 2007.
- The period in the late 1990s when high larval production was observed was precisely the same period in which the abundance of mature males and females on the SSE were at their peak.

The above *circumstantial evidence* suggests that the snow crab resident on the SSE is more than capable of being a self-reproducing system, regardless of inputs from other systems. Even if external sources of larvae do exist, the reproductive potential of the snow crab resident on the SSE proper cannot be dismissed. To this end, the snow crab industry adopted a precautionary approach to the conservation of large mature males (i.e., reduced exploitation rates) to allow them to mate with the more rapidly maturing females in 2006/2007.

2. Movement:

Spaghetti tags have been applied opportunistically to monitor snow crab movement since the early 1990s (Table 11). Movement information was primarily limited to single recaptures of mature, terminally moulted male crab. This was because crab cannot survive a moult once a tag is applied. As tags are returned by the snow crab fishery, a male-only fishery, the movement of immature and female crab is not known and is a major source of uncertainty.

Since 2004, 5,230 tags have been applied and a total of 404 tags (7.7%) have been recaptured and reported with the required information.

The majority (approximately75%) of the tagged snow crab were recaptured within 14.5 km of their release location (Figures 17, 18). The average distance travelled was 12.8 km with a maximum distance travelled of 276.1 km. The mean distance travelled was 2.0 km month^{-1} with a maximum of 53.2 km month^{-1}. These distances are linear distances from mark-recapture and are therefore underestimates as the actual distance travelled by the crab will be greater due to the topographical variations and the meandering nature of most animal movement.

On average, tagged crab were recaptured in the season following the tagging event (mean time to recapture was 9 months) with no reported returns after more than 2 years (Figure 19). During this 4-year period, movement between N-ENS and S-ENS was seldom observed. However, N-ENS fishers in the Glace Bay Hole have explicitly stated that they would not report tagged crab recaptures, rendering this result uncertain. Indeed, historically, movement between N- and S-ENS have been observed.

For the 5,230 snow crab tagged since 2004: 1,426 were CC2 (Carapace Condition 2, or white) crab. Of these white crab, 10.2% have been recaptured (and reported), at an average time interval of 9 months. This return rate is very comparable to that of the harder-shelled crab, indicating that associated handling mortality of tagged white crab is likely to be extremely low.

If the snow crab fishers would like to obtain reliable information on the connectivity of snow crab on the SSE, they must be willing to report all recaptures with the relevant information (tag number, latitude, longitude, crab carapace condition) and abstain from the fabrication of false recapture information. With advice from DFO Science, fishers have begun re-releasing tagged snow crab, as multiple recaptures of crab provide valuable long-term movement records. To date, 15 tagged crab have been recaptured after being re-released.

Environment

Environmental influences refer to the *abiotic influences* upon organisms, such as the physical habitat or temperature variations, oxygen concentrations, that delimit this habitat. Altered environmental conditions over extended periods of time have been observed in the SSE (Figures 14, 20). For example, prior to 1986, the shelf was characterised by relatively warm bottom waters, low volume of the cold intermediate layer, and a Gulf Stream frontal position closer to the continental shelf. The post-1986 period transitioned to an environment of cold bottom waters, a high volume of cold-intermediate layer waters, and a Gulf Stream frontal position distant from the shelf. The principal cause of the cold conditions is thought to have been along-shelf advection from both the Gulf of St. Lawrence and southern Newfoundland, and local atmospherically-induced, cooling. In the southwestern areas (Emerald Basin), the offshore warm slope water kept subsurface temperatures relatively warm throughout the 1980s and 1990s, the exception being in 1997-98, when cold Labrador Slope Water moved into the region along the shelf break and flooded the lower layers of the central and south western regions. While this event produced the coldest near-bottom conditions in these shelf regions since the 1960s, its duration was short, lasting about 1 year.

Juvenile crab (approximately instar 5, or 2 years since settlement) were already present in high numbers in the transitional year of 1986. These crab were therefore the benefactors of environmental amelioration; that is, some other factors(s) had allowed their larval and adolescent numbers to build up to very large level prior to these large environmental changes. What these factors(s) are is not yet fully understood, but the reduction in predation mortality associated with the demise of groundfish is an important hypothesis. Further, it is important to note that bottom temperatures in the distributional centers of snow crab have been increasing consistently since the early 1990s while snow crab continues to dominate the bottom environment in S-ENS, somewhat weakening the validity of the temperature-hypothesis. The orthogonal nature of the second major axis of the ordination of ecosystem indicators which was dominated by climatic indicators suggests that climatic variation may not be the cause of the changes observed in the SSE in the early-1990.

Indeed, the spatial extent of what may be considered potential snow crab habitat in the SSE has been mostly quite stable in the historical record since 1950 (Figures 21, 22). In N-ENS, the surface area of predicted snow crab habitat has varied between 6 to 9 × 10^3 km^2 (mean = 7.8 × 10^3 km^2, $SD_{inter\text{-}annual}$ = 0.6 × 10^3 km^2; Figure 21). For S-ENS, the surface area of potential habitat has varied with similar oscillations, ranging from between 40 to 70 × 10^3 km^2 since 1950 (mean = 59.7 × 10^3 km^2, $SD_{inter\text{-}annual}$ = 6.2 × 10^3 km^2). In the most recent period, the surface area has increased to above normal levels in both areas (Figure 21). In CFA 4X, the southern-most limit of the distribution of snow crab, potential habitat has been variable, ranging from 6 to 13 × 10^3 km^2 (mean = 9.1 × 10^3 km^2, $SD_{inter\text{-}annual}$ = 1.9 × 10^3 km^2). However, there is an important declining trend, evident since the mid-1960s and inverse in phase relative to ENS since the mid 1980s (Figure 21).

Within the area that may be considered potential snow crab habitat, average bottom temperatures were 2.7 ($SD_{inter\text{-}annual}$=0.3), 3.4 ($SD_{inter\text{-}annual}$=0.5) and 4.6 ($SD_{inter\text{-}annual}$=0.6) ^oC in N-, S-ENS and CFA 4X, respectively (Figure 22). Average bottom temperatures in 2008 were similar to these long-term means. Bottom temperature variations have been in phase throughout the 3 sub-areas in the historical record with a strong cooling evident during the mid-1960s. In CFA 4X, bottom temperatures have been particularly erratic since the late 1990s with large magnitude, cyclic fluctuations (approximately 7/8-year) that have been large in amplitude since the mid-1980s (Figure 22). In such areas of larger environmental variability and overall warmer waters such as found in CFA 4X, a more precautionary approach to exploitation is definitely warranted.

Top-down

Top-down influences refer to the *role of predators* in controlling a population (Paine 1966; Tremblay 1997; Worm and Myers 2003). The capacity of predatory groundfish to opportunistically feed upon snow crab (Robichaud et al. 1991), in combination with their numerical dominance prior to the 1990s (Choi et al. 2004, 2005b; Frank et al. 2005), suggests that they may have been an important regulating factor controlling the recruitment of snow crab. For example, snow crab in the size range of 5 to 30 mm CW (with a 7 mm CW mode; that is instars 2 to 7, with instar 7 being strongly selected) were targeted by thorny skate and cod. Soft-shelled males in the size range of 77 to 110 mm CW during the spring moult were also a preferred food item. The demise of these predatory groundfish in the post-1990 period and the resultant release from predation upon the immature and soft-shelled crabs may have been an important determinant of the current rise to dominance of snow crab in the SSE.

Historically, the known predators of snow crab have been, in order of importance: Atlantic halibut (*Hippoglossus hippoglossus*), skates (especially thorny skate, *Raja radiata*), Atlantic cod (*Gadus morhua*), seals, American plaice (*Hippoglossoides platessoides*), squids, and other crabs (Bundy 2004). In particular, Atlantic cod (Figure 23) and thorny skate (Figure 24) have been noted for their high selectivity for snow crab and, therefore, their potential to weaken recruitment to commercial sizes (Bailey 1982; Lilly 1984; Robichaud et al. 1989, 1991). Certainly, in the inshore areas of the Scotian Shelf, the anecdotal information that extremely high densities of these early stage snow crabs are found in lobster traps indicates some degree of habitat overlap with adult lobsters. This suggests that 1 hypothesis for the current increase in lobster abundance in ENS may in part be related to the food base that the juvenile snow crab represent to lobsters. Predation levels upon small immature crabs are also likely to be on the rise in certain offshore areas. High local densities of these more traditional groundfish are found in areas where small immature crab are found in high densities (Figures 23, 24). However, the trends in abundance and condition of groundfish and gadoids in particular continue to be in an impoverished state (Figure 14).

Seals are considered by fishers to be a potential predator of snow crab and their continued increase in abundance (Figure 14) is a source of concern for many fishers. While they have on occasion been observed with snow crab in their stomachs, it should also be emphasised that the highest concentrations of snow crab are currently found in the immediate vicinity of Sable Island, an area where the abundance of grey seals are extremely high. The actual evidence indicating that seals have a negative influence upon the snow crab population therefore seems to be minimal. In fact, it is quite possible that seals may be having a positive influence by physically importing food and food waste (organic matter) from other more outlying areas to the immediate vicinity of Sable Island and so indirectly “feeding” the snow crab and also removing potential predators of crab (in both early pelagic and benthic stages).

Bottom-up

Bottom-up influences refer to changes in a population due to resource (food) *availability*. Diet studies and field observations (Hooper 1986; Bundy 2004) indicate that the primary food items of larger (mature) crab are, in order of importance: echinoderms, polychaete worms (*Maldane* sp., *Nereis* sp.) and other worm-like invertebrates, detritus, large zooplankton, shrimps, smaller crabs (Rock crab, *Cancer irroratus*; Toad crab, *Hyas coarctatus;* Lesser toad crab, *Hyas araneus*), ocean quahog (*Artica islandica*), bivalve molluscs (e.g., *Mytilus edulis, Modiolus modiolus*), brittle stars (*Ophiura sarsi*, *Ophiopholis aculeata*) and sea anemones (*Edwardsia* sp., *Metridium senile*). Smaller crabs primarily feed upon, in order of importance: echinoderms, polychaete worms, large zooplankton, detritus and bivalves (e.g., *Mytilus edulis, Modiolus modiolus, Hiatella arctica*). Recent studies have also demonstrated that cannibalism is also highly prevalent in intermediately sized (morphometrically) mature crabs, especially mature females (Sainte-Marie and Lafrance 2002; Squires and Dawe 2003).

Most of these food items are part of the detrital food web, and so the proliferation of snow crab under the hypothesis of bottom-up control would be indicative of the proliferation of the detrital subsystem (potentially at the expense of the other parts of the shelf ecosystem, including that of the demersals). This hypothesis is consistent with what is known of the current structure of the Scotian Shelf Ecosystem (Choi et al. 2005b):

Phytoplankton abundance in the most recent decade (1991-2001) was considerably higher and more variable than in the 1960s and early 1970s. This likely resulted in increased sedimentation of organic matter to the ocean bottom (Choi et al. 2005b; Figure 14).

The recent proliferation of northern shrimp (*Pandalus borealis*), another detritivore and also a potential food item of snow crab (Figures 14, 25) was co-incident with the rise in abundance of snow crab.

The demise of the groundfish that would competitively feed upon benthic invertebrates (Figure 14).

Certainly the rapid rate of increase in abundance of snow crab would seem to indicate that resource competition was not a limiting factor (up to the late 1990s).

Near the ocean surface, there has been a trend towards increased ocean colour which is an index of chlorophyll concentrations. Therefore, total primary production may be increasing (in the form of diatoms and dinoflagellates). This is likely enhanced by the reduction in abundance of *Calanus finmarchicus,* an important zooplankton link in the pelagic food web. Whether this elevated primary production reaches the detrital system is not yet known.

Lateral

Lateral (and internal) influences refers to the *competitive interactions* with groundfish, other crab species, cannibalism and reproduction-induced mortality (direct and indirect). The diet of snow crab overlap in many ways with that of groundfish, thus the demise of groundfish in the late 1980s and early 1990s would have been doubly beneficial to snow crab: reduction in predation pressure and also resource competition. The spatial distribution of snow crab overlaps with that of other crab species (Figures 26, 27). The centers of high abundance may be areas where interactions may be strong causing resource competition, not only for food but habitat space as well. Of course these interactions are complex in that crabs may also serve as predators upon small snow crab, as well as being food items for large snow crab. Nonetheless, where concentrations are elevated, the likelihood of strong negative (competitive) interactions is greater.

Human

The human influence is quite complex, generally representing perturbations of many kinds. The direct is in the form of fishing. Directed fishing for snow crab is discussed in the next section (Fishery assessment). Here, other forms of human influences are discussed.

1. Bycatch of snow crab in other fisheries:

The bycatch of snow crab in other fisheries remains an area requiring attention.

The spatial distribution of Northern shrimp (*Pandalus borealis*) overlaps with that of snow crab and so represents an industry that requires particular attention. The use of trawls by the shrimp industry is of particular concern as they can cause co-incident damage of snow crab, especially those susceptible to crushing such as crab in newly moulted soft-shelled stages. This is particularly relevant as the relative abundance of soft-shelled crab is expected to remain at high levels for the next 3-4 years with the return of recruitment to the fishery.

The inshore lobster fishery may also represent a source of juvenile and adult female snow crab mortality in some areas due to their capture in lobster traps and (illegal) use as bait. This has been stated by fishers to be more prevalent in CFA 4X.

2. Bycatch of other species in the snow crab fishery:

At-sea observed estimates of bycatch of other species in the commercial catch of the SSE snow crab fishery can be extrapolated to the entire fleet based on (1) landings, or (2) effort (Tables 12, 13). In ENS, a total of 18,638 t of snow crab was landed with associated estimates of bycatch at 0.8 t (landings-based) or 0.9 t (effort-based) for the past 3 fishing seasons combined. This generates bycatch estimates of 0.00429% (landings-based) or 0.00482% (effort-based) of crab landings. CFA 4X shows 2 orders of magnitude higher bycatch rates (though still very low) with a total estimated bycatch of 4.1 t associated with 847 t of snow crab landings (0.485%). The majority of bycatch for all areas is composed of other invertebrate species (e.g., Northern Stone Crab and American Lobster) for which higher survival rates can be expected after being released as compared to fin fish discards. In the 3 year record, observers also reported 1 leatherback turtle as having been entangled in buoy lines. This turtle was reported to be released with minimal or no damage to the animal.

The low incidence of bycatch in commercial catch of the SSE snow crab fishery can be attributed to:

- Trap design – top entry conical traps excludes many fish species.
- Passive nature of fishing gear as opposed to other gear types such as trawl nets.
- Large mesh-size of trap nets (at a minimum 5.25” knot to knot).

3. Oil and gas exploration and development:

The interests of the oil and gas industry to explore and develop areas in the SSE near to, or upstream or even directly over major crab fishing grounds and population centers (both N- and S-ENS) has been identified by numerous fishers as a source of concern. The number of seismic exploration activities (both 2D and 3D) has been increasing in the SSE as has the total number of wells drilled and the GDP associated with this sector (Figure 14). The potential effects of these seismic methods of exploration upon vulnerable components of the snow crab population and the uncertainties associated with the long-term effects of drilling and extraction include the following:

- A major pulse of females have matured and become reproductively active. This will continue for another 3 years minimum. They hold eggs for up to 2 years. As snow crab mating behavior is complex, disruption of their mating rituals is particularly likely as the courting/mating period can last up to several weeks. This can modify the reproductive/regenerative capacity of the snow crab resident in the SSE. Damage to eggs and modification of reproductive behavior can have lasting influences upon the population and fishery.
- A major pulse of males is recruiting into the fishery after many years of a decline. Their soft-shell phase has become proportionately more important. Soft-shelled crab are particularly sensitive to physical trauma.
- Many immature male and female are found in shallower waters. They are currently increasing rapidly in number. Damage to this component will have short- and long-term repercussions to the fishery. In terms of seismic methods of exploration, the shallower areas

are an important area of concern as the magnitude of seismic energy reaching the bottom will be much greater than in offshore applications.

- No information is available for the effects of seismic pressure waves upon the planktonic forms of snow crab. This is particularly important for the megalops stage which are generally found near areas of rapid water density changes (thermoclines and haloclines). Areas of rapid density changes represent areas where the influence of seismic energy upon biota is extremely uncertain.
- Snow crab are known to jettison legs or die when physically shocked (i.e., dropped onto the deck of a boat). This is an important unknown especially as pressure waves can be amplified and wavelengths of pressure waves altered when moving through media of differing densities (e.g., when they are burrowed in mud).
- Being a very long-lived species, the snow crab is exposed to environmental hazards for up to 16 years (since egg extrusion). As such, simple short-term studies (e.g., of exposure to strong pressure impulses and associated direct and indirect phenomena) do not describe the more difficult questions of long-term, compounded (cumulative) effects of seismic energy and oil and gas exploration and development upon snow crab. This is a very large uncertainty.
- Snow crab are important benthic predators. Bioaccumulation of heavy metals and toxic organic chemicals released from oil and gas development is possible, especially as they are so very long-lived. The potential creation of anoxic conditions from drilling is also of concern. Any damage to the health of snow crab can be detrimental to the reproductive capacity of the population which in turn can also have economic repercussions.

Substantial sacrifices were made from 2004 to 2006 by snow crab fishers to reduce any risks of damaging the reproductive potential of Scotian Shelf snow crab. In the face of such uncertainties and sacrifice, Hunt Oil completed seismic exploration directly over the Glace Bay Hole (an area of high abundance of commercial crab) and the Sidney Bight (a refuge area for immature and female crab) in November 2005 (Source: http://ns.energyresearch.ca/files/Norval_Collins.pdf). The numerous uncertainties associated with such oil and gas exploration/development activities increases the risk of destabilising the snow crab population in the SSE.

4. Socio-economics:

A coherent change in many socio-economic indicators occurred in the mid-1990s, in the same time frame as the large-scale changes in the Scotian Shelf Ecosystem (Figure 14). In general, the demographics of Nova Scotia shifted toward an older population base with the ageing of the “baby-boomers”. The total population size has also been increasing over the historical record to approximately 935,000 people in 2007, as well as a trend toward a population with higher levels of education. Nova Scotia’s GDP has also been increasing along with the GDP associated with Oil and Gas exploitation and the number of cruise ships visiting Halifax. Amongst the more fishery-related indicators, there has been an increased importance of invertebrate fisheries with the demise of the groundfish in the early-1990s, both in terms of total landings and landed values of the fisheries. The number of shell-fish closures have increased over time. However, the relative importance of fishing to the Nova Scotia GDP and the total number of fish harvesters have both been on the decline. The recent world-wide economic down-turn in 2008/2009 will have lasting influences upon all economic sectors, by creating greater uncertainty for the economic viability of the snow crab fishery.

The fished species have changed greatly since the early 1990s in conjunction with the rapid changes in species dominance structure. Since this time, all ground fish landings have declined, falling from 232 kt to 59 kt. Exceptions include dogfish, haddock and halibut. Similarly, the pelagic fish landings have decreased from 125 kt to 66 kt. It should be noted that tuna landings have increased since the 1990s, and swordfish landings are now on the rise. In contrast, invertebrate landings have increased from 111 kt to 128 kt since the 1990s as has the total landed value for all fisheries combined, increasing from $445 million in 1990 to $847 million in 2003. It has declined since then to $639 million due in part to snow crab TAC reductions associated with poor recruitment in the mid-2000s.

The links between the socio-economic changes observed and the changes in the Scotian Shelf Ecosystem are complex and cannot be treated in depth in this forum. However, an important issue to consider is whether alterations in social and economic structure can assist in the continued evolution of a precautionary and ecosystem-based management of a sustainable and viable snow crab fishery. Certainly, transparency in management, communication by science and a unity of voice of fishers with a long-term vision for their resource can definitely assist as has been the experience in S-ENS in the post-2004 period – a success that merits emphasis. Maintaining and fostering these positive determinants of stewardship is *essential* for the continued social, economic and ecological sustainability of this fishery.

FISHERY ASSESSMENT

Effort

In S-ENS, fishing effort was spatially distributed more widely relative to the past 2 seasons (Figure 28) and similar to that observed in the early 2000s, coincident with the last population pulse. In both CFAs 23 and 24, additional effort was applied in near-shore areas that have seen little effort in recent seasons. In CFA 24, less effort (proportional to total seasonal effort) was applied North of Sable Bank (often referred to as the “44-10” line). Coincidentally, more effort (proportionally) was applied in Whitehead Hole and Northeast of Middle Bank. Much of the fishing effort in CFA 23 still continued to be focused on the holes found between Misaine and Banquereau Banks though less concentrated than in recent seasons. There was again a complete absence of effort in the western portion of CFA 24.

In N-ENS, a spring season was introduced in 2008 in an effort to combat increased amounts of soft and white crab and associated handling mortality that have been occurring in the past 2 years. This season was in addition to the traditional summer season and individual fishers were able to fish during either (or both) seasons. Some of the fleet was unable to fish during the spring season due to ice conditions. After a brief period of adapting to altered locations of fishable biomass in the spring season, catch rates increased rapidly with almost no soft or white crab. The spring fishing effort was focused on the trench of deep water located along the north-eastern coast of Cape Breton (formerly CFAs 21 and 22 Inside) and along the line between N-ENS and CFA 19. The distribution of the fishing effort in the summer season was similar to the past 2 seasons with effort being focused on the inner trench and the Glace Bay Hole.

In CFA 4X, the fishing effort was also more diffuse than the previous season. In 2007, fishing effort was very concentrated around Sambro with a limited amount of effort applied west of Roseway Bank. In 2008, efforts were centered near Sambro and north of Roseway Bank with some limited effort in various other areas.

In 2008. a calculated total of 85,914 traps hauls were applied in S-ENS, an increase of 74% from 2007 (nearly proportional to the 70% increase in TAC). In N-ENS, 1,809 calculated trap hauls were applied in the spring and 5,229 in the summer, for a total of 7,038. This in a reduction of 29% from 2007 though the TAC was constant between the 2 years.

In CFA 4X, 2 separate gear complements have been used in past seasons: 60 large traps or 200 small traps, complicating the direct comparison of fishing effort. In 2007 (season commencing in late 2006 and finishing in 2007), 2 of the 9 snow crab licences in 4X fished with the 200 trap complement. In 2008 (2007/2008 season), the entire 4X fleet fished a gear complement of 60 large conical traps making comparison within 4X and with other CFAs possible. In 2008, 12,149 calculated trap hauls were applied. In 2007, 8,720 calculated trap hauls were applied with the large traps and 7,916 with the small traps.

Landings

The total landings were 8,253 t in S-ENS, an increase of 67% (corresponding to a 70% increase in TAC (Table 2). In N-ENS, landings rose slightly to 238 t (36% landed in the spring) from 233 t in 2007, with no change in TAC (Table 3). In CFA 4X, 2008/2009 landings were 230 t (versus 220 t in 2007/2008; Table 4) with no change in the TAC (230 t). The spatial distribution of landings in N-ENS and CFA 4X were comparable with those observed in the recent past. However, in S-ENS, a greater proportion of landings were taken from inshore areas north of Canso Bank and near Chedabucto Bay.

Catch Rates[1]

In N-ENS, the 2008 catch rates were 33.7 kg trap^{-1}, a 43% increase relative to 2007. N-ENS catch rates are still well below the 12 year mean (53.8 kg trap^{-1}; Figure 4; Table 2). It should also be noted that the catch rates for the newly commenced spring fishing season were higher than those of the traditional summer fishing season at 47.1 kg trap^{-1} and 29.3 kg trap^{-1}, respectively. The former had a higher proportion of legal sized, hard crab in the at-sea-observed records. The spatial distribution of catch rates in N-ENS was uniformly low with the exception of 1 localised area east of Neils Harbour (Figure 30).

In S-ENS, the 2008 catch rates were 96.1 kg trap^{-1}, a 4% decrease relative to 2007 and above the 12 year mean of 89.9 kg trap^{-1} (Figure 4; Table 3). The spatial distribution of catch rates was well distributed throughout both CFA 23 and CFA 24 as opposed to 2006 and 2007 when the highest catch rates (and landings) were from offshore fishing grounds (Figure 30). Peak levels were found towards the Misaine Bank and Sable Island areas of S-ENS. The lack of very low localised catch rates suggests that fishers were efficiently identifying high abundance locations and therefore avoiding over-depletion of lower abundance areas.

In CFA 4X, the 2008/2009 catch rates were 29.1 kg trap^{-1} (Table 4). The catch rates were marginally higher in the eastern area of CFA 4X (Figure 30), but mostly uniformly low and generally in the range of the N-ENS catch rates during its most impoverished period (2005-2008).

At-sea-observer Coverage

In N-ENS, the at-sea-observer coverage exceeded the target level of 5% of the TAC, at 14.9% (Figure 5, 31). This was due to an increased effort to monitor the capture of soft crab in the spring and summer seasons. A total of 152 traps were sampled (2.2% of estimated commercial trap hauls). Of a total of 5,918 male crab sampled by at-sea-observers, 3,676 were of legal

[1] Recall the caveats about catch rates being inappropriate indicators of fishable biomass, in the Methods.

commercial size. The high proportion of undersize crab in N-ENS (Figure 31, relative to past years and other CFAs) stresses the current reliance of this fishery on animals now recruiting to the fishery and the over-exploitation of snow crab in the past that has left fewer large males available to the fishery.

In S-ENS, 9.1% of the TAC was observed (with a target level of 10%). A total of 1,406 traps (1.6% of estimated commercial trap hauls) were sampled. Of the 49,711 male crab sampled from these traps, 45,027 were of legal commercial size.

In CFA 4X, 11 % of the TAC was observed, relative to a target level of 10%. A total of 186 traps were sampled. Of the 6,075 crab measured, 4,535 were of legal size.

Newly Matured Crab (CC1 and CC2)

Entry of new recruits was expected for 2007 and 2008. This entry was evident in the at-sea-observed fishery data where an increased dominance of CC1 and CC2 crab were observed for legal-sized crab as compared to the years previous to 2007. (Tables 14-16).

In N-ENS, CC1 crab represented 24% of the total catch, while CC2 crab represented 6% (Figure 31). The experimental spring season was adopted to reduce fishing intensity in the summer season and also to encourage fishing during the earlier period when newly moulted crab are too weak and soft to move into traps. As expected, landings during the spring fishery had negligible catches of CC1 and CC2 crab. High incidence of soft-shelled crab has been suggested anecdotally as being a result of localised depletion of hard-shelled males and a consequent increased trapability of soft-shelled males due to the lack of competition/inhibition. However, high soft-shelf incidence occurs in both high and low catches (assuming catch rates reflect relative abundance; Figure 32).

This high incidence of soft-shell crab was observed by at-sea observers predominantly throughout the inside fishing grounds of N-ENS during the summer fishery. If one assumes no recaptures, this amounts to an additional 118.8 t (49% of landings) being discarded as soft crab with potentially high handling-associated mortalities. This continues to represent an important hurdle for the snow crab industry. Future recruitment is being harmed before it is able to mature and benefit reproductive capacity and enter the fishable biomass. Though the spring fishery helped to lower the 2008 soft-shell catches in N-ENS as compared to 2007, a significant amount of damage to these newly moulted crab likely occurred in 2008. This has important negative consequences on the fishable biomass for 2009 and beyond. The implementation of area closures by DFO FAM during the summer fishery based on observer reports and shorter summer fishing period likely helped to control the potential total mortality of soft-shell crab. Further efforts must be made to lower the handling of soft-shell crab in N-ENS.

In S-ENS, the occurrence of CC1 and CC2 crab in 2008 (12% and 8.6%, respectively) was comparable to that observed in 2007 (Figure 31). Catches of high soft-shell percentage (> 20% by count) were widely distributed throughout the fishing grounds in both CFAs 23 and 24 during the 2008 fishery. When extrapolated to the S-ENS TAC, this amounts to a potential additional mortality of 1,087.7 t (13.2% of landings), an increase from 2007 when soft crab catches represented 8.7% of the landings. Voluntary closures of areas showing high incidence of soft crab must be adhered to by all members of the fleet to be effective. Unfortunately, this was not the case in 2008.

In CFA 4X for the 2008/9 season, CC1 and CC2 crab represented a total of 2.5% and 0.3% of the total catch and comparable to those of 2007/2008 (Figure 31). The data from CFA 4X are not directly comparable to ENS as their fishing season is disjunct from that of N- and S-ENS. This winter 4X fishery continues to show negligible levels of soft crab as evidenced by only 0.9% of landings being soft.

Old Crab (CC5)

CC5 crab represented a low proportion of the 2008 at-sea-observed catch in both legal and sub-legal size fractions at 1% or less in all areas (Tables 14-19). Similarly low to undetectable proportions of CC5 crab were observed in the trawl surveys (Tables 20-22). These low rates have been suggested by the Province of Nova Scotia as indications of high exploitation rates.

RESOURCE STATUS

State Variables

1. Size structure:

The size frequency distributions of males in N-ENS (Figure 34) show a pulse of immature male crab (first detected in 2003 and 2004) that continue to grow and propagate through the system. Currently, this main pulse of crab is centered over the 70 to 82 mm modal group (instars 10 - 11). These crab first moulted and entered fishable sizes in the 2007 season and this continued in a significant way in 2008. They were, however, mostly soft-shelled or white crab during the prosecution of the fishery in 2007 and again in 2008 (see Section: Newly matured crab CC1 and CC2, above). There is a continued likelihood that soft-shell incidence will be an issue in the 2009 season which can only be alleviated in any significant manner by prosecuting the fishery at an earlier part of the moult-cycle (e.g, as with CFA 4X and the spring fishery trial in N-ENS). Immature crab were observed now spanning all size ranges from 12 to 110 mm CW. This is a positive sign for N-ENS in that recruitment to the fishery will likely continue steadily for at least the next 4 years. There is even evidence of a new year-class developing in the 10 - 20 mm CW mode (instar 5) that are likely the product of the leading edge of the current reproductive females from 2005/6.

Stronger recruitment is expected in 2009 in N-ENS with the large numbers of immature crab in the sub-legal size classes. The main pulse currently centered over the 70 to 82 mm CW mode will begin entering the fishery in a significant fashion in the 2010/2011 fishing seasons. These expectations are contingent upon no significant increases in natural mortality of crab (e.g., predation, competition, temperature conditions, etc.). The relative number of mature undersized males has also increased due to a fraction of the abundant immature crabs moulting to maturity. It is unlikely that this is due to genetic selection for earlier maturing individuals as the selection pressure upon the snow crab has only been expressed for 2 generations at most. However, the early maturation of organisms that are heavily exploited remains an issue that must not be ignored. A snapshot of spatial variations in the size at 50% maturity is provided in Figure 35.

In S-ENS, the main pulse is centered over the 82-96 mm CW modal group (instar 11 - 13). Based upon established growth patterns, the main peak over the 82-96 mm CW mode should begin entering the fishable biomass by the 2010/2011 fishing seasons. Similar to N-ENS, immature crab were observed spanning all size ranges from 12 to 110 mm CW. This continues to be a positive sign for S-ENS in that recruitment to the fishery will continue steadily for at least the next 4 years. The same pulse of instar 5 crab are evident in S-ENS – again the likely product of newly mature females from 2005/2006.

Size frequency distributions in CFA 4X exist in a very erratic state, with the disappearance in 2008 of the incoming immature crab observed in 2006/7. The large temperature fluctuations in the area and the different predator fields associated with the warmer waters in the area likely result in these highly uncertain population dynamics.

The size frequency distributions of female snow crab clearly indicate that the pulses of immature females detected in 2003 for N-ENS and in 2004 for S-ENS have peaked and now are beginning to decline (Figure 36). The majority of females are now sexually mature and actively reproductive. Reproductive activity should continue for another 3 to 4 years. However, as there is little to no female recruitment evident with the exception of the instar 5 crab generated 2 to 3 years previously, another gap in reproductive output is expected at the end of this time frame.

2. Sex ratios:

When the relative number of mature females is high, the possibility of reproductive limitation becomes a conservation issue. This is particularly the case in heavily exploited areas where there is an absence of large mature males able to mate and protect the more rapidly maturing and smaller females. Conversely, with very low relative numbers of females (e.g., the extended period observed in the early-2000s throughout the Scotian Shelf) there is low egg and larval production. As female snow crab of a given year-class will mature 2 to 4 years earlier than male snow crab from the same year-class, and because the females have a shorter life span, there is a high likelihood that sex ratios will fluctuate over time (Figures 37-40). This is particularly the case when strong year classes dominate a population.

The sex ratios of mature snow crab have been oscillating with peaks observed in 1996 and again in 2007 with a major trough in the early 2000s (Figure 37, 38). This is a very different situation relative to the very high ratios observed in the southern Gulf of St. Lawrence, where male limitation is a known issue. What caused this historically poor reproductive potential in the SSE is not known, especially as this fishery is a male-only fishery. However, the spatial-segregation of males and females in their immature stages and sexual dimorphism may expose females to differential predation pressures (see below). Currently, sex ratios of mature crab are balanced in most areas of the Scotian Shelf with the exception of the offshore slope areas and Sable Island (Figure 38). This should decline for another 6 years minimum.

The sex ratios of immature snow crab (Figures 39) have begun to decline from peak levels in 2004. Currently, they are between 20 to 30% female throughout the shelf region. This reduction is due to the females maturing earlier than males from the same year class. The spatial patterns of the sex ratios are distinct between offshore and inshore areas: immature males are found in greater proportion (blue) in offshore whereas immature females (red) are found in greater proportion towards the inshore areas (Figure 40). This spatial segregation likely exposes the crab to differential predation effects. Inshore females are likely fed upon by inshore fish, other macro-invertebrates (including other female snow crab, other crabs and lobster – immature snow crab have been reportedly caught in large numbers in lobster traps; Sainte-Marie and Lafrance 2002; Squires and Dawe 2003). This pattern would be exacerbated by the sexual dimorphism of snow crab, as males grow to be larger and so escape some of the size-dependent predation to which the smaller females would be exposed.

Primiparous females mate during their moulting period, a period when they are highly vulnerable (Watson 1972; Hooper 1986). If their mate is small and unable to definitively defend against other potential mates, females have been observed to be torn apart during the agonistic behaviour (fighting). When potential mates are small, females have been observed to refuse mating and in the process of refusal are also killed. Thus, an abundance of large males would certainly increase the likelihood of successful reproduction for the new wave of maturing females. Further, in an evolutionary context, if heavy fishing of large males causes increased mating with early maturing dwarf sized males, a greater selection for such traits would be passed onto future generations, potentially leading to stunted populations (a trend observed in many highly exploited species). This, however, is a genetic effect occurring over generational time scales. It is important to note that phenotypic plasticity can accelerate the rate of morphometric change in this adaptive species.

3. Numerical abundance[2]:

The number of immature females caught[2] in the trawl surveys has been increasing since historical lows in 2002 (N-ENS) and 2003 (S-ENS), reaching historical highs in 2006 (Figure 41). Their numbers have since declined rapidly in ENS, mostly due to their entry into the mature segment of the population. However, in CFA 4X, their numbers continued to increase in 2007. Most of the immature females are currently found in very shallow areas nearshore throughout the Scotian Shelf (Figure 42). Numerical estimates for 2008 are not yet available; however, the visualisations in Figure 42 suggest a continued declining trend in 2008.

In all areas, the numerical abundance of mature females declined slightly after reaching peak levels in 2007/2008 (Figures 41, 43, 44). Most of the mature females are currently located in the inshore areas of S-ENS and N-ENS; these were therefore the core areas where larval production occurred in 2006 to 2008. Isolated areas of high concentrations of mature females were also found in CFA 4X, but no strong trends were evident (Figure 43).

The numerical abundance of older immature males of instars 11 and 12 (Figure 45) are increasing coherently in all areas (although there was a slight down-turn in S-ENS and CFA 4X – data not shown). These crab represent the leading edge of the pulse of recruits that the fishery will be dependent upon for the next decade. They are currently located in the core snow crab fishing grounds in all areas, with the exception of the Glace Bay Hole.

Skip moulters have been increasing in number in all area (Figure 46). Most skip-moulters are currently found in the area north of Sable Island and the slope edge off Banquereau Bank.

Newly matured crab (CC1 and CC2; Figure 47) are increasing in numbers in N-ENS and slightly declining in CFA 4X and S-ENS. Their numbers have increased dramatically throughout all core fishing grounds for instars 10 to 12.

Hard-shelled snow crab (CC3 and CC4) have increased in number since 2005 and this continues to propagate throughout the Scotian Shelf (Figure 48).

The numerical abundance estimates of carapace condition 5 crab are close to being undetectable in the SSE by the trawl survey (Figure 49). While this may in part be due to the late fall sampling period, their low representation in both survey data and the fishery-observed data (< 1%) does suggest that exploitation rates upon the hard-shelled phase may be high.

[2] Most categories of snow crab are likely under-estimated as catchability corrections are not applied. Their intended use is, therefore, solely to compare relative trends over time. In contrast, fishable biomass is likely slightly over-estimated due to the more expansive criteria used for determining snow crab habitat (see Methods). Numerical abundance estimates are not complete for 2008. These trends are those from the 2007 survey.

4. Fishable biomass[3]:

In N-ENS, the post-fishery fishable biomass of snow crab in 2008 was 3,200 t (with a 95% confidence range of: 2,500 to 4,000 t; see Figure 50) – an increase of approximately 200% relative to 2007 (1,070 t). The increases were particularly evident in the northern basin of N-ENS (Figure 51).

In S-ENS, the post-fishery fishable biomass of snow crab stayed relatively constant. The fishable biomass was estimated to be 54.3×10^3 t (with a 95% confidence range of: 41.4 to 71.4×10^3 t) – a decrease of 0.3% from 54.5×10^3 t in 2007 (Figures 50, 51).

In CFA 4X, the pre-fishery fishable biomass was 360 t (with a 95% confidence range of 200 to 570 t), representing a 12.5% increase relative to 320 t in 2007.

Process Variables

The following process (flow) variables are dependent upon a correct model representation of fisheries activity and reasonable survey results. As the data driving the model is a short time-series with numerous caveats related to fishery and survey data quality, the results of this section must be treated with appropriate caution.

1. Recruitment:

The true recruitment into the mature fishable biomass has not been computed. It is, however, possible to provide an index of recruitment found during the survey (CC1 and CC2 crab). These indices suggest that recruitment to the fishable biomass was poor between 2003 to 2007 in N-ENS, while in S-ENS recruitment was low between 2004 and 2005. CFA 4X recruitment patterns are erratic (Figure 52). The strong recruitment to fishable biomass in now occurring in N-ENS, mostly in the inshore areas. In S-ENS, recruitment continues near Chedabucto Bay and the area north of Sable Island. In CFA 4X, no recruiting crab were observed – this is consistently observed in CFA 4X and is likely due to the warmer temperatures accelerating their moult cycle and/or their being fully intercepted by the fishery before the initiation of trawl surveys in the area.

It must be emphasised that as the snow crab survey is conducted in late autumn (since 2002), an unknown and variable proportion of the annual recruitment would have also progressed into the mature fishable biomass; and the catchability of soft-shelled crab is likely reduced due to their behaviour of sheltering in rocky burrows. Thus the recruitment index (Figures 52, 53) is only a partial (and biased) index that is sensitive to annual variations in temperature, food availability and crowding, factors that control the onset of moulting and the speed of shell hardening.

2. Movement:

Movement patterns have not yet been analysed in any depth. This will be an area of further research in the near term. Connectivity however seems to be high between most regions. Locomotory capacity seems to be very large (up to 276 km / year). This is particularly important for CFA 4X where much of the fishery is conducted on the border with S-ENS. More crab have been tagging in this area.

[3] Fishable biomass is likely over-estimated in S-ENS in 2006, see Methods.

3. Natural mortality:

Wade et al. (2003) suggested that mortality rates for legal sized crab resident in the southern Gulf of St. Lawrence are within the range of 0.26 to 0.48. Some tentative analysis suggests that for earlier stages, they may be much higher (Z approximately 1). Further, based upon diet studies (Bundy 2004), very few natural predators seem to exist for large snow crabs (i.e., legal sized) in the SSE. This has been particularly the case since the demise of most large-bodied predatory groundfish from the eastern part of the Scotian Shelf (Figure 14). As such, these natural mortality estimates may be higher than those occurring in the SSE. However, concentrations of thorny skate have been found in the offshore slope areas, suggesting that mortality may be high for small crabs (instars 7 and less), as well as soft-shelled crab in these areas. Other potential mortality factors include: seals (near Sable Island; although see arguments to the contrary in Ecosystem considerations, above), soft-shell mortality, unreported landings, bycatch in other fisheries (lobster and other crab traps, long-lining, gill-nets, trawling) and potentially, activities associated with exploration and development of oil and gas reserves. Until a longer time-series is accumulated, it would be premature to estimate natural mortality with this data-series.

4. Fishing mortality:

The index of fishing mortality increased rapidly from 2001 to 2004 in N-ENS (Figure 54). Large reductions in TAC were implemented for the 2005 season, resulting in sharp reductions of exploitation rates from 50% in 2004 to 7% in 2008.

In S-ENS, the relative exploitation rates have been generally stable between 15 to 20% (Figure 54). However, since 2004, exploitation rates have been reduced for reproductive concerns. In 2008, the relative exploitation rate was 13%. Realised exploitation rates are likely higher as not all areas where biomass estimates are provided are utilised (e.g., continental slope areas, inshore areas of CFA 24) and as fishable biomass estimates in general are likely over-estimated in S-ENS (see Methods).

In CFA 4X, exploitation rates have been above 30% since 2005 (Figure 54). In 2008, the relative exploitation rate was 38%. However, due to the very specific spatial extent of the fishery in area 4X, focussed primarily upon the area near Sambro, realised exploitation rates are likely to be high, since the computed exploitation rates incorporate biomass from throughout the CFA 4X area.

RECOMMENDATIONS

General Remarks

High catches of soft-shelled crab will likely continue to be a major issue for the next 3 to 4 years in N- and S-ENS, but not CFA 4X due to their offset fishing season. Timely responses from industry to avoid fishing in areas showing potential or actual high incidence of soft crab must continue if unnecessary mortality of future recruits is to be averted. Unfortunately, only the S-ENS has been able to develop a viable soft-shell protocol to address this concern. The N-ENS solution with a spring season alleviated some of the pressures upon the recruiting crab, but the summer season still resulted in large captures of soft-shelled crab.

The longevity of the fishable biomass (i.e., the stabilisation of the fishery) can be improved by fishing solely upon morphometrically mature crab. The arguments for this approach are as follows:

Fishing mature crab would allow them to mate as the fishing season is post-mating season (in ENS, but not CFA 4X). This has the important result of reducing Darwinian selection for early maturation which is a long-term hazard for any fishery that harvests immature individuals.

The capture of immature crab (“pencil claws”) reduces the longevity of the fishable biomass directly relative to a mature-only fishery. The time difference is 2 to 3 years as immature crab go through a soft- and white shelled phases that exclude them from the fishery. Specifically targeting mature (male) crabs is a more optimal exploitation strategy (CC3 and CC4 crab).

There is a significantly large weight increase if immature crab are allowed to grow and mature (an increase of 250 to even 400%; Figure 8).

In the 2009 season, much of the fishable biomass will still be composed of immature individuals. Indeed many of these immature crab will represent the largest-sized individuals in future catches, if allowed to grow. They will contribute to reproduction and still represent high quality crab for the industry. Excessive fishing of this component of the fishable biomass is unwise.

Southern-Eastern Nova Scotia

The long-term, precautionary approach adopted by the S-ENS fishers over the past 5 years has allowed the S-ENS fishers to position themselves well to benefit from a very vibrant snow crab stock. This is an important consideration, given the current economic woes of the world. Now, with the stronger recruitment pulses entering into the fishable biomass and with large numbers of females having had the opportunity to mate with larger and older males (in 2006 to 2009), the health of the S-ENS stock can be said to be definitely improving, the first signs of which were evident in the instar 5 classes observed in the surveys. While the fishable biomass has not increased relative to 2008, strong and steady recruitment is expected for the next 3-4 years. Forecasts into the future for S-ENS completed in 2007 (Figure 54) indicate that there is a strong potential for at least the next 4 years, but this strength will be dependent upon how aggressively they are exploited. Based upon the crude projection scenarios, maintaining an exploitation rate between 10% and 30% would provide the greatest longevity to this fishery. Ensuring the longevity of the fishable biomass is important as in the SSE, recruitment has so far occurred in pulses and not at a constant rate as is the case in the Gulf of St. Lawrence. A moderate increase in TAC is suggested, contingent upon the better adherence of the fleet to the soft-shell protocol and a fixed season duration policy such that surveys are conducted consistently and efficiently and there exists sufficient time to properly analyze the data.

Northern-Eastern Nova Scotia

The higher exploitation strategies in N-ENS had pushed the fishable component of the N-ENS snow crab population to historic lows for a number years. The consequence was a collateral damage upon the recruitment via soft-shell mortality. This delayed recovery in the region by several years. The reduced exploitation rate in 2008 has helped this recovery to make it through to the fishable biomass. The fishable biomass in 2009 will continue to increase, but the strength of this increase is again contingent upon the magnitude of damage to the soft-shell crab. Reproductive females have mated now have access to larger males rather the predominantly dwarfs and small, immature males in 2008. Soft-shell incidence will continue to be an issue in this fishery until the fishable biomass has had the opportunity to develop significantly in strength. Projections of fishable biomass for N-ENS (Figure 56) suggest that exploitation strategies between 10 and 20% seem to be optimal for this area. A moderate increase in TAC is suggested contingent upon the development of a more effective soft-shell protocol.

CFA 4X

In CFA 4X, exploitation rates prior to 2005 were intermediate to that of N- and S-ENS. However, the realised exploitation rates have increased since to be amongst the highest in the SSE. This is not recommended as CFA 4X is the southern-most area of snow crab distribution, existing in more "marginal" environments relative to the "prime" areas of S- and N-ENS. Crude projections suggest that exploitation rates between 10 and 30% may stabilise the population trajectory into the longer-term (Figure 57). The current practice of relatively high exploitation rates with an offset fishing season which effectively intercepts all incoming recruits prior to their mating period, makes CFA 4X a recruitment- and migration-based fishery and therefore not sustainable. Further, the overall low recruitment actually observed and the large inter-annual temperature variations in the area increase the uncertainty associated with these scenarios. These factors are tempered by excellent control of soft-shell capture and the buffering influence of S-ENS via immigration.

CFA 4X fishable biomass has shown some signs of recovery, but the rate of this recovery has lagged behind that of N- and S-ENS. Environmental variability alone is unlikely to be responsible for this delayed recovery as the abundance trends of females match closely the patterns in N- and S-ENS. Instead, this suggests that the higher exploitation rates (legal and illegal) in CFA 4X may be causing these patterns. A status-quo TAC is recommended until the strength of recovery can be verified.

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GLOSSARY

Agonistic – Behavioural term relating to aggression, appeasement and avoidance behaviour that occurs between members of the same species. Agonistic behaviour is a much broader term than "aggression," which simply refers to behaviour patterns which serve to intimidate or damage another.

Anthropogenic – Resulting from the influence of human beings on nature.

Benthic – Occurring on the ocean floor.

Biomass – The abundance of living organisms measured in terms of it's weight, mass, volume or caloric energy.

Brachyura (Infraorder) – Known as "true crabs" of which the snow crab is a member. Brachyurans are characterised by a body that is short, wide, and flat. The abdomen is reduced from a strong swimming muscle (e.g., shrimp) to a simple flap covering reproductive appendages and carry eggs. The uropods, which along with the telson form the tail fan in other decapods, are totally absent. All 5 pairs of walking legs are generally large with the first pair being chelipeds. The antennae and antennules are greatly reduced and originate before the eye stalks.

CC, Carapace Condition – The condition of the shell of a snow crab. Generally related to the age of the organism and the time since last moult. See Table 6 for more details.

CC1 - Newly moulted crab. The top of carapace is light brown and shiny without surface growth of moss or barnacles. Shell is soft and claw is easily broken.

CC2 - The top of carapace is light brown and less shiny with little to no surface growth of moss or barnacles. Shell is clean but hard.

CC3 - The top of carapace is light brown and not shiny. Some growth of moss or barnacles. Shell is hard.

CC4 - The top of carapace is brown and not shiny. Usually some surface growth of moss or barnacles. Shell is hard with small scars. Underneath is yellow brown.

CC5 - Old crab. Carapace is dark brown with substantially mossy ("dirty") surface. Decalcification (black spots) noticeable often at joints. Shell may be soft.

CW, Carapace width – the distance across the carapace of a snow crab (millimetres).

Chela – pincer-like claw of a crustacean or arachnid.

CFA, Crab fishing area – Refers to an individual management area. On the Scotian Shelf, they are from north to south: 20 to 24 and 4X.

Commercial biomass – see Fishable biomass.

CPUE, Catch per unit effort – The amount caught by a single fishing event: such as the weight or number of crab captured by a single trap haul.

Density – The amount (biomass or number) of crab per unit area.

Distribution, spatial – The geographic area in which an organism exists.

Durometer – A calibrated instrument used to measure the hardness of an object (such as a crab shell), scaled from 0 (soft) to 100 (hard). A durometer reading of ≥ 68 has been historically used to determine a hard shelled crab.

Dynamic – Characterised by continuous change or time. Not fixed.

Ecosystem – The whole of a system with all the interactions between parts (living and non-living).

ENS – Eastern Nova Scotia (essentially NAFO statistical divisions 4VW).

ER, Exploitation rate – The ratio of biomass fished relative to their abundance. Historically, the GFC calculated ER(t) = Landings(t) / Fishable biomass (t-1), where t is time or year. The Fishable biomass was of the mature segment of the male population ≥ 95 mm CW, estimated from kriging. In this document, the exploitation rate is calculated as ER(t) = Landings(t) / (Landings(t) + Fishable biomass(t)). This change was made as the the time interval between the end of trawl surveys [Biomass(t-1)] and the beginning of fishing [Landings(t)] was up to 10 months. With the alternate method, this lag is approximately 2 months and so likely more accurate.

Extrapolate – To infer or estimate by extending or projecting known information.

Fishable biomass, FB – The biomass of snow crab exploited by the commercial fishery: male, mature, ≥ 95 mm CW and hard shell condition (carapace conditions 2 to 5). Note that carapace condition 2 snow crab do not have optimal meat yields at the time of the fishery. While immature crab ≥ 95 mm CW is part of the biomass that can be legally fished, this component is voluntarily returned to allow greater growth.

Fishing mortality, relative – see Exploitation rate.

IBQ – Individual Boat Quota, the amount of snow crab allowed to be legally removed by an individual fisher in a given area over a given period of time.

Instar – A stage of an organism between moults.

Interpolation – The method of determining unknown values through the use of surrounding known values.

Kriging – A method of interpolation for obtaining statistically unbiased estimates of intrinsic variables (i.e., snow crab biomass density) from a set of neighbouring points with known values, constrained by the relative change in variability of the data as a function of distance.

Larvae – The early, immature form of any animal before the assumption of the mature shape.

Metabolic costs – The amount of energy dispensed by an organism in the process of living (heat, organic compounds, faeces, urea/uric acid, etc.).

Metabolic gains – The amount of energy gained through the intake of food or other energy sources.

Morphometric maturity – Maturity status determined from measurements of body shape and size. Male snow crab claw height increases very rapidly in the adult stage (terminal moult), whereas females' abdominal width increases with maturity. While morphometric maturity generally coincides with physiological maturity, morphometrically immature males are known to be able to fertilise females.

Moult – The act of growing, through the shedding of an organism's current shell.

Multiparous – Females bearing eggs resulting from their second or third breeding event (mating).

Numerical density – The number of snow crab in a given surface area.

Pelagic – Occurring in the water column (not on bottom).

Pencil-clawed crab – Immature crab that are legally exploitable (≥ 95 mm CW) but not yet terminally moulted. The final growth increment is estimated to increase the body weight by approximately 250%.

Physiological maturity – Biologically (functionally) able to reproduce.

Primiparous – Females bearing eggs resulting from their first breeding event (mating).

Recruitment – Snow crab that will enter the fishable biomass in the next fishing season, designates as “R-1”.

Sexual dimorphism – When shape and/or size differences exists between sexes of a species.

Soft-shell – Carapace condition in which the shell produces a durometer reading of less than 68 durometer units.

Spatial – Relating to space (such as a given geographic region such as the Scotian Shelf).

Substrate – Bottom type on which an animal exists (rocks, boulders, mud, sand, etc.).

TAC – Total Allowable Catch, the amount of snow crab allowed to be legally removed in a given area over a given period of time.

Temporal – Relating to time (such as a given period of time).

Terminal moult – Snow crab moulted for a final time once mature. The size of these crab will not increase further.

Variogram – The manner in which the variability of data changes with distance from a given location. Empirical variograms depict the data-derived variation as a function of distance. Theoretical/modelled variograms are fitted curves which are ultimately used by the kriging methodology.

APPENDIX 1: ECOSYSTEM INDICATORS

The variables used as indicators in this study are listed and described in the following:

NS: Population size	Total population size for Nova Scotia, a proxy of the influence of human of the Scotian Shelf
CIL volume	Cold intermediate layer (water temperature < 3 C) in the Gulf of St. Lawrence from the September groundfish hydrographic survey.
CPR: Calanus finmarchicus 1-4	Continuous Plankton Recorder (CPR) relative abundance estimates: Calanus finmarchicus instars 1 to 4
CPR: Calanus finmarchicus 5-6	Continuous Plankton Recorder (CPR) relative abundance estimates: Calanus finmarchicus instars 5 to 6
CPR: colour	Continuous Plankton Recorder (CPR) relative estimate surface ocean colour, a proxy for Chl-a concentrations
CPR: diatoms	Continuous Plankton Recorder (CPR) relative abundance estimates: Diatoms
CPR: dinoflagellates	Continuous Plankton Recorder (CPR) relative abundance estimates: Dinoflagellates
Employment per total landed value	Number of fishers employed per total landed value of the fishery
Employment per total landings	Number of fishers employed per total landings of fish
GDP: fish processing	Gross Domestic Product: fish processing sector in Nova Scotia
GDP: fishing and hunting	Gross Domestic Product: fishing and hunting sector in Nova Scotia
GDP: NS total	Gross Domestic Product:Total for Nova Scotia
GDP: oil and gas	Gross Domestic Product: Oil and gas sector in Nova Scotia
Gulf stream front: lat@-62 lon	Gulf stream front location at -62 longitude (latitude)
Ice coverage	Sea ice coverage, cumulative seasonal sum
Landed value: all	Landed value of all fish and invertebrates
Landed value: groundfish	Landed value of all groundfish in Nova Scotia
Landed value: pelagics	Landed value of all pelagic fish in Nova Scotia
Landed value: shellfish	Landed value of all shellfish
Landings: all	Total landings of all fish and invertebrates
Landings: groundfish	Total landings of all groundfish
Landings: pelagic	Total landings of all pelagic fish
Landings: shellfish	Total landings of all shellfish
NAO index	North Atlantic Oscillation index anomaly of December-February sea level atmospheric pressure difference (kPa) between the Azores and Iceland. This index has been shown to be related to air temperatures, SST, convection and circulation changes in the North Atlantic and through atmospheric teleconnections, even broader-scale forcings.
No. fish harvesters	Number of fish harvesters in Nova Scotia
No. shellfish closures	Number of shellfish closures
No. wells drilled	Number of oil and gas wells drilled on the Scotian Shelf
NS: % 65 and older	Nova Scotia demographics
NS: % attending university	Nova Scotia demographics
PCBs: puffins	PCB concentrations in Atlantic puffins
PCBs: seals	PCB concentrations in Grey seals
RV: biomass capelin	Research survey estimates of capelin biomass
RV: biomass cod	Research survey estimates of cod
RV: biomass elasmobranchs	Research survey estimates of elasmobranch fish
RV: biomass flatfish	Research survey estimates flatfish
RV: biomass gadoids	Research survey estimates gadoids
RV: biomass large demersals	Research survey estimates large demersal fish
RV: biomass large pelagics	Research survey estimates large pelagic fish
RV: biomass small demersals	Research survey estimates of small demersal fish
RV: biomass small pelagics	Research survey estimates small pelagic fish
RV: bottom oxygen	Research survey estimates of bottom oxygen concentration
RV: bottom salinity	Research survey estimates bottom salinity
RV: bottom temperature	Research survey estimates bottom temperature

RV: condition elasmobranchs	Research survey estimates of elasmobranch physiological condition
RV: condition flatfish	Research survey estimates of flatfish physiological condition
RV: condition gadoids	Research survey estimates of gadoid physiological condition
RV: condition large demersals	Research survey estimates of large demersal physiological condition
RV: condition large pelagics	Research survey estimates of large pelagic physiological condition
RV: condition small demersals	Research survey estimates of small demersal physiological condition
RV: condition small pelagics	Research survey estimates of small pelagics physiological condition
RV: groundfish SMR	Research survey estimates of mass specific metabolic rates of all fish
RV: no. taxa predicted at 100 km^2	Research survey estimates of the number of taxa predicted at 100 km^2
RV: Shannon index	Research survey estimates of the Shannon diversity index of fish species
RV: species-area exponent	Research survey estimates the mean species-area exponent on the Scotian Shelf. The average scaling exponent derived from a species richness vs surface area relationship for the fish community, using a spatially constrained (locally calculated saturation curves within a radius of 10 to 300 km) fractal-like approximation method.
RV: species-area intercept	Research survey estimates the mean species-area intercept on the Scotian Shelf. The average scaling exponent derived from a species richness vs surface area relationship for the fish community, using a spatially constrained (locally calculated saturation curves within a radius of 10 to 300 km) fractal-like approximation method.
RV: taxonomic richness (100km)	Research survey estimates the mean number of taxa observed at 100 km^2 scale
Seal abundance adult	Abundance of seal adults
Seismic 2D; km	The length of seismic exploration tracks; km
Seismic 3D; km^2	The amount of seismic exploration conducted (3D); km^2
Shelf front: lat@-62 lon	Shelf front location at -62 longitude (latitude)
Shrimp: abundance index	Shrimp abundance index from shrimp surveys
Shrimp: capelin abundance index	Capelin abundance index for areas overlapping the shrimp fishery
Snow crab: habitat area	Snow crab survey estimates of snow crab potential habitat area (km^2) determined from temperature and depth masks
Snow crab: immature female abundance	Snow crab survey estimates of immature female abundance (no.)
Snow crab: landings	Snow crab total landings
Snow crab: male recruitment	Snow crab survey estimates of male recruitment
Snow crab: mature female abundance	Snow crab survey estimates of mature female abundance (no.)
Snow crab: mature female mean size	Snow crab survey estimates of female mean size
Snow crab: mature male biomass	Snow crab survey estimates of male mean biomass (kt)
Snow crab: mature male mean size	Snow crab survey estimates of mature male mean size
Snow crab: temperature mean	Snow crab survey estimates of mean temperature in the snow crab potential habitat
Snow crab: temperature SD	Snow crab survey estimates of the standard deviation of the mean temperature in the snow crab potential habitat
Temperature: Sable Is.	Temperature at Sable Island
Temperature: SST Halifax	Temperature: sea surface temperature at Halifax station

TABLES

Table 1: Snow crab fishing seasons on the Scotian Shelf in the year 2008.

Area	Season
N-ENS	Apr 26 – May 2 & July 19- Aug 2 (+ extension to Aug 7)
S-ENS (CFA 23)	June 1 – Sept 15 (+ 2 extensions to Oct 7)
CFA 23 (Slope)	May 10, Sept 15
S-ENS (CFA 24)	June 15 – Sept 30 (+ extension to Oct 7)
CFA 24 (Slope)	May 10 – Sept 30
CFA 4X	Jan 1 – May 31

Table 2: Summary of snow crab fisheries activity of N-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997	74	540	534	23.3	22.9
1998	74	660	657	41.6	15.8
1999	78	900	899	54.8	16.4
2000	79	1,015	1,017	68.3	14.9
2001	80	1,065	1,066	94.3	11.3
2002	80	1,493	1,495	101.0	14.8
2003	80	1,493	1,492	76.8	19.4
2004	79	1,416	1,418	60.6	23.4
2005	78	566	562	30.6	18.4
2006	78	487	486	35.6	13.7
2007	78	244	233	23.6	9.9
2008	78	244	238	33.7	7.0

Table 3: Summary of snow crab fisheries activity of S-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997	59	1,163	1,157	50.9	22.7
1998	67	1,671	1,558	68.9	22.6
1999	-	2,700	2,700	71.1	38.0
2000	158	8,799	8,701	85.0	102.4
2001	163	9,023	9,048	87.8	103.1
2002	149	9,022	8,891	111.7	79.6
2003	145	9,113	8,836	98.6	89.6
2004	130	8,241	8,022	105.6	76.0
2005	114	6,353	6,407	109.5	58.5
2006	114	4,510	4,486	90.9	49.4
2007	115	4,950	4,942	100.1	49.3
2008	115	8,316	8,253	96.1	85.9

Table 4: Summary of snow crab fisheries activity of CFA 4X. From 1994 to 1996, 4 exploratory permits were active with an average of 10.6 t landed each year. Catch rates and calculated effort are for the large trap compliments only. "Year" indicates the year of the start of the fishing season. The first scientifically determined "TACs" in area 4X was provided in 2005. However, due to the novelty of the scientific approach in the area, this advice has been ignored and higher TACs have been negotiated by industry.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997/08	4		42		
1998/09	4		70		
1999/2000	4		119		
2000/01	6		213		
2001/02	8	520.0	376		
2002/03	9	600.0	221	10.1	21.9
2003/04	9	600.0	289	12.7	22.8
2004/05	9	600.0	413	20.3	20.8
2005/06	9	337.6	306	28.6	10.8
2006/07	9	337.6	317	27.7	11.5
2007/08	9	230.0	220	18.1	12.1
2008/09	9	230.0	230	29.1	6.3

Table 5: Snow crab carapace conditions and their description. Hardness is measured by a durometer.

Carapace Condition	Category	Hardness	Description	Age after Terminal Moult (approx.)
1	New soft	< 68	claws easily bent, carapace soft, brightly coloured, iridescent, no epibionts	0 - 5 months
2	Clean	variable	claws easily bent, carapace soft, brightly coloured, iridescent, some epibionts	5 months - 1 year
3	Intermediate	> 68	carapace hard, dull brown dorsally, yellow-brown ventrally, no iridescence, shell abrasion, epibionts	8 months - 3 years
4	Old	> 68	carapace hard, very dirty, some decay at leg joints, some epibionts	2 - 5 years
5	Very old	variable	carapace soft, very dirty, extensive decay, extensive epibionts	4 - 6 years

Table 6: Mean carapace width of male snow crab instars and life stages obtained from trawl surveys. The stages are immature (imm), immature skip moulters (imm.sm), carapace condition 1 and 2 (CC1to2), carapace condition 3 and 4 (CC3to4) and carapace condition 5 (CC5). The numeric suffix to stage indicates the instar. Thus: CC1to2.9 is carapace condition 1 or 2 of instar 9.

	Mean Carapace Width (cm)			
Stage	**N-ENS**	**S-ENS**	**CFA 4X**	**Scotian Shelf**
imm.5	15.1	14.8	14.9	14.9
imm.6	20.1	20.0	19.3	20.0
imm.7	27.0	26.8	26.8	26.9
imm.8	35.1	35.6	36.5	35.6
imm.9	47.1	48.3	49.0	48.1
imm.10	64.3	65.2	64.4	65.1
imm.11	88.3	86.8	84.2	87.0
imm.12	107.6	107.7	108.4	107.7
imm.sm.9	50.6	50.4	52.9	50.4
imm.sm.10	67.5	68.2	67.1	68.1
imm.sm.11	89.2	88.1	87.9	88.3
imm.sm.12	109.0	108.4	108.5	108.4
CC1to2.9	46.0	47.6	49.7	47.3
CC1to2.10	66.1	65.9	64.8	66.0
CC1to2.11	88.1	87.2	87.8	87.4
CC1to2.12	113.9	113.9	110.0	114.4
CC1to2.13	137.2	139.1	138.5	138.5
CC3to4.9	50.7	51.2	50.6	50.6
CC3to4.10	68.3	68.1	65.7	68.2
CC3to4.11	89.4	89.9	90.0	89.7
CC3to4.12	112.8	114.0	110.4	113.9
CC3to4.13	138.2	138.1	138.1	138.1
CC5.9	51.9	53.9	52.9	52.9
CC5.10	67.9	69.5	68.8	68.8
CC5.11	87.6	88.5	87.9	87.9
CC5.12	109.1	110.5	112.9	109.9
CC5.13	141.1	141.1	141.1	141.1

Table 7: Mean body mass of male snow crab instars and life stages. The stages are immature (imm), immature skip moulters (imm.sm), carapace condition 1 and 2 (CC1to2), carapace condition 3 and 4 (CC3to4) and carapace condition 5 (CC5). The numeric suffix to stage indicates the instar. Thus: CC1to2.9 is carapace condition 1 or 2 of instar 9.

	Mean Body Mass (g)			
Stage	**N-ENS**	**S-ENS**	**CFA 4X**	**Scotian Shelf**
imm.5	0.7	0.8	1.9	0.8
imm.6	2.0	2.0	2.6	1.9
imm.7	5.2	5.2	6.4	5.2
imm.8	12.4	14.2	18.8	13.6
imm.9	33.2	38.5	43.0	37.3
imm.10	97.4	105.7	108.6	104.7
imm.11	277.1	265.4	250.0	266.4
imm.12	511.0	512.8	547.0	510.0
imm.sm.9	51.6	50.9	58.1	51.0
imm.sm.10	125.3	129.8	124.1	129.4
imm.sm.11	299.2	288.7	286.2	290.4
imm.sm.12	557.7	545.9	548.2	545.5
CC1to2.9	32.4	37.0	48.9	35.2
CC1to2.10	114.0	113.0	102.3	113.4
CC1to2.11	275.7	261.9	285.4	263.9
CC1to2.12	591.6	585.5	533.1	590.2
CC1to2.13	1036.9	1101.3	1082.2	1082.2
CC3to4.9	51.3	53.3	51.5	51.5
CC3to4.10	130.1	129.4	116.0	129.5
CC3to4.11	301.4	307.4	307.9	305.7
CC3to4.12	618.6	640.4	575.6	637.6
CC3to4.13	1141.1	1139.3	1139.0	1139.0
CC5.9	54.9	61.6	58.2	58.2
CC5.10	126.8	136.9	133.0	133.0
CC5.11	284.3	293.1	287.5	287.5
CC5.12	556.6	579.3	608.7	569.6
CC5.13	1217.6	1217.6	1217.6	1217.6

Table 8: Pseudo-Markov transition matrix used for projections in N-ENS.

Stage(t+1)		Immature 5	Immature 6	Immature 7	Immature 8	Immature 9	Immature 10	Immature 11	Immature 12	Immature skip moulters 9	Immature skip moulters 10	Immature skip moulters 11	Immature skip moulters 12	CC1/2 9	CC1/2 10	CC1/2 11	CC1/2 12	CC1/2 13	CC3/4 9	CC3/4 10	CC3/4 11	CC3/4 12	CC3/4 13
Immature	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	6	1.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	7	-	1.82	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	8	-	-	1.88	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	9	-	-	-	1.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	10	-	-	-	-	1.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	11	-	-	-	-	-	0.93	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	12	-	-	-	-	-	-	0.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	9	-	-	-	-	0.76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	10	-	-	-	-	-	0.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	11	-	-	-	-	-	-	0.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	12	-	-	-	-	-	-	-	1.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	9	-	-	-	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	10	-	-	-	-	0.18	-	-	-	0.26	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	11	-	-	-	-	-	0.33	-	-	-	0.28	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	12	-	-	-	-	-	-	0.36	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-
CC1/2	13	-	-	-	-	-	-	-	-	-	-	-	0.28	-	-	-	-	-	-	-	-	-	-
CC3/4	9	-	-	-	-	-	-	-	-	-	-	-	-	1.24	-	-	-	-	0.67	-	-	-	-
CC3/4	10	-	-	-	-	-	-	-	-	-	-	-	-	-	1.39	-	-	-	-	0.67	-	-	-
CC3/4	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.09	-	-	-	-	0.67	-	-
CC3/4	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.24	-	-	-	-	0.67	-
CC3/4	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.24	-	-	-	-	0.67
CC5	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-
CC5	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-
CC5	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-
CC5	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-

Column header: Stage(t)

Table 9: Pseudo-Markov transition matrix used for projections in S-ENS.

Stage(t+1)		Immature								Immature skip moulters				CC1/2					CC3/4				
	Stage(t)	5	6	7	8	9	10	11	12	9	10	11	12	9	10	11	12	13	9	10	11	12	13
Immature	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	6	1.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	7	-	1.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	8	-	-	1.29	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	9	-	-	-	1.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	10	-	-	-	-	1.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	11	-	-	-	-	-	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	12	-	-	-	-	-	-	0.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	9	-	-	-	-	0.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	10	-	-	-	-	-	0.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	11	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	12	-	-	-	-	-	-	-	0.98	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	9	-	-	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	10	-	-	-	-	0.1	-	-	-	0.08	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	11	-	-	-	-	-	0.17	-	-	-	0.11	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	12	-	-	-	-	-	-	0.15	-	-	-	0.15	-	-	-	-	-	-	-	-	-	-	-
CC1/2	13	-	-	-	-	-	-	-	-	-	-	-	0.2	-	-	-	-	-	-	-	-	-	-
CC3/4	9	-	-	-	-	-	-	-	-	-	-	-	-	1.84	-	-	-	0.67	-	-	-	-	-
CC3/4	10	-	-	-	-	-	-	-	-	-	-	-	-	-	1.42	-	-	-	0.67	-	-	-	-
CC3/4	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.23	-	-	-	0.67	-	-	-
CC3/4	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	-	-
CC3/4	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.84	-	-	-	-	0.67	-
CC5	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-
CC5	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-
CC5	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-
CC5	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-
CC5	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-

Table 10: Pseudo-Markov transition matrix used for projections in CFA 4X.

Stage(t+1)		Stage(t) Immature 5	Immature 6	Immature 7	Immature 8	Immature 9	Immature 10	Immature 11	Immature 12	Immature skip moulters 9	Immature skip moulters 10	Immature skip moulters 11	Immature skip moulters 12	CC1/2 9	CC1/2 10	CC1/2 11	CC1/2 12	CC1/2 13	CC3/4 9	CC3/4 10	CC3/4 11	CC3/4 12	CC3/4 13
Immature	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	6	1.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	7	-	0.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	8	-	-	1.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	9	-	-	-	1.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	10	-	-	-	-	1.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	11	-	-	-	-	-	1.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature	12	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	9	-	-	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	10	-	-	-	-	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	11	-	-	-	-	-	-	0.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	12	-	-	-	-	-	-	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	9	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	10	-	-	-	-	0.13	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	11	-	-	-	-	-	0.06	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	12	-	-	-	-	-	-	0.25	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-
CC1/2	13	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-
CC3/4	9	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-	-	-
CC3/4	10	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-	-
CC3/4	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-
CC3/4	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	-	-
CC3/4	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	-	0.67	-
CC5	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-
CC5	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-
CC5	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-
CC5	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-
CC5	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-

Table 11: Tagging efforts since 2004.

Year	CFA	Vessels Involved	Tags Applied
2004	23 (Slope)	1	290
	24 (Slope)	1	497
2005	23	1	246
2006	23	2	1637
	24	2	1182
	N-ENS	2	399
2008	N-ENS	2	239
	23	1	267
	24	1	318
	4X	1	155
		Total	**5230**

Table 12: Bycatch (kg) estimates from the ENS snow crab fishery. The estimates are extrapolated from at-sea-observed bycatch and at-sea-observed biomass of catch (left) and by observed effort. Both estimation methods provide similar conclusions: the snow crab fishery is very species-specific. Bycatch levels have been averaging between 0.01% (by landings) and 0.02% (by effort) of total landings in the past 3 years, with most bycatch species being other crabs. At-sea-observers have noted that 3 leatherback turtles had been entangled in buoy lines; however, they were all released with little to no visible harm.

	***Extrapolated by Weight Bycatch in KG**				****Extrapolated by Effort Bycatch in KG**			
Species	**2006**	**2007**	**2008**	**3 Year Total**	**2006**	**2007**	**2008**	**3 Year Total**
American Lobster	75	0	65	140	83	0	70	153
Jonah Crab	11	0	0	11	12	0	0	12
Northern Stone Crab	171	48	32	251	190	52	35	277
Redfish	32	12	0	44	36	13	0	49
Rock Crab	32	0	0	32	36	0	0	36
Sea Cucumber	21	36	0	57	24	39	0	63
Sea Urchin	11	0	0	11	12	0	0	12
Spotted Wolffish	54	0	0	54	59	0	0	59
Striped Wolffish	54	0	32	86	59	0	35	94
Thorny Skate	32	0	0	32	36	0	0	36
Toad Crab	32	12	11	55	36	13	12	61
Snow Crab Landings	**4971930**	**5174710**	**8491000**	**18637640**	**4971930**	**5174710**	**8491000**	**18637640**
* Extrapolated by Weight = Observed Weight of Bycatch Species / (Observed Landings of Snow Crab / Total Landings of Snow Crab).								
** Extrapolated by Weight = Observed Weight of Bycatch Species / (Observed Trap Hauls / Total Calculated Trap Hauls).								

Table 13: Bycatch (kg) estimates from the CFA 4X snow crab fishery. The estimates are extrapolated from at-sea-observed bycatch and at-sea-observer coverage, by biomass. Note that the snow crab fishery is in general a highly species-specific fishery with extremely low bycatch of other species. Bycatch levels have been averaging at 0.324% of total landings in the past 3 years, with most bycatch species being other crabs and lobster.

Species	*Extrapolated by Weight Bycatch in KG			
	2006	**2007**	**2008**	**3 Year Total**
Jonah Crab	21	0	0	21
Northern Stone Crab	170	26	3393	3589
Deepsea Red Crab	0	0	56	56
Sea Raven	0	0	45	45
Sea Cucumber	0	0	11	11
Sculpin	0	0	45	45
American Lobster	149	0	11	160
Rock Crab	64	0	0	64
Toad Crab	21	0	45	66
Snow Crab Landings	**308000**	**319000**	**220000**	**847000**
* Extrapolated by Weight = Observed Weight of Bycatch Species / (Observed Landings of Snow Crab / Total Landings of Snow Crab)				

Table 14: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for N-ENS from at-sea-observed data.

	Carapace Condition				
Year	**1**	**2**	**3**	**4**	**5**
2004	2.5	4.9	72.5	19.8	0.4
2005	18.1	2.1	61.0	18.0	0.8
2006	4.4	9.5	71.6	13.4	1.1
2007	44.0	11.3	36.6	7.4	0.6
2008	28.6	3.2	60.8	6.7	0.7

Table 15: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for S-ENS from at-sea-observed data.

	Carapace Condition				
Year	**1**	**2**	**3**	**4**	**5**
2004	3.2	3.6	74.5	18.0	0.7
2005	5.9	11.0	68.2	14.3	0.7
2006	6.7	17.4	68.4	7.2	0.3
2007	8.8	15.0	58.4	16.3	1.5
2008	11.9	8.4	66.6	12.8	1.0

Table 16: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for CFA 4X from at-sea-observed data.

	Carapace Condition				
Year	**1**	**2**	**3**	**4**	**5**
2004/5	0.3	1.5	94.1	4.0	0.05
2005/6	0.04	11.5	85.3	3.1	0
2006/7	0.1	0.5	98.0	1.4	0
2007/8	1.2	0.1	78.2	20.4	0.2

Table 17: Carapace condition of crab < 95 mm CW (percent by number) over time for N-ENS from at-sea-observed data.

	Carapace condition				
Year	**1**	**2**	**3**	**4**	**5**
2004	4.0	0.3	56.2	38.5	1.0
2005	12.3	1.2	41.2	43.3	2.1
2006	10.8	25.0	43.4	17.7	3.1
2007	50.1	14.5	20.0	4.2	1.3
2008	17.3	10.2	64.6	7.2	0.8

Table 18: Carapace condition of crab < 95 mm CW (percent by number) over time for S-ENS from at-sea-observed data.

Year	Carapace Condition 1	2	3	4	5
2004	7.1	2.8	64.4	24.2	1.5
2005	11.4	17.2	49.3	19.8	2.3
2006	15.1	22.7	53.7	7.6	0.9
2007	11.3	21.5	54.5	11.8	0.9
2008	15.9	12.6	61.2	9.8	0.5

Table 19: Carapace condition of crab < 95 mm CW (percent by number) over time for CFA 4X from at-sea-observed data.

Year	Carapace Condition 1	2	3	4	5
2004/5	0.9	7.5	47.9	43.3	0.3
2005/6	0.1	7.7	37.9	54.1	0.1
2006/7	1.3	1.8	76.3	20.2	0.4
2007/8	6.0	0.2	66.0	27.1	0.6

Table 20: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for N-ENS from trawl surveys. The transition from a spring to a fall survey occurred in 2002/2003. Crude unadjusted proportions.

Year	Carapace Condition 1	2	3	4	5
2003	6.6	18.3	56.5	18.6	0.0
2004	2.5	3.6	51.0	38.4	4.6
2005	5.4	0.0	52.0	33.1	9.5
2006	16.8	9.4	15.9	40.2	17.8
2007	16.6	12.4	62.8	6.9	1.4
2008	38.2	4.2	50.9	6.7	0.0

Table 21: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for S-ENS from trawl surveys. The transition from a spring to a fall survey occurred in 2002/2003. Crude unadjusted proportions.

Year	**Carapace Condition**				
	1	**2**	**3**	**4**	**5**
2003	30.6	7.4	48.4	12.2	1.3
2004	10.1	12.5	56.0	20.8	0.7
2005	7.9	16.2	60.5	15.1	0.4
2006	13.9	10.7	57.0	17.0	1.4
2007	15.2	46.4	29.6	8.5	0.3
2008	13.5	3.75	69.7	12.6	0.4

Table 22: Carapace condition of crab ≥ 95 mm CW (percent by number) over time for CFA 4X from trawl surveys. The transition from a spring to a fall survey occurred in 2002/2003. Crude, unadjusted proportions.

Year	**Carapace Condition**				
	1	**2**	**3**	**4**	**5**
2003	27.7	8.7	49.2	13.0	1.2
2004	9.5	11.7	55.8	22.0	1.0
2005	7.8	14.6	60.9	15.8	0.9
2006	13.7	10.5	56.0	17.7	2.1
2007	15.1	44.3	31.9	8.4	0.3
2008	17.0	3.76	67.1	11.8	0.4

Table 23: Analysis of deviance of fishable snow crab habitat (presence/absence) modelled as a binomial Generalised Additive Model. The "s(.)" indicates a smoothed term. The factors were year (year), mean annual temperature (temperature), annual amplitude of temperature oscillations (tamp.annual), week number of annual temperature minima, easting and northing (plon, plat), substrate grain size (substrate mean), bottom curvature (ddZ) and bottom slope (dZ). The dominant influences were spatial location, temperature, depth, substrate and year, in order of statistical significance.

Parametric coefficients:

	Estimate	Standard Error	z-value	Pr(>|z|)
(Intercept)	1.0615	0.0487	21.8	< 2e-16***

Approximate significance of smooth terms:

	edf	Ref.df	Chi.sq	p-value	
s(yr)	8.06	8.56	57.54	2.6e-09	***
s(t)	2.44	2.94	92.71	< 2e-16	***
s(tamp.annual)	2.75	3.25	2.61	0.5010	
s(wmin.annual)	7.39	7.89	31.71	9.6e-05	***
s(plon,plat)	27.96	28.46	436.82	< 2e-16	***
s(z)	3.22	3.72	74.55	1.6e-15	***
s(substrate.mean)	4.36	4.86	63.84	1.6e-12	***
s(ddZ)	6.83	7.33	20.13	0.0066	**
s(dZ)	6.02	6.52	13.39	0.0495	*

R-sq.(adj) = 0.345 Deviance explained = 30.7%
UBRE score = -0.095993 Scale est. = 1 n = 3877

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

FIGURES

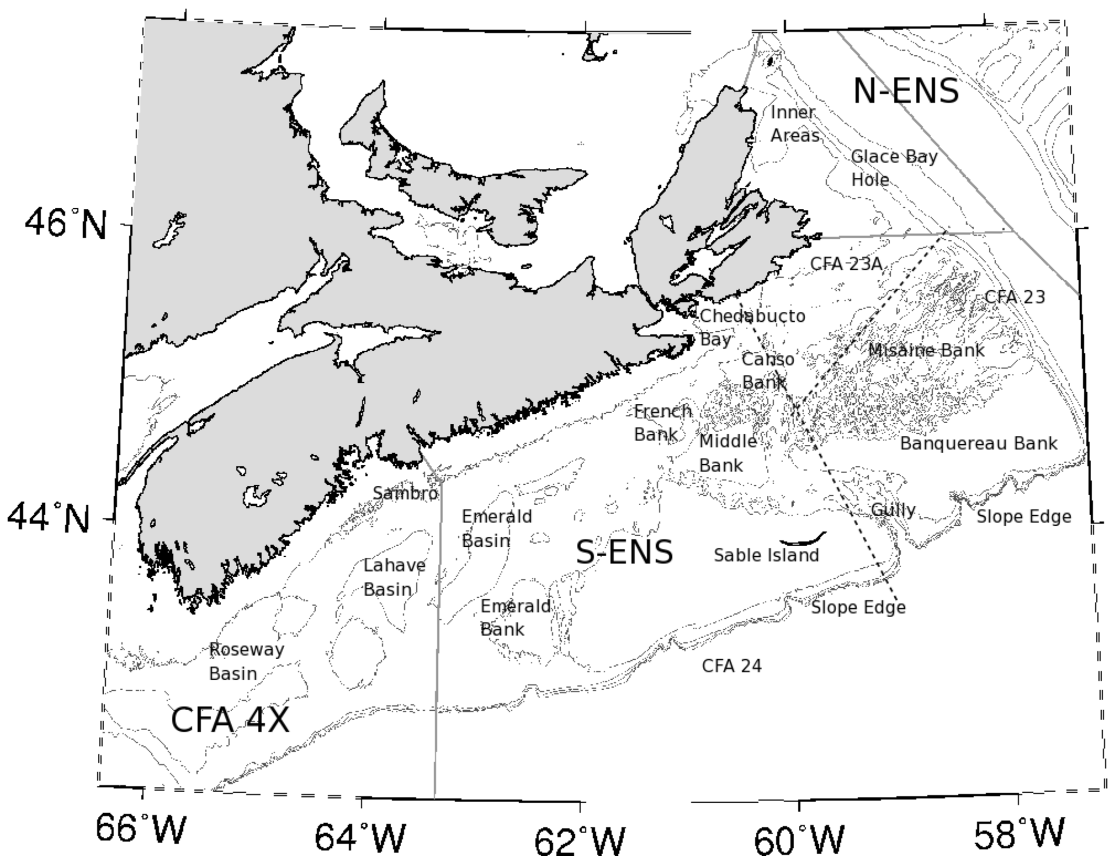


Figure 1: Location of geographic areas and management areas on the Scotian Shelf.

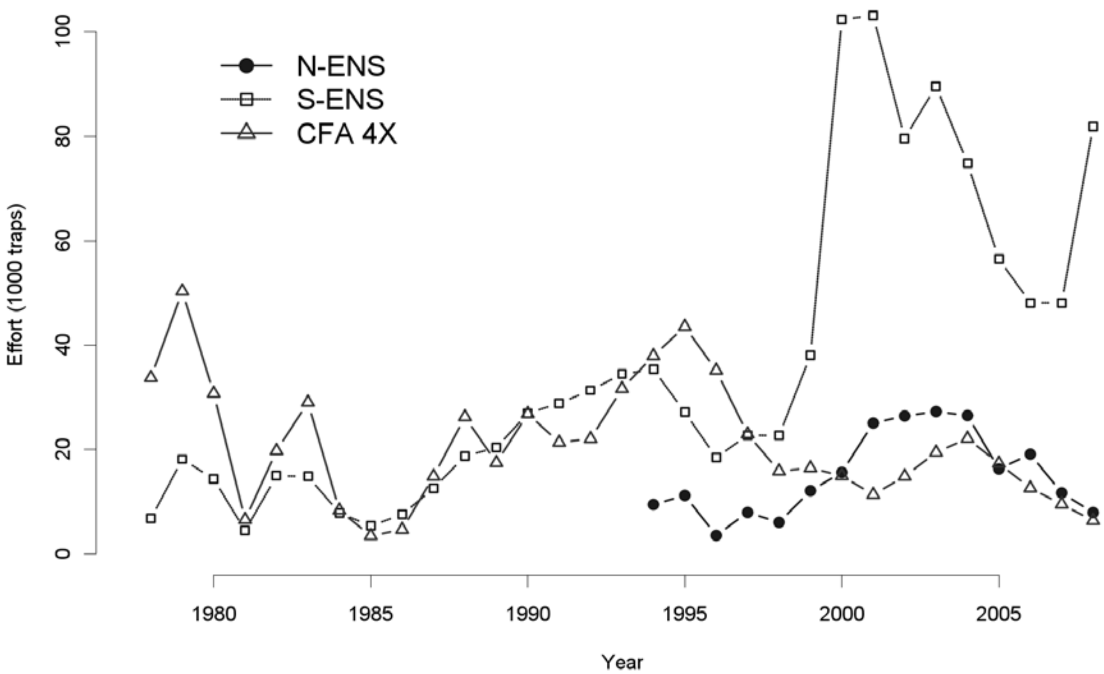


Figure 2: Temporal variations in the fishing effort, expressed as the number of trap hauls. For CFA 4X, year refers to the starting year.

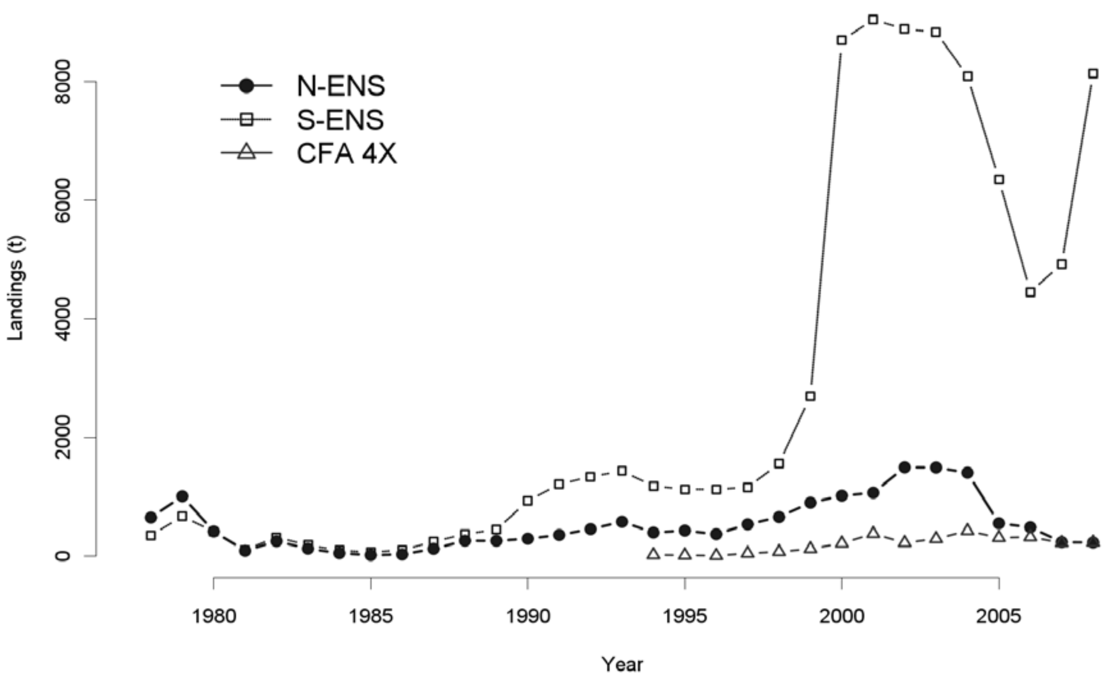


Figure 3: Temporal variations in the landings of snow crab on the Scotian Shelf (t). Note the sharp increase in landings associated with dramatic increases to TACs and a doubling of fishing effort in the year 2000. The landings follow the TACs with little deviation (and so are not shown). For CFA 4X, year refers to the starting year.

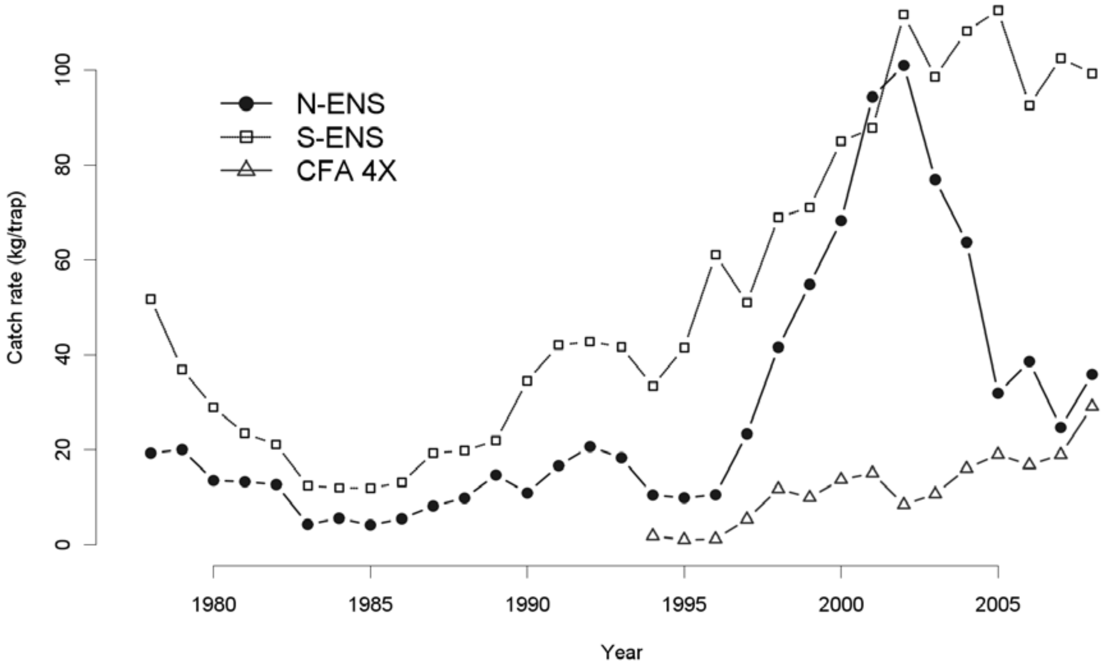


Figure 4: Temporal variations in catch rates of snow crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No correction for these varying trap-types nor soak time and bait-type has been attempted (see Methods). For CFA 4X, year refers to the starting year.

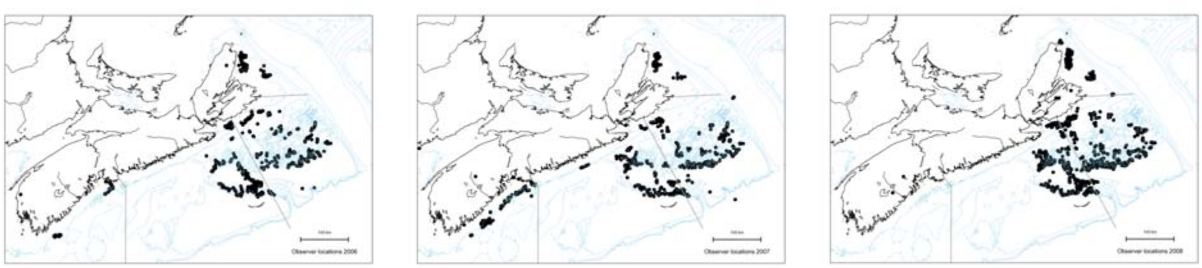


Figure 5: At-sea-observer monitored locations on the Scotian Shelf.

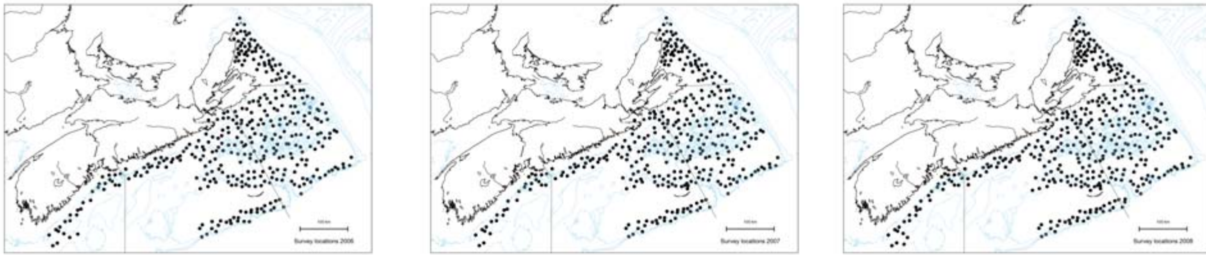


Figure 6: Trawl survey locations on the Scotian Shelf.

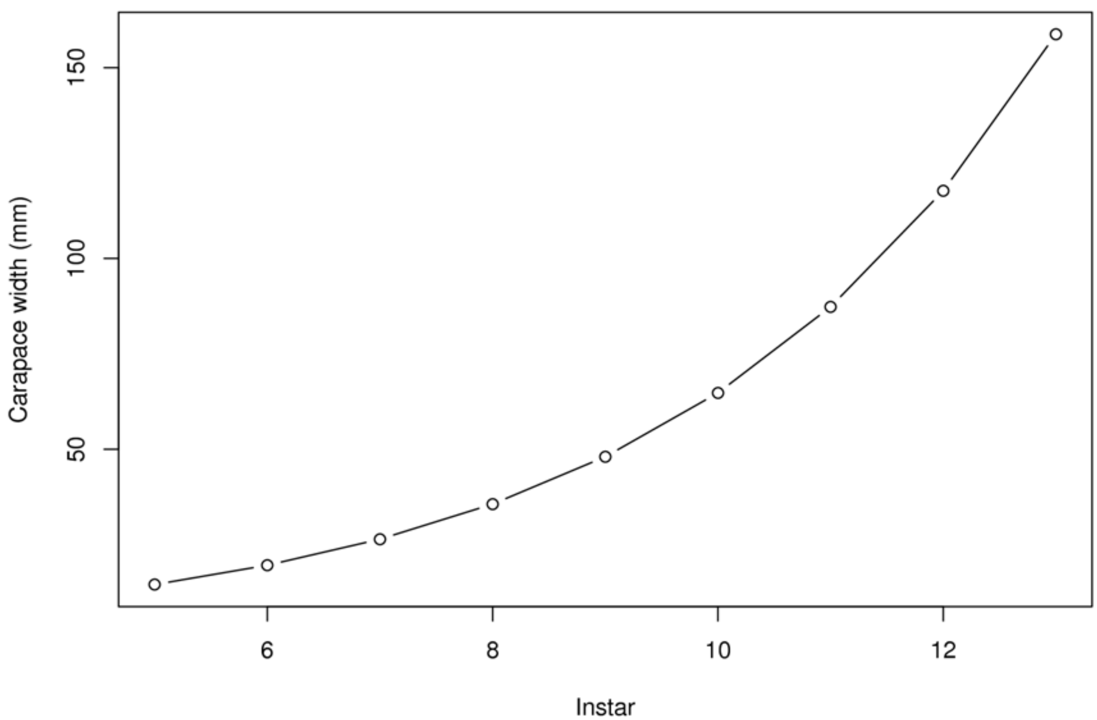


Figure 7: Growth in carapace width (cm) by instar, determined from Scotian Shelf male snow crab.

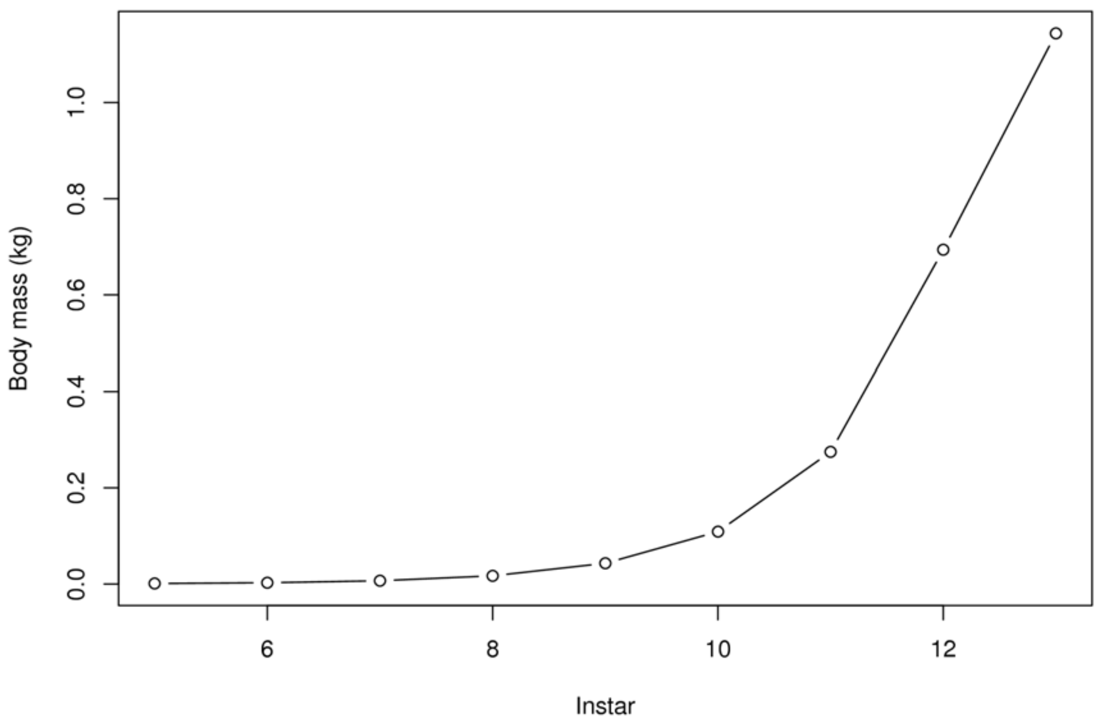


Figure 8: Growth in body mass (kg) by instar, determined from Scotian Shelf male snow crab.

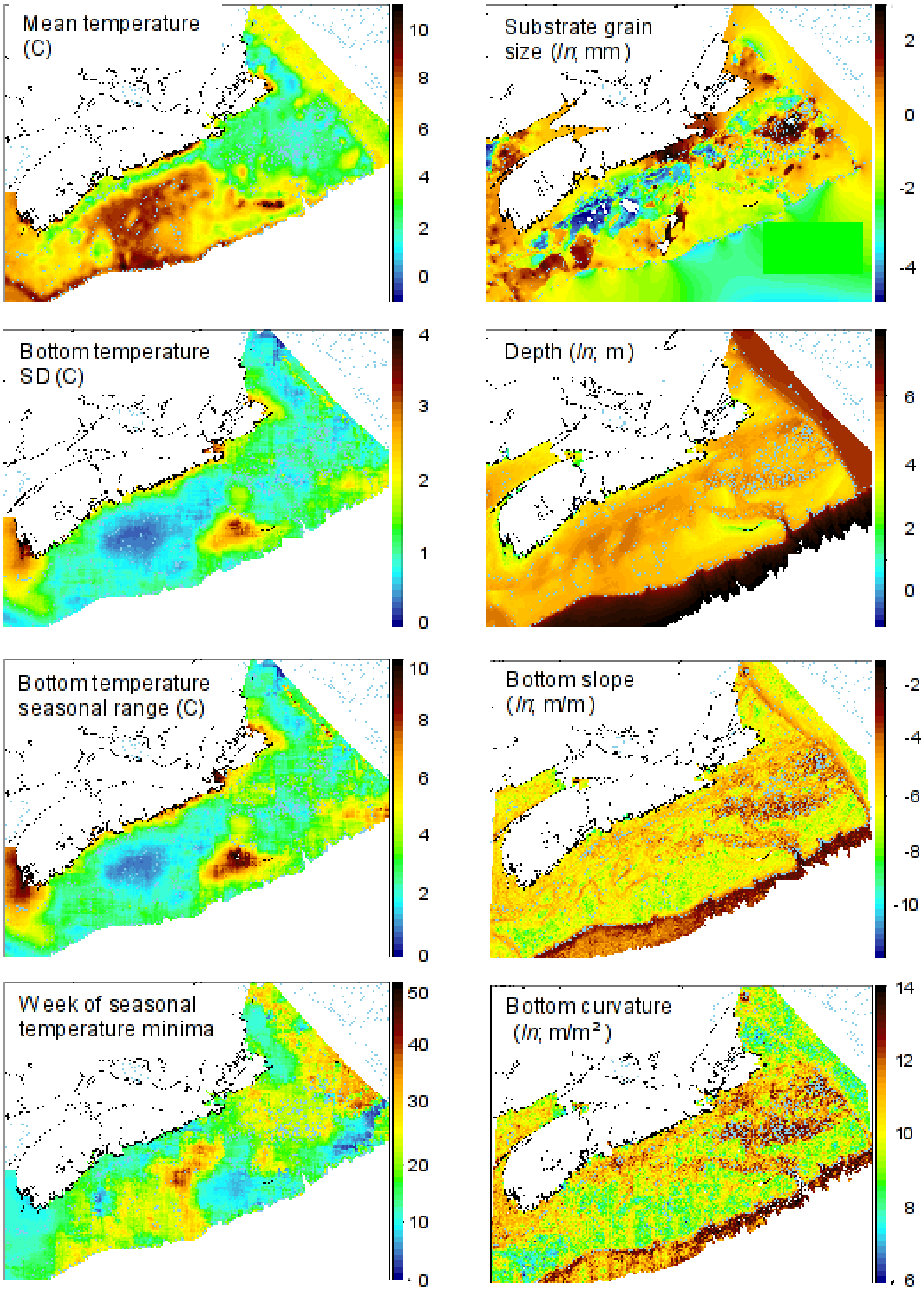


Figure 9: Bottom characteristics used for modelling snow crab habitat delineation. The visualisations of temperature variations are for climatological means. Annual temperature variation estimates were used for modelling.

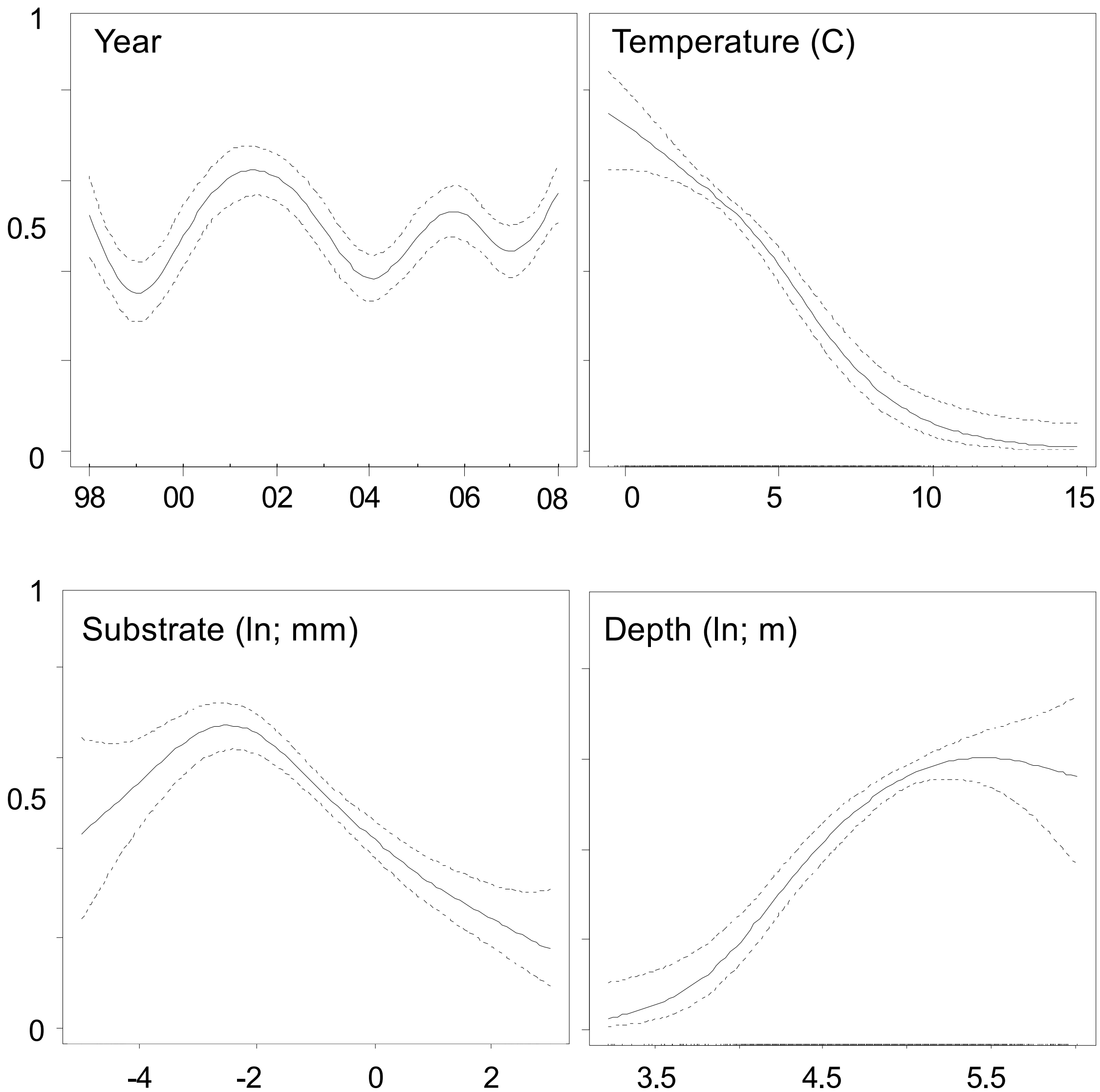
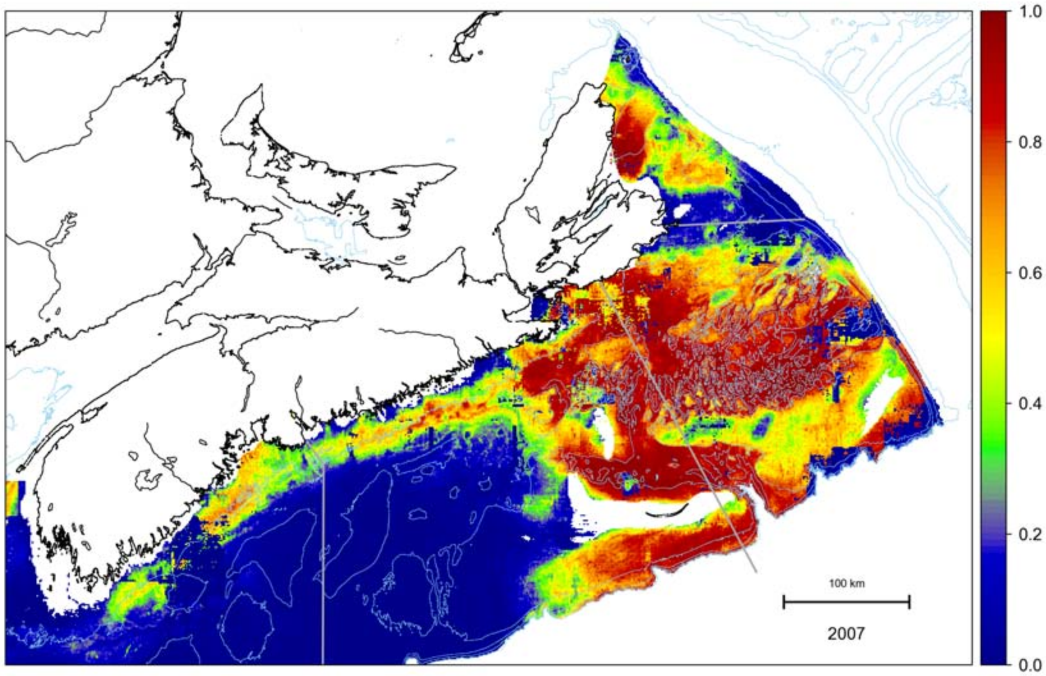


Figure 10: The empirically modelled relationship of snow crab habitat suitability as a function of key environmental key. Presented are 95% confidence intervals.

2007



2008

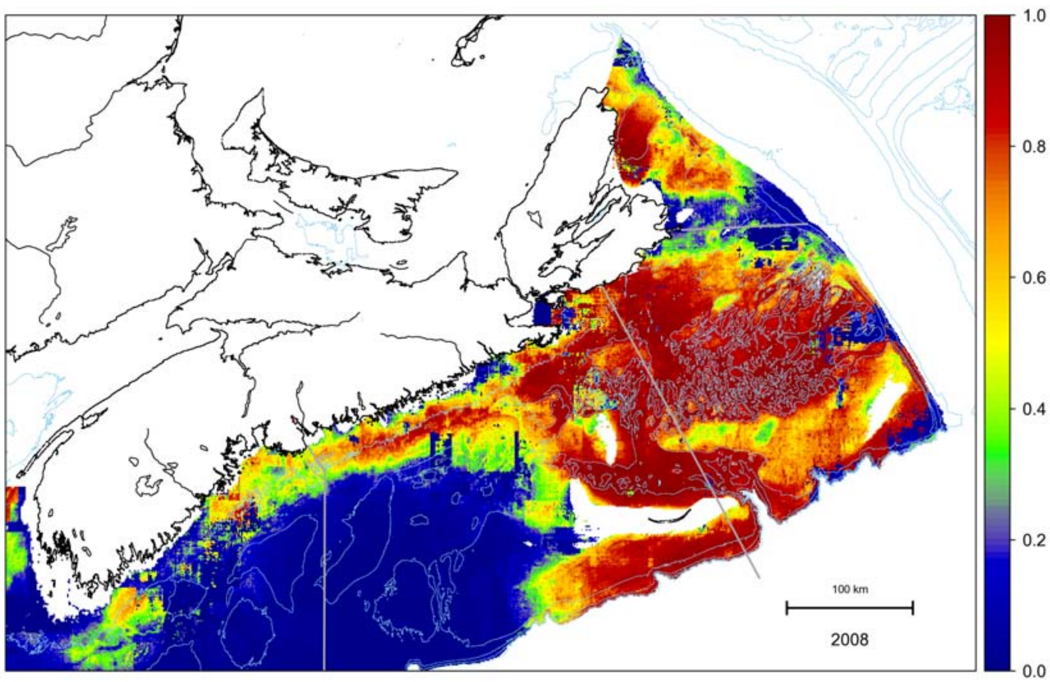


Figure 11: Predicted probabilities of viable habitat for fishable snow crab, used for kriging.

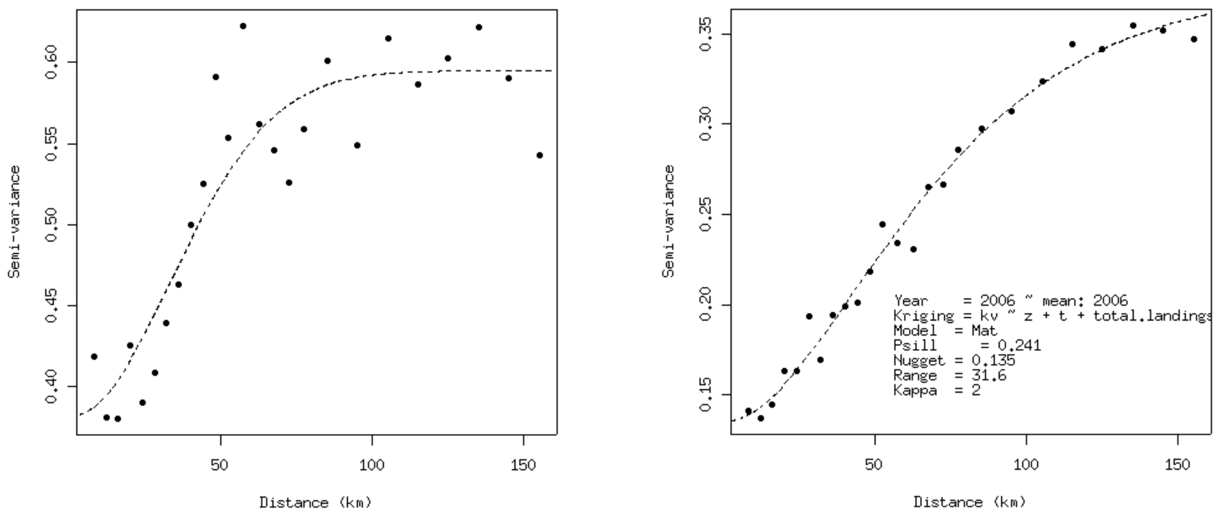


Figure 12: Example variograms of berried females (left) and fishable biomass (right) in 2006, used to constrain the spatial interpolation of snow crab abundance estimates via universal kriging with external drift. Variogram form is more erratic with less abundant categories of crab.

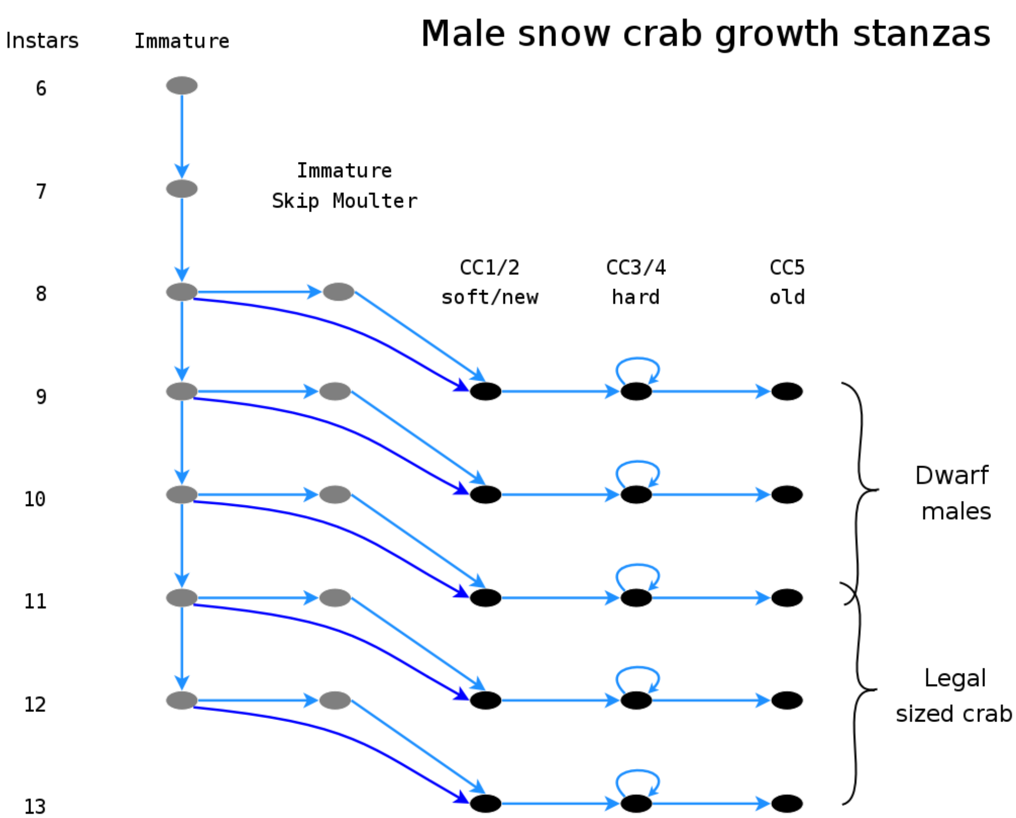


Figure 13: The growth stanzas of male snow crab. Each instar is determined from carapace width bounds obtained from modal analysis and categorised to carapace condition (CC) and maturity from visual inspection and/or maturity equations. Snow crab are resident in each growth stanza for 1 year, with the exception of CC2 to CC4, which are known from mark-recapture studies to last from 2 to 5 years.

Figure 14: Sorted ordination of anomalies of key social, economic and ecological patterns on the Scotian Shelf relevant to snow crab. Red indicates below the mean and green indicates above the mean.

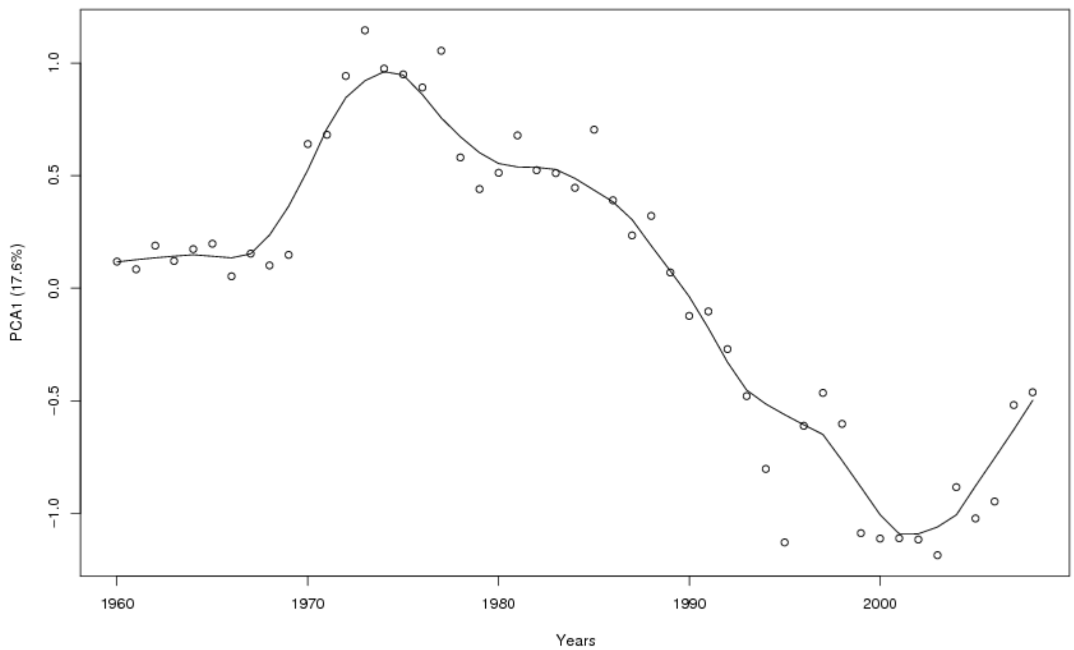


Figure 15: First axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf. Note strong variability observed near the time of the fishery collapse in the early 1990s.

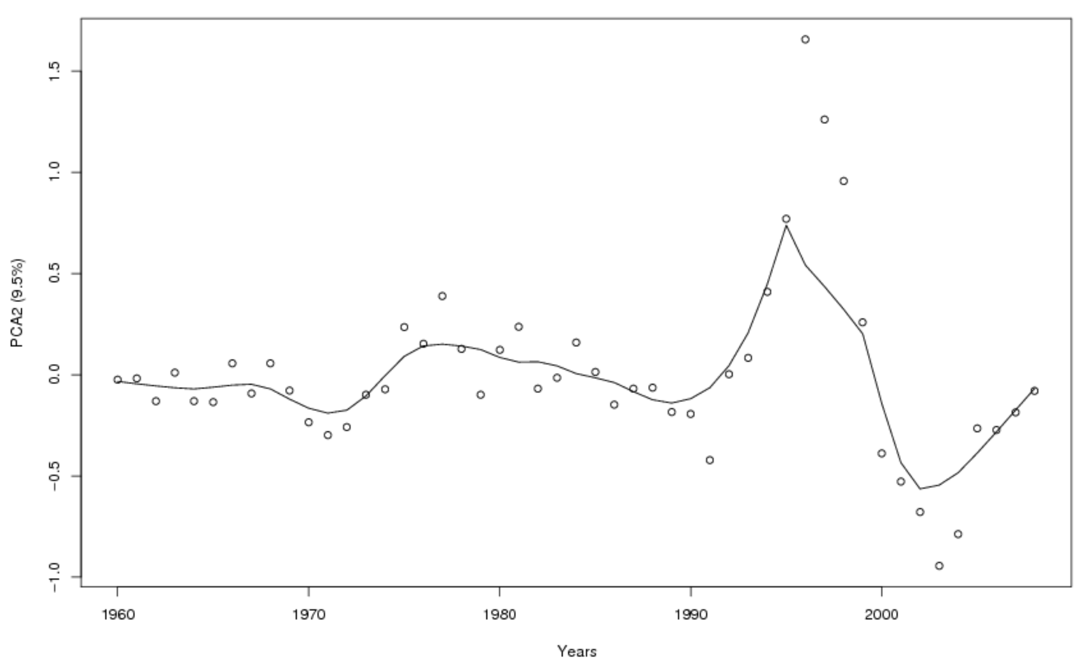


Figure 16: Second axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf. Note strong variability observed near the time of the fishery collapse in the early 1990s.

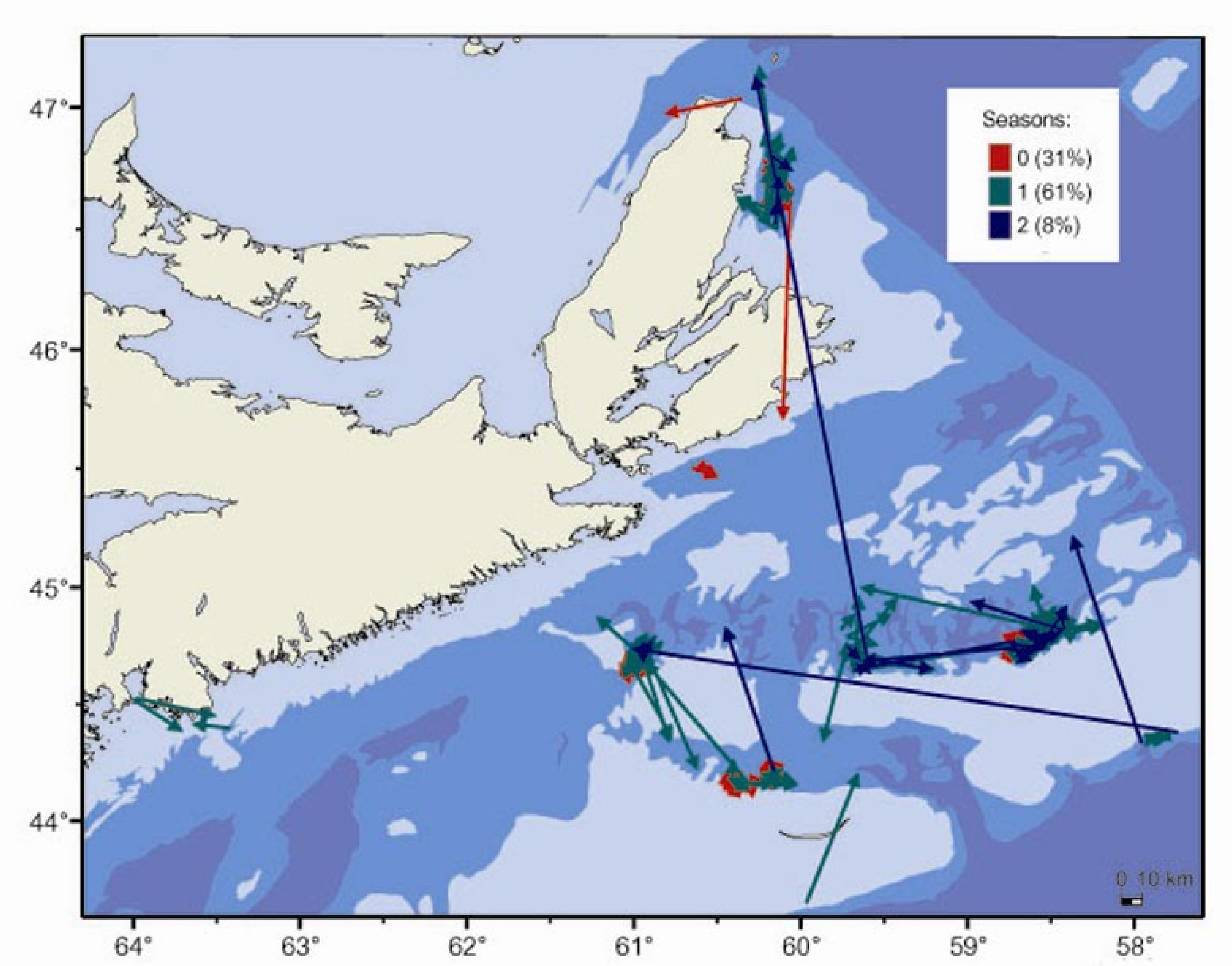


Figure 17: Movement of tagged snow crab reported since 2005. Season refers to number of years between tag release and tag recapture.

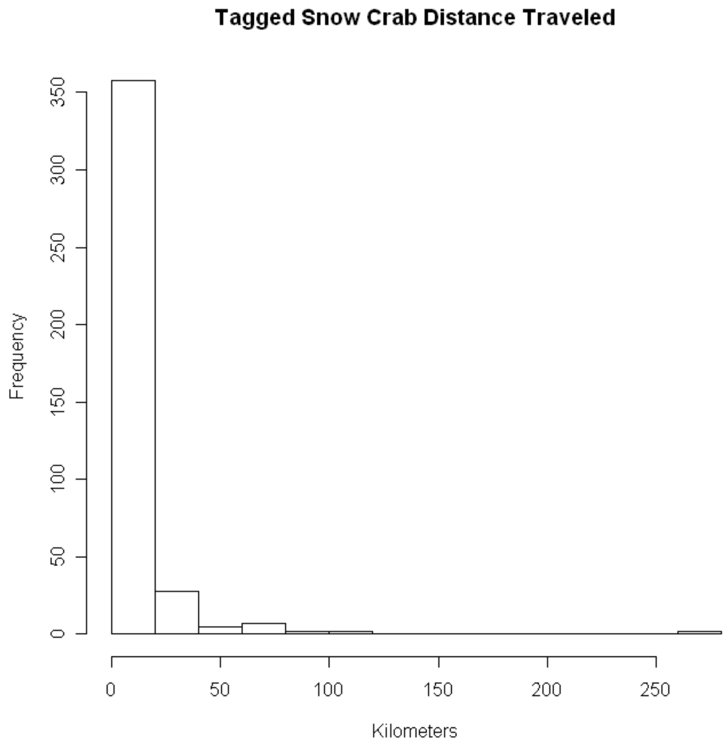


Figure 18: Distance travelled by tagged snow crab in ENS 2004-2008.

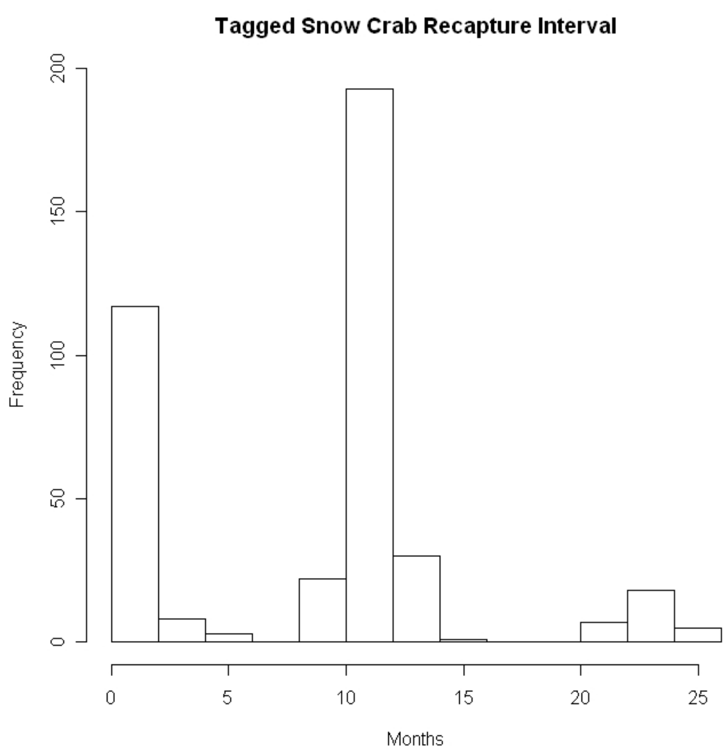
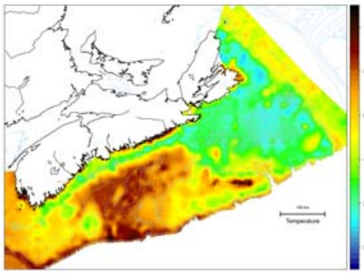
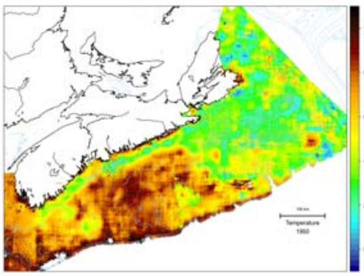


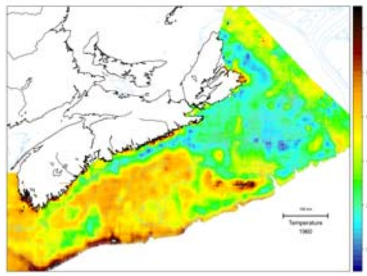
Figure 19: Tagged snow crab in ENS. return interval in months between initial release and first recapture.



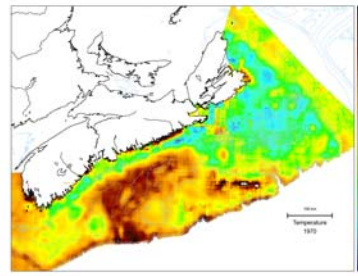
Mean: 1950 – present



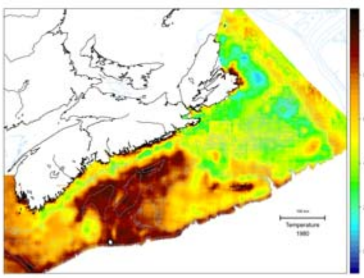
1950



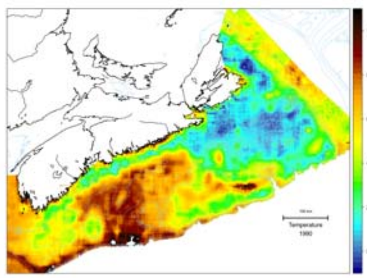
1960



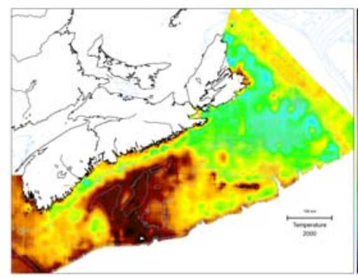
1970



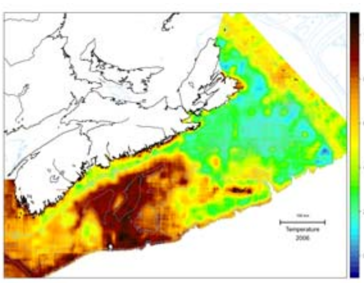
1980



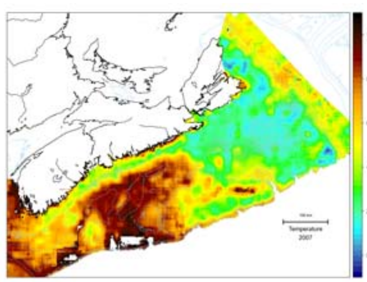
1990



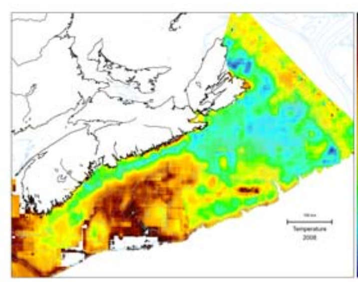
2000



2006



2007



2008

Figure 20: Mean annual bottom temperatures on the Scotian Shelf for selected years. Temperature scale is from -1 (blue) to 11 (black).

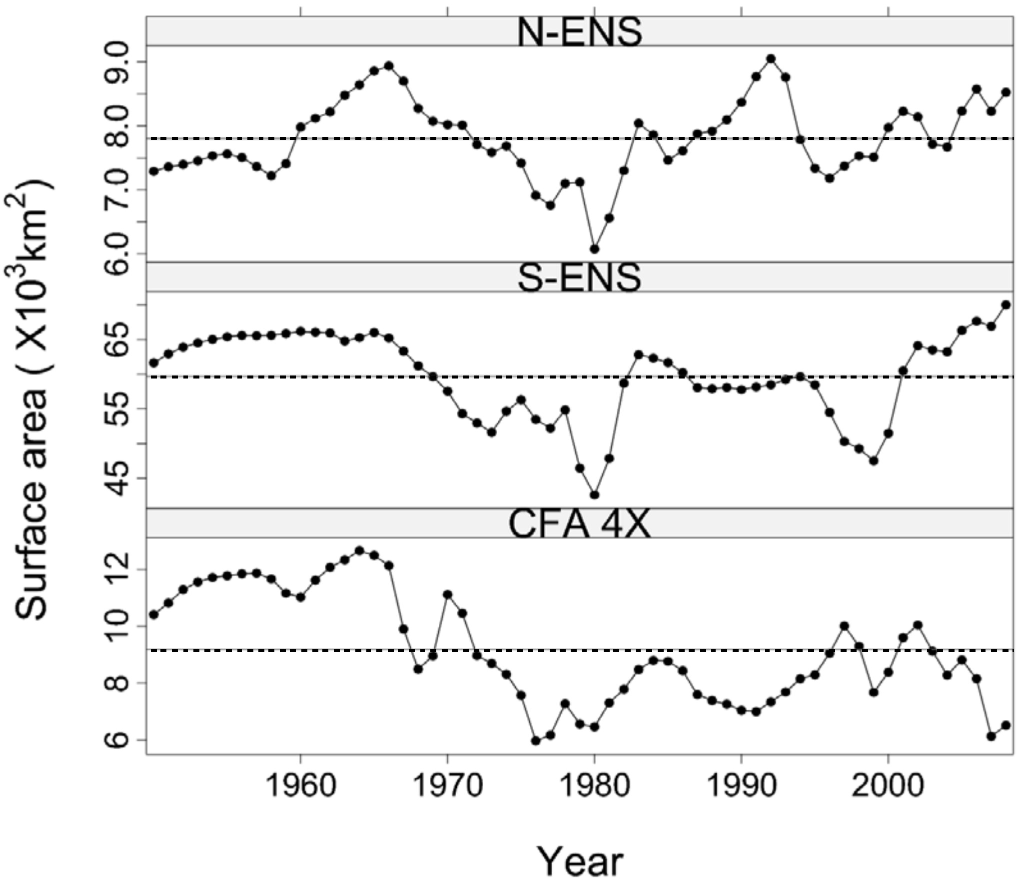


Figure 21: Annual variations in the surface area of potential snow crab habitat. N-ENS and S-ENS have had similar variations in the total amount of habitat space over time. Peak amounts were observed in the mid-1960s, mid-1980s and mid-2000s. Stronger variations (amplitudes) have been evident since the late 1970. In CFA 4X, the southern-most limit of the distribution of snow crab, the fluctuations have been evident; however, there has been a significant reduction since 1970, mostly associated with warming in the area. The stippled horizontal line indicates the long-term arithmetic mean surface area within each subarea.

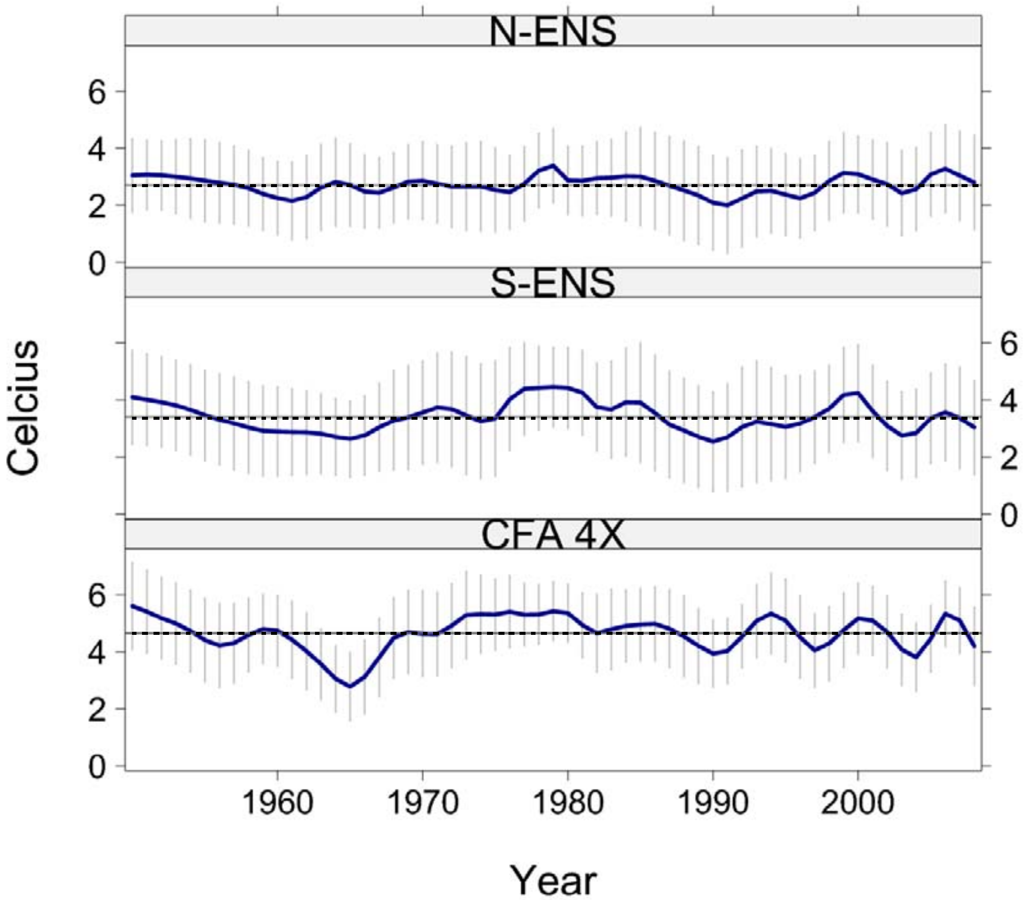


Figure 22: Annual variations in the annual mean bottom temperature within the areas of potential snow crab habitat. The stippled horizontal line indicates the long-term (1950 to 2008) arithmetic mean temperature within each sub-area. Error bars are 1 standard deviation.

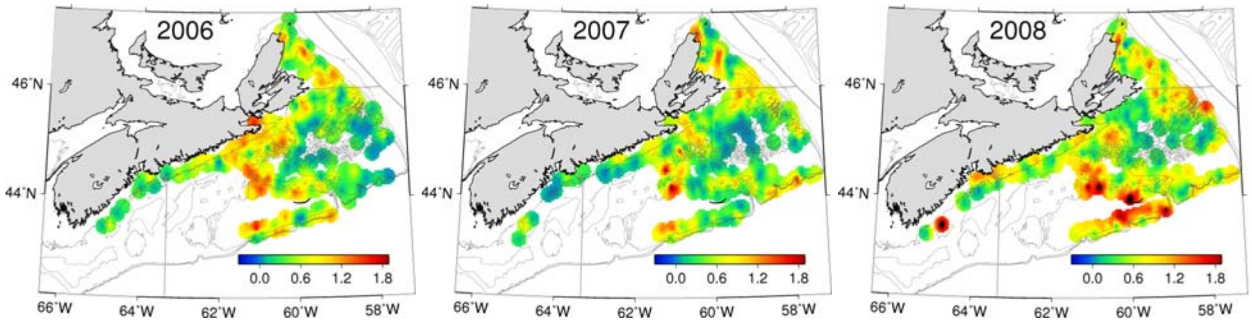


Figure 23: Locations of potential predators of snow crab: cod. Scale is log_{10} (numerical density [number/km^2]).

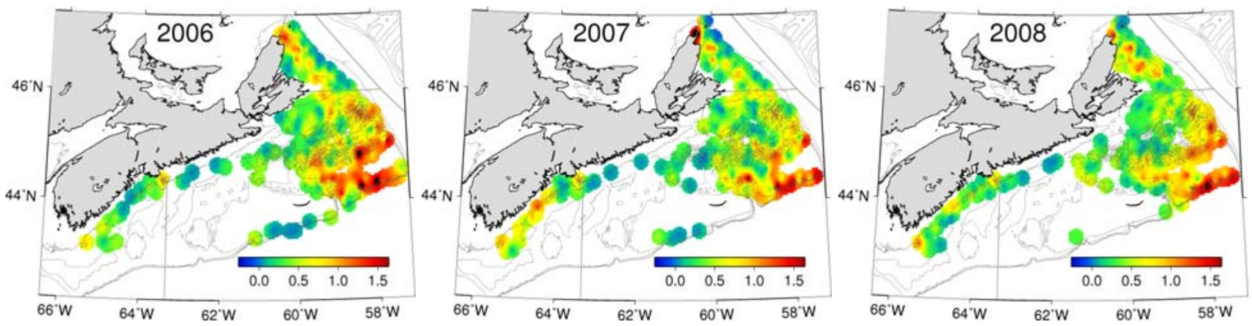


Figure 24: Locations of potential predators of snow crab: thorny skate. Scale is log_{10} (numerical density [number/km^2]).

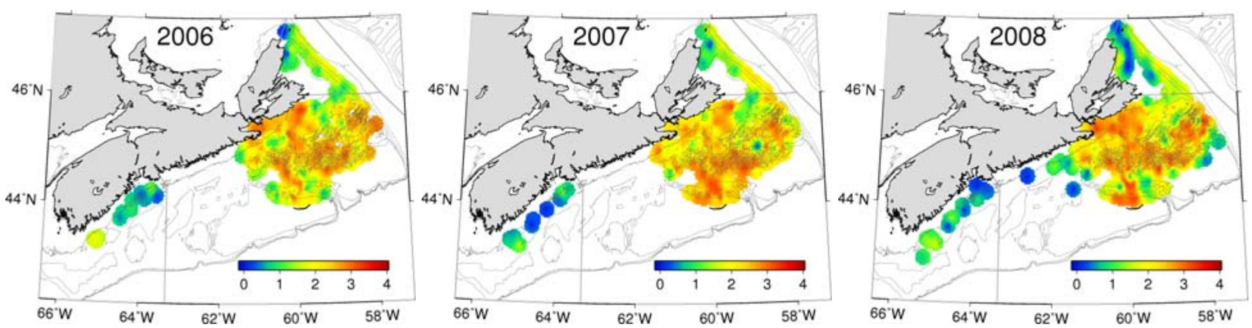


Figure 25: Locations of potential food items of snow crab: northern shrimp. Abundance of these potential food sources roughly match the spatial distributions of snow crab. Scale is log_{10} (numerical density [number/km^2]).

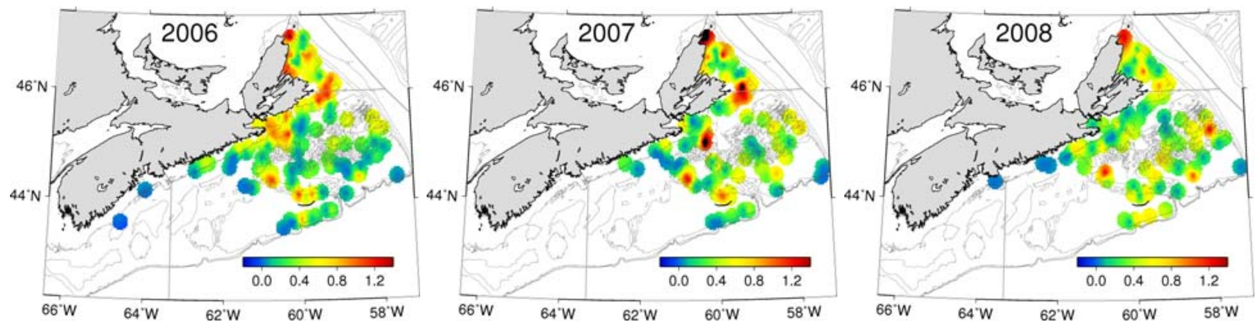


Figure 26: Locations of potential competitors of snow crab: lesser toad crab. High competitive interactions are probable in inshore areas. Scale is log_{10} (numerical density [number/km^2]).

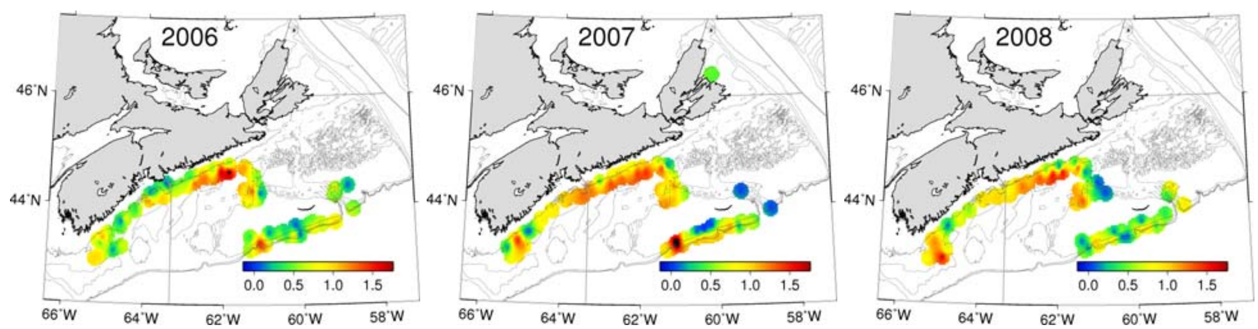


Figure 27: Locations of potential competitors of snow crab: Jonah crab. High competitive interactions are probable in inshore areas. Scale is log_{10} (numerical density [number/km^2]).

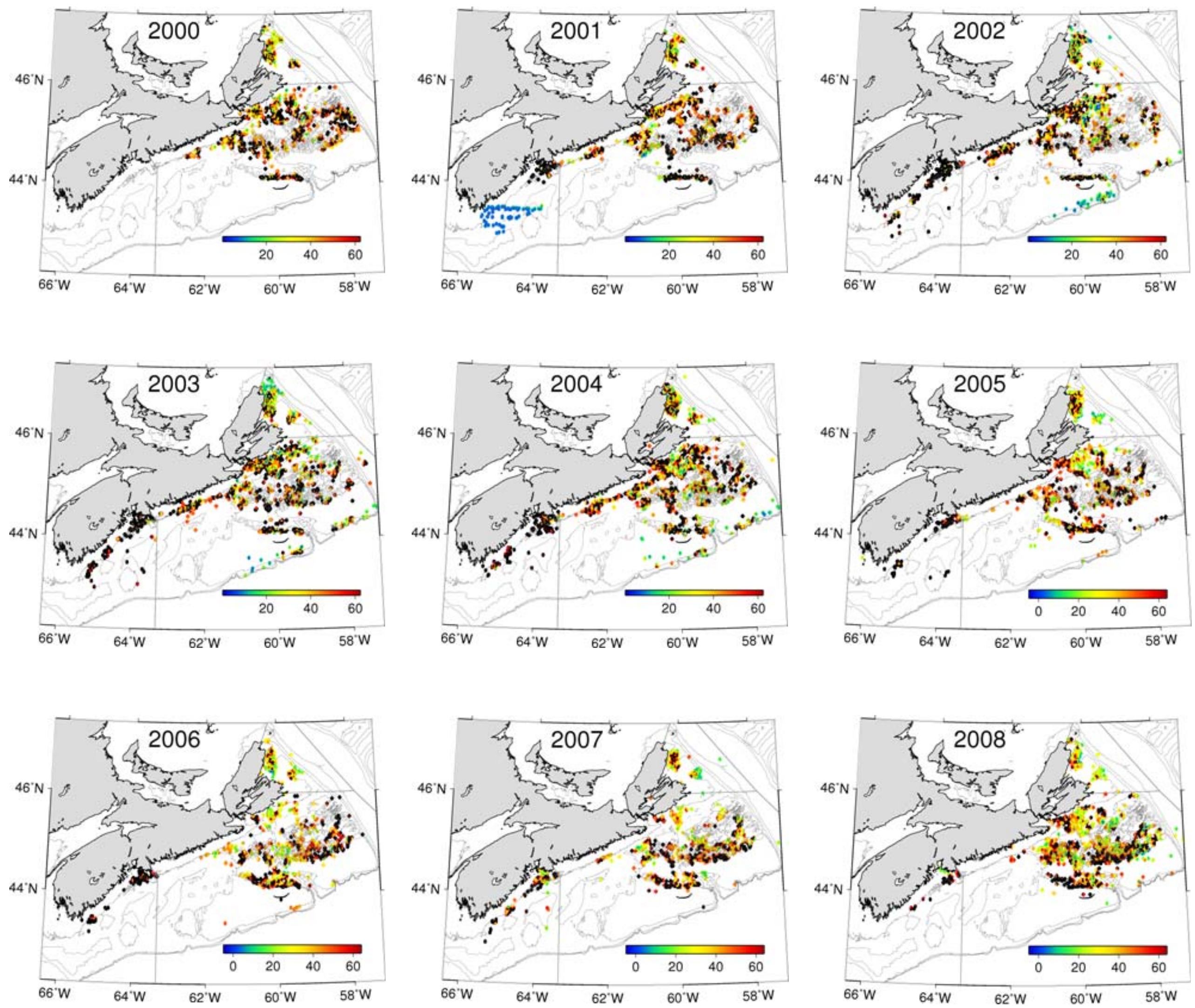


Figure 28: Fishing effort (number of trap hauls / 1 minute grid) from fisheries logbook data. Note the increase in effort offshore and reduction inshore in S-ENS. No visible changes are evident in N-ENS. For CFA 4X, year refers to the starting year.

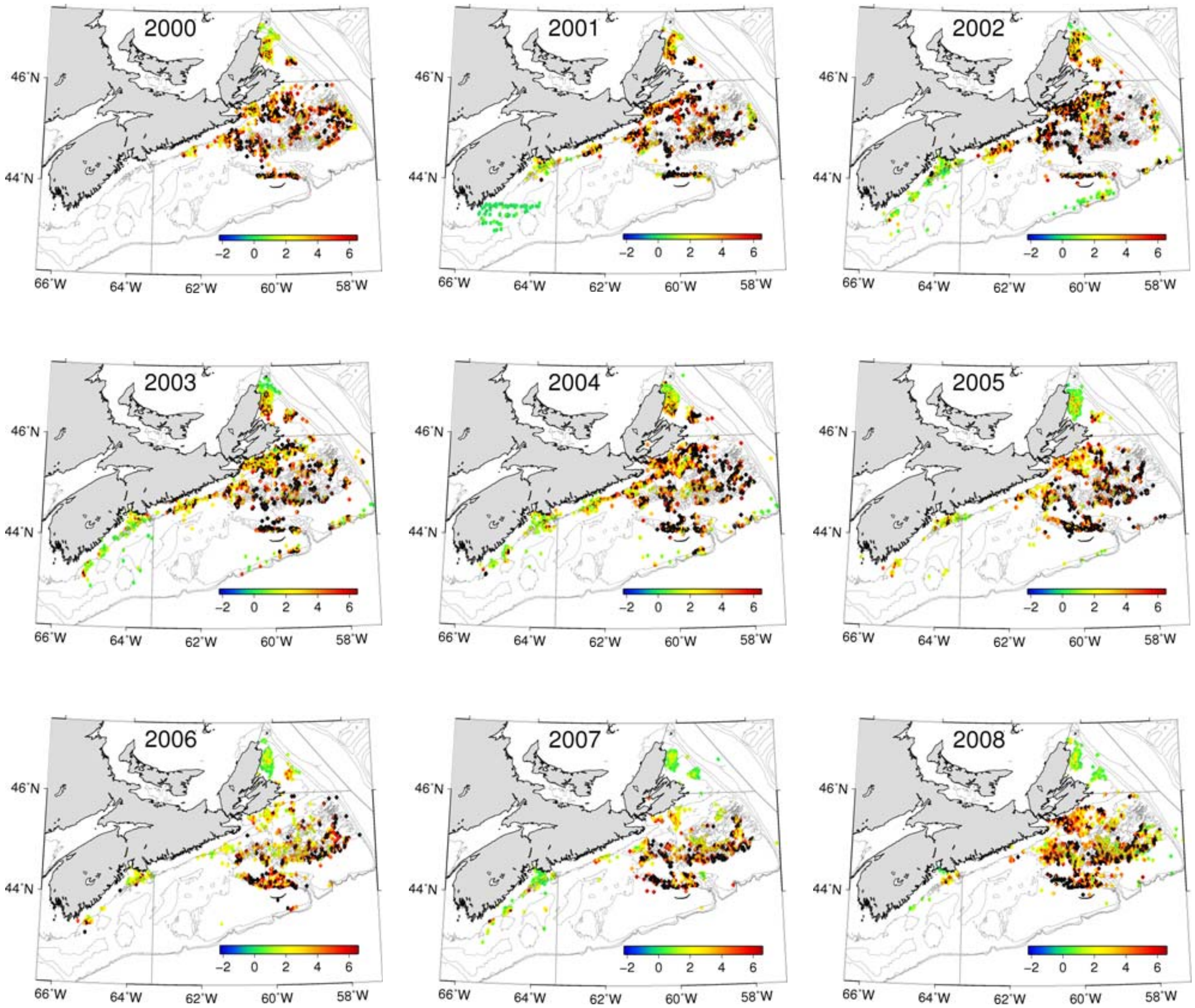


Figure 29: Crab landings (kg / 1 minute grid) from fisheries logbook data. Note the increase in landings offshore and reduction inshore for S-ENS. No visible changes are evident in N-ENS. For CFA 4X, year refers to the starting year.

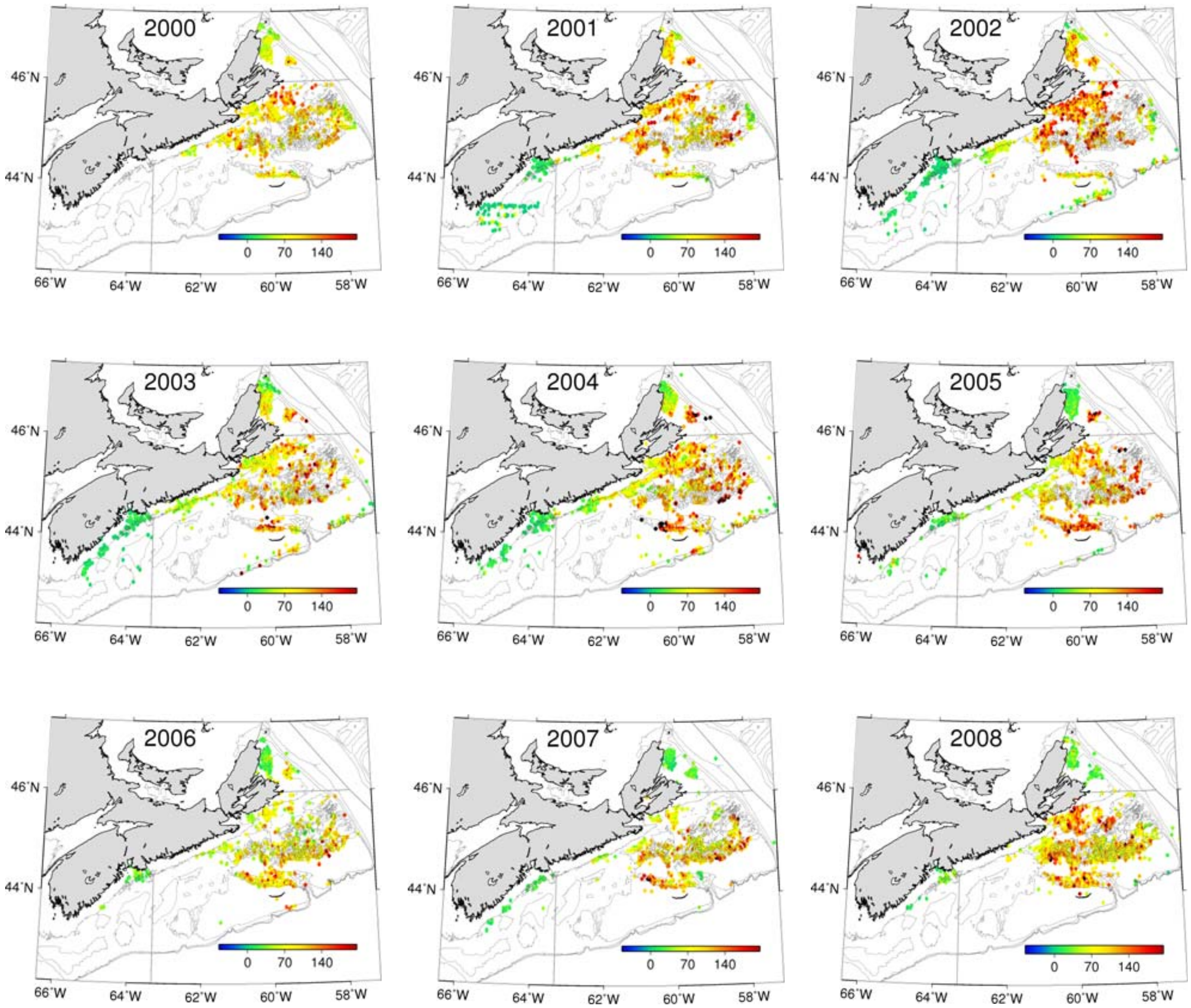


Figure 30: Catch rates (kg trap^{-1}) in each 1 minute grid from logbook data. Note the expansion of fisheries activity to more offshore locations with time. TACs were raised dramatically in 2000. Since that time, large decreases of catch rates in the inshore areas have become evident, indicating strong depletion. The movement to more offshore areas (S-ENS) has offset this lowering of catch rates, where previously unexploited areas became more fully exploited. The temporal increases in crude catch rates of S-ENS are therefore due to the spatial expansion of the targeted areas and the fishers learning to find newer fishing grounds. For CFA 4X, year refers to the starting year.

N-ENS *S-ENS* *CFA 4X*

2005 *2006* *2007* *2008*

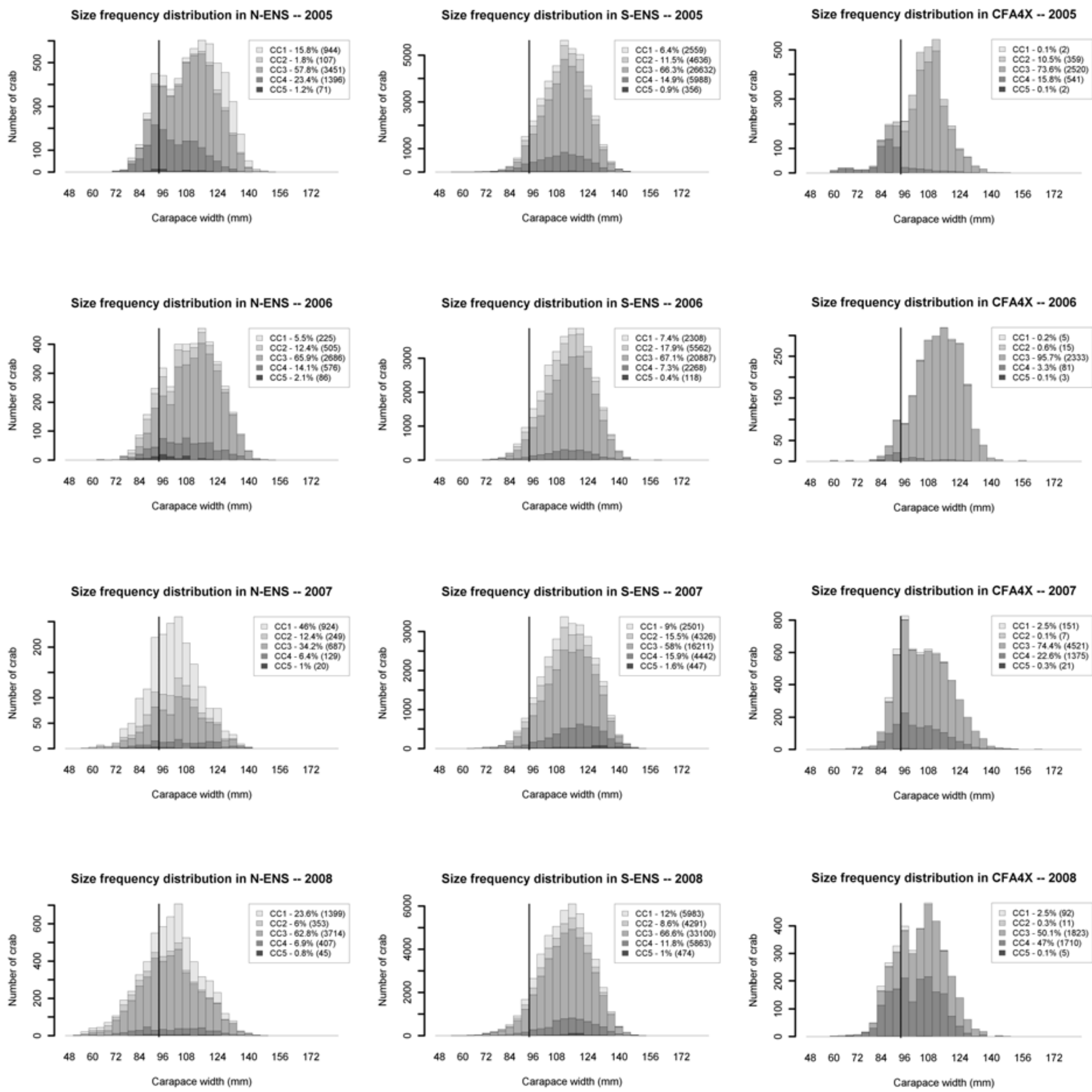


Figure 31: Size frequency distribution of all at-sea-observer monitored snow crab broken down by carapace condition. For CFA 4X, the year refers to the starting year of the season. Vertical lines indicates 95 mm CW.

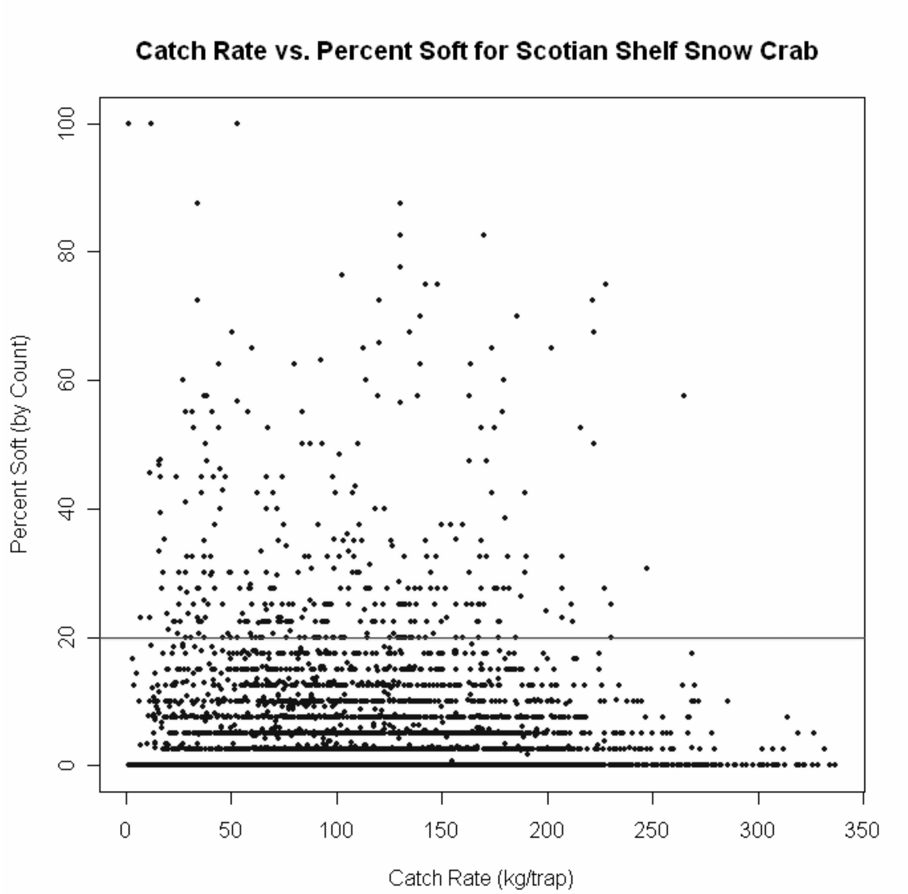


Figure 32: The relationship between the percentage soft-shell in the observed commercial landings as a function of the catch rates in at-sea-observed catches. Higher relative numbers of soft-shelled crab are expected in depleted areas as soft-shelled crab generally avoid hard-shelled males. However, high proportions of soft-shelled crab are found even in areas with high catch rates indicating that there is a large potential for damaging the fishable biomass if soft-shell catches are not carefully managed.

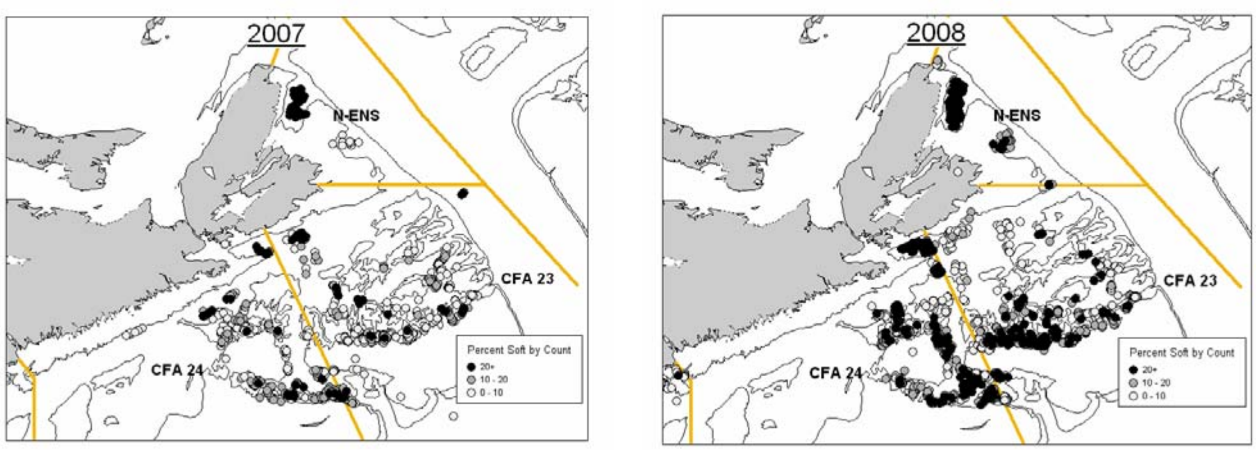


Figure 33:. Location of soft-shell snow crab occurrence in the commercial fishery. For CFA 4X, the year refers to the end year.

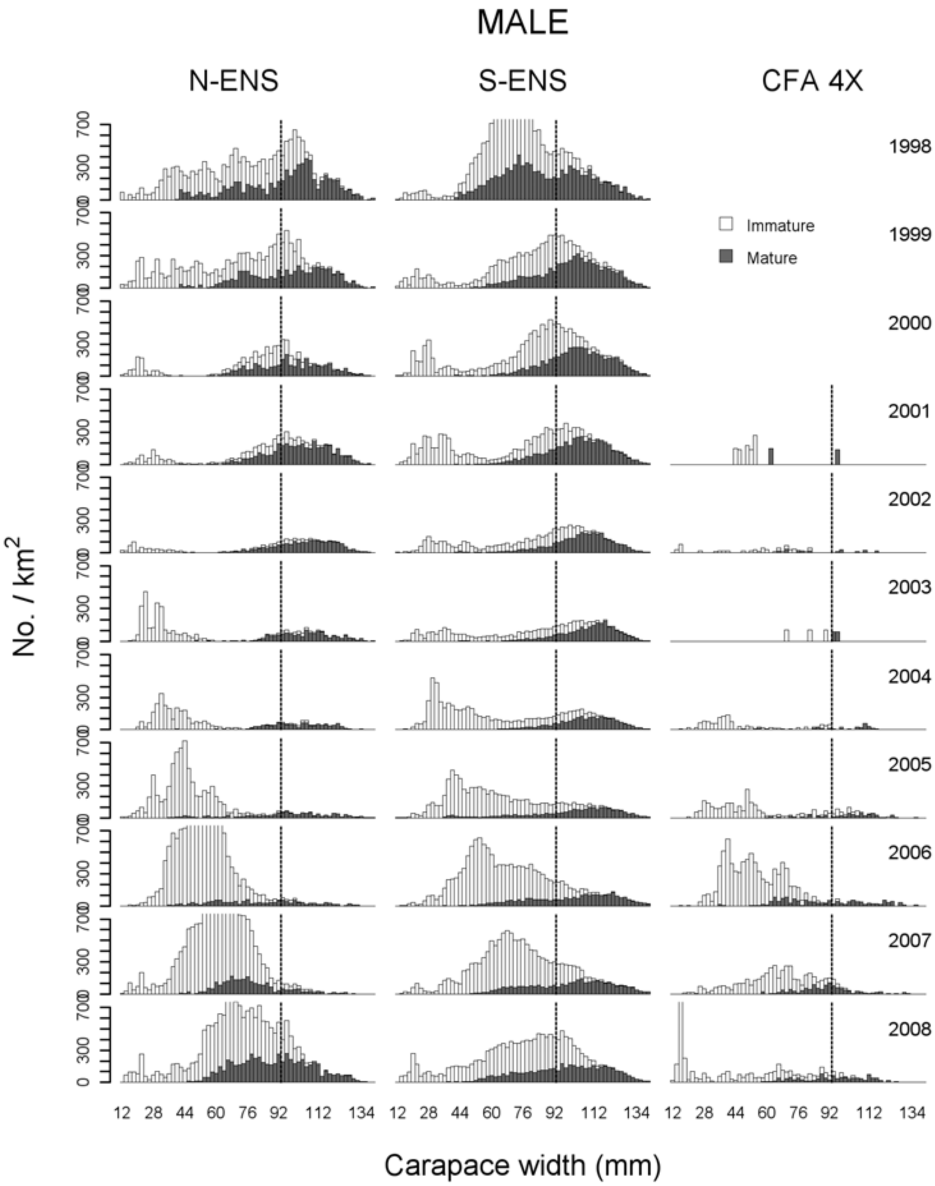
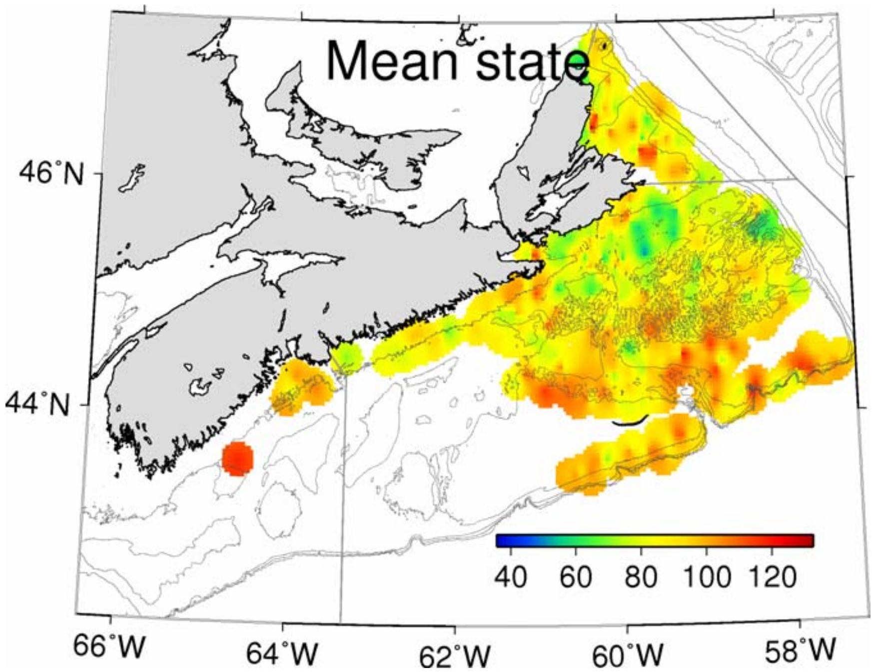


Figure 34. Size-frequency histograms of carapace width of male snow crabs. Note the increasing numbers of juvenile crab, 1 to 3 years from entering morphometrically mature size classes. Due to the expansion of the survey from core areas to the full extent of the snow crab grounds, the areal densities of crab in S-ENS and CFA 4X are not directly comparable between all years. For N-ENS, however, the relative heights are comparable. For S-ENS and CFA 4X, 2004 to the present are comparable.

Male



Female

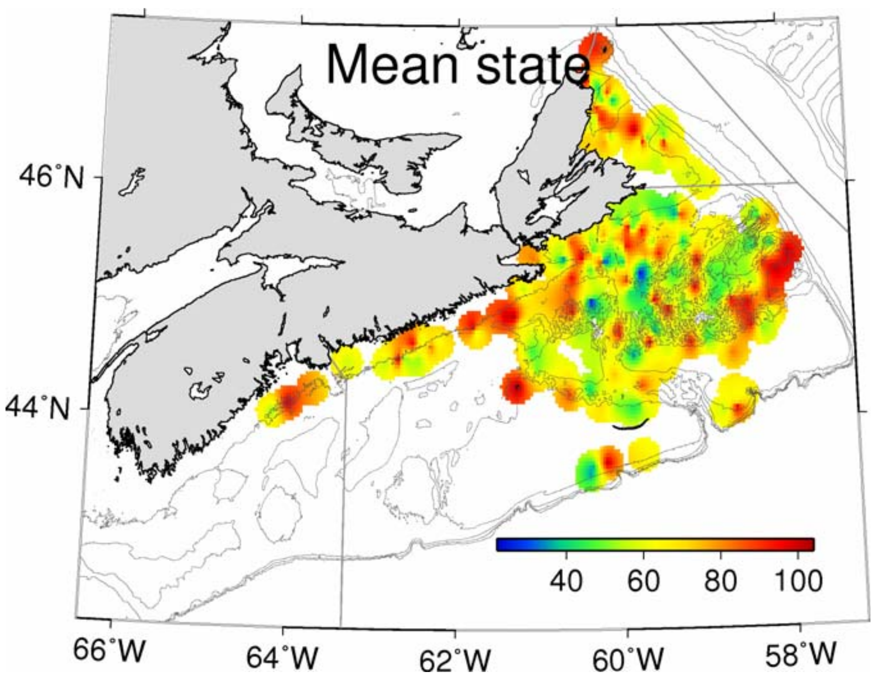


Figure 35. The spatial variations in size (CW; mm) at 50% maturity of male and female snow crab on the Scotian Shelf. Large size at maturity for males is generally observed in warmer areas. Inshore regions generally show smaller size at 50% maturity for males. For females, size at 50% maturity is heterogeneous, although crab found in warmer areas tend to mature at a larger size.

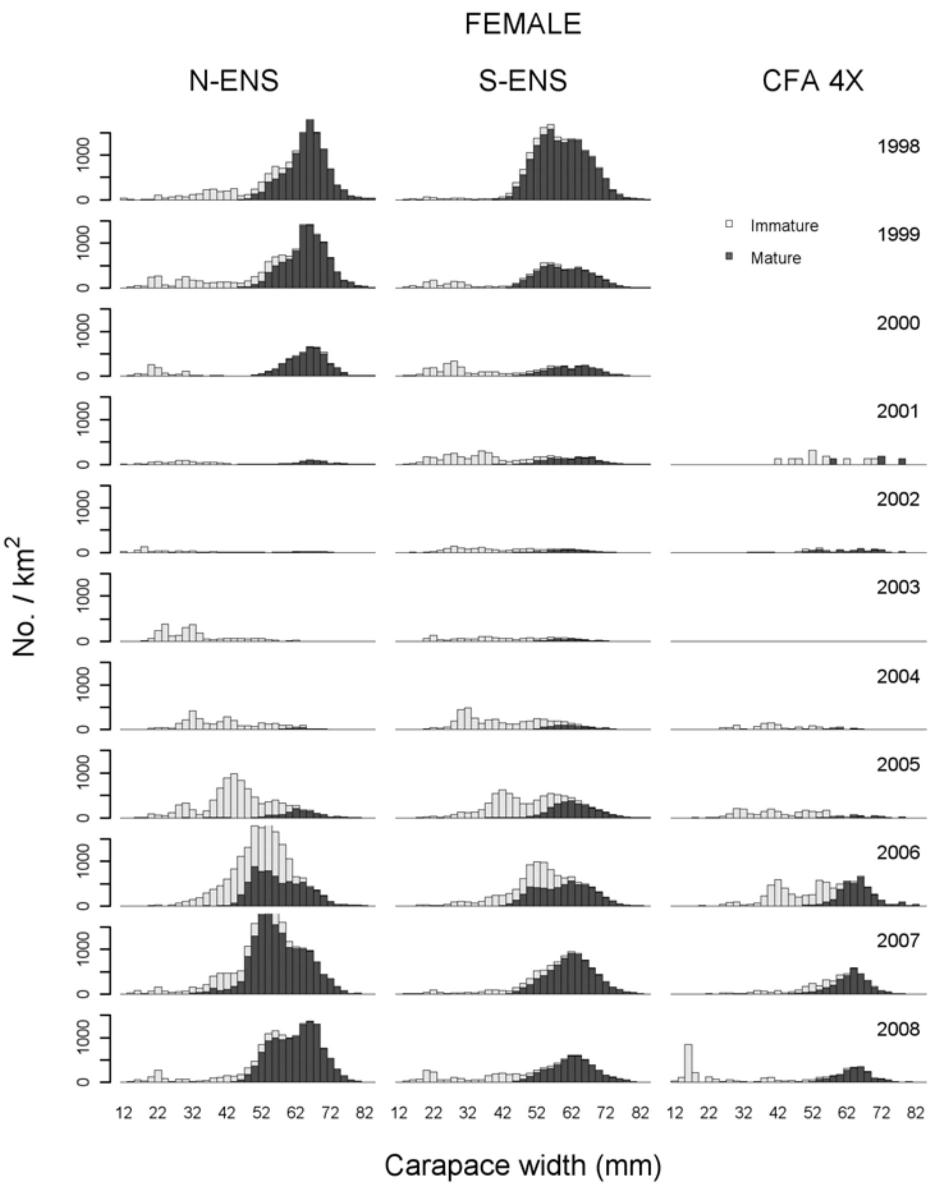


Figure 36: Size-frequency histograms of carapace width of female snow crabs. Note the increasing numbers of juvenile crab in recent years. The leading edge of the recruitment pulse has begun to enter morphometrically mature size classes. Due to the expansion of the survey from core areas to the full extent of the snow crab grounds, the areal densities of crab in S-ENS and CFA 4X are not directly comparable between all years. For N-ENS, the relative heights are comparable between all years. For S-ENS and CFA 4X, data from 2004 to the present are comparable.

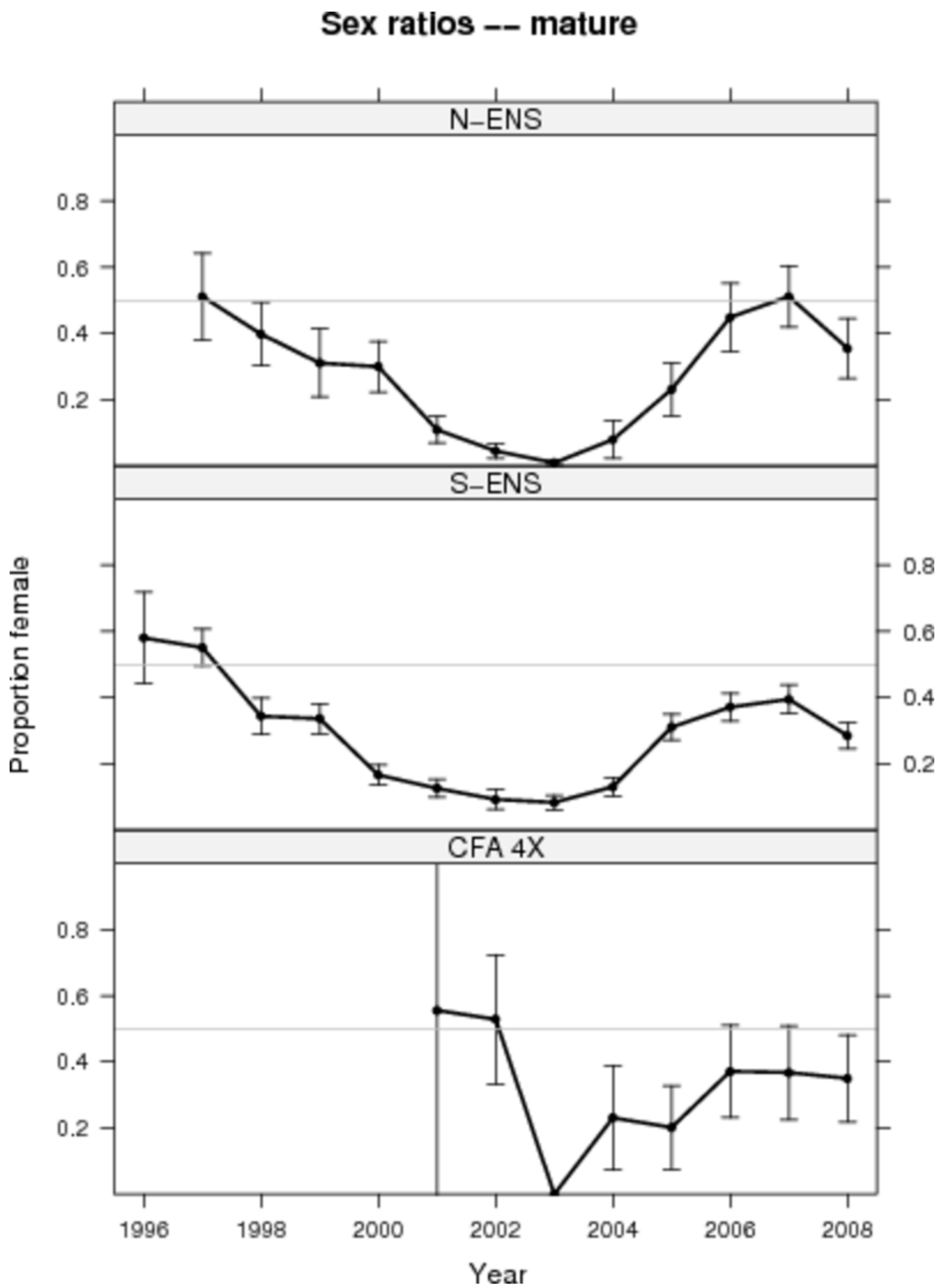


Figure 37: Annual variations in the mean sex ratio (proportion female) for morphometrically mature crabs. One standard error bars are presented.

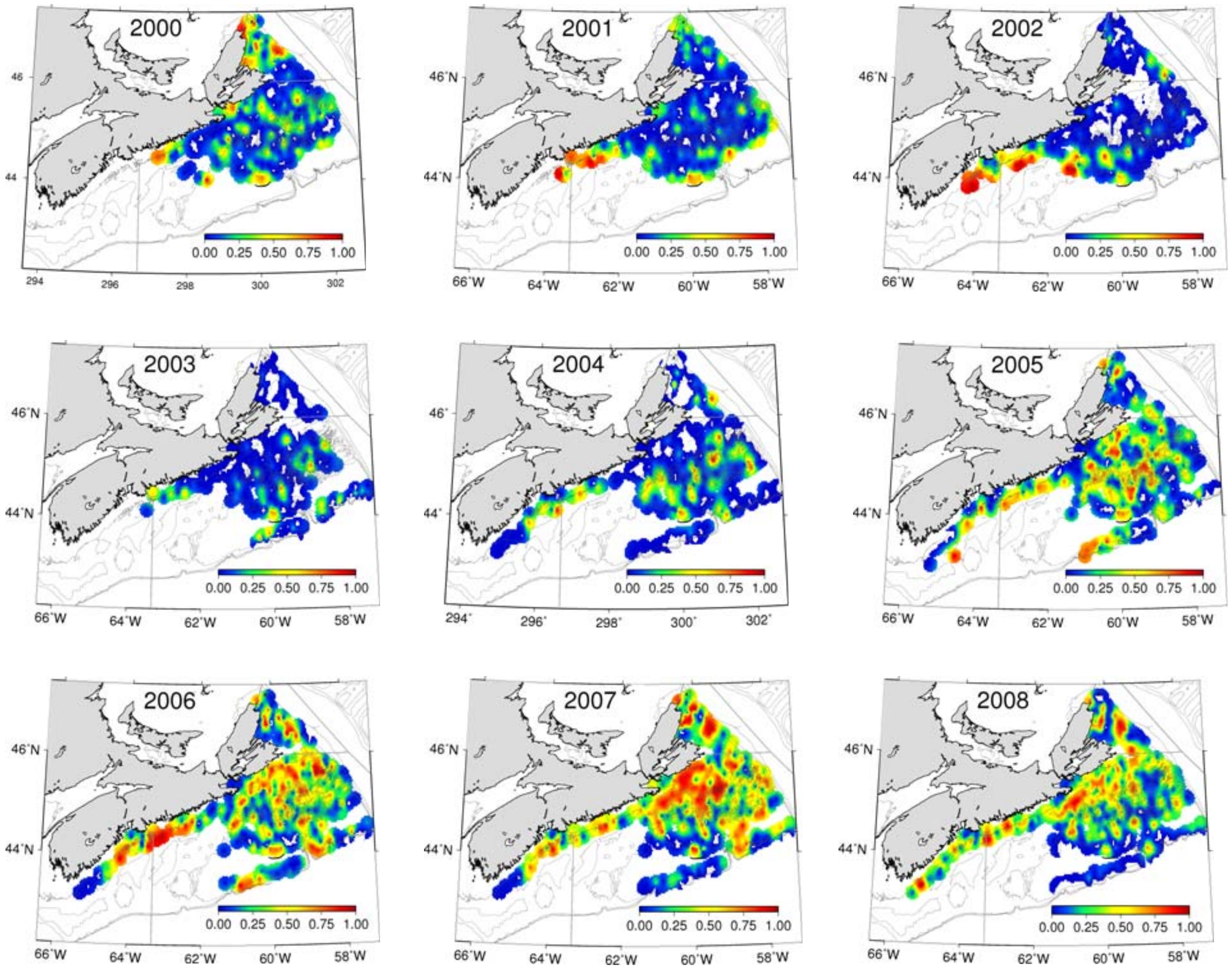


Figure 38. Morphometrically mature sex ratios (proportion female). Since the early 2000s, most of the Scotian Shelf was uniformly male dominated (low values; blue). More balanced and spatially heterogeneous sex ratios were seen during the main reproductive period in the late 1990s have been observed again, since 2005.

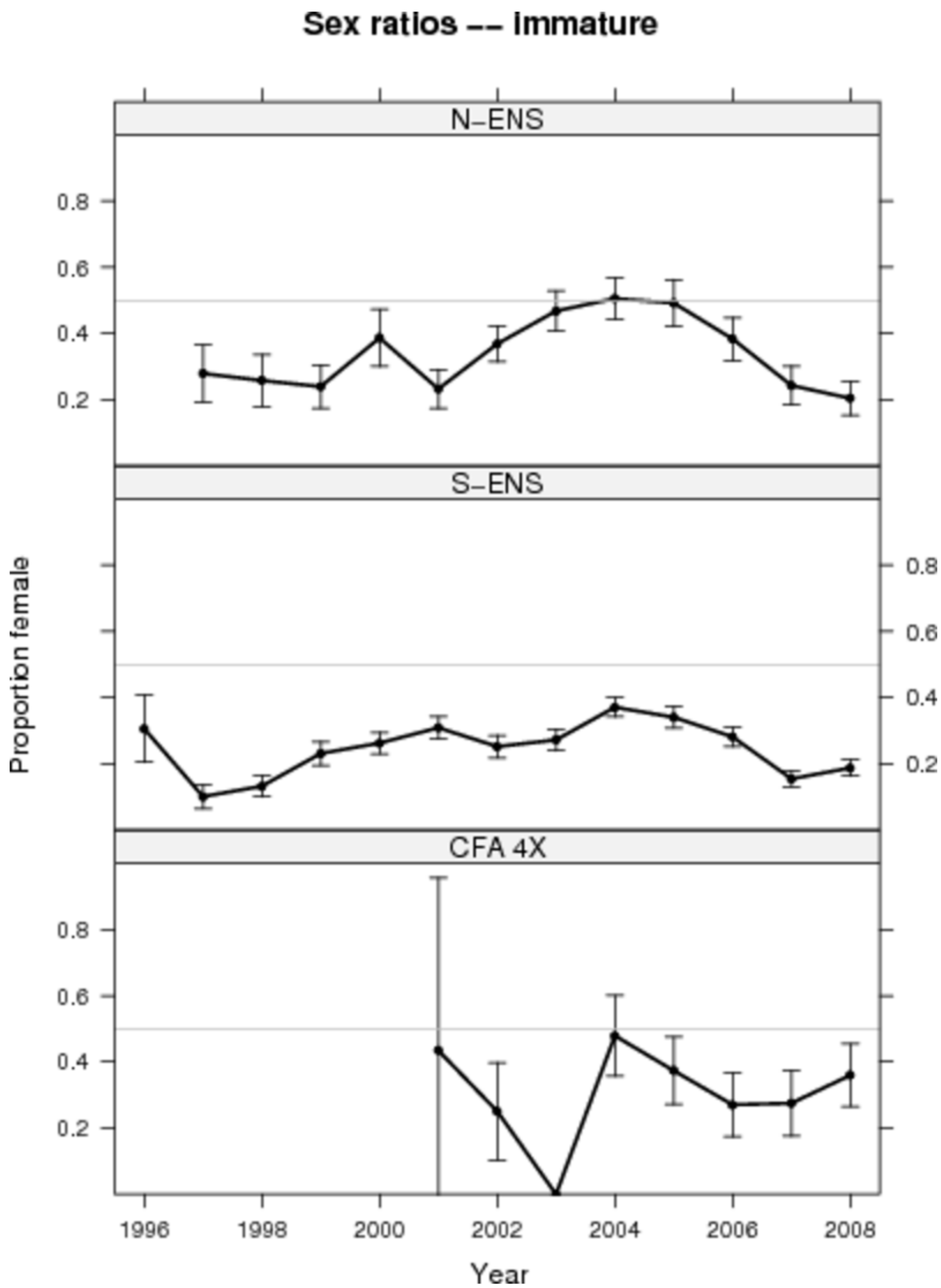


Figure 39. Annual variations in the mean sex ratio (proportion female) for morphometrically immature crabs. One standard error bars are presented.

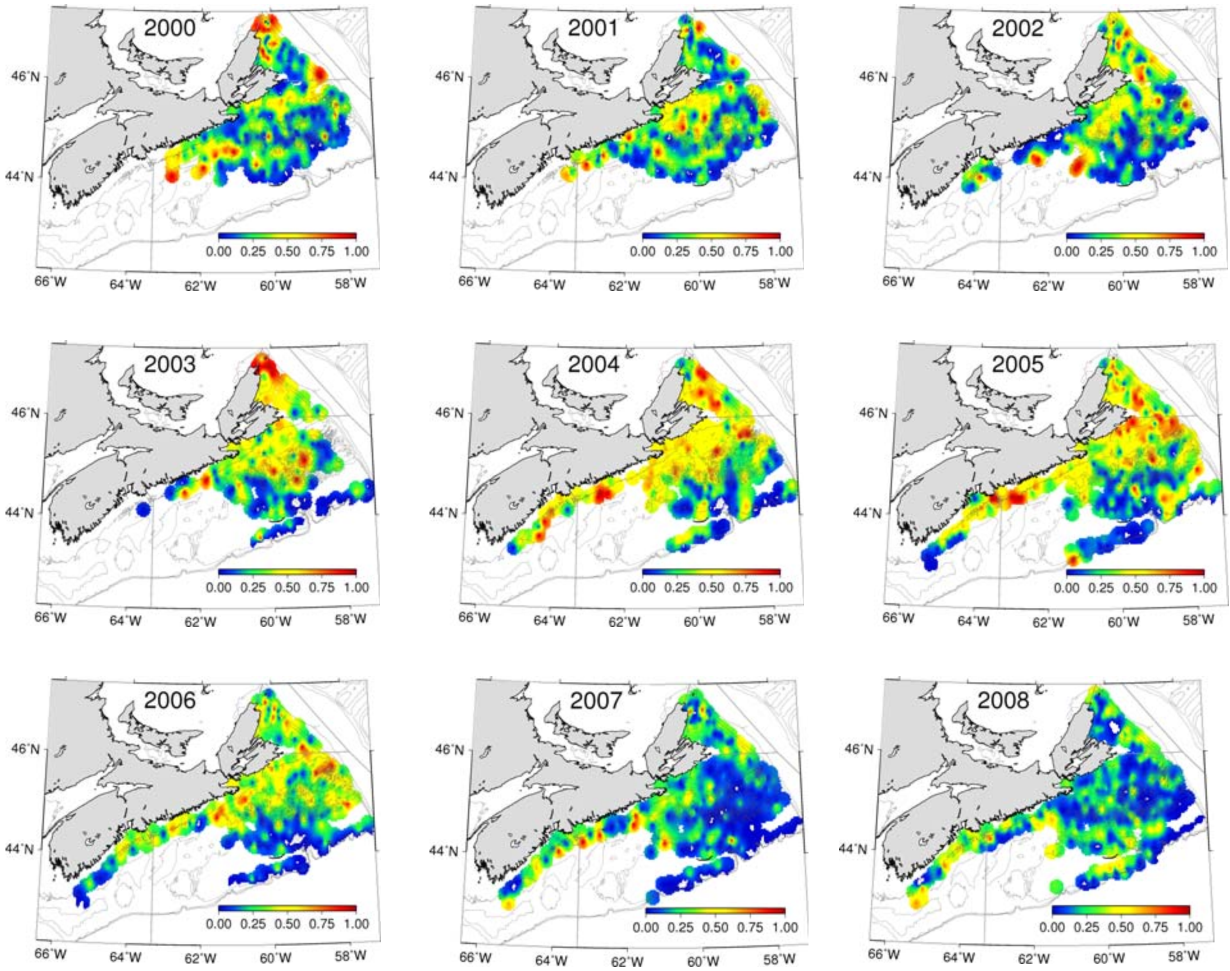


Figure 40. Morphometrically immature sex ratios (proportion female). Inshore areas are generally more balanced in sex ratios or more female dominated. Offshore areas were more male dominated. In the past, this was not always the case and sex ratios of immature crabs were more heterogeneous. Currently, a return to this more heterogeneous state has been observed.

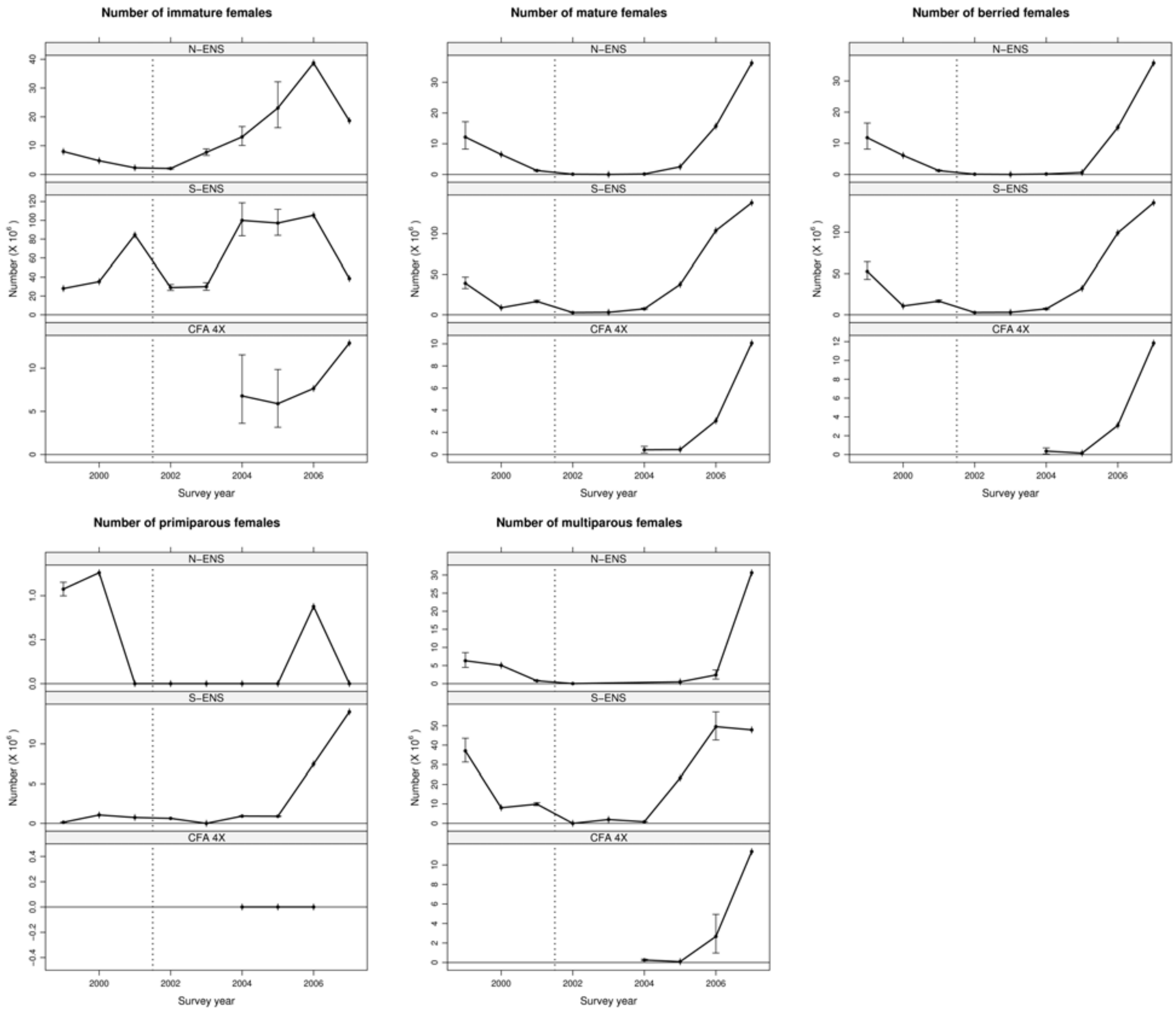


Figure 41: Temporal variations in female snow crab abundance obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

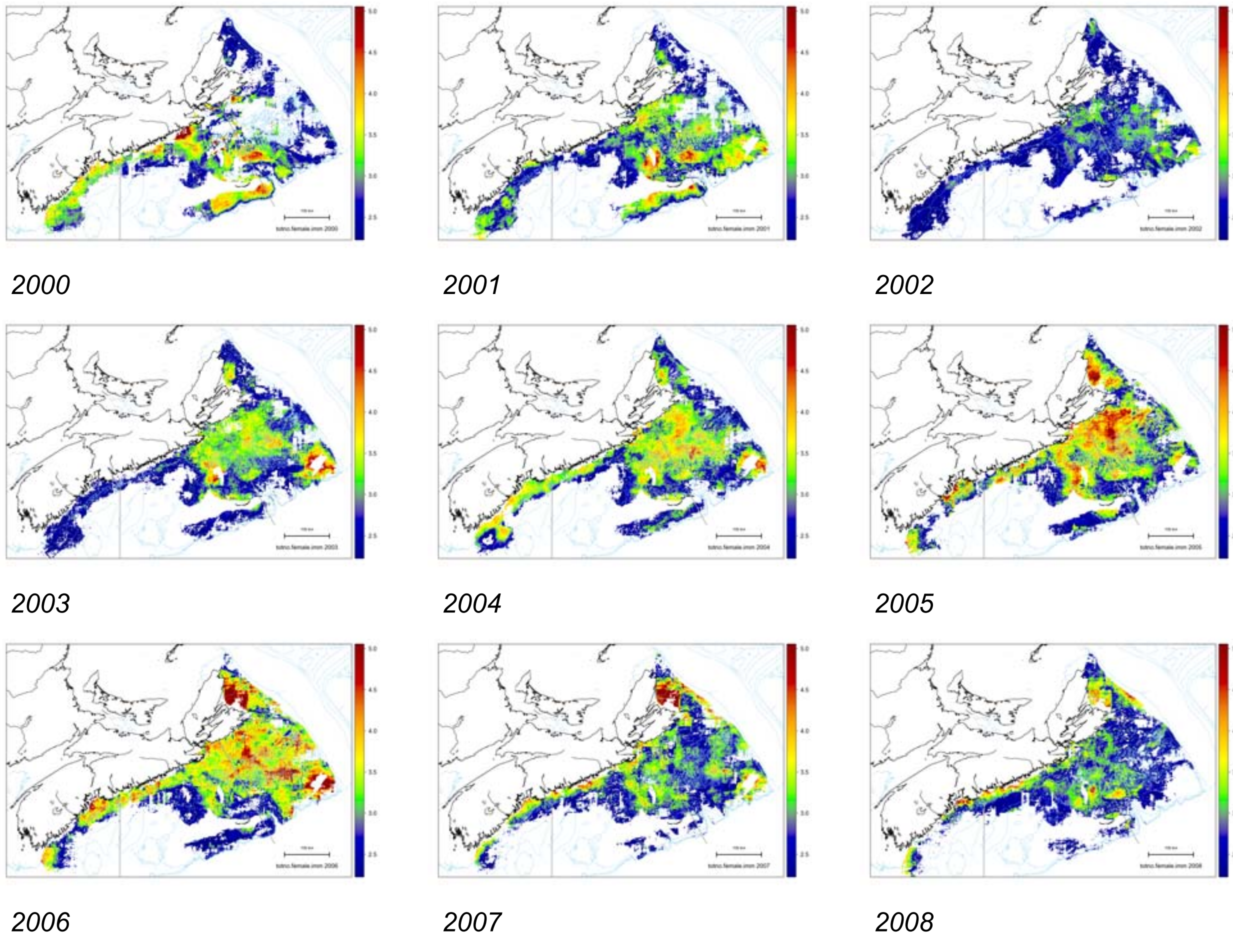


Figure 42: Numerical densities of the immature female snow crabs on the Scotian Shelf; $\log_{10}$ (number/km^2).

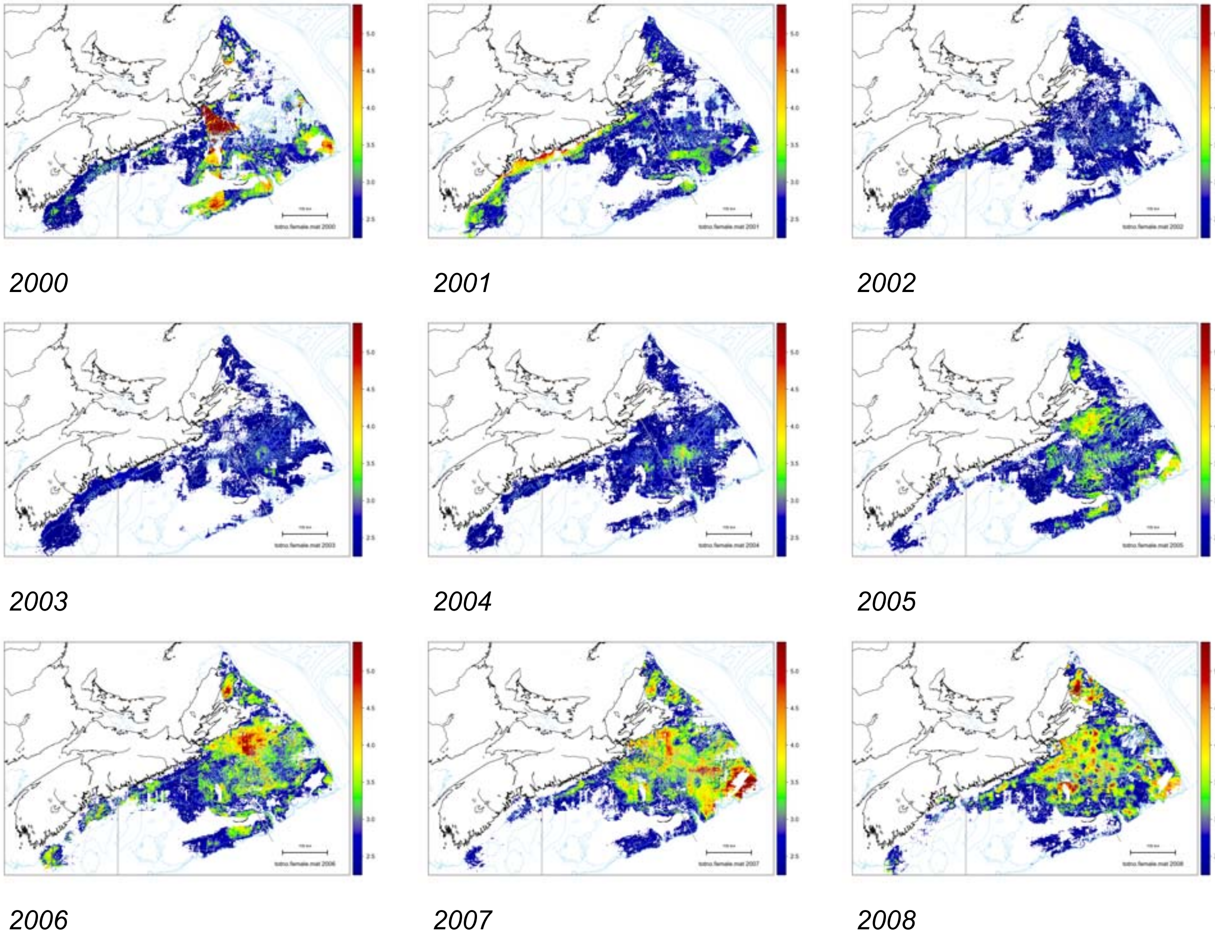


Figure 43. Numerical densities of the mature female snow crabs on the Scotian Shelf; log_{10} (number/km^2).

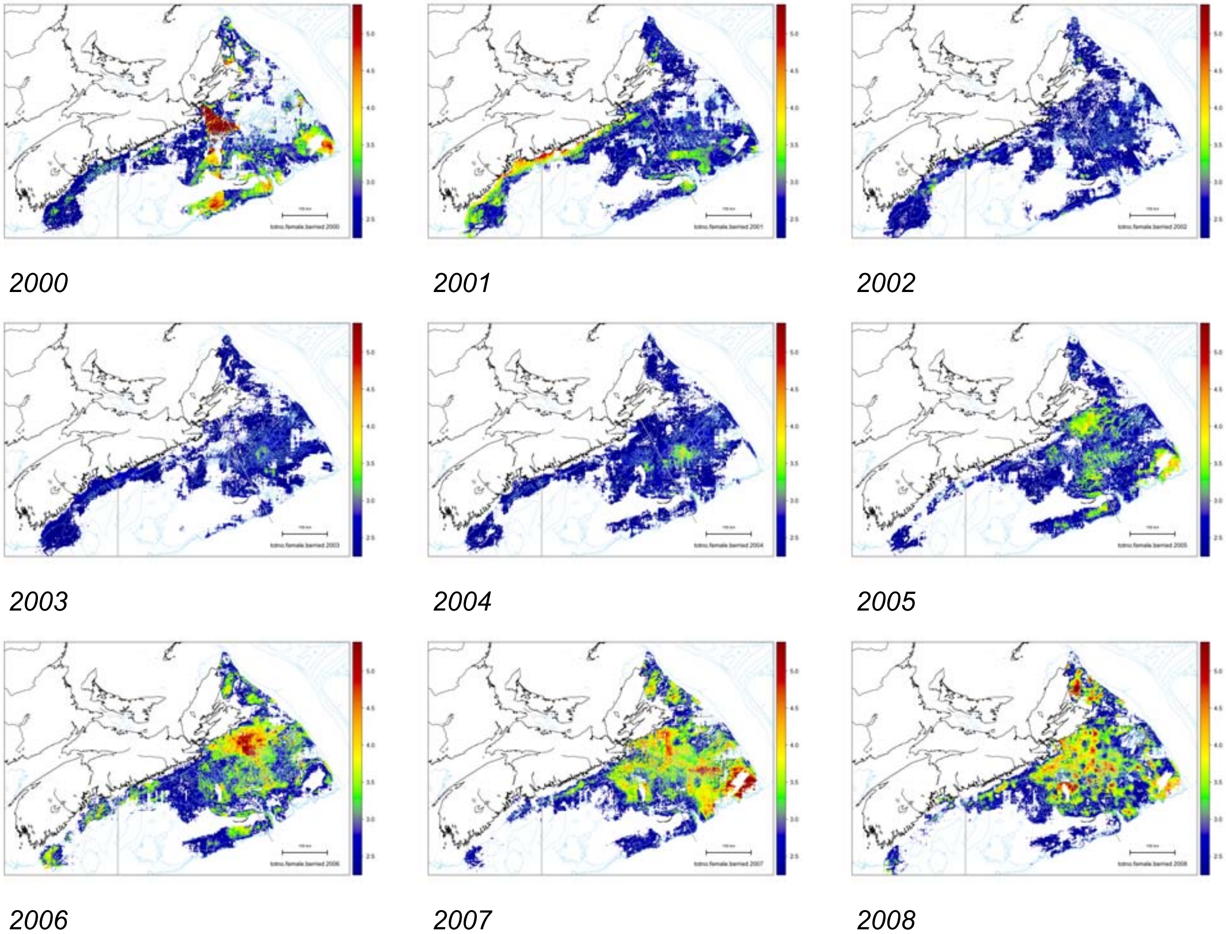


Figure 44. Numerical densities of the berried female snow crabs on the Scotian Shelf; log_{10} (number/km^2).

N-ENS *S-ENS* *CFA 4X*

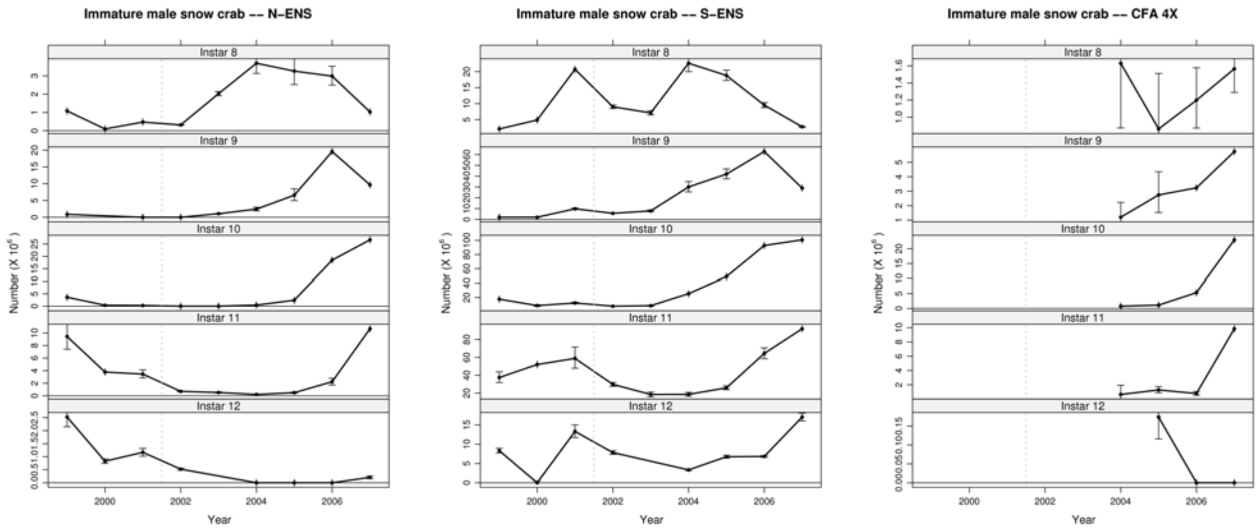


Figure 45. Temporal variations in immature instars (9 to 12) of male snow crab abundance obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period. Note 2008 data are not yet available.

N-ENS *S-ENS* *CFA 4X*

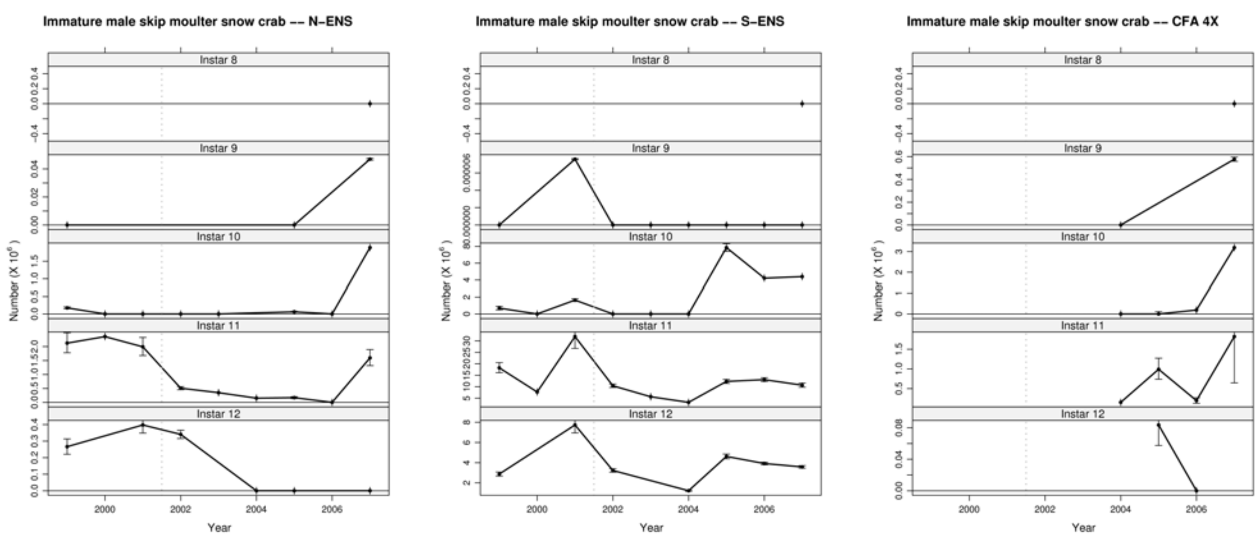


Figure 46. Temporal variations in immature skip moulting instars (9 to 12) of male snow crab abundance in N-ENS obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

N-ENS *S-ENS* *CFA 4X*

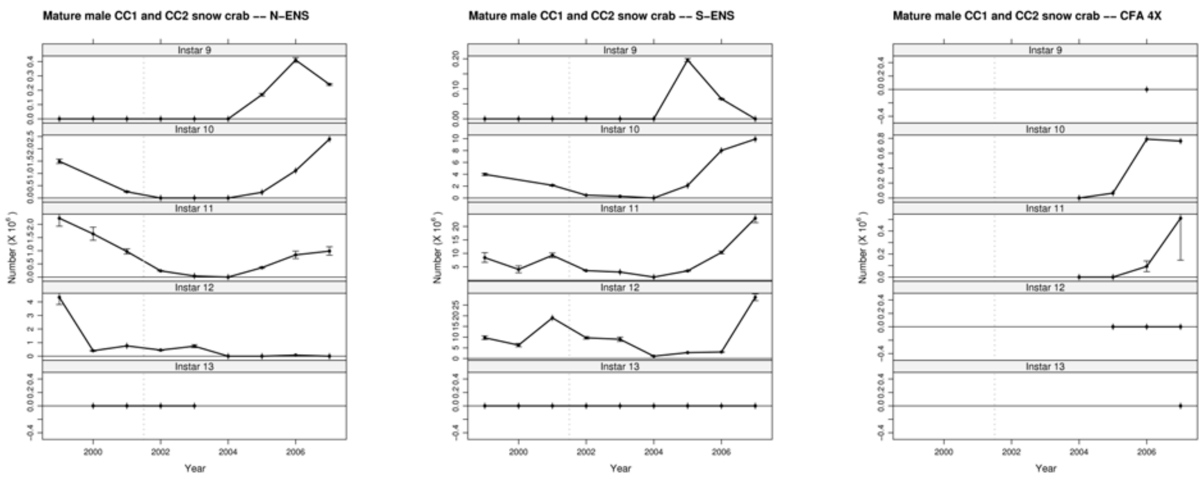


Figure 47. Temporal variations in mature CC1 and CC2 instars (9 to 13) of male snow crab abundance obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

N-ENS *S-ENS* *CFA 4X*

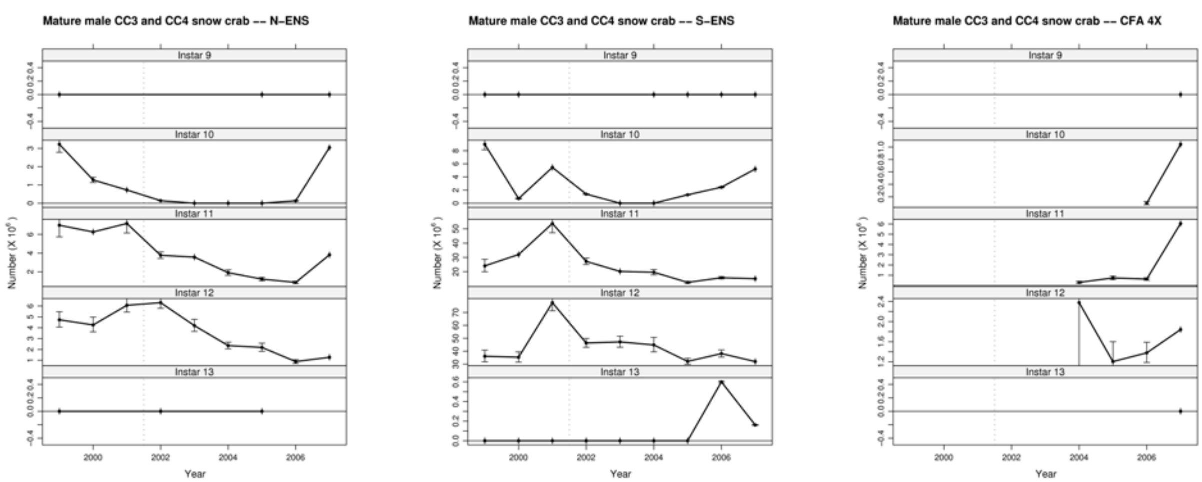
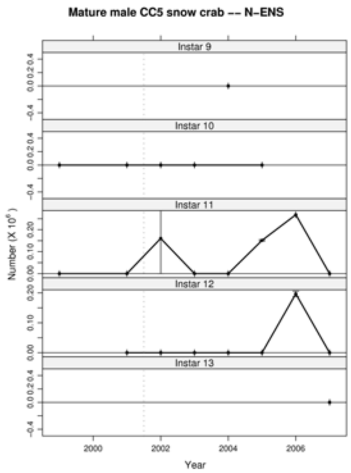
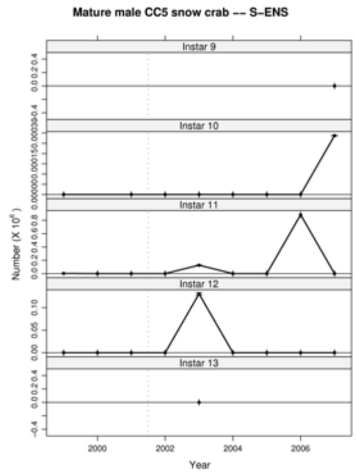


Figure 48. Temporal variations in mature CC3 and CC4 instars (9 to 13) of male snow crab abundance obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

N-ENS



S-ENS



CFA 4X

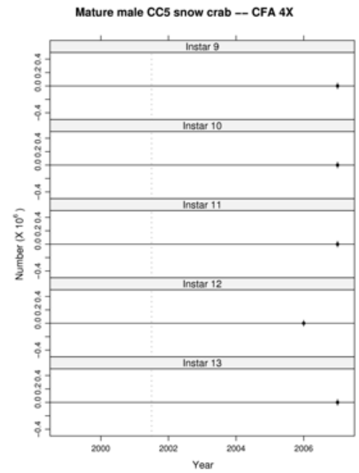


Figure 49. Temporal variations in mature CC5 instars (9 to 13) of male snow crab abundance obtained from kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period. Note that in CFA 4X, CC5 instars are below the detection limit. Note data from 2008 are not yet available.

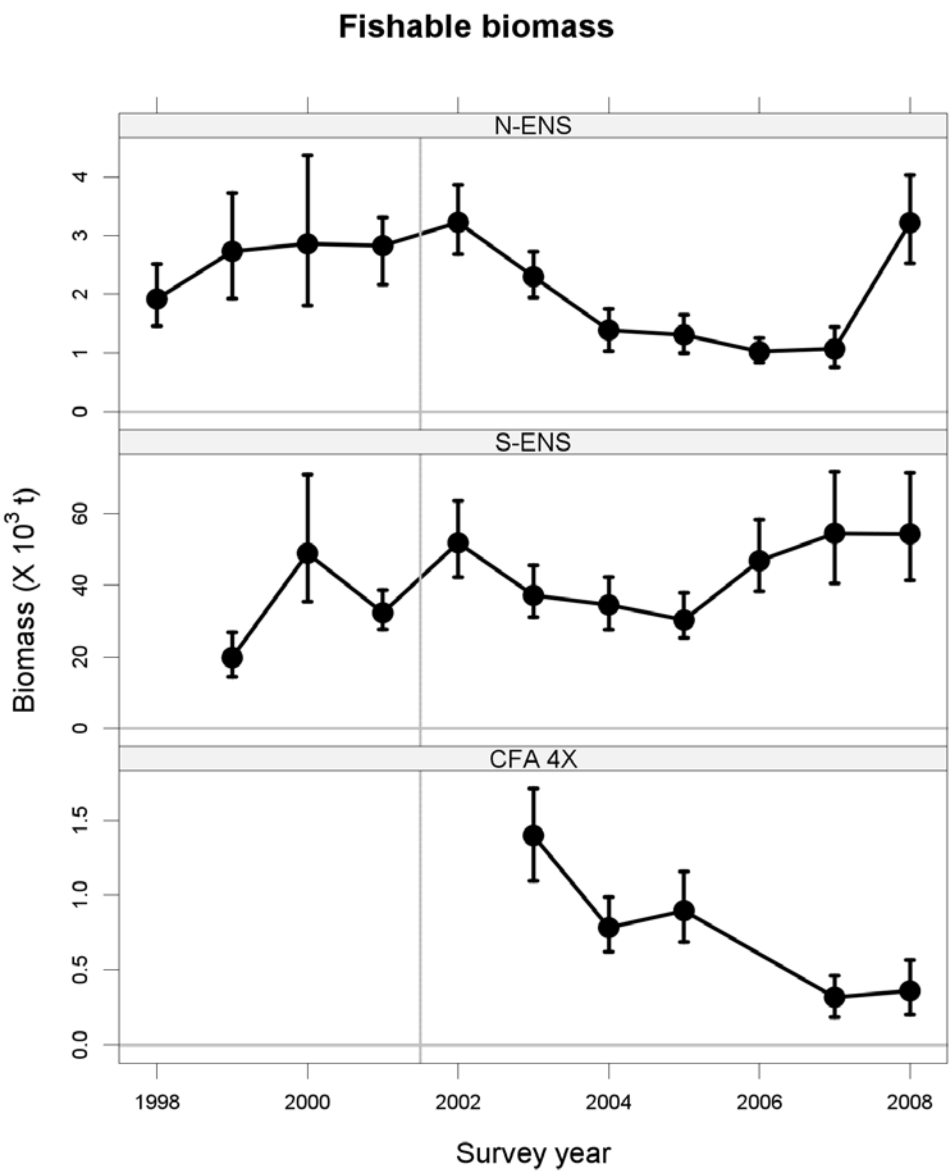
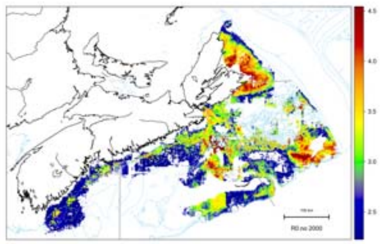
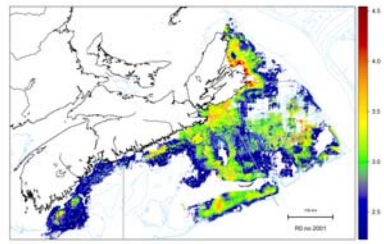


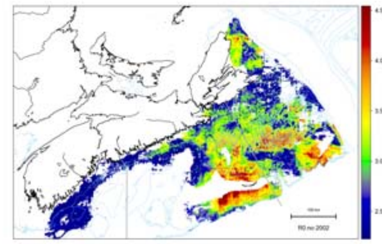
Figure 50: Temporal variations in fishable biomass estimates. Error bars are 95% confidence intervals about the estimated total biomass. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.



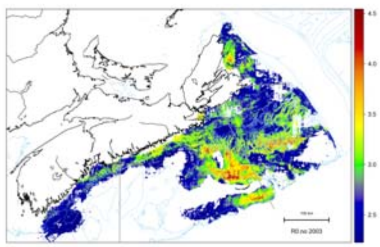
2000



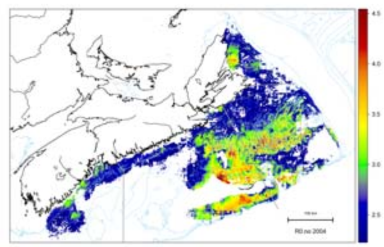
2001



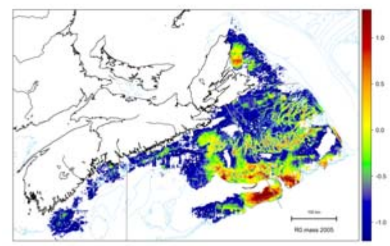
2002



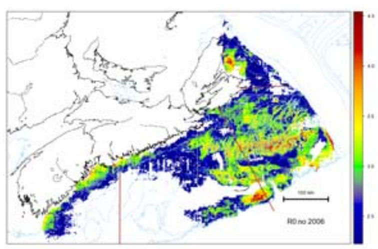
2003



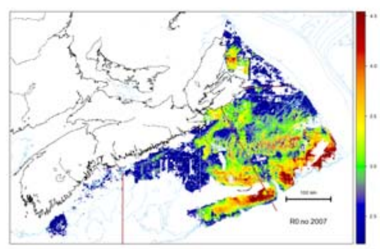
2004



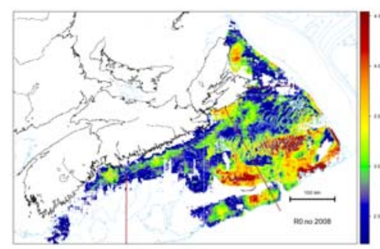
2005



2006



2007



2008

Figure 51: Fishable biomass densities on the Scotian Shelf; log_{10} *(t/km^2).*

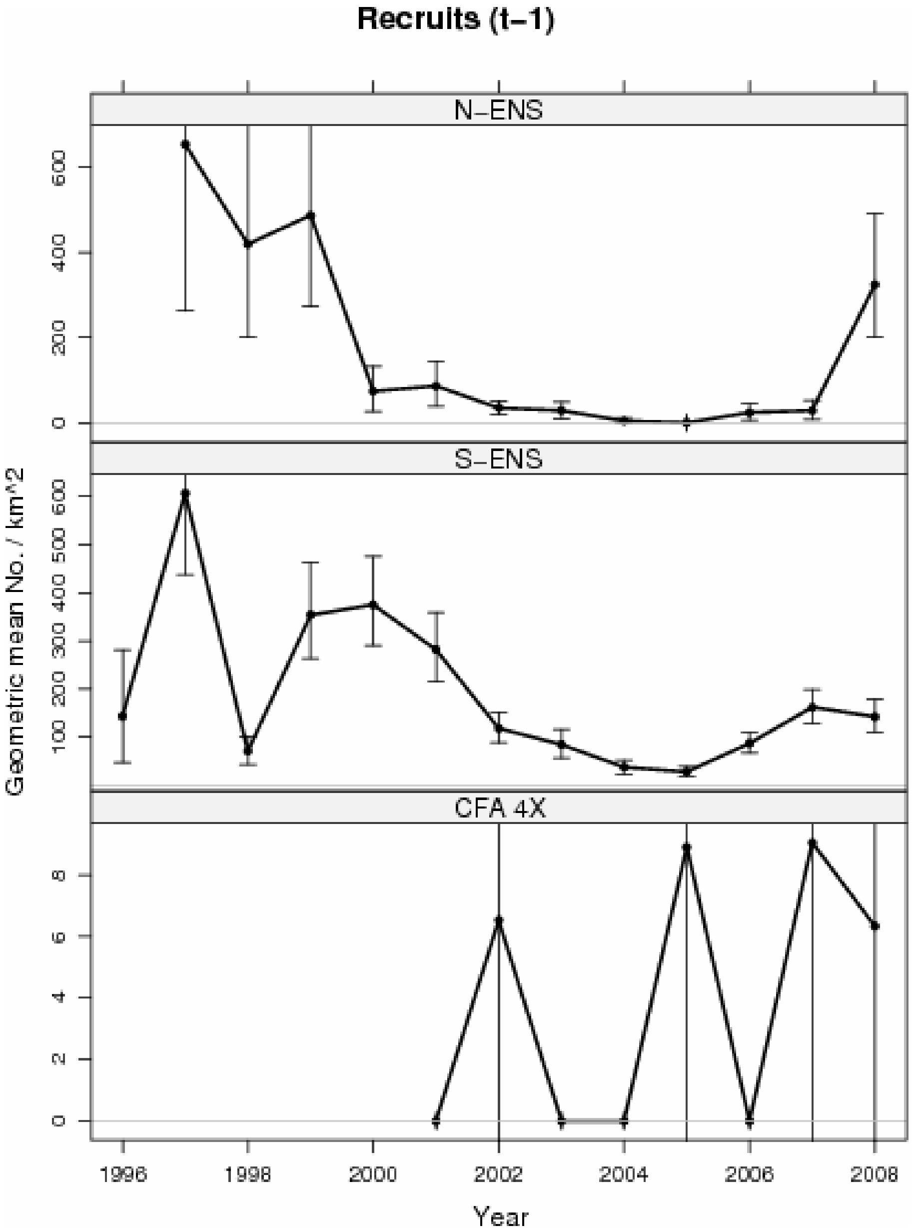


Figure 52: Temporal variations in the expected recruitment into the fishable biomass. This includes only legal sized soft crab. As surveys are conducted in the autumn (since 2002/2003), the majority of recruitment into the fishable biomass has already occurred. This figure shows the additional recruitment expected that has not yet become part of the fishable biomass. Error bars are 95% confidence intervals about the estimated total biomass. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

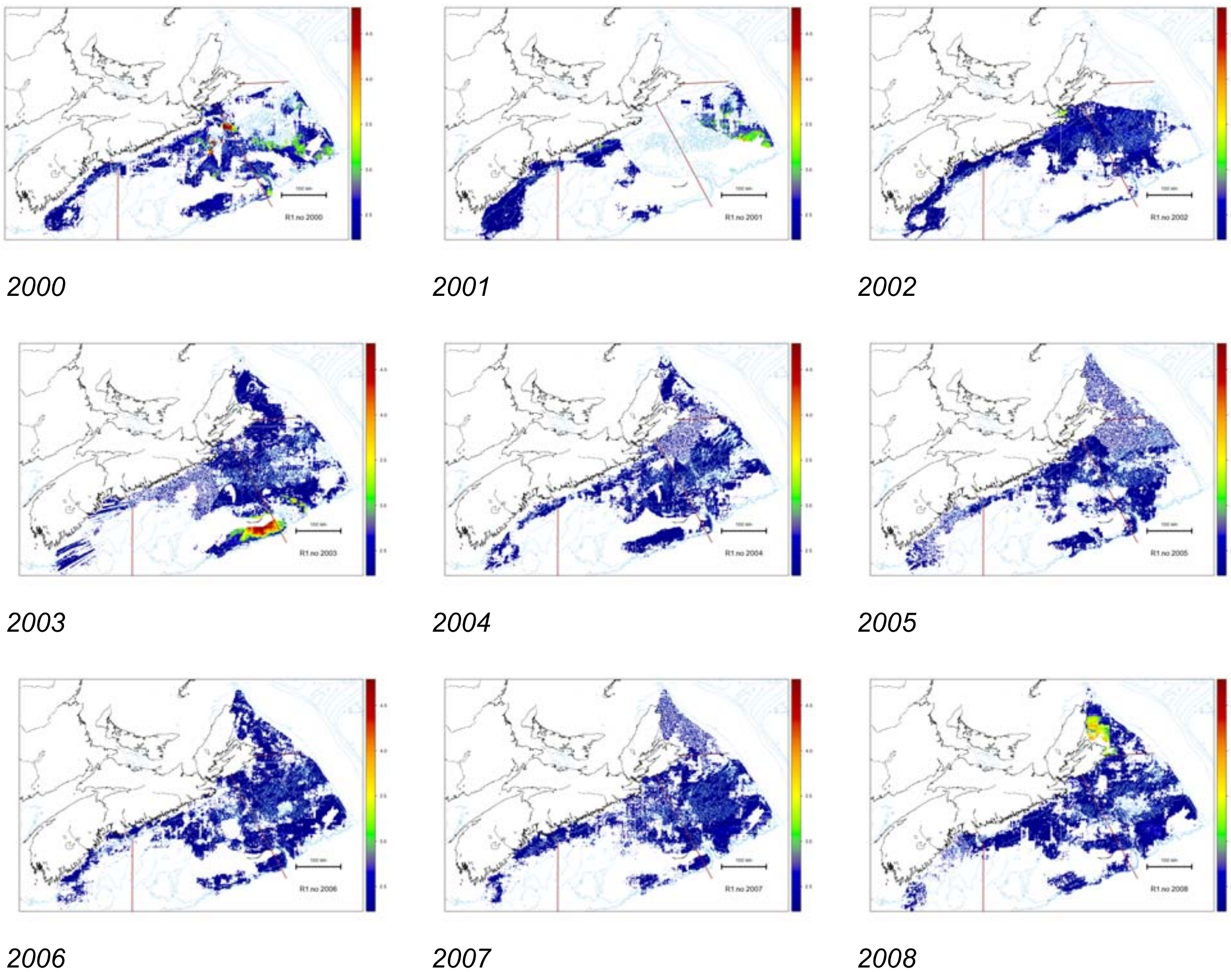


Figure 53. Numerical densities of snow crab recruiting into the next year; $\log_{10}$ *(number/km^2).*

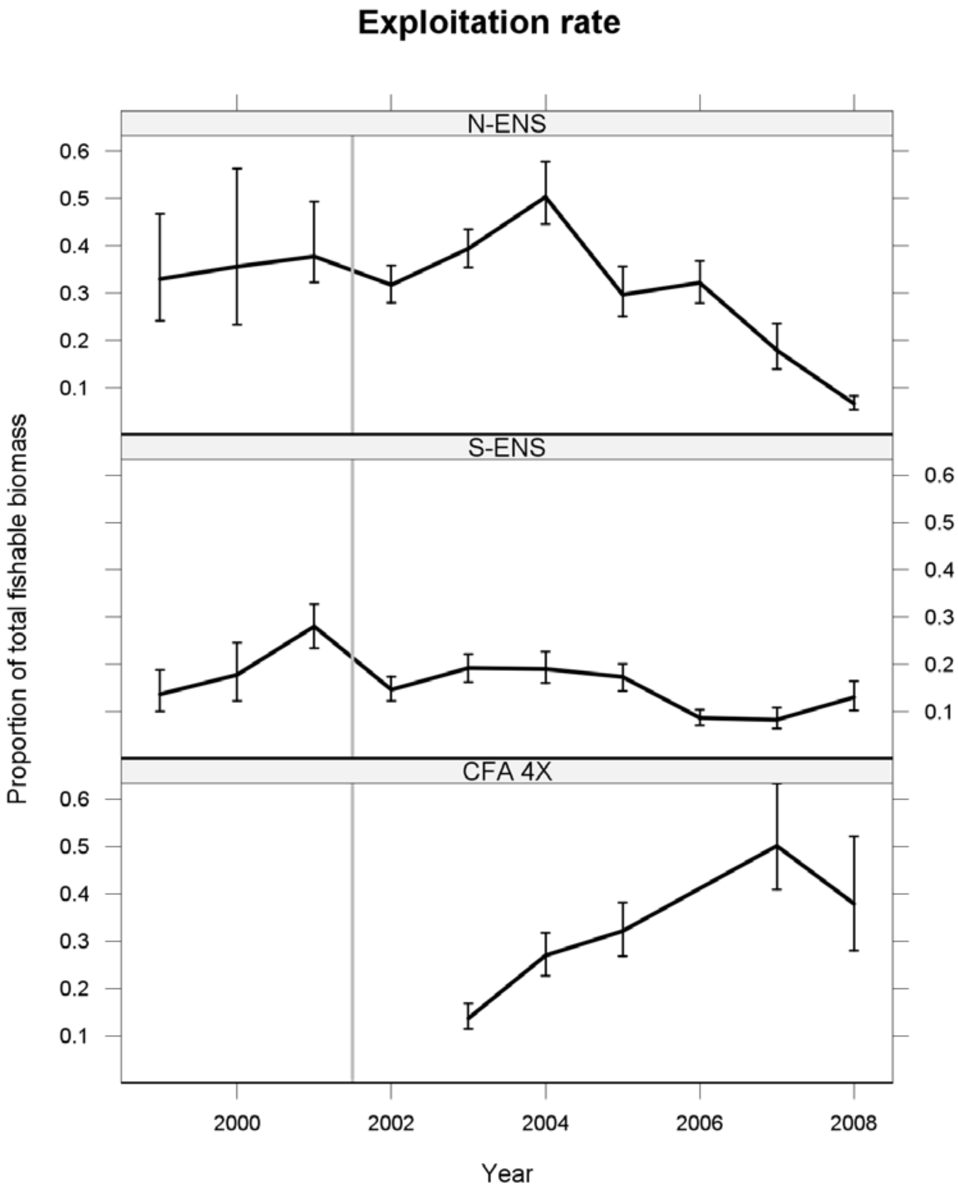


Figure 54: Relative exploitaiton rate (Landings$_{(t)}$ / [Landings$_{(t)}$ + Fishable biomass$_{(t)}$]) of snow crab. Vertical line represents the shift in survey timing from spring to autumn.

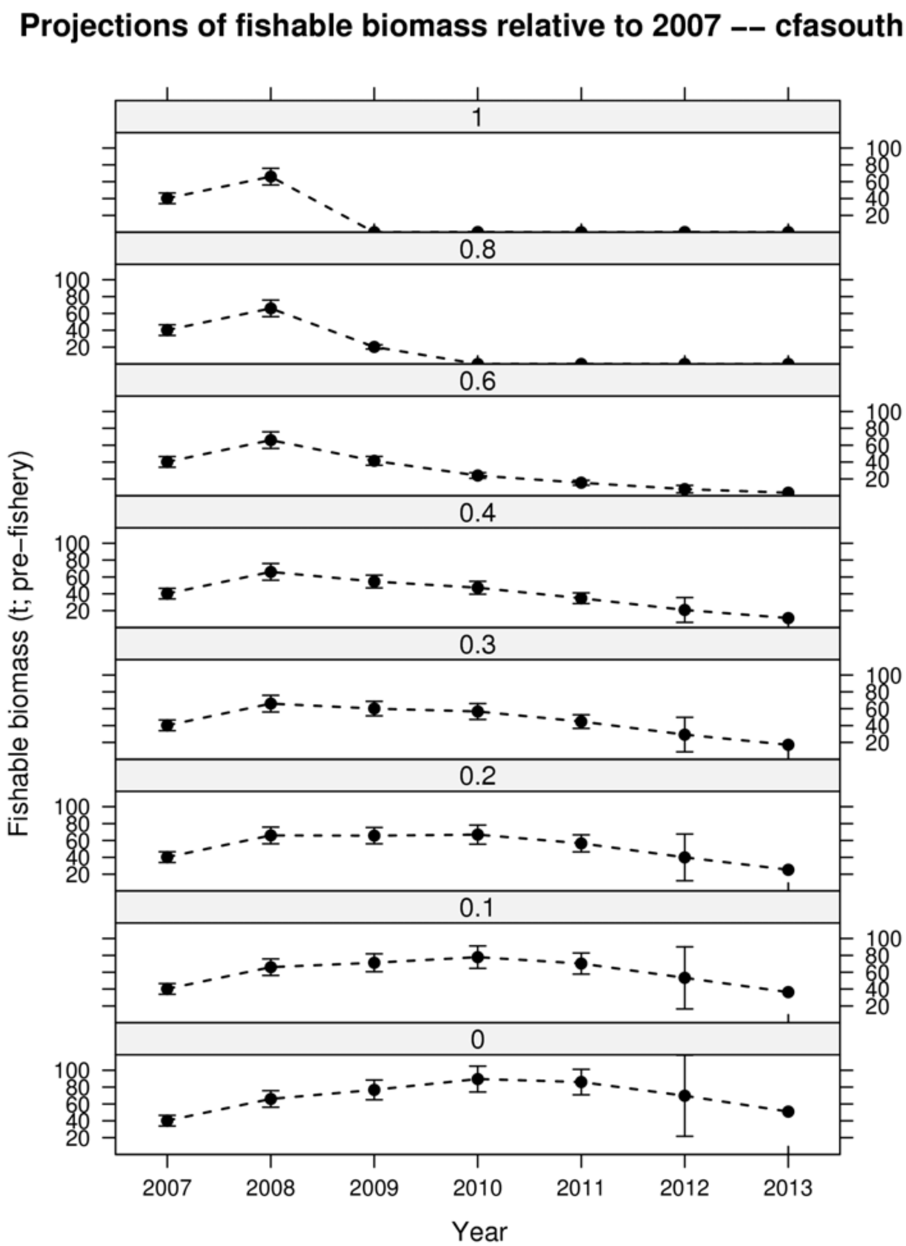


Figure 55: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for S-ENS. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.

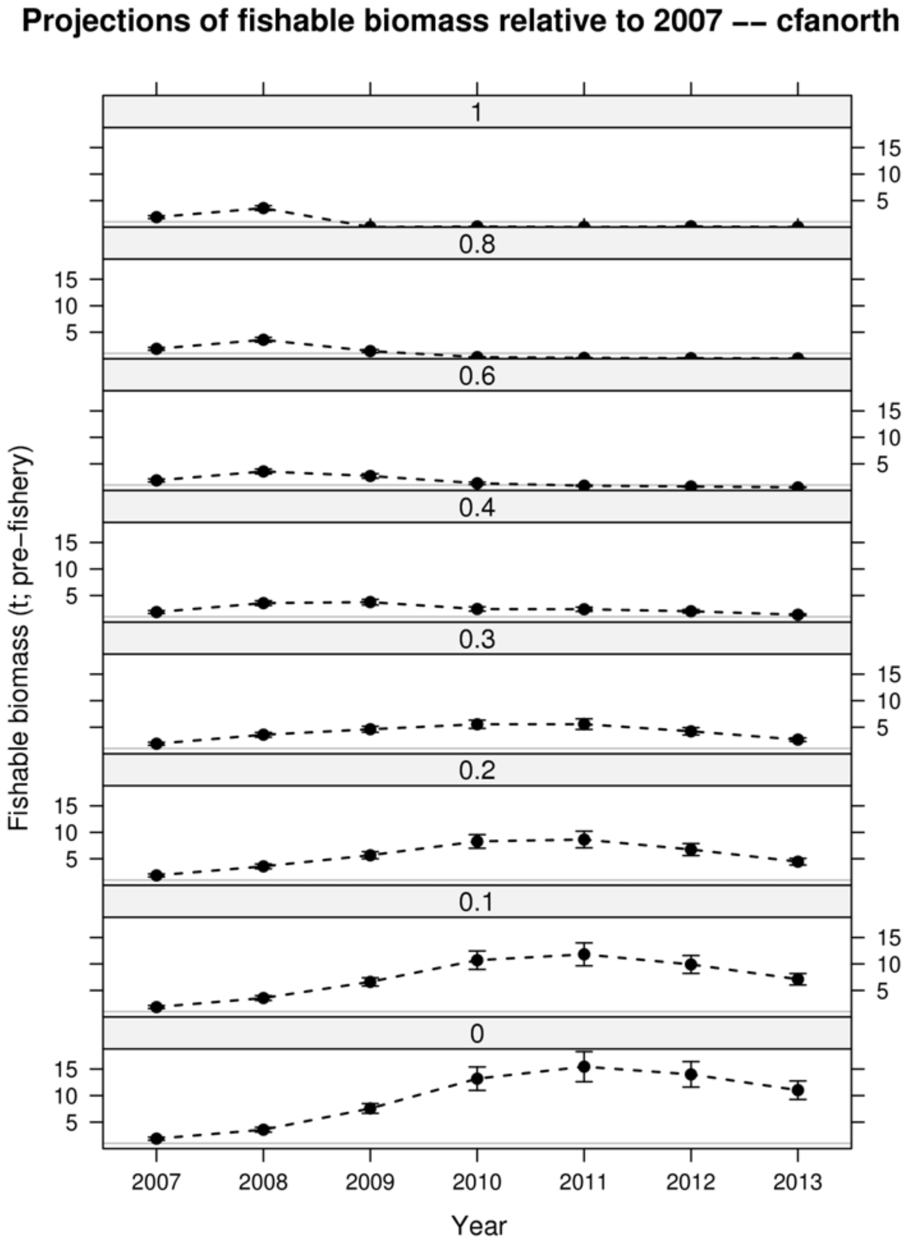


Figure 56: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for N-ENS. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.

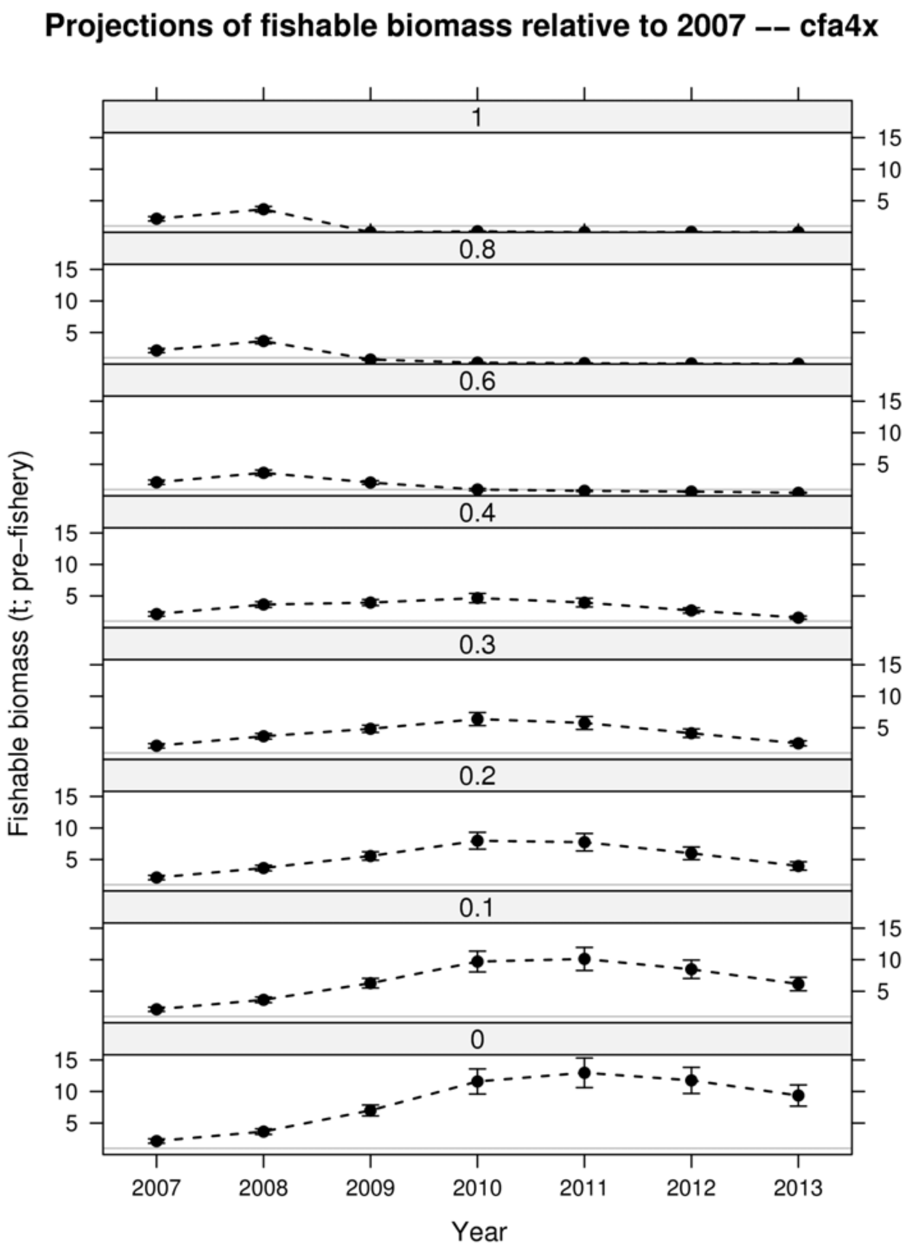


Figure 57: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for CFA 4X. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.