Fisheries and Oceans Canada — Science
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Research Document 2008/012
Document de recherche 2008/012

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Integrated assessment of the snow crab resident on the Scotian Shelf in 2007

Évaluation intégrée du stock de crabes des neiges résidant sur le plateau néo-écossais en 2007

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ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Landings in 2007 were 233 and 4,942 t for N- and S-ENS, respectively and 317 t for CFA 4X in 2006/2007. The associated TACs were 244, 4950 and of 337.6 t, respectively. Average, non-standardized catch rates were 23.6, 100.1 and 27.7 kg $trap^{-1}$, respectively. These catch rates were the lowest in the historical record for N-ENS, an increase in S-ENS, and a marginal decline in CFA 4X, relative to 2006. Soft-shelled crab incidence in the commercial catch of legal sized crab was very high in N-ENS at 41%. In contrast, S-ENS maintained a lower rate of incidence at 9% 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 in 2008. By-catch of non-target species is estimated to be less than 0.02% and 0.33% of total snow crab landings in ENS and CFA 4X, respectively.

In the short-term, recruitment is expected to continue to increase for the next 4 years. Pre-recruits near a 68 mm CW modal group (instars 10/11) have been found in large numbers. The leading edge of this modal group have begun to recruit to the fishable biomass in 2007 and full entry is expected in 2011. In the long-term, the reproductive potential of the Scotian Shelf population has increased with the substantial increase in berried female abundance in all areas. Larval production should continue for another 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. This adds uncertainty to the potential strength of future fishable biomass recruitment. Increasing bottom temperatures on the Scotian Shelf resulting in shrinking of potential habitat is also an uncertainty that may have particularly negative consequences upon the snow crab resident in CFA 4X and parts of S-ENS.

The post-fishery fishable biomass of snow crab was estimated to be 970 t (with a 95% confidence range of: 730 t to 1,230 t) – an increase of approximately 28% relative to 2006 (750 t). This increase was most evident in the northern basin of N-ENS. In S-ENS, the post-fishery fishable biomass increased rapidly in 2007 to 41.59×10^3 t (with a 95% confidence range of: 37.26 to 46.32×10^3 t) – an increase of 47% from 28.22×10^3 t in 2006. The majority of the increases were evident in all core areas of S-ENS, including the Chedabucto area. In CFA 4X, fishable biomass was estimated to be 1,030 t (with a 95% confidence range of: 470 to 1,710 t). This represents no significant change relative to 2006, however the uncertainty about the 2007 estimate was double that of 2006, mostly due to the large temperatures differences between the two years for the 4X region and the lack of sampling stations in these potential habitats.

Relative exploitation rates (by biomass) in N-ENS were 19% in 2007. Projections suggest that an exploitation rate between 10 and 20% may be suitable for long-term sustainability in N-ENS, especially as the area is not able to manage soft-shell capture. A reduction in TAC is recommended.

Relative exploitation rates in S-ENS were 10% in 2007. Maintaining exploitation rates between 10% and 30% would provide the greatest longevity to this fishery. Good recruitment and good control of soft-shell crab capture suggests a positive outlook. An increase in TAC is recommended.

Relative exploitation rates in CFA 4X for 2006/7 was 23%. The region has been exploiting crab at rates between 18 and 36%, which is closer to the range observed in N-ENS, where environmental conditions are thought to be more favourable to crab. Caution is warranted for 2007/8 due to low fishable biomass, high exploitation rates and variable environmental conditions. However the presence of immigration and low soft-shell capture suggests a slightly more positive outlook. A status-quo to reduction in TAC is recommended.

RÉSUMÉ

En 2007, les débarquements ont atteint respectivement 233 et 4 942 t dans le nord-est et le sud-est de la Nouvelle-Écosse, et se sont chiffrés à 317 t dans la zone de pêche au crabe (ZPC) 4X en 2006-2007. Les TAC connexes ont quant à eux été de 244, de 4950 et de 337,6 t respectivement. Les taux de prise moyens non normalisés ont totalisé de leur côté établis 23,6, 100,1 et 27,7 kg casier-1 respectivement. Par rapport à 2006, ces taux de prise sont les moins élevés de la série historique pour le nord-est de la Nouvelle-Écosse, représentent une augmentation dans le sud-est de la Nouvelle-Écosse et constituent un déclin négligeable dans la ZPC 4X. L'incidence de 41 % des individus à carapace molle dans les prises commerciales de crabes de taille réglementaire est très élevée dans le nord-est de la Nouvelle-Écosse. Par contre, dans le sud-est de la Nouvelle-Écosse, l'incidence demeure moins élevée à 9 %, même avec le recrutement d'immigrants observé dans la zone. Dans la ZPC 4X, pratiquement aucun individu à carapace molle n'a été capturé en raison du décalage de la saison. L'incidence des individus à carapace molle demeurera un problème dans le nord-est de la Nouvelle-Écosse en 2008. Les prises accessoires d'espèces non visées devraient respectivement être inférieures à 0,2 et à 0,33 % du total des débarquements de crabes des neiges dans l'est de la Nouvelle-Écosse et dans la ZPC 4X.

À court terme, le recrutement devrait continuer à augmenter au cours des quatre prochaines années. Les pré-recrues s'approchant du groupe modal de 68 mm de LC (stade larvaire 10/11) sont nombreuses. Le recrutement des premiers individus de ce groupe modal dans la biomasse exploitable a débuté en 2007 et devrait être à son maximum en 2011. À long terme, le potentiel reproducteur de la population du plateau néo-écossais s'est accru avec l'augmentation substantielle de l'abondance des femelles oeuvées dans toutes les zones. La production de larves devrait se poursuivre pendant quatre années supplémentaires. Toutefois, des concentrations de prédateurs potentiels du crabe des neiges (immature et à carapace molle) ont été observées dans des zones où se trouvent des densités élevées de crabes des neiges immatures. Cela augmente l'incertitude quant à l'effectif qui pourra faire son entrée dans la biomasse exploitable. L'augmentation des températures de fond sur le plateau néo-écossais, qui entraîne un rétrécissement de l'habitat potentiel, constitue également une incertitude qui peut avoir des répercussions particulièrement négatives sur les crabes des neiges résidant dans la ZPC 4X et dans certaines parties du sud-est de la Nouvelle-Écosse.

On a estimé que la biomasse de crabes des neiges exploitable après la pêche était de 970 t (avec un intervalle de confiance de 95 % : 730 à 1 230 t), ce qui constitue une augmentation d'environ 28 % par rapport à 2006 (750 t). Cette augmentation était la plus évidente dans le bassin nord du nord-est de la Nouvelle-Écosse. Dans le sud-est de la Nouvelle-Écosse, la biomasse exploitable après la pêche s'est accrue rapidement en 2007 pour atteindre 41,59 × 103 t (avec un intervalle de confiance de 95 % : 37,26 à 46,32 × 103 t), soit une augmentation de 47 % par rapport à 28,22 × 103 t en 2006. La majorité de ces augmentations était évidente dans l'ensemble des zones principales du sud-est de la Nouvelle-Écosse, y compris la zone de Chedabucto. Dans la ZPC 4X, on a estimé que la biomasse exploitable était de 1 030 t (avec un intervalle de confiance de 95 % : 470 à 1 710 t), ce qui ne représente aucun changement significatif par rapport à 2006. Toutefois,

l'incertitude concernant l'estimation de 2007 était deux fois plus grande que celle de 2006, notamment en raison des importants écarts de température entre les deux années pour la région 4X et l'absence de stations d'échantillonnage dans ces habitats potentiels.

Les taux d'exploitation relatifs (par biomasse) dans le nord-est de la Nouvelle-Écosse ont été de 19 % en 2007. Selon les projections, un taux d'exploitation se situant entre 10 et 20 % pourrait assurer la durabilité à long terme dans le nord-est de la Nouvelle-Écosse, particulièrement du fait que l'on est incapable de gérer les prises d'individus à carapace molle dans cette zone. On recommande de réduire le TAC.

Les taux d'exploitation relatifs dans le sud-est de la Nouvelle-Écosse ont été de 10 % en 2007. Le maintien des taux d'exploitation entre 10 et 30 % pourrait assurer une longévité optimale à cette pêche. Un bon recrutement et une bonne régie des captures d'individus à carapace molle pourraient soutenir des perspectives positives. On recommande d'augmenter le TAC.

Les taux d'exploitation relatifs dans la ZPC 4X en 2006-2007 ont été de 23 %. Dans la région, on exploite le crabe à des taux variant entre 18 et 36 %, ce qui est plus proche des taux observés dans le nord-est de la Nouvelle-Écosse, où les conditions environnementales seraient plus favorables pour le crabe. La prudence est de mise en 2007-2008 en raison de la faible biomasse exploitable, des taux d'exploitation élevés et des conditions environnementales variables. Toutefois, la présence d'immigrants et les faibles prises d'individus à carapace molle laissent entrevoir des perspectives un peu plus positives. On recommande de maintenir le TAC ou de le réduire.

INTRODUCTION

In keeping with the Oceans Act (1996) and DFO's mandated approach towards the management of the oceans 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. Due to the intrinsic complexities of both natural and exploited ecosystems, this attempt at developing an ecosystem-based assessment is necessarily incomplete.

MANAGEMENT

On the Scotian Shelf, the snow crab fishery is managed as three main areas: N-ENS, S-ENS and CFA 4X (Figure 1, Table 1). 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 Crab Fishing Areas (CFAs) 23A, 23 and 24.

Similarly, 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. In particular, the CFA 4X season was set to run from the beginning of November to the end of May, completely disjoint from the ENS fishing period of June to September. The rationale for this choice was that better quality snow crab were caught during this period for the commercial market with the least amount of overlap with the lobster season. The fishing seasons for 2007 are summarised in Table 1.

From 1982 to 1993, the management of the N- and S-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 gradually implemented in this fishery. Voluntary management measures requested by fishermen 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 due to the expectation of an increased incidence of soft-shelled snow crab and the potential harm associated with handling mortality. The relative abundance of soft-shelled crab observed by at-sea-observers was relayed within 24 hours of landing to DFO, which was subsequently plotted on a 2-minute grid and 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). However, this approach was not adopted in all areas due to logistical issues (low observer coverage and/or short fishing period) in N-ENS and CFA 4X (and resulted in extremely high incidence of soft-shelled crab in N-ENS in 2007; see below). Finally, the voluntary return to the sea of immature legal sized crab ("pencil-clawed" crab) was implemented in 2006 for all areas on the Scotian Shelf 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 & Dallaire 2003). On the Scotian Shelf, the snow crab fishery has been in existence since the late 1970's (Figure 2). The earliest records of landings were at levels of < 1,000 t, mostly in the nearshore areas of Eastern Nova Scotia (ENS; Figure 3). By 1979, this rose to 1,500 t subsequent to which the fishery declined substantially in the mid-1980s and was considered a collapsed fishery. Strong recruitment to the fishery returned 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 and continues at low levels.

A trawl survey of snow crab on the Scotian Shelf was developed by the Gulf Fisheries Centre, Moncton, New Brunswick (GFC) as a fisheries-independent assessment approach in 1996 and accepted in 1999. These surveys demonstrated the presence of previously 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). Trawl surveys were formally extended to CFA 4X in 2004.

Annual TACs continued to increase to historical maxima in 2002/2003 at 9,113 t in S-ENS and 1,500 t in N-ENS; landings were stable at approximately 10,000 t 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 exploitation. However in 2004, with persistently low levels of recruitment and a steady decline in fishable biomass since the early-2000s, a more precautionary exploitation tact was adopted throughout N-ENS, S-ENS and CFA 4X. This approach continued to 2007 (Tables 2-4) due to continued signs of low recruitment. Signs of over-exploitation were particularly evident in N-ENS and CFA 4X.

METHODS

This assessment uses a species-specific trawl-based survey as the primary source of information about the current status of snow crab. The analytical approaches used to assess this snow crab population have developed to accommodate for the high inter-annual variability in the spatial distribution of this population of snow crab that exists on the southern-most extreme of their distributional range.

General analytical tools

All analytical tools were open-sourced software. Maps for visualisations were constructed with GMT (Generic Mapping Tools, Wessel & Smith 1998, version 4.1). For results that were not kriged (due to biological categories with highly heterogeneous distributions), the *splines-in-tension* data smoothing and interpolation technique was used with the tension parameter T set at 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 (see below). Conversions between cartographic and cartesian co-ordinate systems for analytical purposes were computed with PROJ (Evenden 1995, version 4.4.9), using a Lambert conformal conic projection and the WGS84 spheroid with the central meridian at 63^{o}W and standard parallels at 43^{o}N and 47^{o}N. All other data analyses were implemented in the statistical computing language and environment R (R Development Core Team 2007, version 2.6.1; Venebles & Ripley 2002) to allow migration and documentation of methods into the future. Kriging was conducted with the R package, GSTAT (Pebesma 2004, version 0.9-35). The complete analytical suite, coded in R, has now been completed and posted to http://autocatalysis.googlepages.com/snowcrabanalysis.

Fisheries data

Catch rates are biased indicators of abundance as both the spatial and temporal distribution of crabs and the fishing effort are not uniform, varying strongly with season, bottom temperatures (potentially causing crowding into core areas), food availability, timing of spring plankton blooms, reproductive behaviour and 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). Exhaustive data quality checks were completed. Catch rates (kg $trap^{-1}$) were computed as the ratio of total landings to total trap hauls, using data from properly completed logbook records. Catch rates are reported without standardisation. Total trap hauls for a given group is computed by dividing the total landings by their respective catch rate.

At-sea-observer data provide information about the size structure and the carapace condition of the commercially exploited stock (Table 5). The data are stored in a centrally organised relational database (Observer Database System). At-sea-observers are deployed randomly (Figure 5) with the coverage being as evenly distributed between areas as possible. 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 by-catch of other non-snow crab species by the snow crab fishery. By-catch estimates of each species *i*, was extrapolated from the biomass of species *i* observed in the catch and the relative observer coverage in two manners as follows:

By Landings:

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

By Effort:

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

Research survey data

Assessments are based upon a survey dedicated to snow crab assessment on the Scotian Shelf, introduced by the GFC in 1996 (Biron et al. 1997) and funded by the snow crab industry through a Joint Project Agreement. Spatial coverage in the survey is (1) **extensive**, going well beyond all known commercial fishing grounds and (2) **intensive**, with a minimum of one 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 & Legendre 1998; Kern & Coyle 2000). Since 2004, over 350 stations have been sampled annually on the same fishing vessel, The Gentle Lady (a 65 foot trawler) with the same captain. In the 2007 survey, 378 stations were sampled, 4 more than in 2006.

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 even 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.

With the 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. The survey is 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 (April to July; i.e., pre-fishing season in ENS). As a consequence, temporal trends are most reliable for the post-2002 period. In the southern-most area of snow crab distribution (CFA 4X) trawl survey coverage has been historically sporadic. A renewed effort has been made to stabilise the spatial coverage in this area 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). Tows were conducted for ~ 5 minutes in duration with actual duration of bottom contact being monitored by Netmind sensors. The width of the mouth of the net was also monitored with Netmind sensors. The ship speed was maintained at ~ 2 knots. The warp length was ~ 3 × the depth. Positional information as well as water temperature measurements were collected using a global positioning system and Minilog data recorders, respectively. The surface area swept by the net was calculated from swept distance and net width information.

All crab were enumerated, measured with callipers, shell condition described (Table 5), claw hardness determined 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).

Pre-2004 snow crab biomass estimates were approximated from carapace width (CW) measurements by applying the allometric relationships developed for the Scotian Shelf 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 morphometric maturity. 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 carapace width (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 the 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 carapace width (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):

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

where the individual is considered mature if $M_{female} > 0$.

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

$$\begin{aligned} Sex\ ratio_{(immature)} &= \frac{N_{(female,\ immature)}}{N_{(female,\ immature)} + N_{(male,\ immature)}} \\ Sex\ ratio_{(mature)} &= \frac{N_{(female,\ mature)}}{N_{(female,\ mature)} + N_{(male,\ mature)}} \end{aligned}$$

Size-frequency histograms were constructed (expressed as number per unit area swept by the trawl (km^{-2}); i.e., the arithmetic mean numerical density per unit area in each size interval). Modes and the bounds of the each modal group were identified from size frequency distributions. Each instar was determined after an analysis of size-frequency distributions to have a lower bound of carapace width (mm) approximated by (see also Figure 7):

$$\begin{aligned} CW_{(lower,\ male)}\ [mm] &= \exp(1.918 + 0.299 \times (Instar - 3)) \\ CW_{(lower,\ female)}\ [mm] &= \exp(2.199 + 0.315 \times (Instar - 4)) \end{aligned}$$

The locations of "*most likely snow crab habitats*" were determined on high resolution depth maps (15 arc-second resolution) obtained from the Canadian Hydrographic Service. The range of observed depths of Scotian Shelf snow crab (between 60 m to 280 m; Figures 8, 9) were used to delineate these potential snow crab grounds. For each year, maps of preferred snow crab temperature locations were made using Optimally Estimated bottom temperature maps (obtained from the Ocean Science Division of BIO, DFO). Preferred snow crab temperatures on the Scotian Shelf ranged between -1^{o}C to +6 ^{o}C (Figure 10). These two sources of information were combined to delineate the most probable locations of snow crab habitat (Figure 11). This dynamically changing habitat range was used to predict the biomass and numerical densities of crab.

The ranges chosen were expansive to allow abundance estimates of both the females, immatures, and CC5 crab as well as the fishable biomass. Due to the choice of these more expansive ranges, it is likely that fishable biomass is slightly over-estimated while the numerical abundance of females, immatures and CC5 crab are likely underestimated due to the greater abundance of non-commericially exploited crabs in warmer and shallower environments. These biases will be corrected in the near future. Further, deviating slightly from the 2005 assessment protocol, additional areas were included as potential snow crab habitat even if they were warmer than +6 C to a spatial extent of 10 km radius from a survey station. This modification was implemented as on occasion, crab (mostly immature and female crab) were observed in warm waters (e.g., CFA 4X and continental slope waters). This result may have been due to rapid changes in bottom temperatures trapping crab into pockets of high local density and/or adaptation (acclimation) to the warmer temperatures of some areas and the overall very warm bottom conditions in 2006. This issue will be studied further in the future. It should be emphasized that this was mainly an issue with immature and female snow crab in S-ENS and so will likely contribute to their under-estimation. Conversely, this addition of the extra surface area may also contribute to the over-estimation of fishable biomass in S-ENS.

The estimation of biomass and numerical densities involved the use of 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 an isotropic 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.

An alternative and more robust formulation used in this assessment is Cressie's *modulus* estimator (Cressie 1993):

$$2\hat{\gamma}(\triangle x) = \frac{\left[\frac{1}{N_{\triangle x}}\sum_{N_{\triangle x}}|Z(x_{i+\triangle x}) - Z(x_i)|^{1/2}\right]^4}{0.457 + 0.494/|N_{\triangle x}|}$$

Variograms were constructed using an automated process that chose a functional form (bessel, spherical, exponential, circular, gaussian or generalised Matern) that best described the spatial variance using a nonlinear least-squares criterion (an example is provided in Figure 12). When solutions did not converge, moving time-averaged empirical variograms (scaled to unit variance) of variable window sizes (i.e., in both space and time) were constructed until reliable solutions were obtained. A three-year window was generally sufficient for stabilisation. The final solution was re-scaled to the local variance of the region and year of interest.

Spatially explicit means and variances were then obtained using Universal Kriging with External Drift (UKED), whose solutions were also used for visualisations. UKED is a technique that linearly accounts for variations in external parameters under the kriging formalism. The most significant such variables were determined from bivariate analyses to be: depth, bottom temperature, average fishery catch rates (domain of fishing core areas), all discretised to 2×2 km^2. Where the relationships with abundance measures were nonlinear, the variables were transformed to a linear relationship. Due to the extreme irregularity of the potential snow crab habitat space, Ordinary Block Kriging, using blocks of 1×1 km^2 resolution was used to estimate 95% confidence bounds of the predicted intensive variables (biomass and numerical densities). When problems of solution convergence were observed (due to sparse spatial coverage as with some classes such as immature, female, carapace condition 1 and 5 crabs), categories were agglomerated when appropriate. 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.

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

$$ER_t = \frac{Landings_t}{Landings_t + Mature\ fishable\ biomass_t}$$

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:

$$ER_{t,i} = \frac{Number\ landed_{t,i}}{Number\ landed_{t,i} + Number\ surveyed_{t,i}}$$

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. No information on reproduction and early pelagic and benthic survival were assumed and so these transition matrices are referred to as *pseudo-transition matrices* as the full life cycle is not modelled. Further, the relative differences in catchability of the various size and maturity classes 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-observer 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:

$$z = f(x_1, x_2, \ldots, x_n)$$
$$(\Delta z)^2 = \left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2 + \ldots + \left(\frac{\partial f}{\partial x_n}\Delta x_n\right)^2$$

Synthetic analysis of indicators

We adopt an approach similar to the traffic light framework used in stock assessments (Brodziak & Link 2002, Koeller et al. 2000,2006) in combination with a multivariate data simplification method known as ordination (see methods in Choi et al. 2005*b*). 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. On the Scotian Shelf, commercially fished snow crab are generally observed between depths of 60 to 280 m (Figures 8, 9) and between temperatures of -1 to 6 ^{o}C (Figure 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 & Hazel 1992; Comeau et al. 1998).

Snow crab eggs are brooded by their mothers for up to 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 & Beninger 1995; Webb et al., 2007). A primiparous female of ~ 57.4 mm carapace width (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). On the Scotian Shelf, 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 ~ twice a year (Sainte-Marie et al. 1995; Comeau et al. 1998). The first inter-moult stage (instar 1) is ~ 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 ~ 250% with each moult (Figure 7; Tables 6, 7). On the Scotian Shelf, the terminal moult has been determined 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 one 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 ~ 9 years since settlement to the bottom and 11 years since egg extrusion. Thereafter, the life expectancy of a male is ~ 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.

ECOSYSTEM CONTEXT

Synthetic 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 summary and synthesis of indicators as in Choi et al. (2005*b*), key environmental (climatic), social, economic and fishery-related indicators were identified and summarized as relative anomalies 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 temperature and volume, bottom temperatures and variabity 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 Scotian Shelf, 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.

<u>**Connectivity**</u>

Connectivity referes 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 two 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 Scotian Shelf has been studied by J. Chassé (Ocean Sciences Division, BIO, DFO; pers. comm.). By treating larvae as passive particles, he was able to demonstrate that a large number of larvae can be transported onto the Scotian Shelf and deposited in eddies (e.g., near the

Sable Bank area and in the shallow areas 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 Scotian Shelf 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 Scotian Shelf population is currently acting as an autonomously reproducing system:

- The temporal dynamics of the Scotian Shelf snow crab population is generally out-of-phase with the cycles seen thus far in the Southern Gulf of St. Lawrence. If the Scotian Shelf were completely dependent upon the larval drift from the Gulf region, the temporal dynamics of the populations would be in-phase.
- The spatial distribution of the Brachyuran larvae on the Scotian Shelf obtained from the Ichthyoplankton Sampling program in the 1980s (see summary in Choi et al. 2005a, page 14) have been observed to be quite pervasive throughout the Scotian Shelf 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.
- Planktonic samples from the Scotian Shelf obtained from the Continuous Plankton Monitoring Program (see summary in Choi et al. 2005a, page 14) indicate that the number of Brachyuran larvae have been consistently low, even with the assumed constant input from upstream sources, from 1976 to 1996 (with a small pulse being detected in 1980).
- A clear 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 Scotian Shelf were at their peak (Choi et al. 2005a, page 14).

The above *circumstantial evidence* suggests that the snow crab resident on the Scotian Shelf 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 Scotian Shelf 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 2006/7.

2. Movement

Spaghetti tags have been applied opportunistically to monitor snow crab movement since the early 1990s (Table11). 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, 4,251 tags have been applied and a total of 306 tags (7.2%) have been recaptured and reported with the required information. On average, tagged crab were recaptured in the season following the tagging event (mean time to recapture was 11 months) with no reported returns after more than 2 years. During this 3-year period, movement between N-ENS and S-ENS was not 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.

The majority (~75%) of the tagged snow crab were recaptured within 12.5 kilometres of their release location (Figures 17, 18). The average distance travelled was 10.4 km with a maximum distance travelled of 263.1 kilometres. The mean distance travelled was 22 km yr^{-1} with a maximum of 215.4 km yr^{-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.

For the 4,251 snow crab tagged since 2004: 1,213 were CC2 (white) crab. 9.2% of these white crab have been recaptured (and reported), also at an average time interval of 11 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 (Figure 19).

If the snow crab fishers would like to obtain reliable information on the connectivity of snow crab on the Scotian Shelf, 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. It is also advisable to return marked crab to the water, as multiple recaptures of crab provide valuable long-term movement records.

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 on the Scotian Shelf (Figures 14, 20). For example, prior to 1986, the shelf was characterised by relatively warm bottom waters, low volume of the cold intermediate layer of water, and a Gulf Stream frontal position close 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 one year.

Juvenile crab (~ 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 on the Scotian Shelf in the early-1990.

The spatial extent of what may be considered potential snow crab habitat based upon bottom temperature and depth preferences in N-ENS has been very stable at a mean of 7.28×10^3 km^2 (SD = 0.05×10^3 km^2; Figure 21). For S-ENS, the surface area of potential habitat has been much more variable, ranging from between 40 to 70×10^3 km^2 over the past three decades and a mean of 53.9 $\times 10^3$ km^2 (SD=6.88×10^3 km^2). In the most recent period, the surface area has increased to above normal levels (62.3×10^3 km^2). In CFA 4X, the southern-most limit of the distribution of snow crab, potential habitat has been most variable: ranging from near 0 to 25×10^3 km^2 and a mean of 11.2×10^3 km^2 (SD=6.13×10^3 km^2). In 2007, the potential habitat was above average in CFA 4X, at 17.36×10^3 km^2.

Within the area that may be considered potential snow crab habitat, average bottom temperatures were 3.1, 3.3 and 5.1 ^{o}C in N-, S-ENS and CFA 4X, respectively (Figure 22). Average bottom temperatures in 2007 were similar to these long-term means. An overall warming trend has been evident since the early 1990s when persistent below-average bottom temperatures were observed in most areas. In CFA 4X, bottom temperatures have been particularly erratic since the late 1990s with large magnitude, cyclic fluctuations (4-year) that have been increasing in amplitude. In such areas of large environmental variability as 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 & 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 crabs. 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 on the Scotian Shelf.

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 and thorny skate 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 one 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 fishermen 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 and Lesser toad crabs, *Hyas coarctatus*, *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 & Lafrance 2002; Squires & 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. However, the recent declines in their abundance since 2002 may be an indication that some form of a carrying capacity has been reached. This interpretation is of course confounded by the heavy exploitation of crabs at levels of almost the same order of magnitude as their biomass and the more recent absence of recruitment on the Scotian Shelf since 2002/3.

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. By-catch of snow crab in other fisheries

The by-catch 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 increase for the next 4/5 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.

2. By-catch of other species in the snow crab fishery

At-sea observed estimates of by-catch of other non-snow crab species by the snow crab fishery can be extrapolated to the entire fleet based on (1) Observed landings (landings-based), or (2) Observed number of trap hauls (effort-based). Both methods are applied for ENS (Table 12), whereas only weight-based extrapolation is used for 4X (Table 13) due to their use of mixed-gear complements. In ENS, a total of 17,115 t of snow crab was landed with associated estimates of by-catch at 3 t (landings-based) or 3 t (effort-based). This generates by-catch estimates of 0.015% (landings-based) or 0.018% (effort-based) of crab landings. CFA 4X shows an order of magnitude higher by-catch rates (though still very low) with a total estimated by-catch of 3 t associated with 1,049 t of snow crab landings (0.325%). The majority of by-catch for all areas is composed of other invertebrate species (e.g., Jonah Crab and American Lobster) for which higher survival rates can be expected after being released as compared to fin fish discards. In the three year record, observers also reported three leatherback turtles as having been entangled in buoy lines. All turtles were reported to be released with minimal or no damage to the turtle.

The low by-catch rates at < 1% by-catch for the snow crab fishery relative to other fisheries operating in the Maritimes region where rates can be 30% or more of target species landings. This low incidence of by-catch 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 (generally 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 on the Scotian Shelf 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 fishermen as a source of concern. The number of seismic exploration activities (both 2D and 3D) has been increasing on the Scotian Shelf 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 4 years minimum. They hold eggs for up to two 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 on the Scotian Shelf. 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 as yet

unknown effect 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 would also have economic repercussions.

Substantial sacrifices were made from 2004 to 2006 by snow crab fishermen to reduce any risks of damaging the reproductive potential of Scotian Shelf snow crab. In the face of such uncertainties, 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 on the Scotian Shelf.

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; Choi et. al 2004). 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 in our province. 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 fished species have changed greatly since the early 1990s in conjunction with the rapid changes in species composition. Since this time all ground fish landings have declined, falling from 232 kt to 59 kt. Exceptions include dogfish, whose landings have increased since the 1990s, and haddock and halibut whose landings have been rising over the past 4-5 years. 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. Since the early 1990s the invertebrate landings have increased from 111 kt to 128 kt. The total landed value for all fisheries combined increased steadily from $445 million in 1990 to $847 million in 2003 and has decreased to $639 million since then.

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 grass-roots unity of voice of fishers can definitely assist as has been the experience in S-ENS in the post-2004 period.

FISHERY ASSESSMENT

Effort

Overall, the spatial distribution of fishing effort continued the trend of increasing effort in offshore areas and declines in inshore areas, observed since 2005 (Figure 28). In N-ENS, the spatial distribution of effort in 2007 was comparable to 2006. In S-ENS, the majority of the fishing effort was observed north of Sable Island, southeast of French Bank, northeast of Middle Bank, and south of Misaine Bank (between Misaine and Banquereau Banks). In CFA 4X, the majority of fishing effort continued to be similar to the past with high effort in two core areas near LaHave and Roseway basins.

In 2007 a calculated total of 49,345 and 9,880 traps hauls were applied in S-ENS and N-ENS, respectively. Relative to 2006, this represents a decline of 0.1 and 28%, respectively. This decline in N-ENS is due in large part to reduced TAC.

In CFA 4X, two separate gear complements have been used in past seasons: 60 large traps or 200 small traps. However, since 2007/2008, all fishers have moved to the 60 large conical trap complements. A total of 11,500 trap haul equivalents were applied in the 2006/2007 season as compared to 10,800 in the 2005/2006 season, an increase of 6%.

Landings

The total landings in 2007 were 233 t in N-ENS, and 4,942 t in S-ENS (Tables 2 & 3), representing a decline of 48% and a 10% increase, respectively, relative to 2006. TACs were reduced 50% in N-ENS and increased 10% in S-ENS. In CFA 4X, the 2006/2007 landings were 317 t (Table 4), a 4% increase relative to 2005/2006 (Figure 3), although TACs did not change. The geographical distribution of landings mirrored the geographical distribution of fishing effort (Figure 29).

Catch rates[1]

The spatial distribution of catch rates in N-ENS was uniformly low. In S-ENS, the spatial distribution of catch rates largely reflected the distribution of effort and landings and suggests that fishers were efficiently identifying high abundance locations and therefore avoiding over-depletion of lower abundance areas (and therefore also the associated problems of elevated high soft-shell catches) such as found in the inshore areas of S-ENS. In CFA 4X, the 2006/7 spatial distribution of catch rates was also uniformly low.

In N-ENS, the 2007 catch rates were 23.6 kg $trap^{-1}$, a 34% decline relative to 2006. N-ENS catch rates are still well below the 10 year mean (60.0 kg $trap^{-1}$; Figure 4; Table 2).

In S-ENS, the 2007 catch rates were 100.1 kg $trap^{-1}$, a 10% increase relative to 2006 and above the 10 year mean of 93.2 kg $trap^{-1}$ (Figure 4; Table 3). The spatial distribution of catch rates was highest in the offshore areas and very low in most inshore areas (Figure 30). Peak levels were found towards the Misaine Bank and Sable Island areas of S-ENS.

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

In CFA 4X, the 2006/2007 catch rates were 27.7 kg trap^{-1}, a 3% decline relative to 2005/2006. The spatial distribution of catch rates was highest near Sambro (Figure 30). Note that while this is the second-highest in the historical record (Table 4), it is still lower than the N-ENS catch rates where the fishery is considered to be nearly collapsed.

At-sea-observer coverage

In N-ENS, the at-sea-observer coverage level fell short of the target level of 5% of the TAC, at 2.4% (Figure 5, 31). A total of 61 traps were sampled (0.6% of estimated commercial trap hauls). Of a total of 1,761 male crab sampled by at-sea-observers, 1,151 were of legal commercial size.

In S-ENS, 8.6% of the TAC was observed (with a target level of 10%). A total of 891 traps (1.8% of estimated commercial trap hauls) were sampled. Of the 28,351 male crab sampled from these traps, 26,119 were of legal commercial size.

In CFA 4X, 3.4% of the TAC was observed, relative to a target level of 10%. A total of 66 traps were sampled. Of the 2,461 crab measured, 2,239 were of legal size.

Newly matured crab (CC1 and CC2)

Entry of new recruits was expected for 2006 and 2007. 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 (Tables 14-16).

In N-ENS, CC1 crab represented 41% of the total catch while CC2 crab represented 13% (Table 14). The incidence of soft-shelled crab was not an observation found only in areas of low catches (Figures 30, 32, 33); rather both high and low catches were found to demonstrate high soft shell incidence. This high incidence of soft shell crab was observed by at-sea observers predominantly throughout the inside fishing grounds of N-ENS. If one assumes no recaptures, this amounts to an additional 270.8 t being discarded as soft crab with potentially high handling-associated mortalities. This represents 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. A significant amount of damage to these newly moulted crab likely occurred in N-ENS in 2007, which will have important negative consequences on the fishable biomass for 2008 and beyond. The absence of a functional soft-shell protocol in N-ENS is unfortunate.

In S-ENS, the dominance of CC1 and CC2 crab in 2007 (8.8% and 15%, respectively) was comparable to that observed in 2006 when the first signs of strong recruitment into the fishable biomass were observed (Table 15). Catches of high soft shell percentage (>20% by count) were distributed throughout the fishing grounds with a higher occurrence of soft shell crab being observed near the Chedabucto Bay area as in past seasons. When extrapolated to the whole of the S-ENS TAC, this would amount to a potential additional mortality of 353.3 t.

In CFA 4X for the 2006/7 season, CC1 and CC2 crab represented a total of 0.1% and 0.5% of the total catch, relative to 0.04 and 11.5% in 2005 (Table 16). Anecdotal information from CFA 4X fishers suggests that soft-shell occurrence was much higher in 2006/7. The data from CFA 4X are not directly comparable to ENS as their fishing season is disjunct from that of N- and S-ENS. However, the trend towards reduced numbers of newly moulted crab is potentially indicative of lowered recruitment in the area.

Old crab (CC5)

CC5 crab represented a low proportion of the 2007 at-sea-observed catch in the size fraction less than 95mm CW: 1.21% in N-ENS; and 0.91% in S-ENS. In CFA 4X, CC5 crab were observed in 0.3% of the 2006/7 catch by at-sea observers (Tables 17-19). For the commercially sized crab >= 95 mm CW, CC5 crab represented even lower proportions of the 2007: 0.73% in N-ENS; and 1.54% in S-ENS. In CFA 4X, CC5 crab were not observed in 2006/7 by at-sea observers (Tables 14-16). Similarly low to undetectable proportions of CC5 crab were observed in the trawl surveys (Tables 20-22).

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 immature crab is centered over the 68 mm modal group (instar 10/11). As suggested in Choi and Zisserson (2007), a fraction of this crab moulted and entered fishable sizes in the 2007 season. They were however mostly soft-shelled or white crab during the prosecution of the fishery (see Section: Newly matured crab CC1 and CC2, above). There is a continued likelihood that soft-shell incidence will be an issue in the 2008 season; this is especially the case as the relative abundance of fishable hard-shelled crab is low. Stronger recruitment is expected in 2008 in N-ENS. The main pulse currently centered over the 68 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 in 2006 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, similar to N-ENS, the main pulse is also centered over the 68 mm CW modal group (instar 10/11). However, unlike the N-ENS, immature crab were also observed spanning all size ranges from 40 to 110 mm CW in 2005 and 2006. This continues to be a positive sign for S-ENS in that recruitment to the fishery will continue to steadily increase for at least the next four years. Based upon established growth patterns, the main peak over the 68 mm CW mode should begin entering the fishable biomass by the 2010/2011 fishing seasons. Size frequency distributions in CFA 4X exist in a state intermediate between N-ENS and S-ENS and similar time trends may be expected.

The size frequency distributions of female snow crab in 2007 clearly indicate that the pulses of immature females detected in 2003 for N-ENS and in 2004 for S-ENS are continuing to grow and intensify (Figure 36). A large fraction of the females are now sexually mature and reproductive. This trend should continue for another 3 to 4 years. A similarly important increase in the number of mature females has been observed in S-ENS and CFA 4X for the first time since the late 1990s. However, little to no recruitment was observed for size classes less than 35 mm CW in all areas.

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 3 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. This is particularly the case when strong year classes dominate a population.

The sex ratios of immature snow crab have begun to decline from peak levels in 2004 (Figures 37, 38). 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 38). 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 & Lafrance 2002; Squires & 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.

The sex ratios of mature snow crab have been consistently very low since 1998 for all areas, being dominated by males (Figure 39). This is a very different situation relative to the very high ratios observed in the Gulf of St. Lawrence, where male limitation is an issue. What caused this historically poor reproductive potential on the Scotian Shelf 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. There has however been an increase in sex ratios (% female) of mature snow crab in 2005 and 2006 to levels comparable with pre-1998 levels (just under 40% female in all areas; Figure 39). 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 40). This more balanced sex ratio is indicative of the ENS crab entering an important reproductive mode after almost 5 years of low reproductive output.

A strong coherence in the manner in which sex ratios have been changing over time throughout the Scotian Shelf was evident (Figure 37, 39). For the first time since the late 1990s, a more heterogeneous (mixed) distribution of sexes was observed: pockets of male dominated areas were mixed with pockets of female dominated areas (Figures 38, 40). During mating periods, mature crab would therefore be able find the other sex with minimal movement. Indeed, in many inshore areas, sex ratios are dominated by females.

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).

In all areas, the numerical abundance of mature females continued to increase due to the newly matured females from 2007 and the continued longevity of the older mature female population (Figures 41, 43, 44). Most of the mature females are currently located in the inshore areas of S-ENS as well the main fishing grounds in N-ENS; these were therefore the core areas where larval production occurred in 2006/2007. Isolated areas of high concentrations of mature females were also found in CFA 4X.

The numerical abundance of older immature males of instars 11 and 12 consistently declined throughout the Scotian Shelf (Figure 45). However, a resurgence of instars 8 and 9 was seen in 2003 and 2004. Currently, rapid increases in instars 10 to 12 immature males have been occurring coherently in all areas. 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 similarly decreasing in number throughout the Scotian Shelf for most of the historical record. However, their numbers have begun to increase in 2007, especially in N-ENS and CFA 4X for instars 11 and 12 (Figure 46). In S-ENS, the relative number of skip moulters have marginally declined for instars 10 to 12. Most skip-moulters are currently found in the area north of Sable Island.

Newly matured crab (CC1 and CC2; Figure 47) are also currently in low numbers in N-ENS and CFA 4X. However, in S-ENS, their numbers have increased dramatically throughout all core fishing grounds for instars 10 to 12. Temporal patterns in N-ENS and CFA 4X seem to be offset by 1 year relative to S-ENS and may represent the results of higher exploitation strategies in those areas.

The gradual and consistent reduction in hard-shelled snow crab (CC3 and CC4) is evident for all instars on the Scotian Shelf throughout most of the historical record (Figure 48). However, for the first time increases were observed in N-ENS and CFA 4X. The increases in S-ENS were evident since 2005.

[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).

The numerical abundance estimates of carapace condition 5 crab are close to being undetectable on the Scotian Shelf 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.

4. Fishable biomass[3]

In N-ENS, the post-fishery fishable biomass of snow crab in 2007 was 970 t (with a 95% confidence range of: 730 t to 1,230 t; see Figure 50) – an increase of approximately 28% relative to 2006 (750 t). The increases were evident in the northern basin of N-ENS (Figure 51).

In S-ENS, the post-fishery fishable biomass of snow crab increased rapidly in 2007. The fishable biomass was estimated to be 41.59×10^3 t (with a 95% confidence range of: 37.26 to 46.32×10^3 t; Figure 50) – an increase of 47% from 28.22×10^3 t in 2006. The majority of the increases were evident on the continental slope areas as well as a slight amelioration in the Chedabucto area (Figure 51).

In CFA 4X, the pre-fishery fishable biomass was estimated to be 1,030 t (with a 95% confidence range of: 470 to 1,710 t; see Figure 50). This represents no significant change relative to 2006 (pre-fishery), however the uncertainty about the 2007 estimate was double that of 2006, mostly due to the large temperatures differences between the two years for the 4X region.

<u>Process variables</u>

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 since 2005 has been increasing in both N- and S-ENS and extremely variable in CFA 4X (Figure 52). The strongest recruitment to fishable biomass has been occurring S-ENS, centered over Chedabucto Bay and the area north of Sable Island. The inshore areas of the northern basin in N-ENS continue to show signs of positive recruitment.

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 have 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.

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

2. 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. Further, based upon diet studies (Bundy 2004), very few natural predators seem to exist for large snow crabs (i.e., legal sized) on the Scotian Shelf. 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 on the Scotian Shelf. 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, by-catch 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.

3. 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 48% to 19% by biomass. In 2007, the exploitation rate was 19%.

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 2007, the relative exploitation rate was 10%. 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 ranged from 36% to 18% in the historical record (Figure 54). In 2006/7, the relative exploitation rate was 23%. Due to the very specific spatial extent of the fishery in area 4X, focussed primarily upon the area near Sambro, realized exploitation rates are likely to be much higher 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. N-ENS does not have a viable solution at present.

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 would be 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 7).

In the 2008 season, much of the fishable biomass may be composed of immature individuals. Excessive fishing of this component of the fishable biomass is unwise.

S-ENS

The long-term, forward-thinking precautionary approach adopted by the S-ENS fishers over the past 4 years has allowed the S-ENS fishers to successfully bridge the recruitment gap that had lasted for more than 5 years on the Scotian Shelf. 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, 2007 and spring 2008), the health of the S-ENS stock can be said to be definitely improving. For the second time since 2001, a significant increase in fishable biomass has been observed and a strong and steady recruitment is expected for the next 3-4 years. This recovery in S-ENS is about 1 year ahead of what is observed in N-ENS and CFA 4X, where exploitation strategies were historically more aggressive. Forecasts into the future for S-ENS (Figure 54) indicate that there is a strong potential for at least the next five 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 on the Scotian Shelf, recruitment has so far occurred in pulses and not at a constant rate as is the case in the Gulf of St. Lawrence. An increase in TAC is suggested.

N-ENS

In contrast, higher exploitation rates in N-ENS have pushed the fishable component of the N-ENS snow crab population to an historic low. They have not been able to "bridge" the recruitment gap. Continued exploitation and high soft-shell catches likely damaged the expected recruitment into this fishery. The fishable biomass in 2008 will increase but the strength of this increase is likely far diminished relative to what could have been realised due to the damage incurred upon the soft-shell crab in 2007. Reproductive females have mated, but the males that were there to mate were predominantly small, immature males. Associated female mortality may have been elevated as a consequence and long-term consequences are possible. With the more depleted fishable biomass and expected recruitment, the occurrence of soft and white crab that was expected to increase in N-ENS for 2007 was indeed observed. 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 at recent rates of 40 to 50% are unlikely to help maintain the longevity of a strong fishable biomass. Exploitation strategies between 10 and 20% seem to be optimal for this area. A reduction in TAC is suggested until stronger signs of recovery are observed.

CFA 4X

In CFA 4X, exploitation rates have been intermediate to that of N- and S-ENS. However, the realised exploitation rates are likely closer to those of N-ENS due to the spatial specificity of the fishing. This elevated exploitation rate continues, even though 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). (*Please note that the projections in CFA 4X were highly unstable, likely due to strong movement effects, and must only be used in the heuristic sense.*) However, 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. In adopting a precautionary ecosystem-based approach to the long-term management of CFA 4X, the reduction of TAC in 2007 seems appropriate and no incremental increase of TAC is recommended. Further, a reduced or status quo TAC is recommended for 2008-2009, until more information from the 2008 survey can be brought to bear for this fishery.

ACKNOWLEDGMENTS

We thank W. T. Grover Fisheries Ltd., the captain John Baker and the crew of the M/V Gentle Lady for the provision of a safe and hospitable environment for the conduct of the survey and the considerable fishing experience.

Linda Worth-Bezanson has been the enabler working tirelessly in the background, ensuring that all aspects of the assessment run optimally. Her efforts are again gratefully acknowledged.

Finally, this assessment could not have been completed without the contributions of experience, time and financial aid of the stewards of the fishery, the snow crab fishers of the Scotian Shelf.

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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 characterized 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 five 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 – Characterized 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 ~ 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 fertilize 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 ~ 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
Landed value: groundfish 4VW	Landed value of all groundfish, specifically for NAFO Div. 4VW
Landed value: pelagics	Landed value of all pelagic fish
Landed value: pelagics 4VW	Landed value of all pelagic fish specifically for NAFO Div. 4VW
Landed value: shellfish	Landed value of all shellfish
Landed value: shellfish 4VW	Landed value of all shellfish: specifically for NAFO Div. 4VW
Landings: all	Total landings of all fish and invertebrates
Landings: groundfish	Total landings of all groundfish
Landings: groundfish 4VW	Total landings of all groundfish specifically in NAFO Div. 4VW
Landings: invertebrate 4VW	Total landings of all invertebrates specifically in NAFO Div. 4VW
Landings: pelagic	Total landings of all pelagic fish
Landings: pelagic 4VW	Total landings of all pelagic fish specifically in NAFO Div. 4VW
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.
Nitrate concentrations	Nitrate concentrations at Halifax station
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 km2	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: bottom Emerald	Temperature estimates at the bottom of Emerald basin
Temperature: bottom Misaine	Temperature estimates at the bottom of Misaine basin
Temperature: CIL min	Temperature: minimum value of the CIL
Temperature: Sable Is.	Temperature at Sable Island
Temperature: SST Halifax	Temperature: sea surface temperature at Halifax station

Table 1: Snow crab fishing seasons on the Scotian Shelf in the year 2007.

Area	Season
N-ENS	July 21 – Sept 15
S-ENS (CFA 23)	June 1 – Sept 30 (includes 2 week extension)
S-ENS (CFA 24)	June 15 – Sept 30
CFA 4X	Nov 1 (2006) – May 31 (2007)

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

Year	Landings (t)	TAC (t)	Licenses	CPUE (kg/trap)	Effort (X1000 trap hauls)
1997	534	540	74	23.3	22.9
1998	657	660	74	41.6	15.8
1999	899	900	78	54.8	16.4
2000	1,017	1,015	79	68.3	14.9
2001	1,066	1,065	80	94.3	11.3
2002	1,495	1,493	80	101.0	14.8
2003	1,492	1,493	80	76.9	19.4
2004	1,338	1,416	79	62.9	21.3
2005	562	566	78	30.6	18.4
2006	486	487	78	35.6	13.7
2007	233	244	78	23.6	9.9

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

Year	Landings (t)	TAC (t)	Licenses	CPUE (kg/trap)	Effort (X1000 trap hauls)
1997	1,157	1,163	59	51.0	22.7
1998	1,558	1,671	67	68.9	22.6
1999	2,700	2,700	-	71.1	38.0
2000	8,701	8,799	158	85.0	102.4
2001	9,048	9,023	163	87.8	103.1
2002	8,891	9,022	149	111.7	79.6
2003	8,836	9,113	145	98.6	89.6
2004	7,914	8,241	130	108.6	72.9
2005	6,406	6,353	114	109.5	58.5
2006	4,486	4,510	114	90.9	49.4
2007	4,942	4,950	115	100.1	49.3

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	Landings (t)	TAC (t)	Licenses	CPUE (kg/trap)	Effort (X1000 trap hauls)
1997/8	42		4		
1998/9	70		4		
1999/2000	119		4		
2000/1	213		6		
2001/2	376	520	8		
2002/3	221	600	9	10.1	21.9
2003/4	289	600	9	12.7	22.8
2004/5	413	600	9	20.3	20.8
2005/6	306	337.6	9	28.6	10.8
2006/7	317	337.6	9	27.7	11.5
2007/8	94.3 (mid-season)		9		

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.

Stage	**Mean carapace width (cm)**			
	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.

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

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

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

Stage(t+1)	Stage(t)	Immature								Immature skip moulters				CC1/2					CC3/4				
		5	6	7	8	9	10	11	12	9	10	11	12	9	10	11	12	13	9	10	11	12	13
Immature	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	6	1.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	7	-	0.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	8	-	-	1.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	9	-	-	-	1.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	1.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	-	-	-	-	-	1.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	-	-	-	-	-	-	0.14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Immature skip moulters	9	-	-	-	-	0.27	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	-	0.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	-	-	-	-	-	-	0.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	-	-	-	-	-	-	-	0.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CC1/2	9	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10	-	-	-	-	0.13	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	-	-	-	-	-	0.06	-	-	-	0.06	-	-	-	-	-	-	-	-	-	-	-	-
	12	-	-	-	-	-	-	0.25	-	-	-	0.25	-	-	-	-	-	-	-	-	-	-	-
	13	-	-	-	-	-	-	-	-	-	-	-	0.03	-	-	-	-	-	-	-	-	-	-
CC3/4	9	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-	-	-
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-	-
	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	0.67	-	-	-
	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.67	-	-
	13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.29	-	-	-	-	0.67	-
CC5	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-	-
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-	-
	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-	-
	12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.33	-	-
	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
Total			**4251**

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

ENS								
	*Extrapolated by landings (kg)				**Extrapolated by effort (kg)			
Species	2005	2006	2007	3 Year Total	2005	2006	2007	3 Year Total
American lobster	0	75	0	**75**	0	83	0	**83**
American plaice	10	0	0	**10**	12	0	0	**12**
Basket star	68	0	0	**68**	68	0	0	**68**
Cod	10	0	0	**10**	12	0	0	**12**
Grenadier	10	0	0	**10**	12	0	0	**12**
Halibut	887	0	0	**890**	1104	0	0	**1104**
Hermit crab	0	0	0	**0**	0	0	0	**0**
Iceland scallop	10	0	0	**10**	12	0	0	**12**
Jellyfish	0	0	0	**0**	0	0	0	**0**
Jonah crab	587	11	0	**598**	728	12	0	**740**
Northern shrimp	10	0	0	**10**	12	0	0	**12**
Northern stone crab	127	171	48	**347**	158	190	52	**400**
Red crab	19	0	0	**20**	24	0	0	**24**
Redfish	10	32	12	**54**	12	36	13	**61**
Rock crab	0	32	0	**32**	0	36	0	**36**
Sea cucumber	58	21	36	**117**	73	24	39	**136**
Sea raven	29	0	0	**29**	36	0	0	**36**
Sea urchin	0	11	0	**11**	0	12	0	**12**
Snailfish	10	0	0	**10**	12	0	0	**12**
Spiny crab	0	0	0	**0**	0	0	0	**0**
Spotted wolffish	0	54	0	**54**	0	59	0	**59**
Striped wolffish	0	54	0	**54**	0	59	0	**59**
Thorny skate	10	32	0	**42**	12	36	0	**48**
Toad crab	49	32	12	**93**	61	36	13	**110**
Turbot	0	0	0	**0**	0	0	0	**0**
Windowpane flounder	0	0	0	**0**	0	0	0	**0**
Witch flounder	10	0	0	**10**	12	0	0	**12**
Total by-catch	1904	525	108	2537	2360	583	117	3060
By-catch (% of landings)	0.03	0.01	0.002	0.01	0.03	0.01	0.002	0.02
Snow crab landings	**6968360**	**4971930**	**5174710**	**17115000**	**6968360**	**4971930**	**5174710**	**17115000**

* Biomass of by-catch = (Observed by-catch biomass) * (Total landings of snow crab) / (Observed landings of snow crab)

** Biomass of by-catch = (Observed by-catch biomass) * (Total calculated no. trap hauls) / (Observed no. trap hauls)

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

4X				
Species	*Extrapolated by landings (kg)			
	2004/5	2005/6	2006/7	3 Year Total
Jonah crab	2308	21	0	2329
Northern stone crab	500	170	26	696
American lobster	0	149	0	149
Deepsea red crab	77	0	0	77
Sea raven	77	0	0	77
Rock crab	0	64	0	64
Toad crab	0	21	0	21
Total by-catch	2962	425	26	3413
By-catch (% of landings)	0.7	0.14	0.01	0.33
Snow crab Landings	**422000**	**308000**	**319000**	**1049000**

* Biomass of by-catch = (Observed by-catch biomass) * (Total landings of snow crab) / (Observed 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.

Year	Carapace condition				
	1	2	3	4	5
2004	2.46	4.9	72.49	19.78	0.37
2005	18.09	2.1	61.01	18.03	0.77
2006	4.33	9.51	71.83	13.29	1.04
2007	40.95	12.74	37.67	7.92	0.73

Table 15: 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	3.17	3.58	74.54	17.99	0.72
2005	5.86	11	68.16	14.26	0.71
2006	6.66	17.43	68.42	7.21	0.28
2007	8.77	14.99	58.39	16.32	1.54

Table 16: 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	0.32	1.54	94.1	3.99	0.05
2005/6	0.04	11.53	85.34	3.09	0
2006/7	0.09	0.5	98	1.41	0

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

Year	Carapace condition				
	1	2	3	4	5
2004	3.97	0.29	56.18	38.53	1.03
2005	12.41	1.2	41.1	43.24	2.05
2006	10.77	25	43.46	17.69	3.08
2007	49.85	15.26	29.61	4.08	1.21

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	7.14	2.75	64.3	24.34	1.47
2005	11.33	17.21	49.56	19.67	2.23
2006	15.11	22.67	53.74	7.59	0.88
2007	11.33	21.38	54.53	11.86	0.91

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	7.1	35.5	57.2	0.1
2006/7	1.3	1.7	75.0	21.6	0.3

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.

Year	Carapace condition				
	1	2	3	4	5
1999	45.37	4.67	31.75	18.22	0
2000	5.07	0	72.72	22.21	0
2001	6.85	0	66.85	26.29	0
2002	0	1.97	68.48	29.19	0.36
2003	0.97	15.73	62.55	20.75	0
2004	0	0	64.26	35.74	0
2005	0	0	57.71	40.3	1.99
2006	0	14.36	14.63	51.25	19.76
2007	0	20.16	79.84	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.

Year	Carapace condition				
	1	2	3	4	5
1999	21.98	3.52	65.05	9.45	0
2000	14.38	0	83.08	2.55	0
2001	17.89	0	75.43	6.69	0
2002	4.81	16.08	74.57	4.54	0
2003	4.11	7.76	67.51	19.32	1.3
2004	0	6.5	61.87	31.63	0
2005	0	8.55	74.87	16.58	0
2006	0	17.19	63.49	18.83	0.49
2007	0	56.5	37.16	6.34	0

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.

Year	Carapace condition				
	1	2	3	4	5
1999	21.73	2.95	64.23	11.09	0
2000	12.86	0	86.45	0.7	0
2001	16.84	0	75.68	7.48	0
2002	0	0	100	0	0
2003	2.51	2.39	74.34	20.26	0.5
2004	0	0	100	0	0
2005	0	0	100	0	0
2006	0	2.31	95.92	1.76	0
2007	0	22.66	76.3	1.04	0

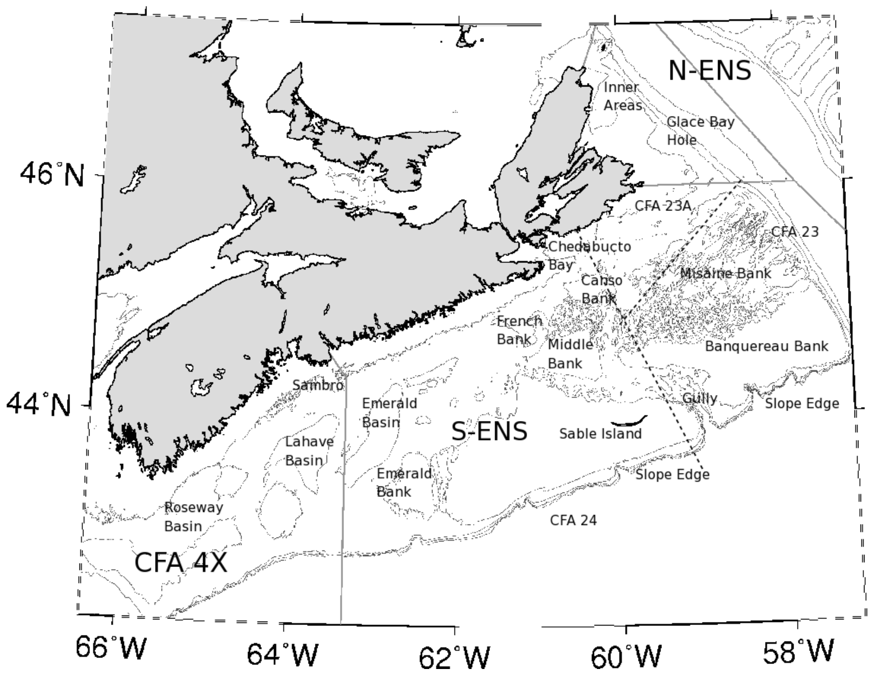


Figure 1: Location of geographic areas and management areas on the Scotian Shelf.

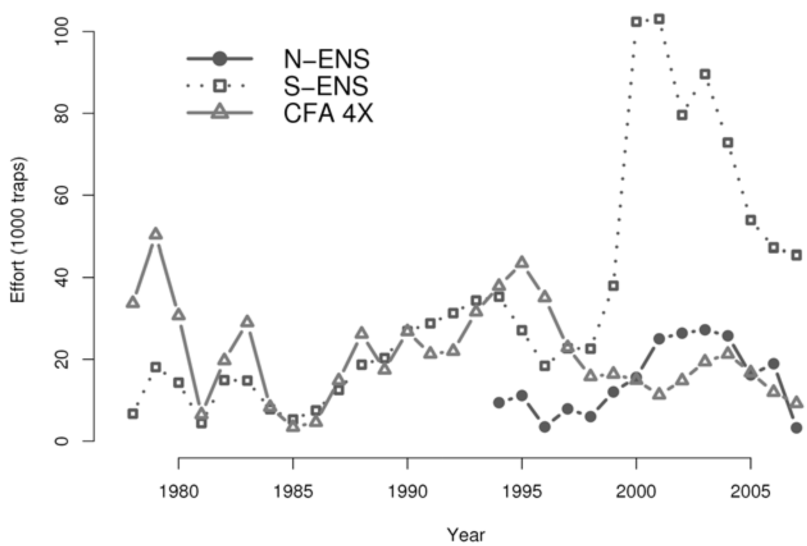


Figure 2: Temporal variations in the fishing effort, expressed as the number of trap hauls. For CFA 4X, year refers to the starting year.

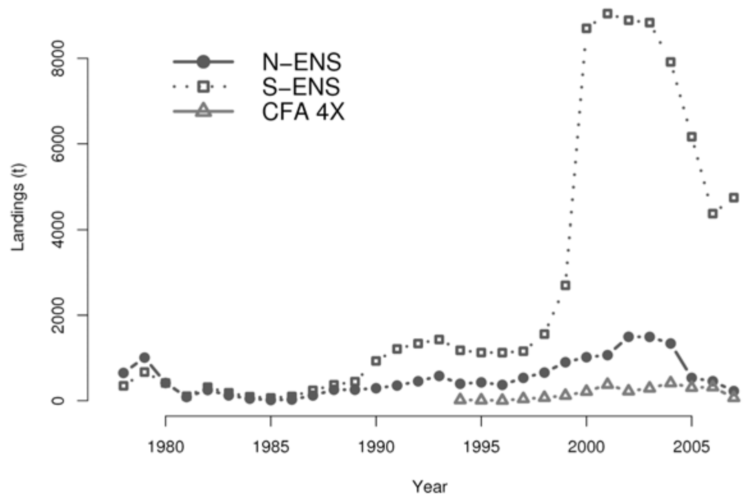


Figure 3: Temporal variations in the landings of snow crab on the Scotian Shelf (t). Note the sharp increase in landings associated with dramatic increases to TACs and a doubling of fishing effort in the year 2000. The landings follow the TACs with little deviation (and so are not shown). For CFA 4X,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

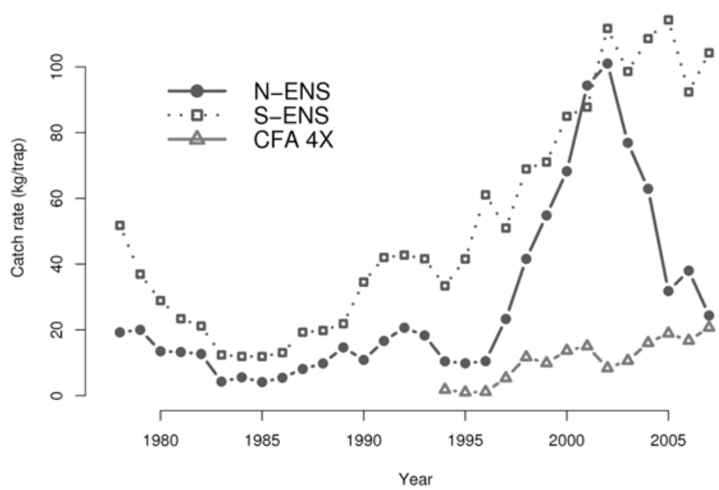


Figure 4: Temporal variations in catch rates of snow crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No correction for these varying trap-types nor soak time and bait-type has been attempted (see Methods). For CFA 4X, year refers to the starting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

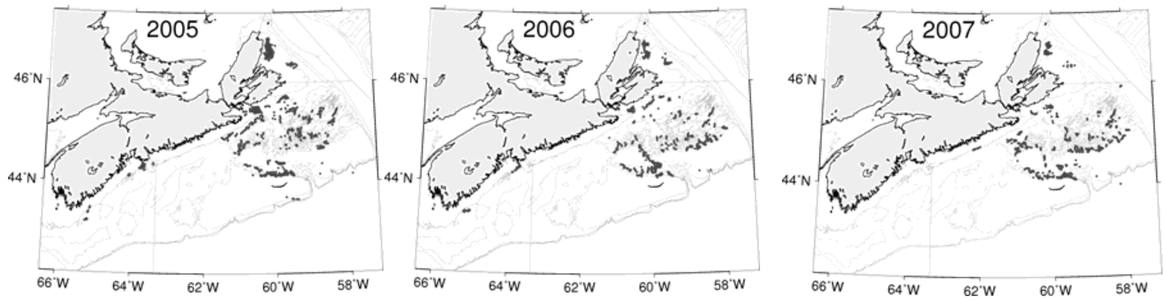


Figure 5: At-sea-observer monitored locations on the Scotian Shelf.

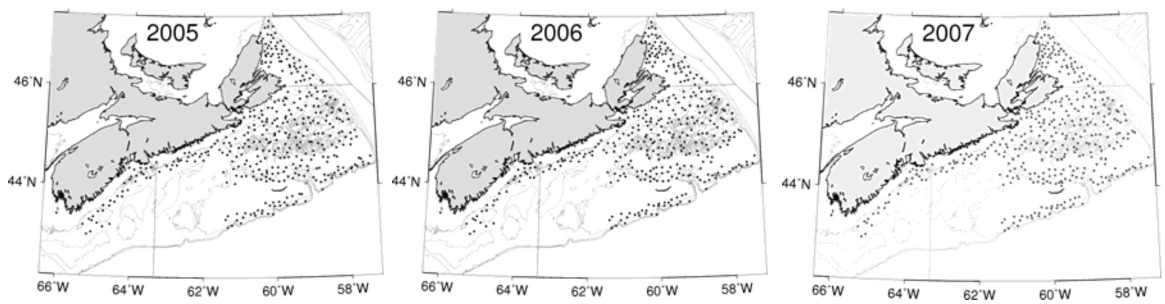


Figure 6: Trawl survey locations on the Scotian Shelf.

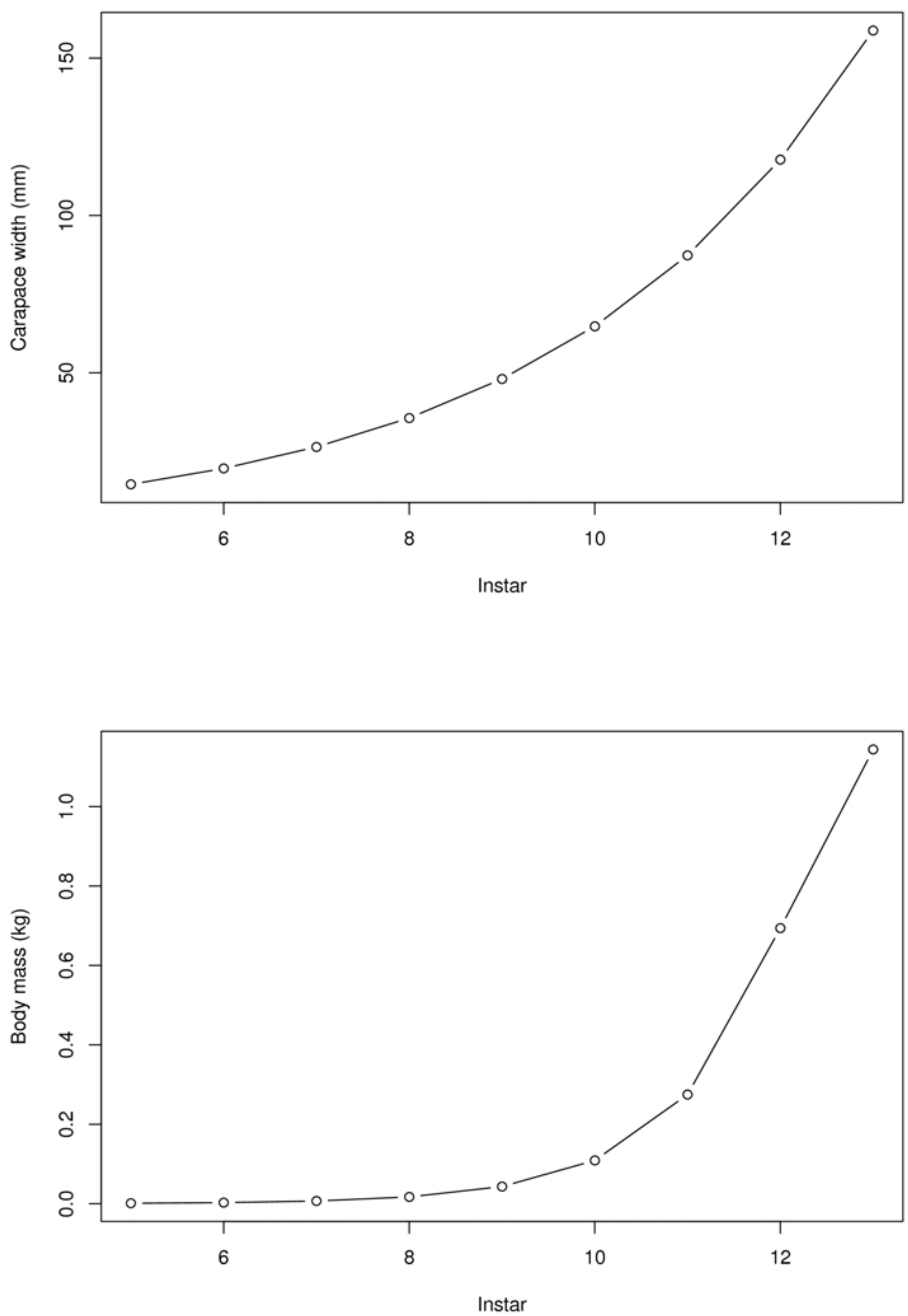


Figure 7: Growth curves determined from Scotian Shelf male snow crab.

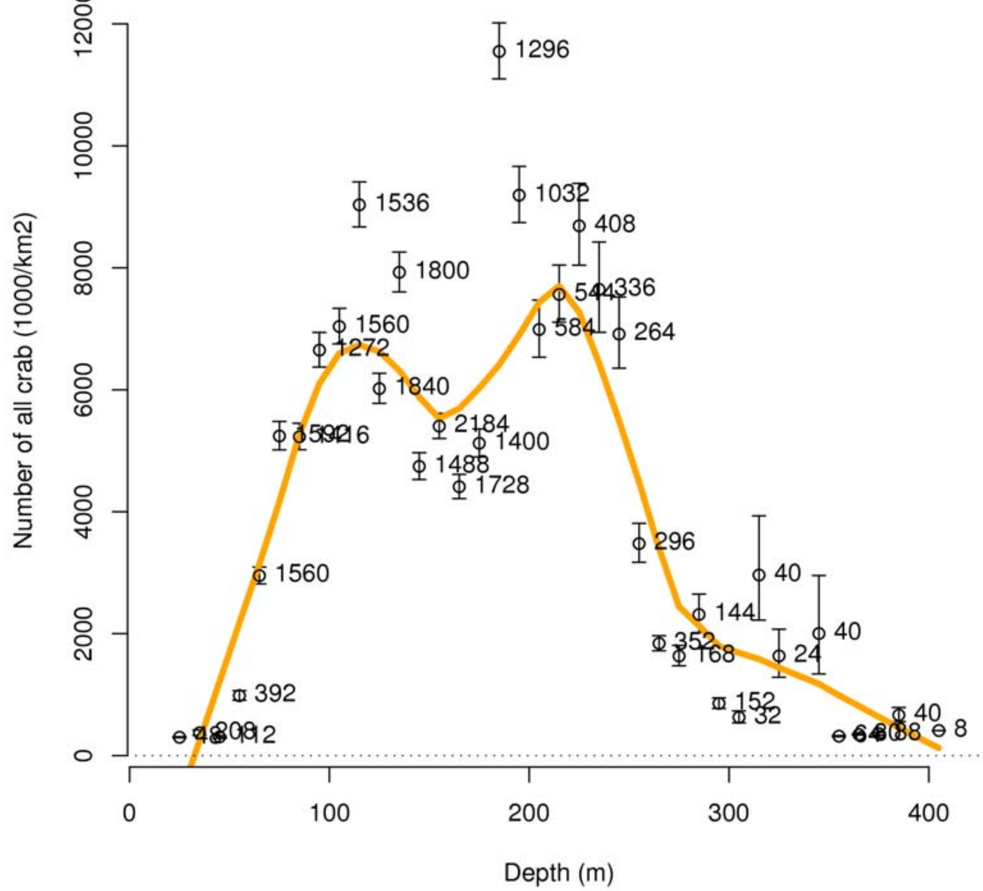


Figure 8: Habitat preferences of fishable snow crab on the Scotian Shelf. Numerical density of snow crab ($\times 10^3$ kg/km^2) as a function of sampling depth (m). 1 standard error bars are presented with numbers indicating the number of stations. A loess filter was used for the heuristic trend line.

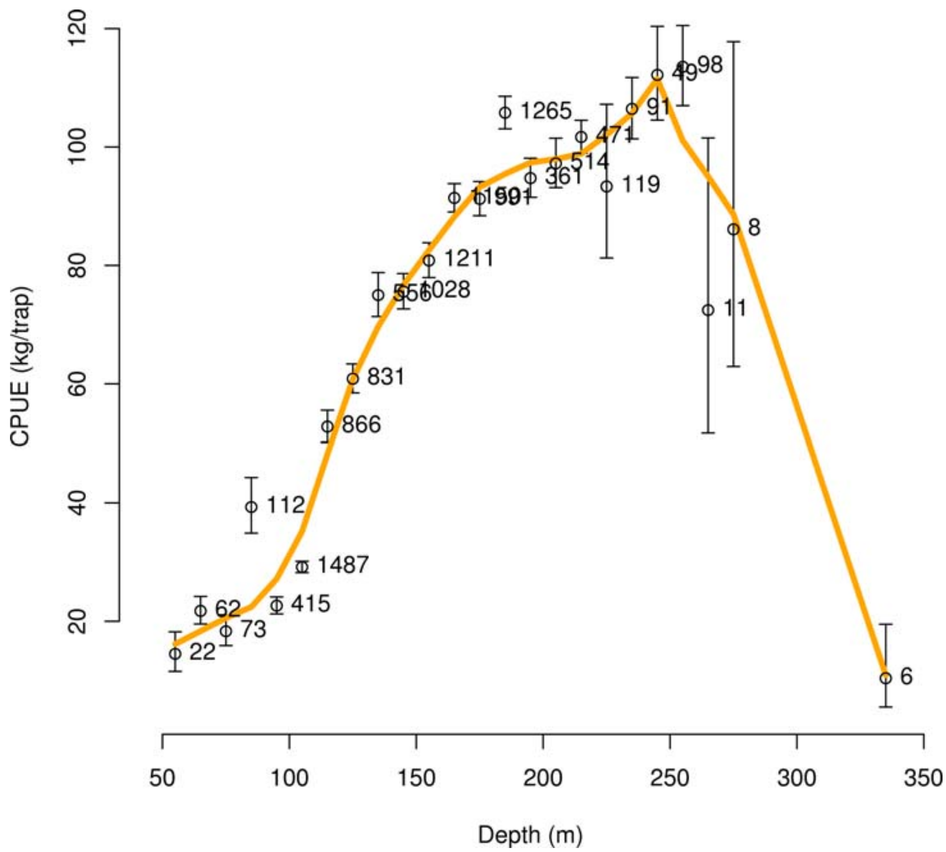


Figure 9: Habitat preferences of snow crab on the Scotian Shelf. Fishery catch rates (kg/trap) as a function of trap depth (m). 1 SE bars are presented. Numbers indicate number of trap hauls. A loess filter was used for the trend line.

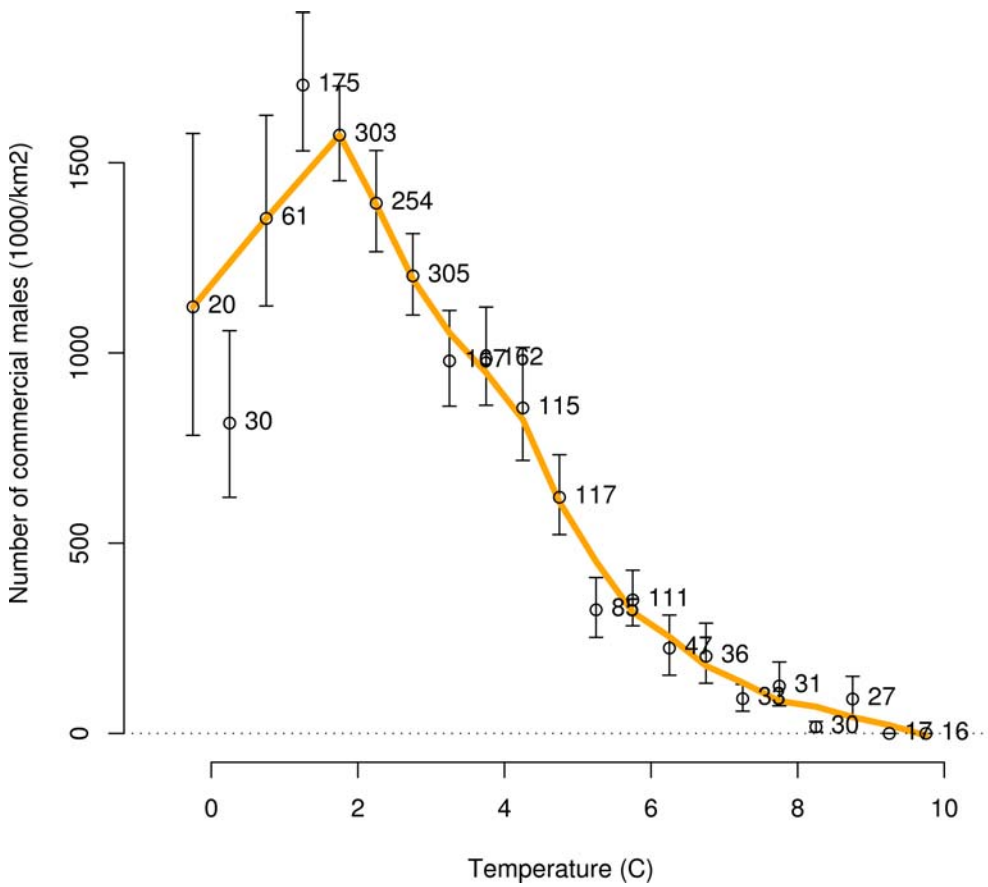


Figure 10: Habitat preferences of fishable snow crab on the Scotian Shelf. Numerical density of snow crab (× 10^3 kg/km^2) as a function of bottom temperature (°C). 1 standard error bars are presented with numbers indicating the number of stations. A loess filter was used for the trend line.

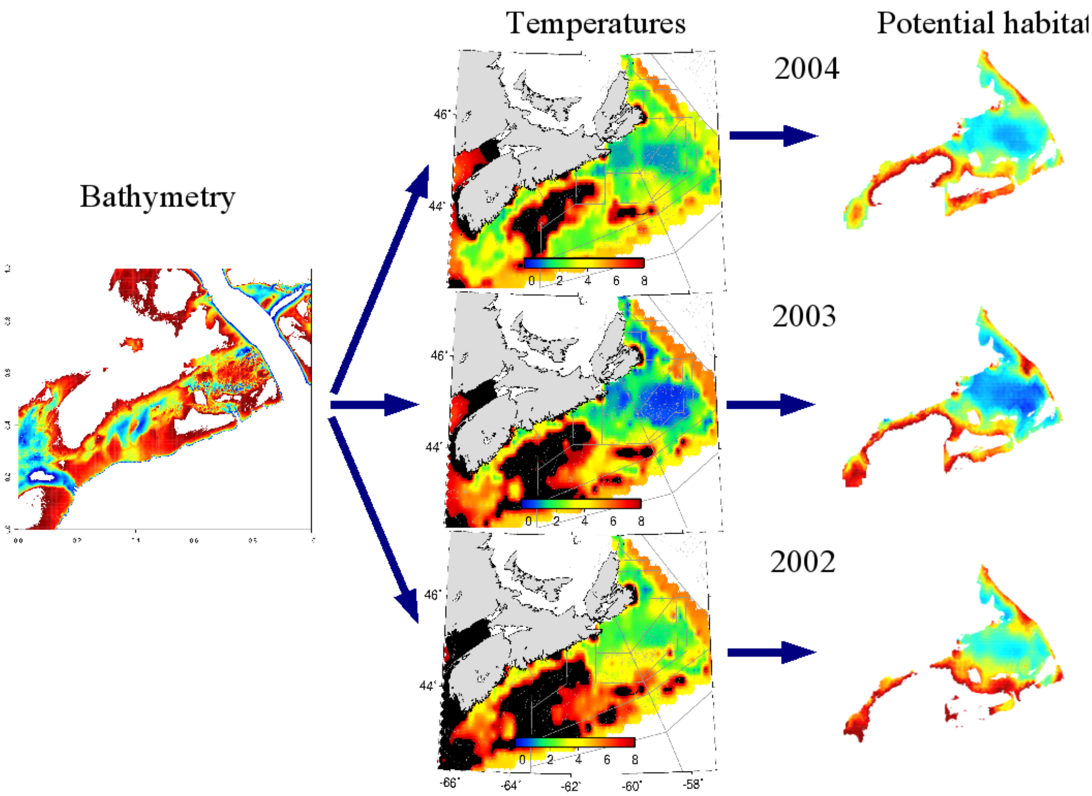


Figure 11: Schematic of geostatistical methods used to estimate potential snow crab habitat area.

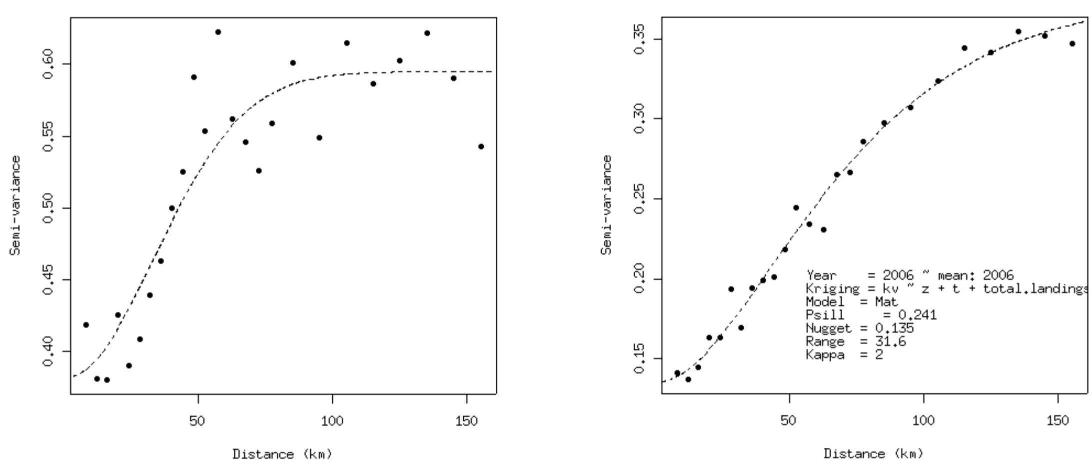


Figure 12: Example variograms of berried females (left) and fishable biomass (right) in 2006, used to constrain the spatial interpolation of snow crab abundance estimates via universal kriging with external drift. Variogram form is more erratic with less abundant categories of crab.

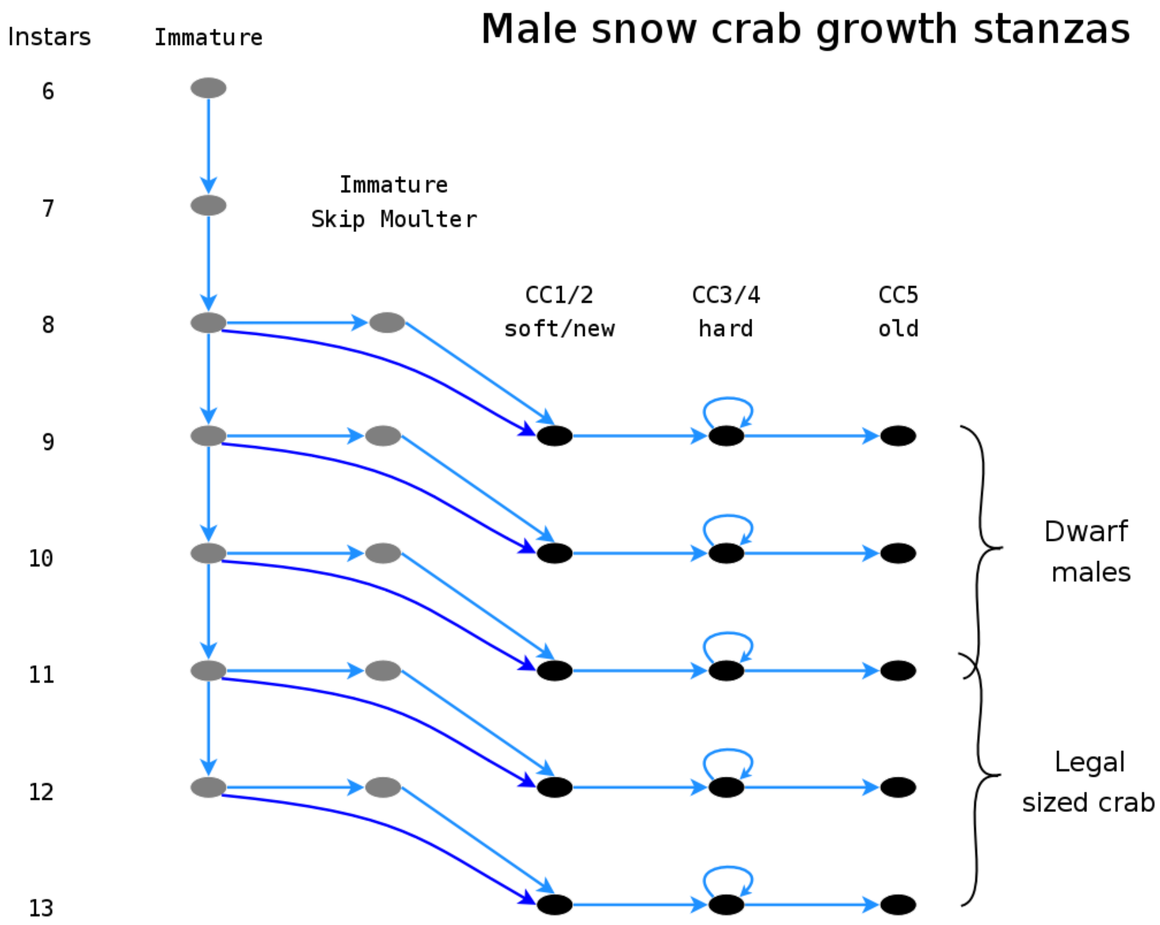


Figure 13: The growth stanzas of male snow crab. Each instar is determined from carapace width bounds obtained from modal analysis and categorized to carapace condition (CC) and maturity from visual inspection and/or maturity equations. Snow crab are resident in each growth stanza for 1 year, with the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

Figure14: 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.

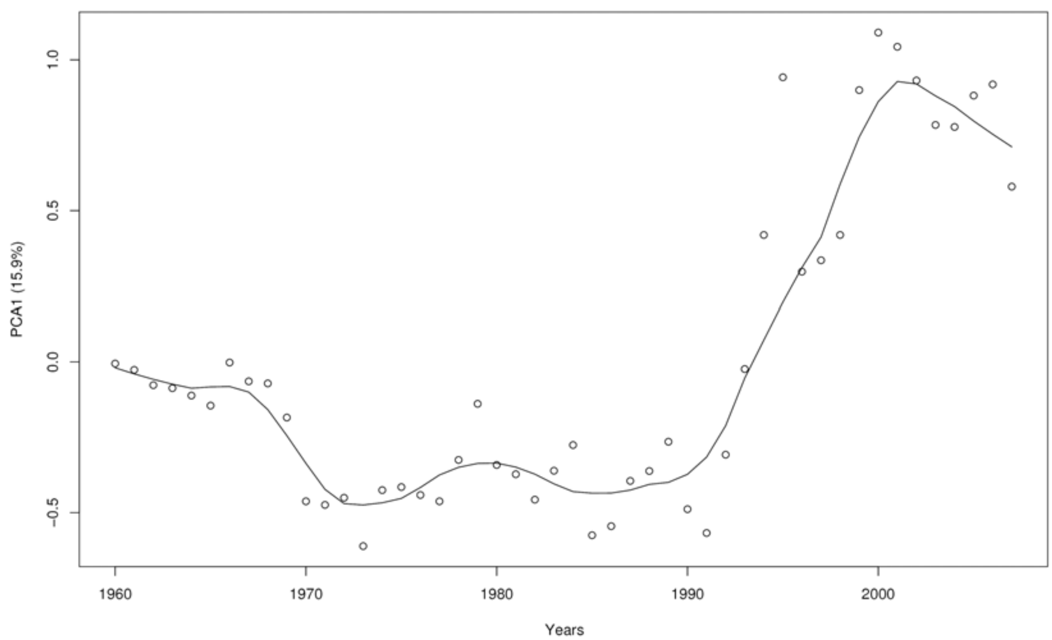


Figure 15: First axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf. Note strong variability observed near the time of the fishery collapse in the early 1990s.

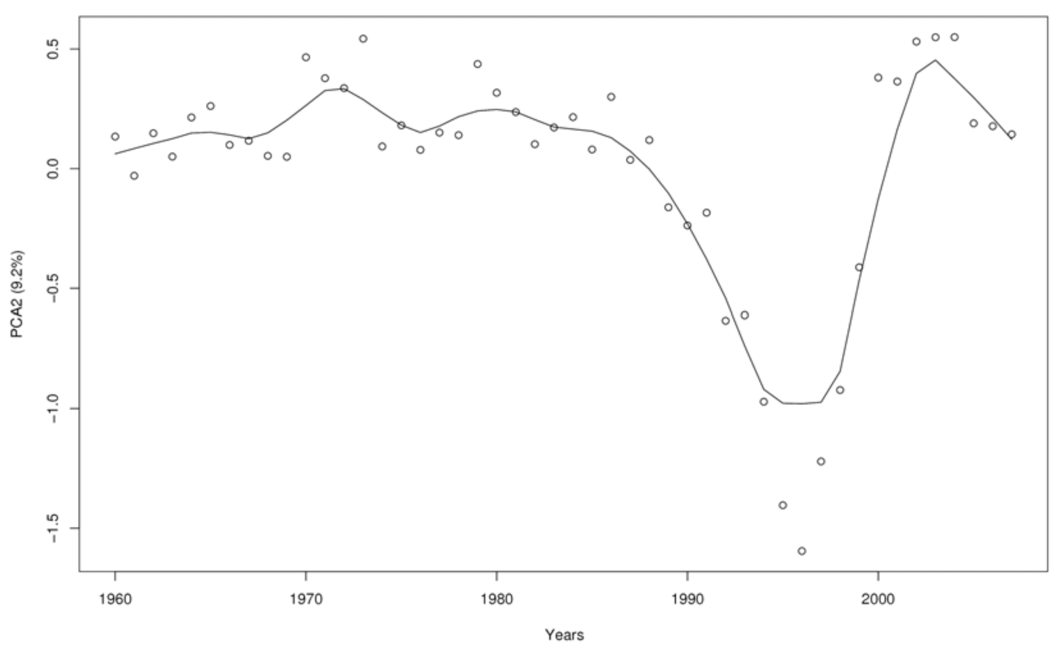


Figure 16: Second axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf. Note strong variability observed near the time of the fishery collapse in the early 1990s.

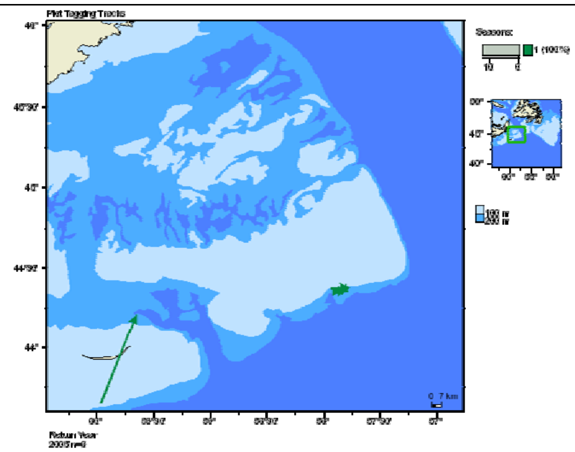
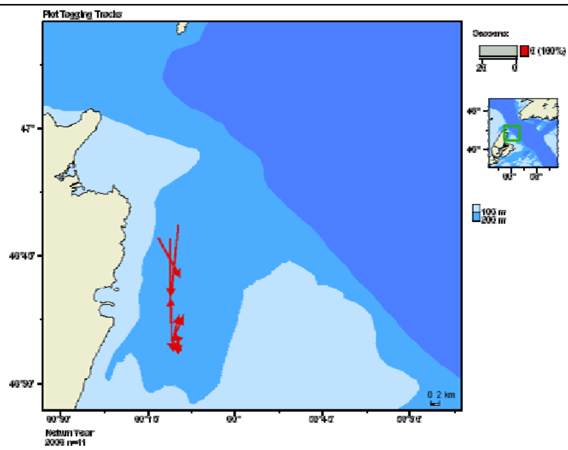
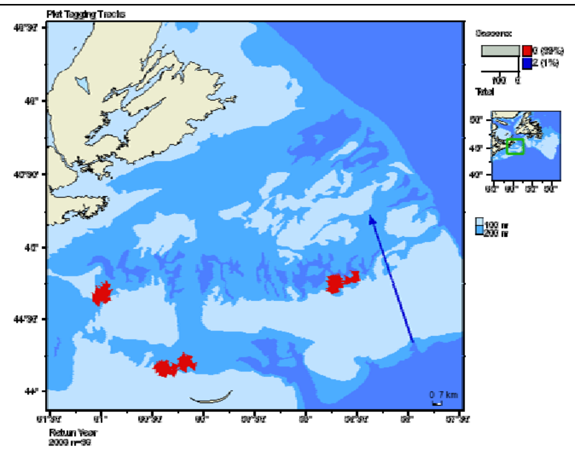
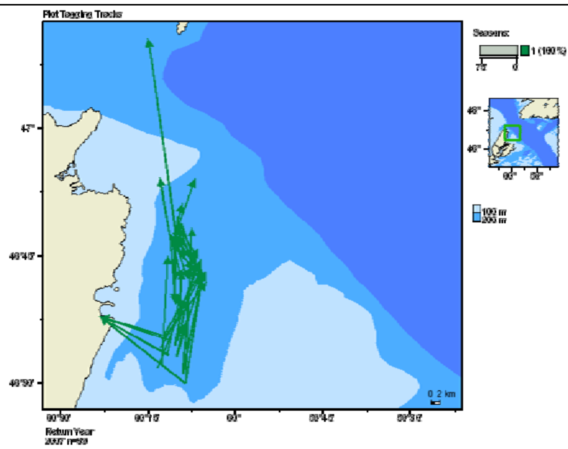
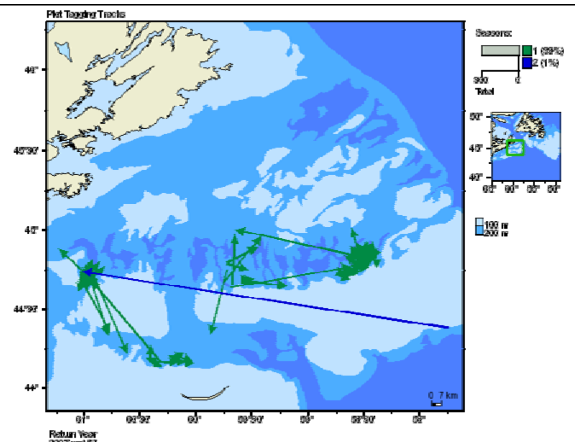
	N-ENS	S-ENS
2005		
2006		
2007		

Figure 17: Annual movement from tag-returns from N- (left) and S-ENS (right). Note participation rates of fishers from the Glace Bay Hole have been minimal in the above time-series.

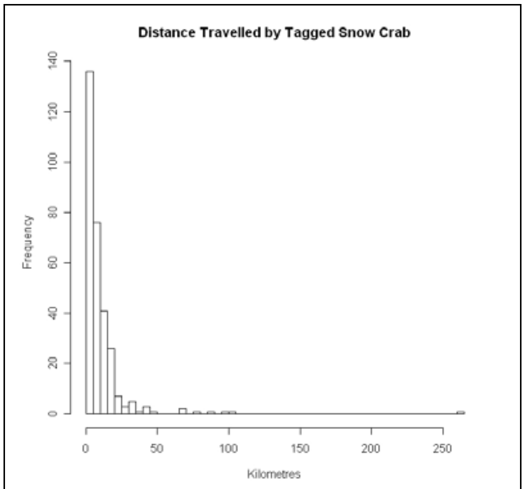


Figure 18. Distance traveled by Tagged Snow Crab in ENS 2004-2007.

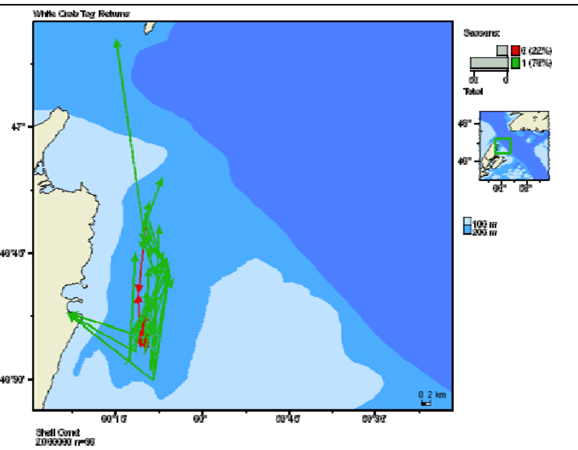
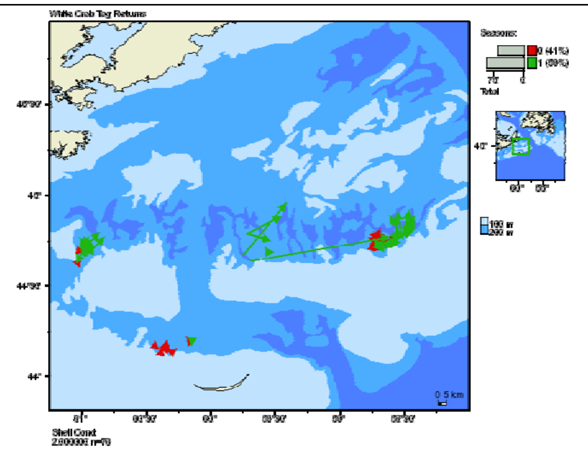
	N-ENS	S-ENS
2004 to 2007		

Figure 19. Annual movement of snow crab tagged as white crab from N- (left) and S-ENS (right). Note participation rates of fishers from the Glace Bay Hole have been minimal in the above time-series.

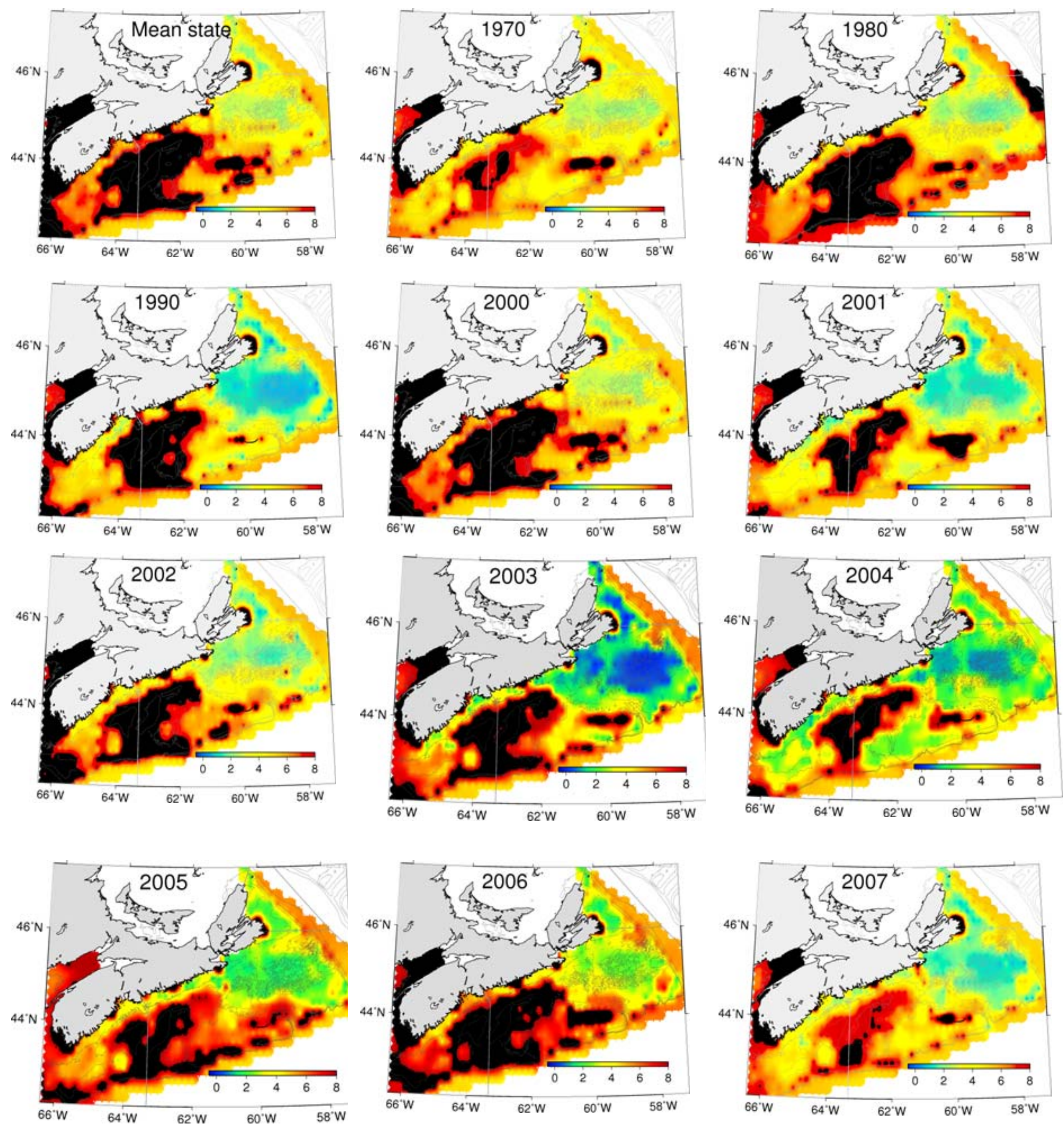


Figure 20. Map of bottom temperatures on the Scotian Shelf during late summer / early autumn. The mean state is the climatological mean since 1970.

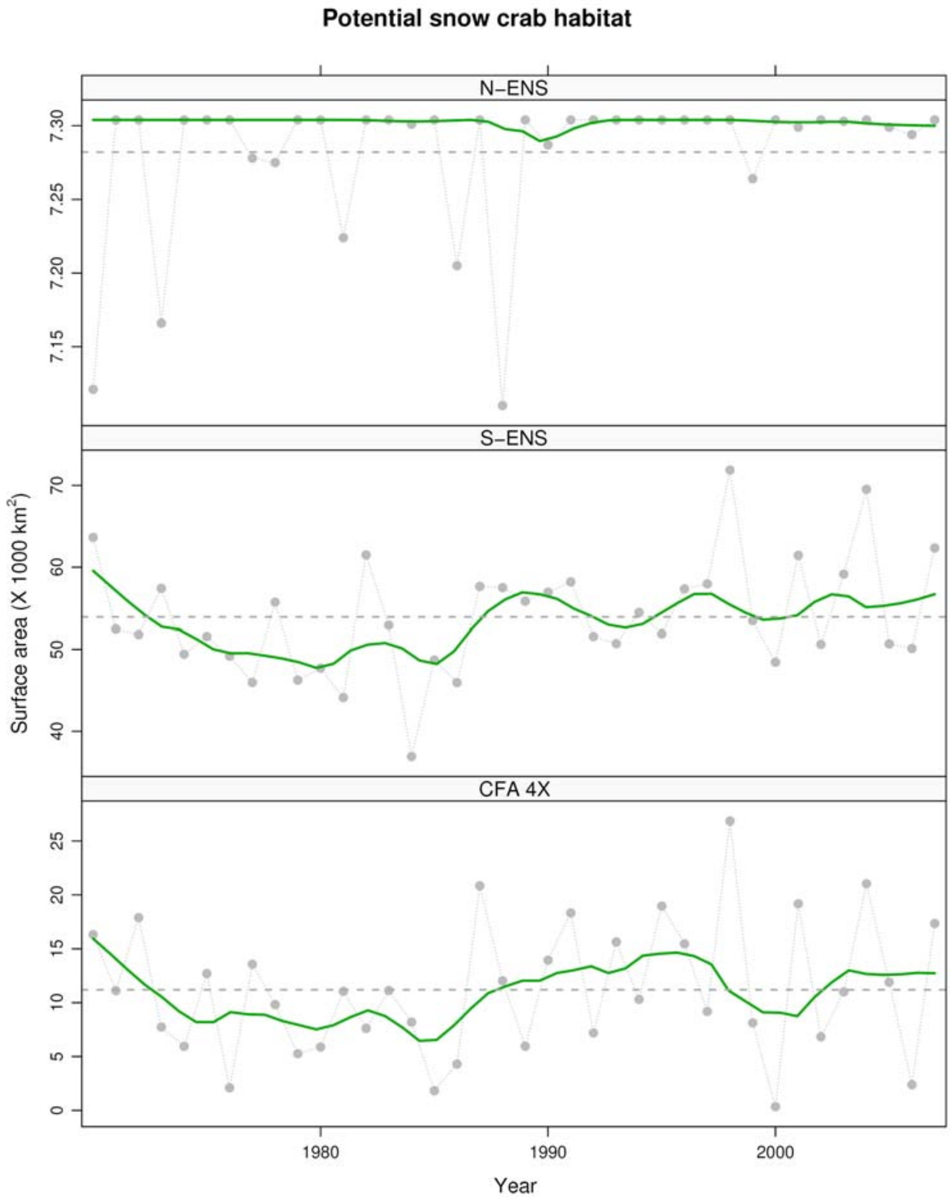


Figure 21. Annual variations in the surface area of potential snow crab habitat. Note that in N-ENS, very little variations occur between years (i.e., total habitat space does not change, although the quality of the habitat does vary (see Figure 17). In S-ENS, the potential surface has been more variable with the 2005 season being at near the long-term mean for the area. Stronger variations have been occurring in the area since the late 1990s, relative to the historical record. In CFA 4X, the southern-most limit of the distribution of snow crab, the fluctuations are also quite pronounced. The stippled horizontal line indicates the long-term arithmetic mean surface area within each subarea.

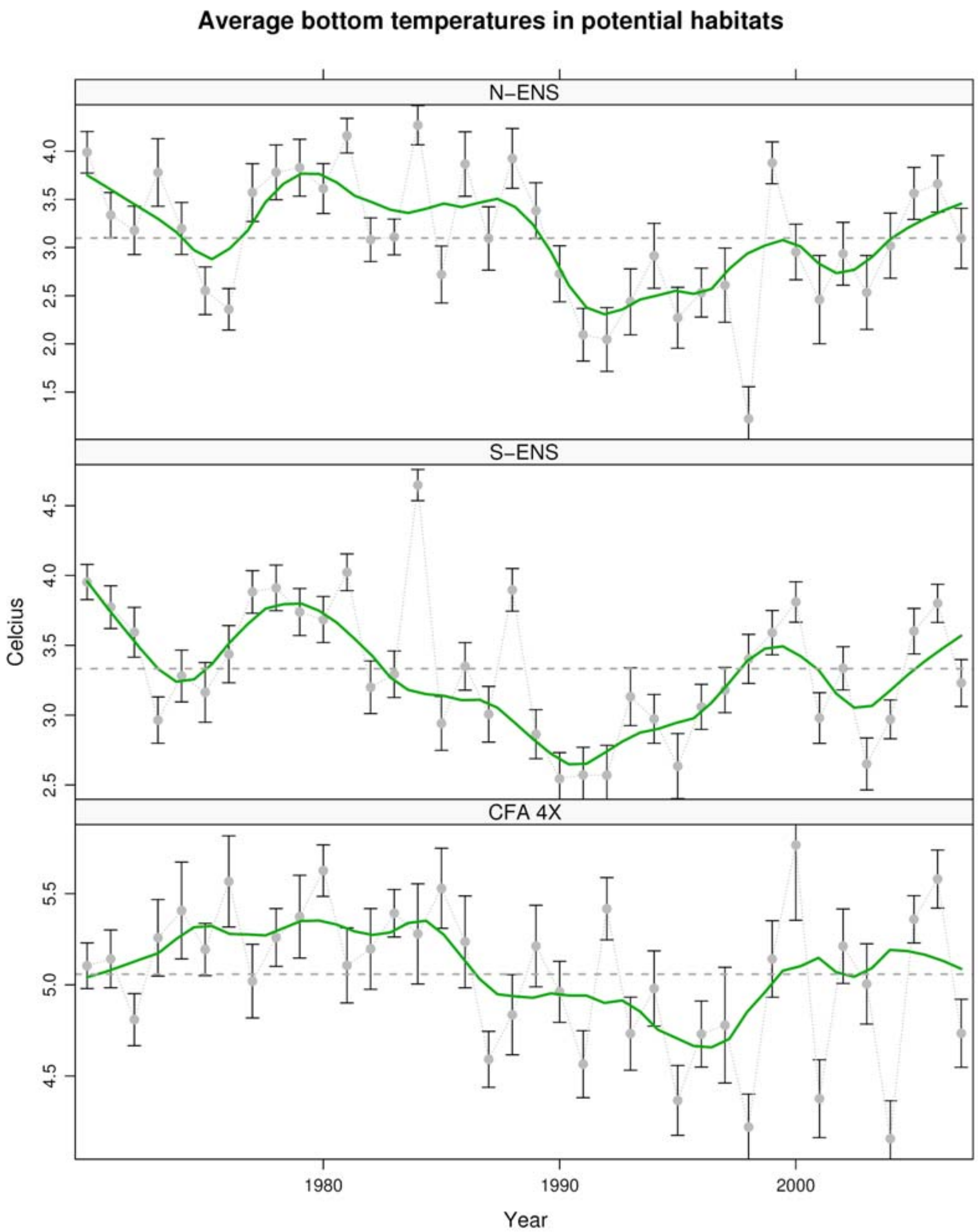


Figure 22. Annual variations in the summer/autumn mean bottom temperature in the areas of potential snow crab habitat. The stippled horizontal line indicates the long-term arithmetic mean temperature within each sub-area.

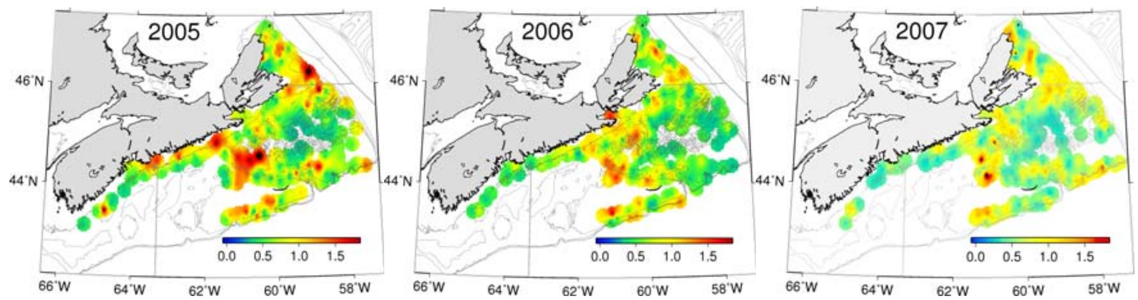


Figure 23: Locations of potential predators of snow crab: cod. Scale is $\log_{10}$ (numerical density [number/km^2]).

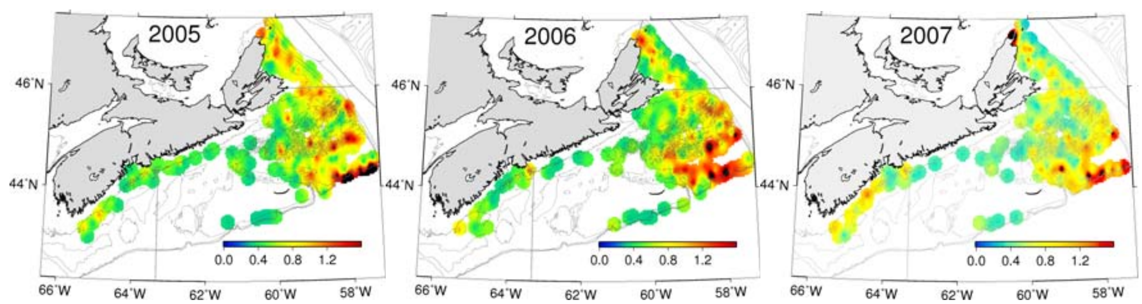


Figure 24: Locations of potential predators of snow crab: thorny skate. Scale is $\log_{10}$ (numerical density [number/km^2]).

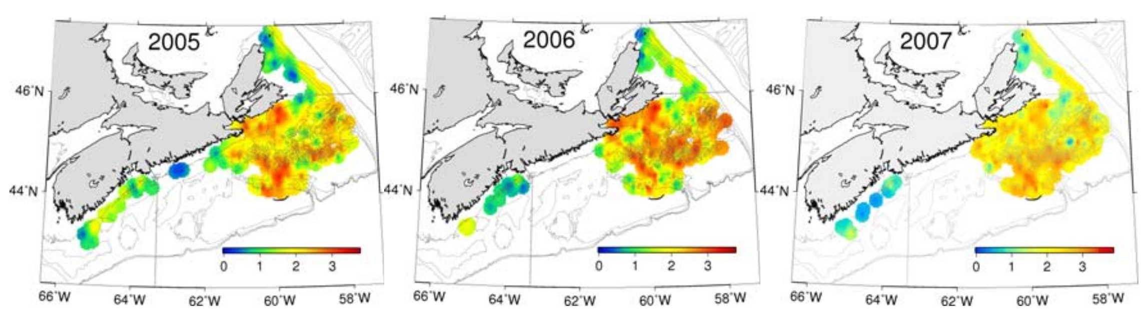


Figure 25: Locations of potential food items of snow crab: northern shrimp. Abundance of these potential food sources roughly match the spatial distributions of snow crab. Scale is $\log_{10}$ (numerical density [number/km^2]).

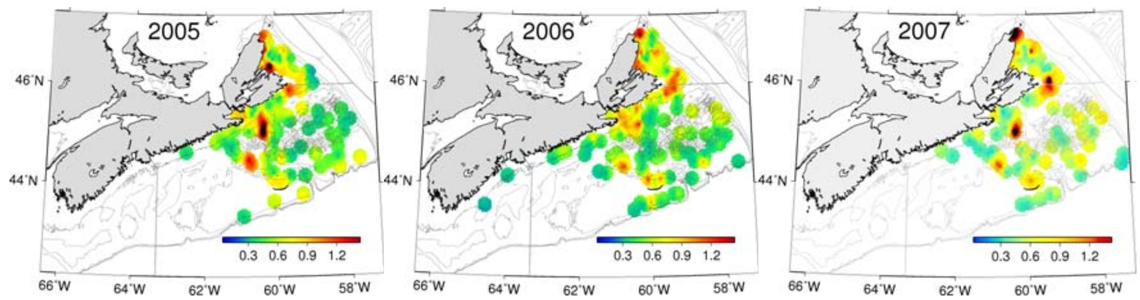


Figure 26: Locations of potential competitors of snow crab: lesser toad crab. High competitive interactions are probable in inshore areas. Scale is $\log_{10}$ (numerical density [number/km^2]).

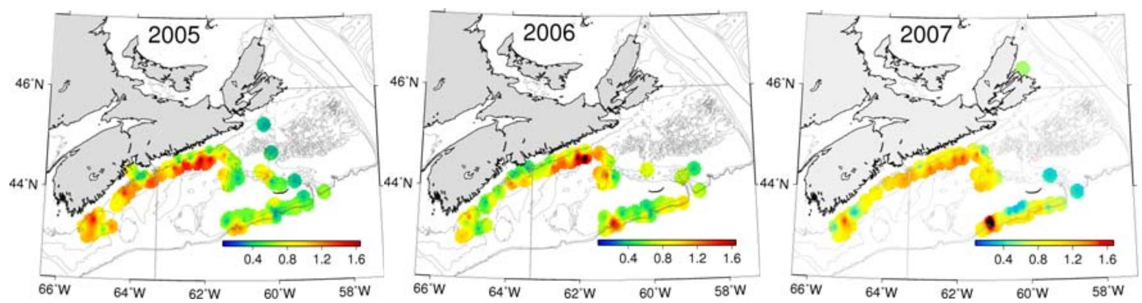


Figure 27: Locations of potential competitors of snow crab: Jonah crab. High competitive interactions are probable in inshore areas. Scale is $\log_{10}$ (numerical density [number/km^2]).

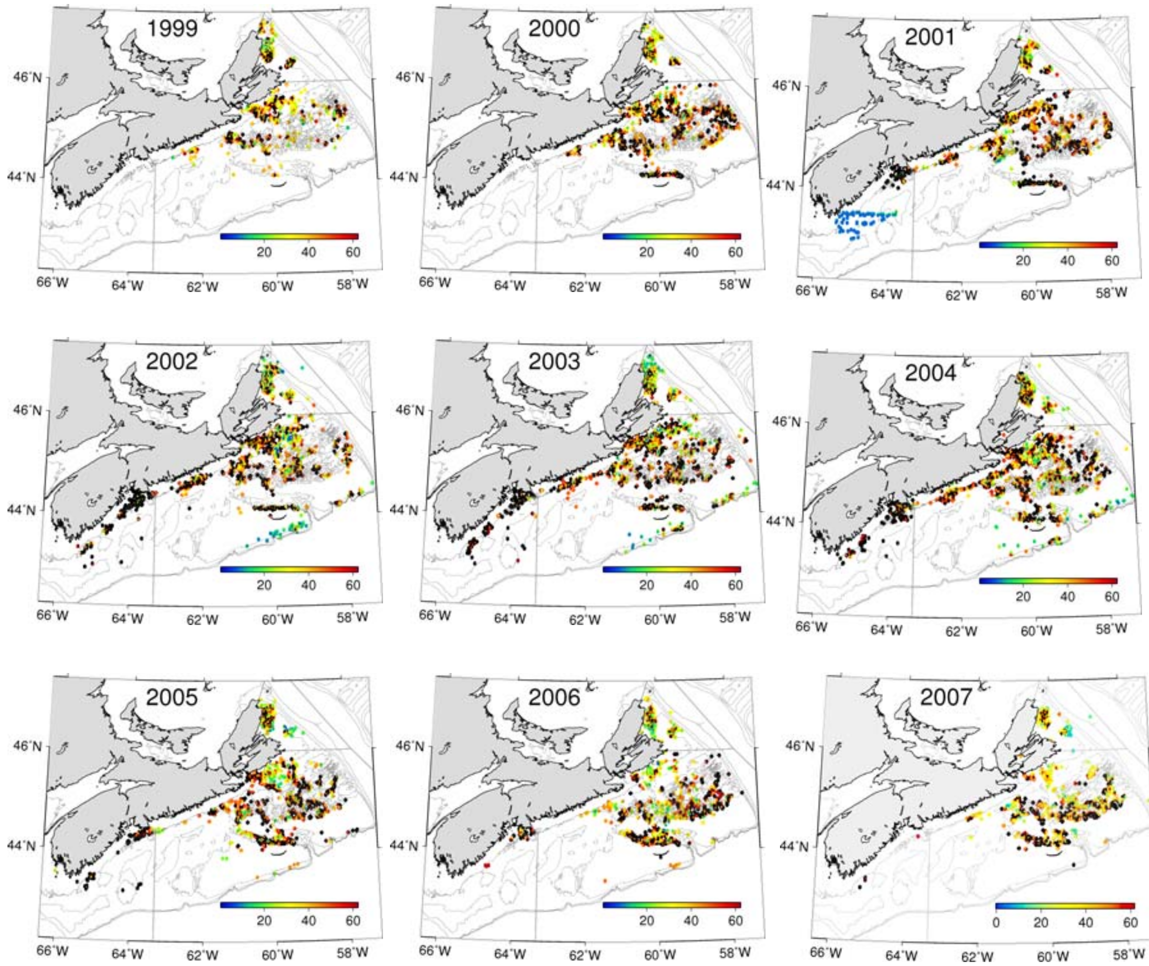


Figure 28. Fishing effort (number of trap hauls / 1 minute grid) from fisheries logbook data. Note the increase in effort offshore and reduction inshore in S-ENS. No visible changes are evident in N-ENS. For CFA 4X, year refers to the starting year.

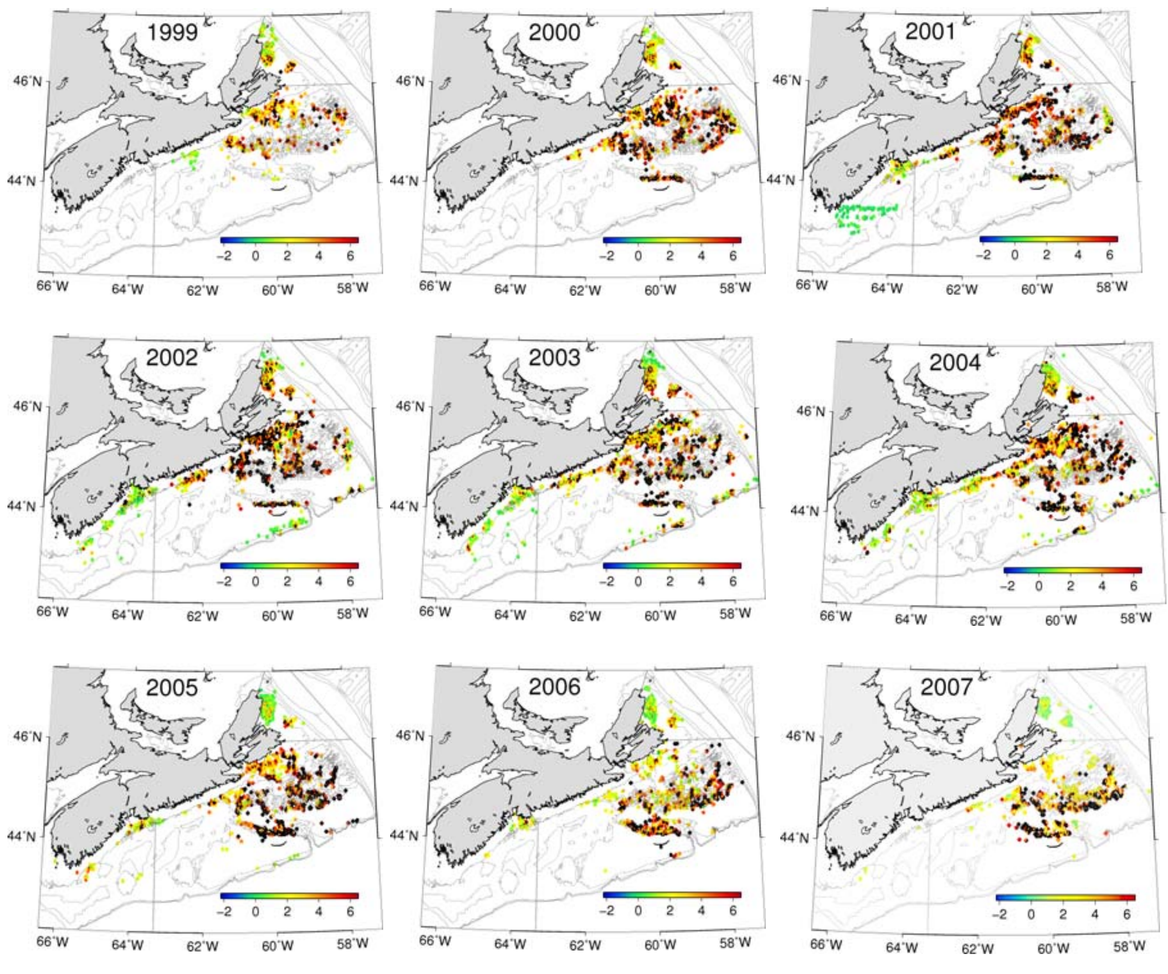


Figure 29. Crab landings (kg / 1 minute grid) from fisheries logbook data. Note the increase in landings offshore and reduction inshore for S-ENS. No visible changes are evident in N-ENS. For CFA 4X, year refers to the starting year.

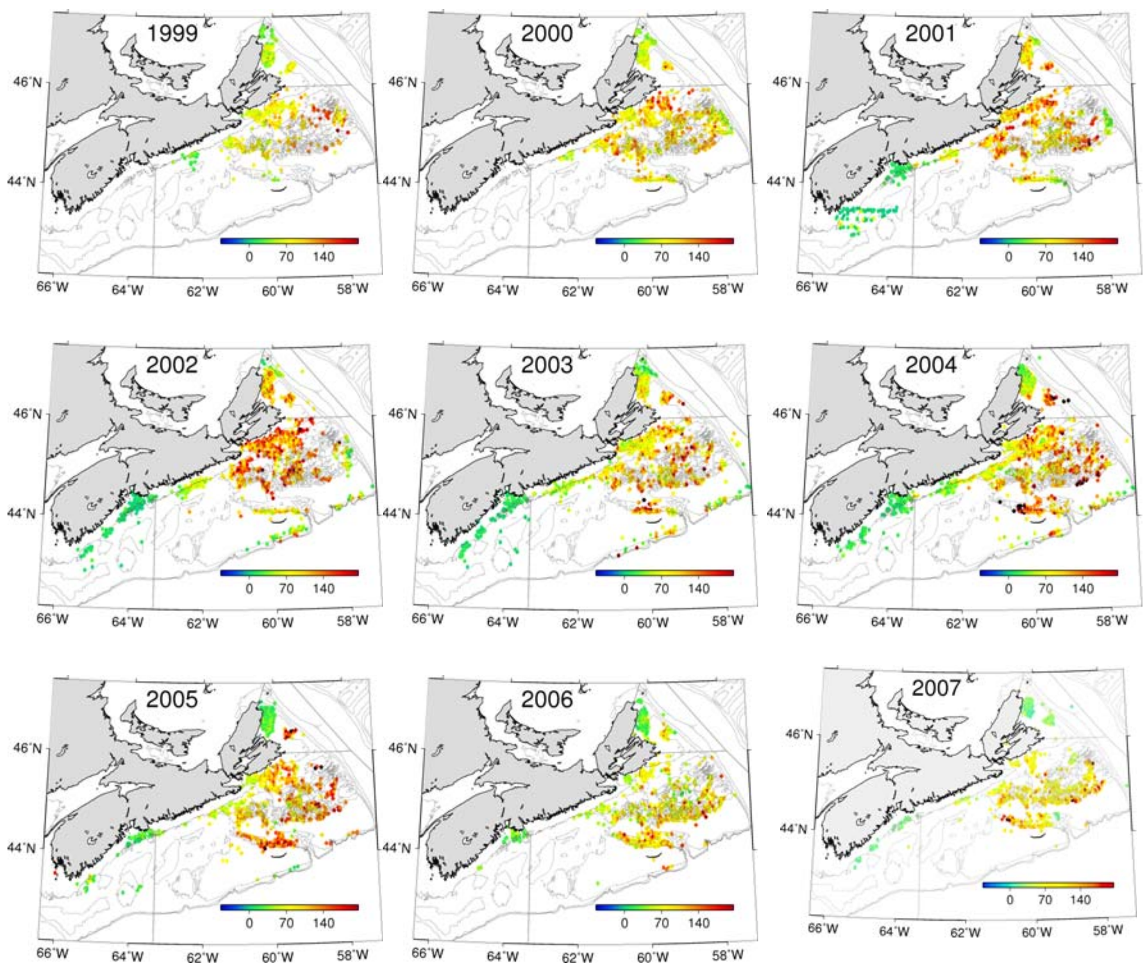


Figure 30. Catch rates (kg trap^{-1}) in each 1 minute grid from logbook data. Note the expansion of fisheries activity to more offshore locations with time. TACs were raised dramatically in 2000. Since that time, large decreases of catch rates in the inshore areas have become evident, indicating strong 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.

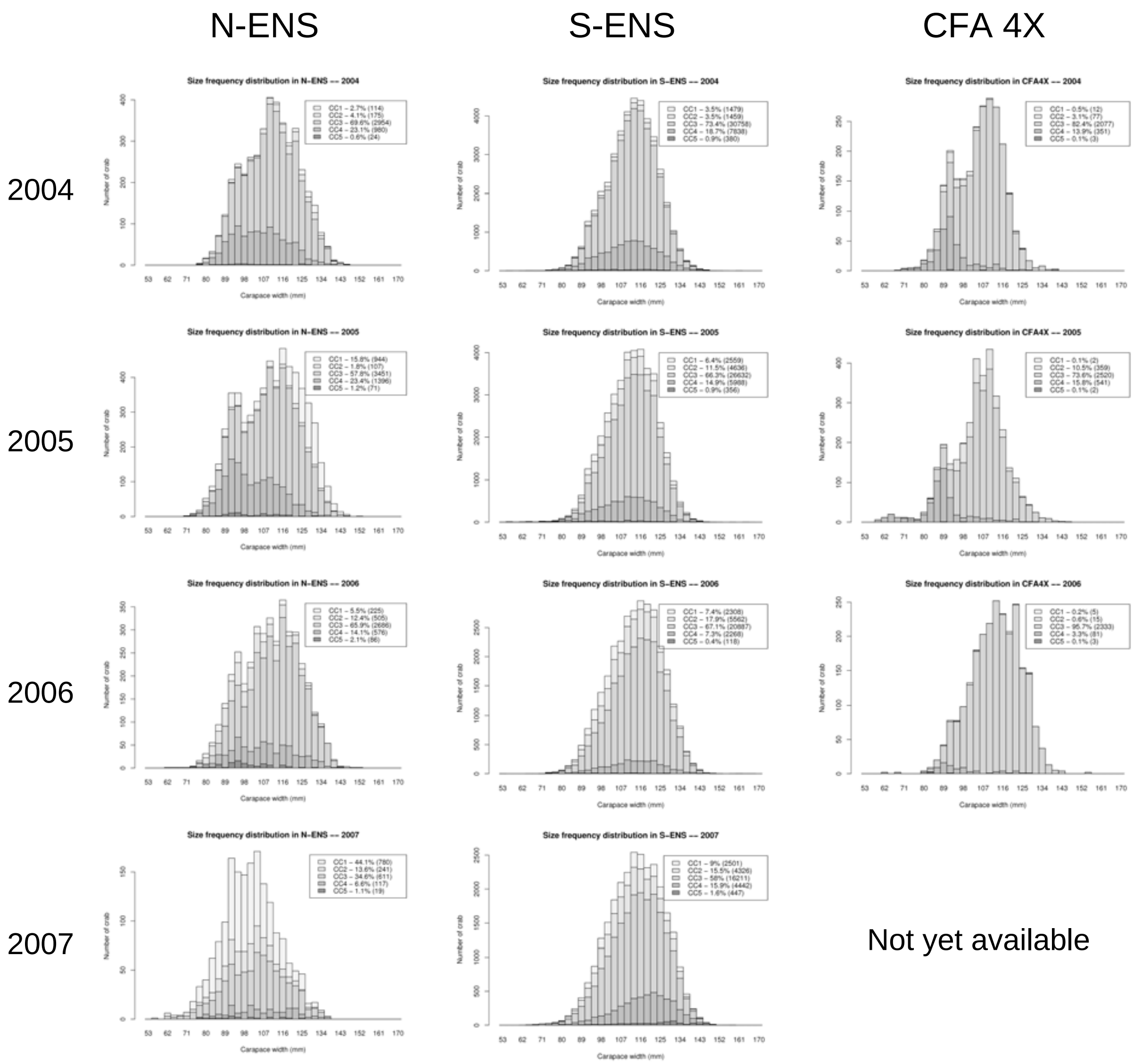


Figure 31: Size frequency distribution of at-sea-observer monitored snow crab broken down by carapace condition. For CFA 4X, the year is the starting year.

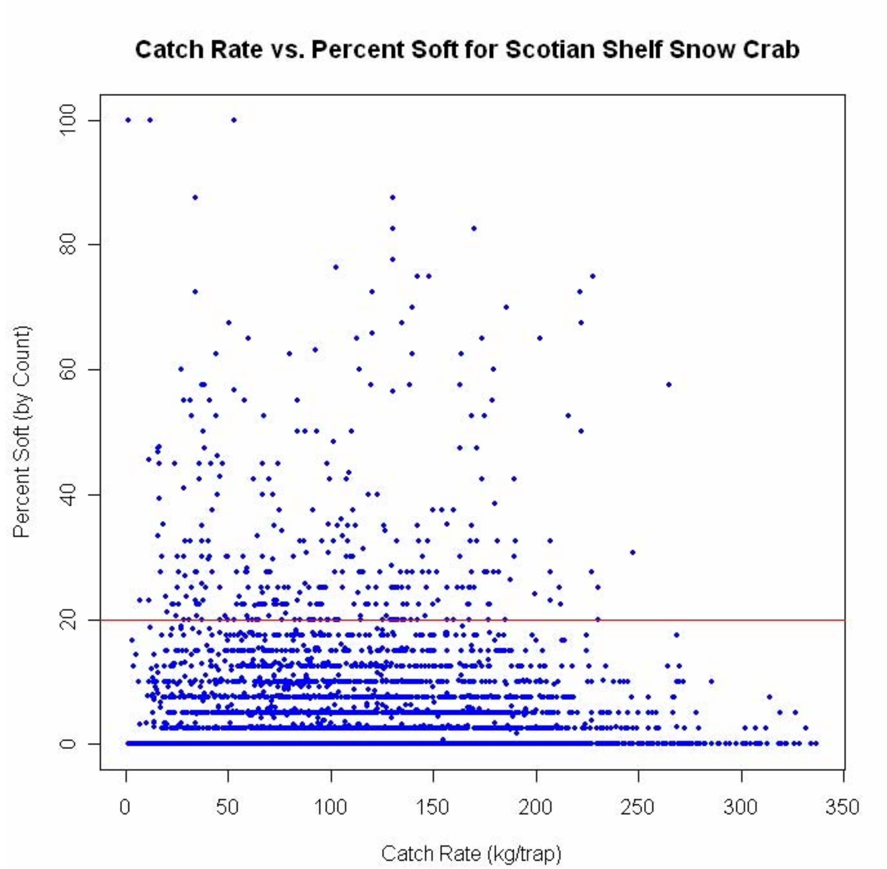
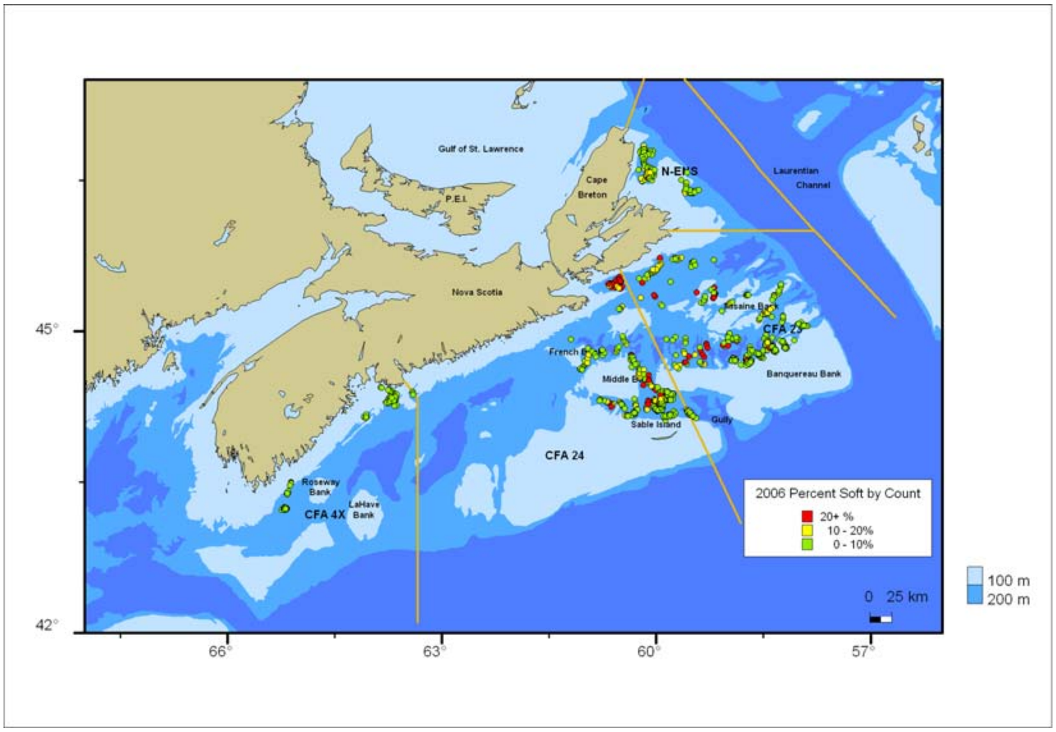


Figure 32: The relationship between the percentage soft-shell in the observed commercial landings as a function of the catch rates in at-sea-observed catches. Higher relative numbers of soft-shelled crab are expected in depleted areas as soft-shelled crab generally avoid hard-shelled males. However, 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.

2006



2007

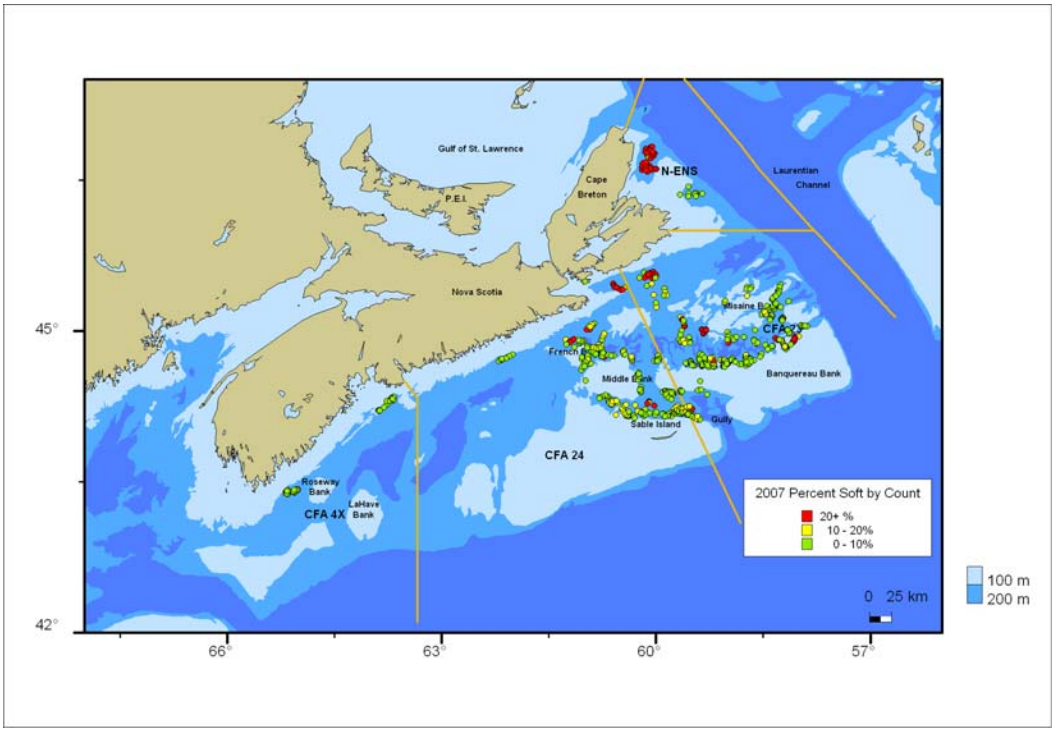


Figure 33: Location of soft-shell snow crab occurrence in the commercial fishery.

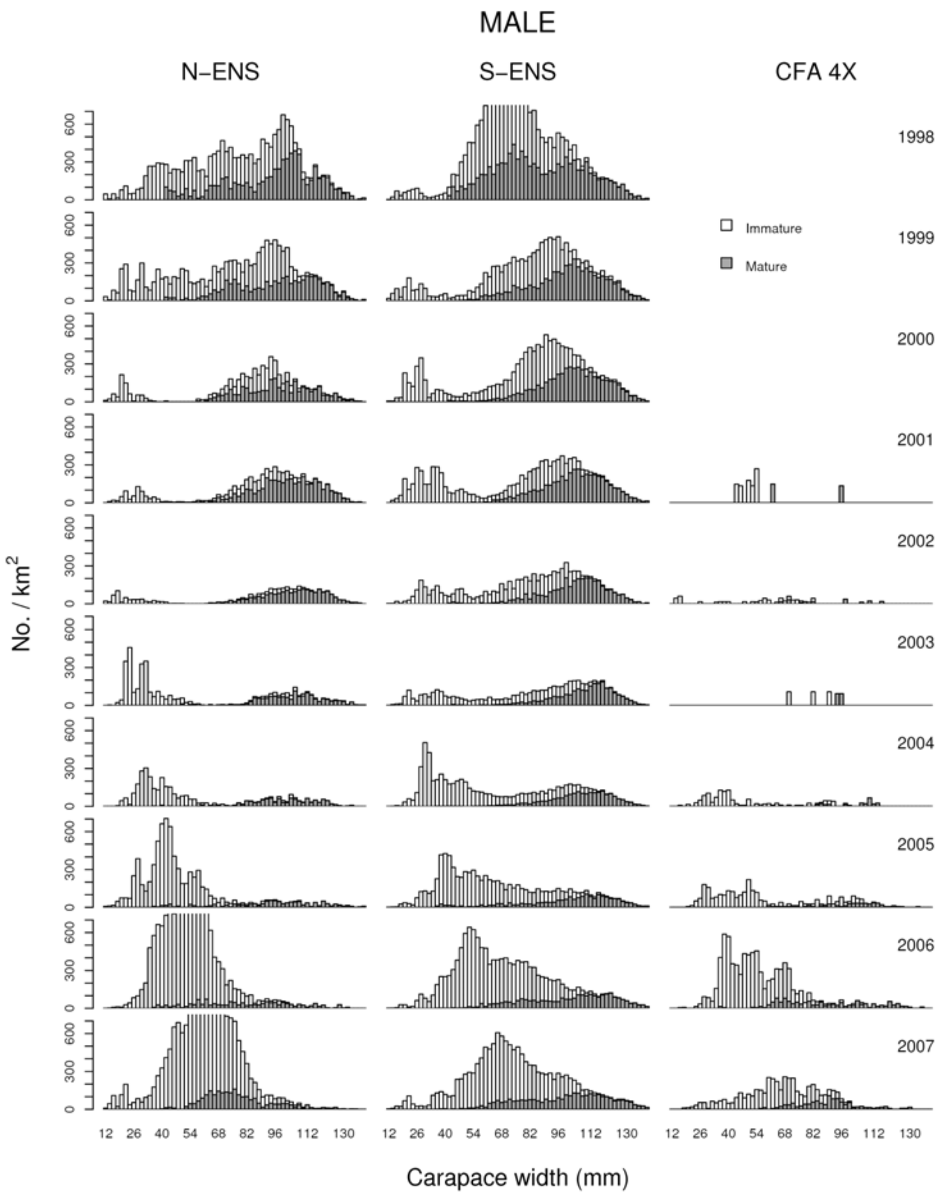


Figure 34: Size-frequency histograms of carapace width of male snow crabs. Note the increasing numbers of juvenile crab, 1 to 3 years from entering morphometrically mature size classes. Due to the expansion of the survey from core areas to the full extent of the snow crab grounds, the areal densities 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.

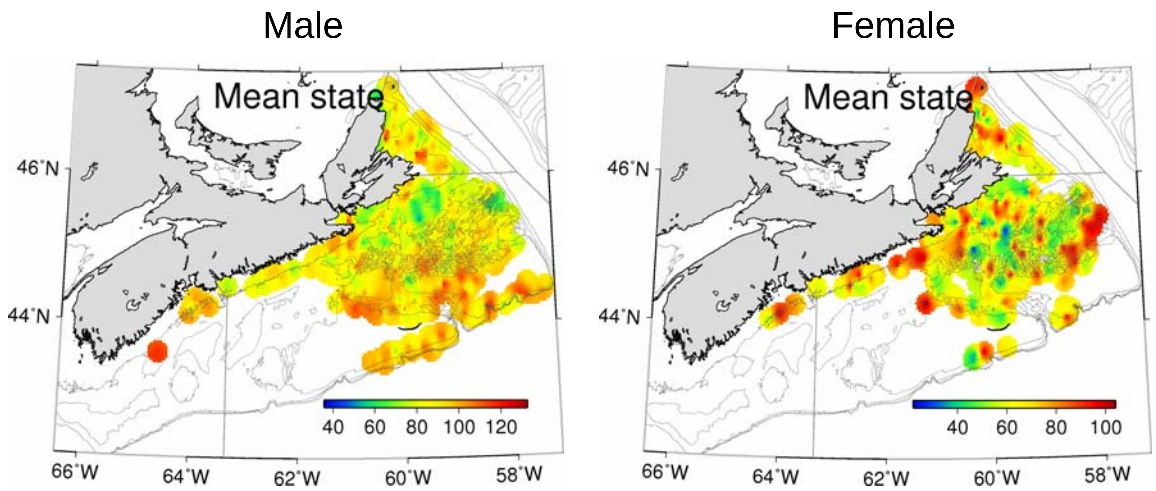


Figure 35. The spatial variations in size (CW; mm) at 50% maturity of male and female snow crab on the Scotian Shelf. Large size at maturity for males is generally observed in warmer areas. Inshore regions generally show smaller size at 50% maturity for males. For females, size at 50% maturity is heterogeneous,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

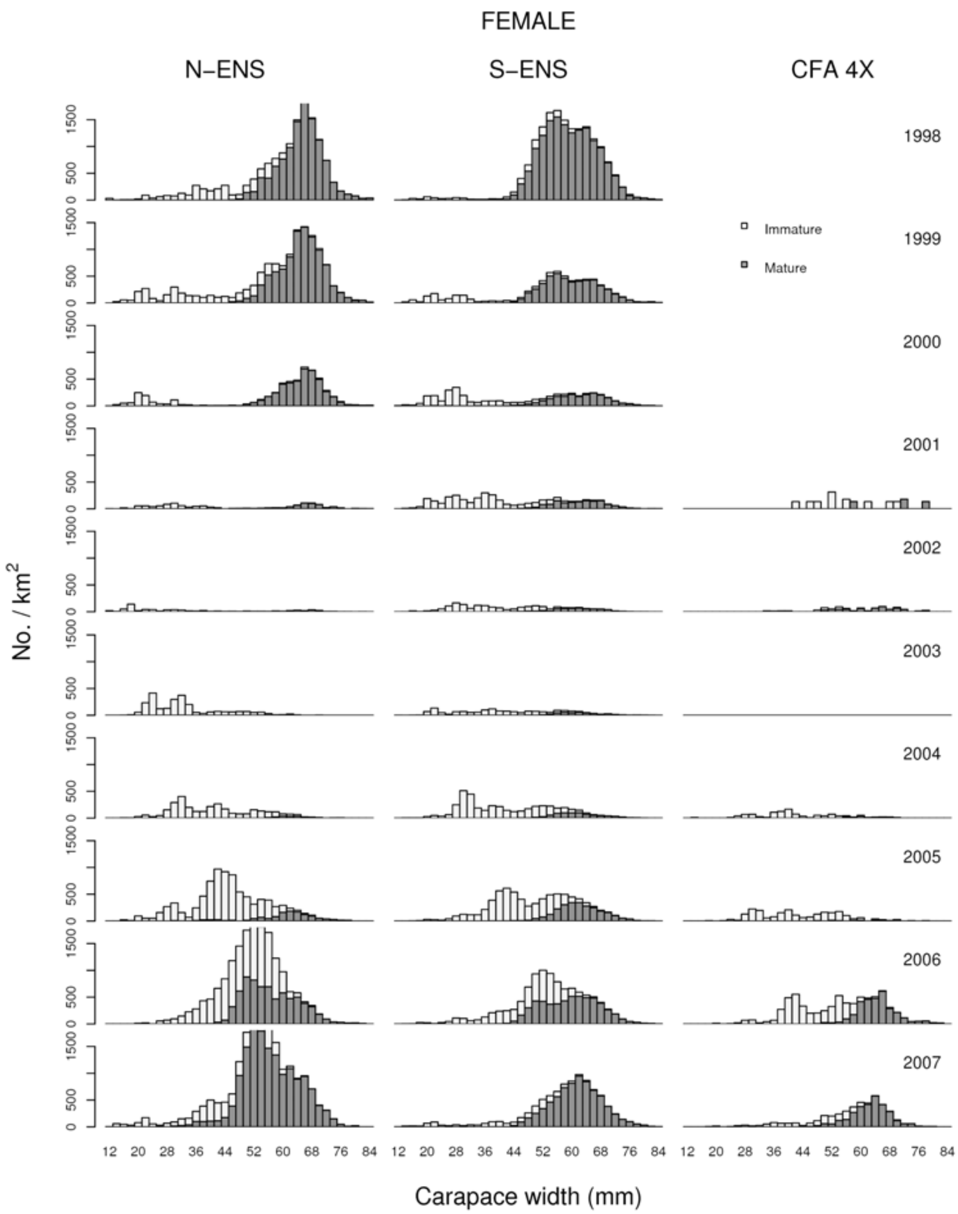


Figure 36: Size-frequency histograms of carapace width of female snow crabs. Note the increasing numbers of juvenile crab in recent years. The leading edge of the recruitment pulse has begun to enter morphometrically mature size classes. Due to the expansion of the survey from core areas to the full 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.

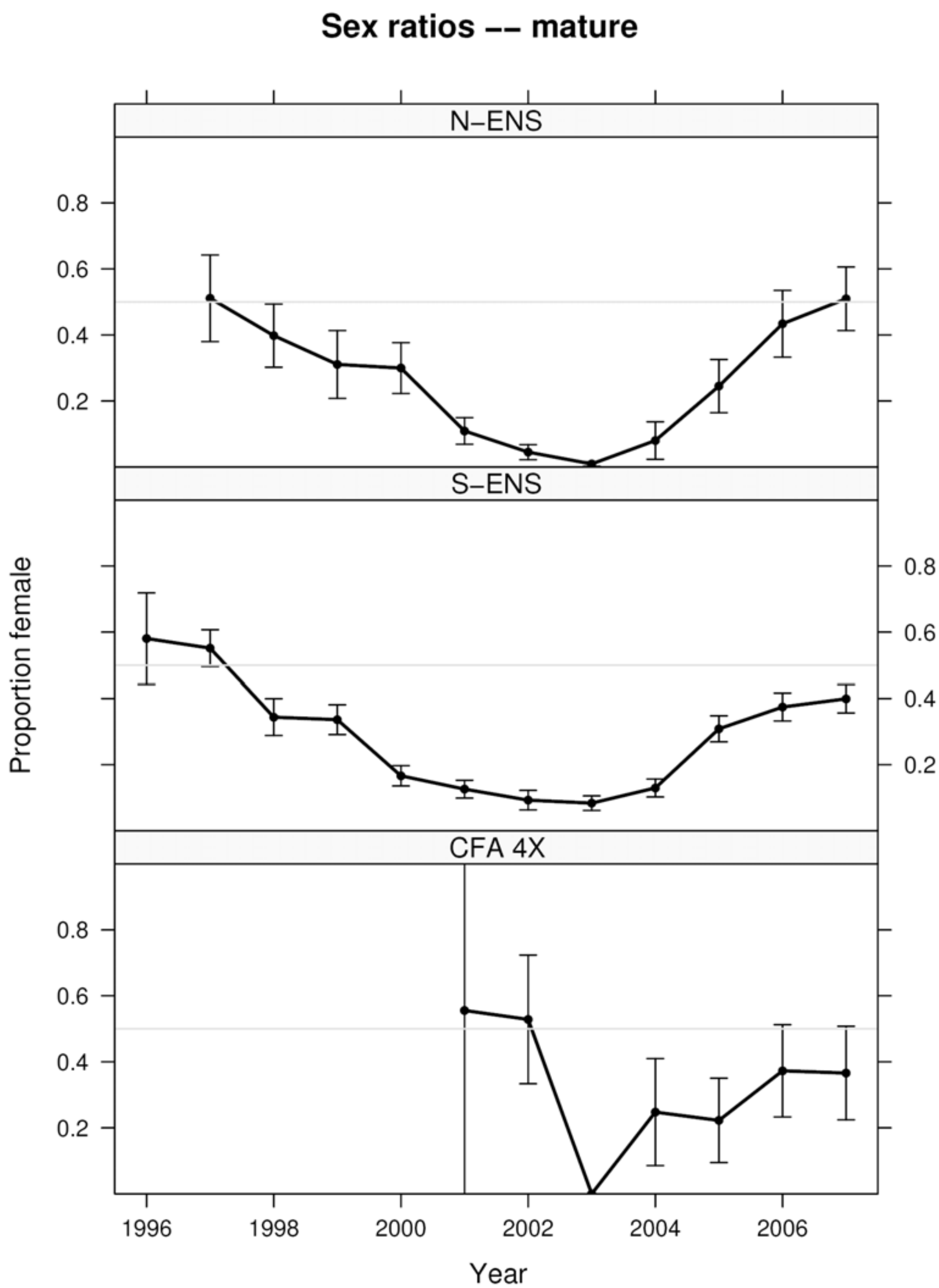


Figure 37: Annual variations in the mean sex ratio (proportion female) for morphometrically mature crabs. One standard error bars are presented. The sex-ratio of mature crabs has been declining steadily since 1996 and increasing since historic lows in 2003.

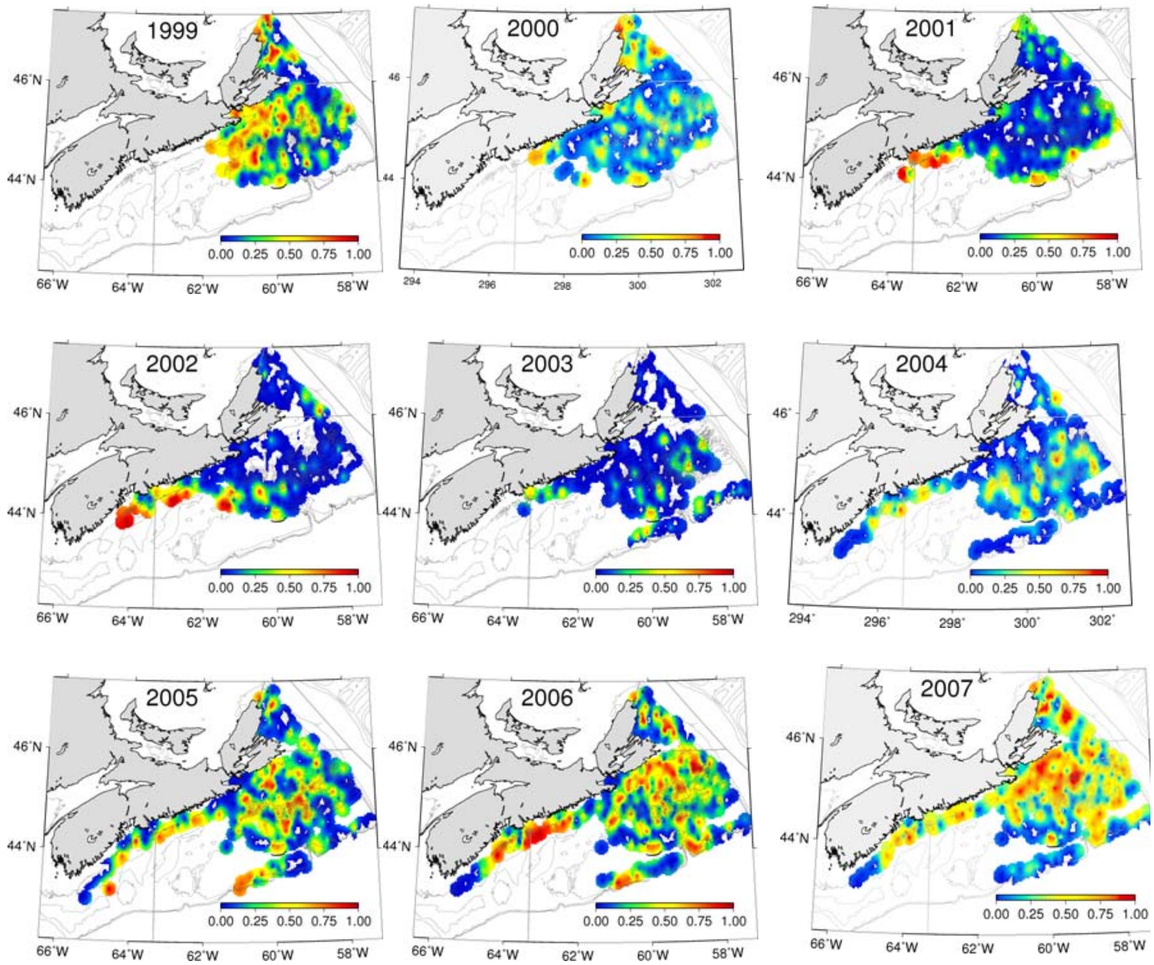


Figure 38: Morphometrically mature sex ratios. Since the early 2000s, most of the Scotian Shelf was uniformly male dominated (low values; blue). More balanced and spatially heterogeneous sex ratios as was seen during the main reproductive period in the late 1990s have been observed again, since 2005.

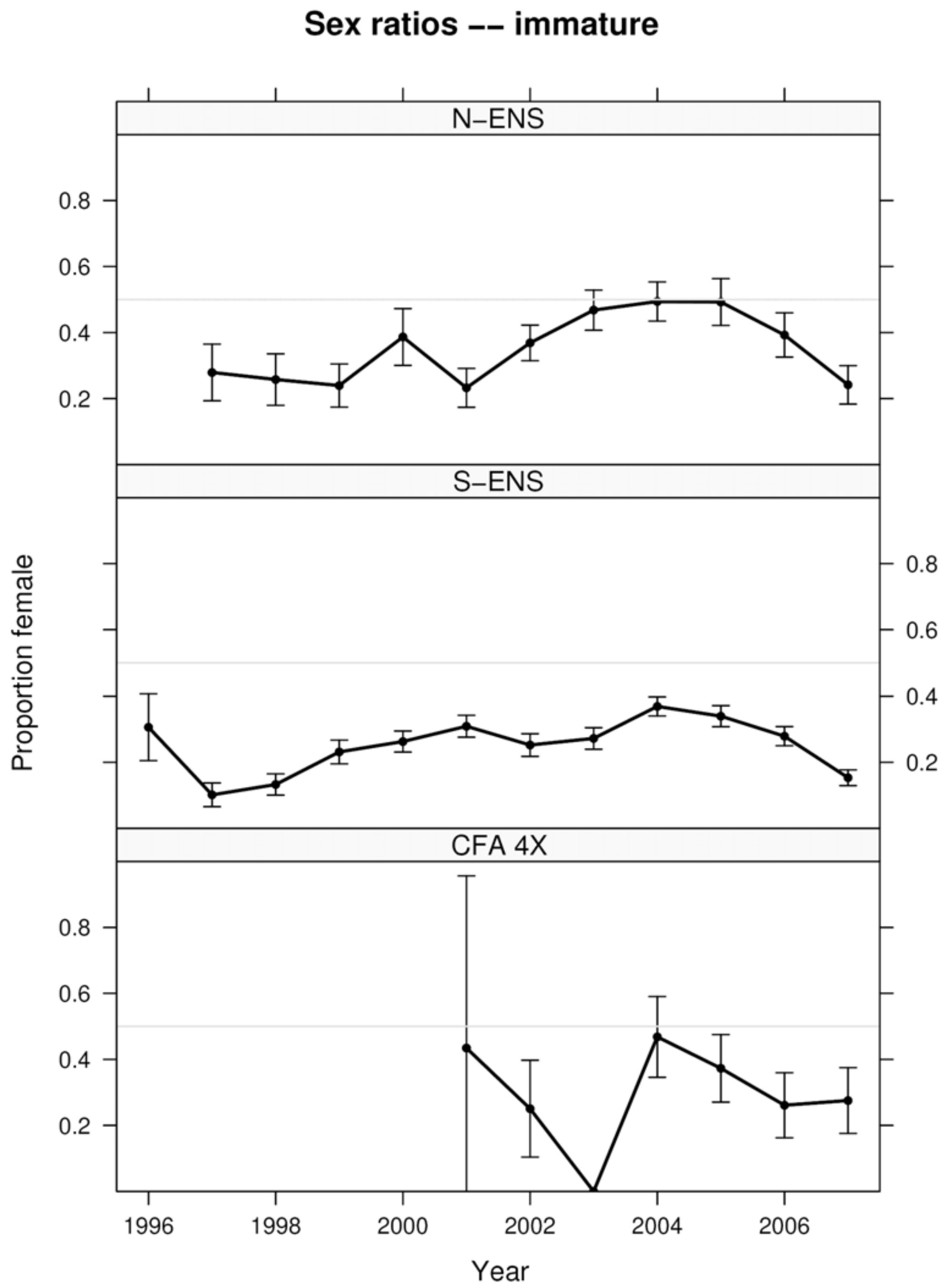


Figure 39: Annual variations in the mean sex ratio (proportion female) for morphometrically immature crabs. One standard error bars are presented. The sex-ratio of immature crabs have been steadily returning to more balanced numbers. The initial decline of immature sex ratios may have been due to size-selective snow crab cannibalism and/or predation from groundfish and macro-invertebrates (other crabs, lobsters).

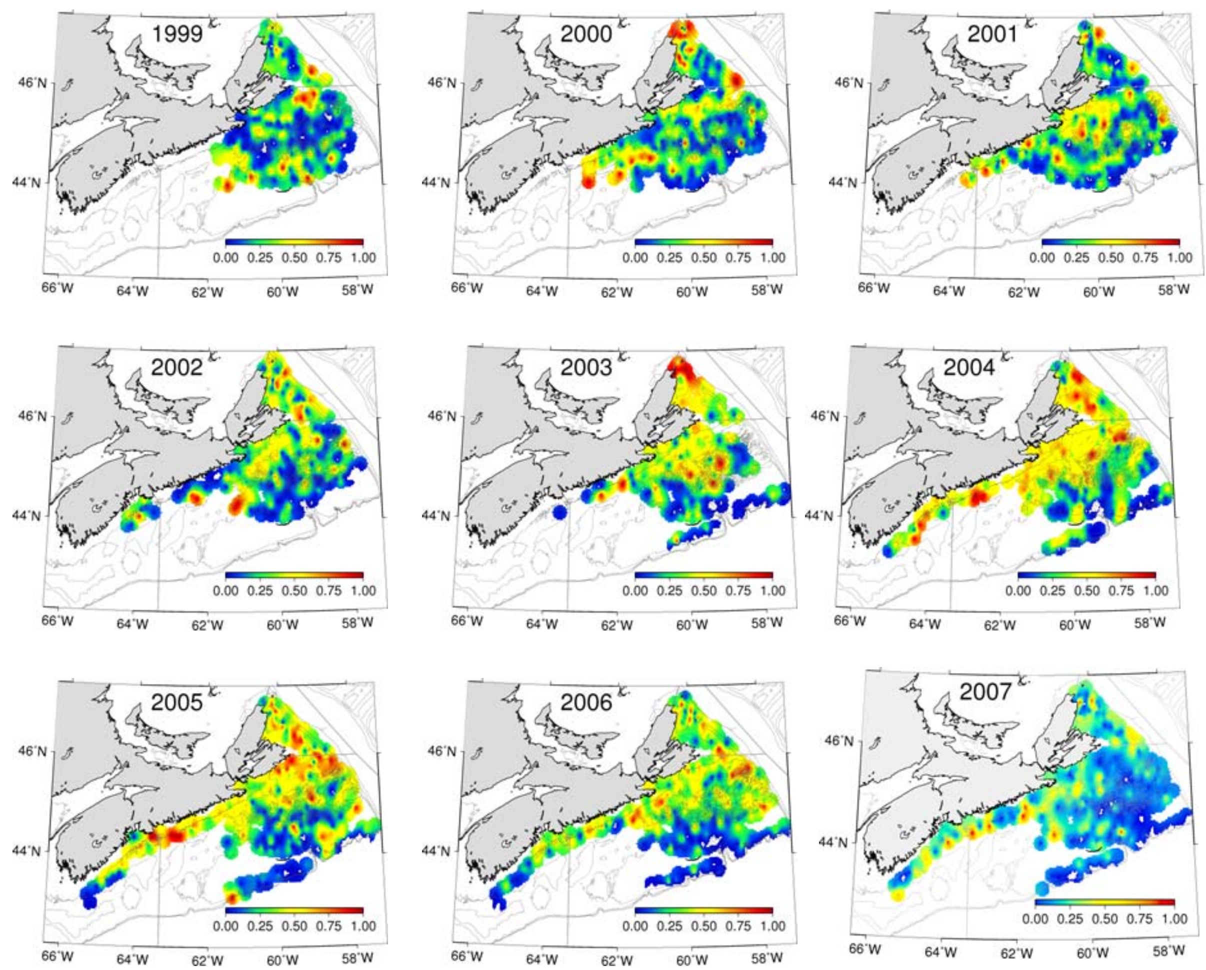


Figure 40: Morphometrically immature sex ratios. Inshore areas are generally more balanced in sex ratios or more female dominated. Offshore areas were more male dominated. In the past, this was not always the case and sex ratios of immature crabs were more heterogeneous. Currently, a return to this more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

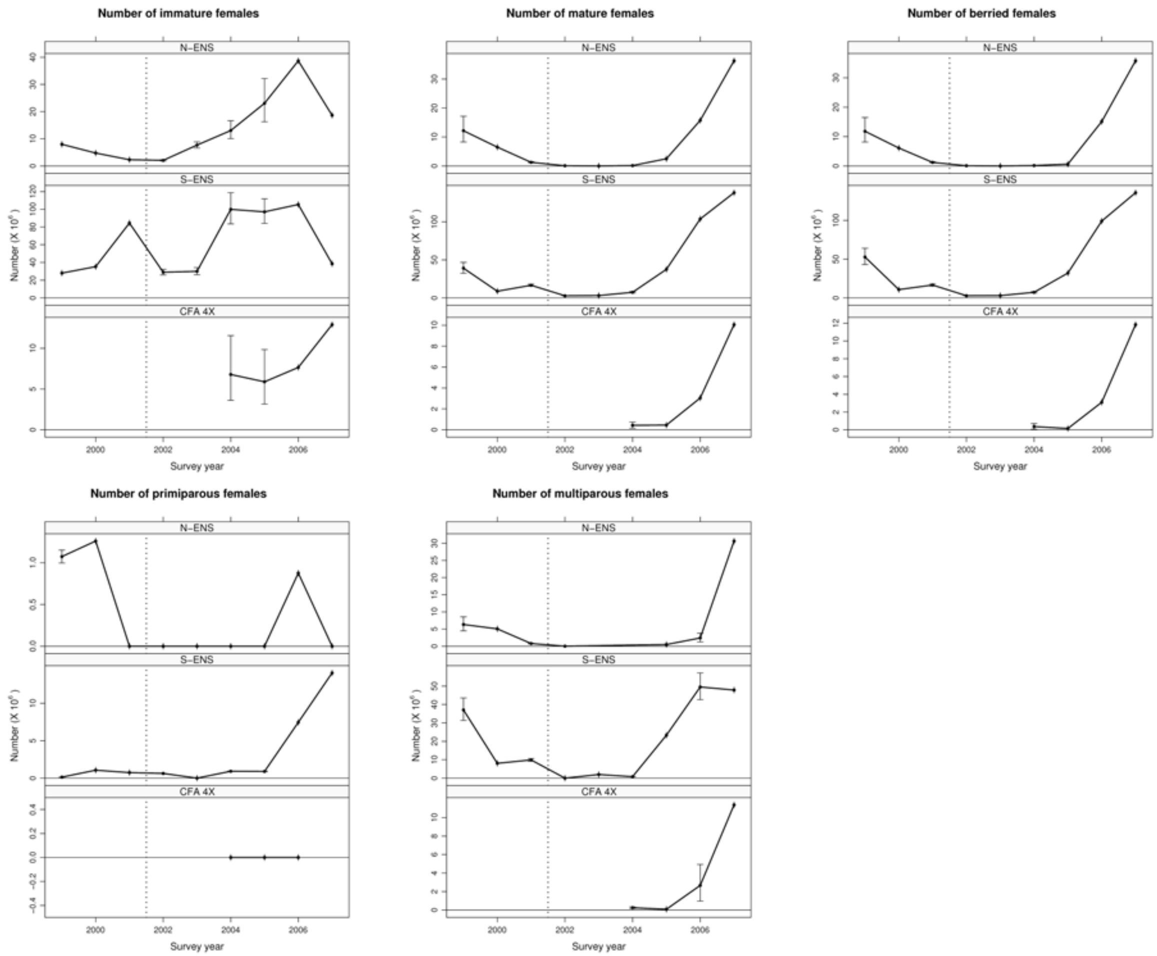


Figure 41: Temporal variations in female snow crab abundance obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

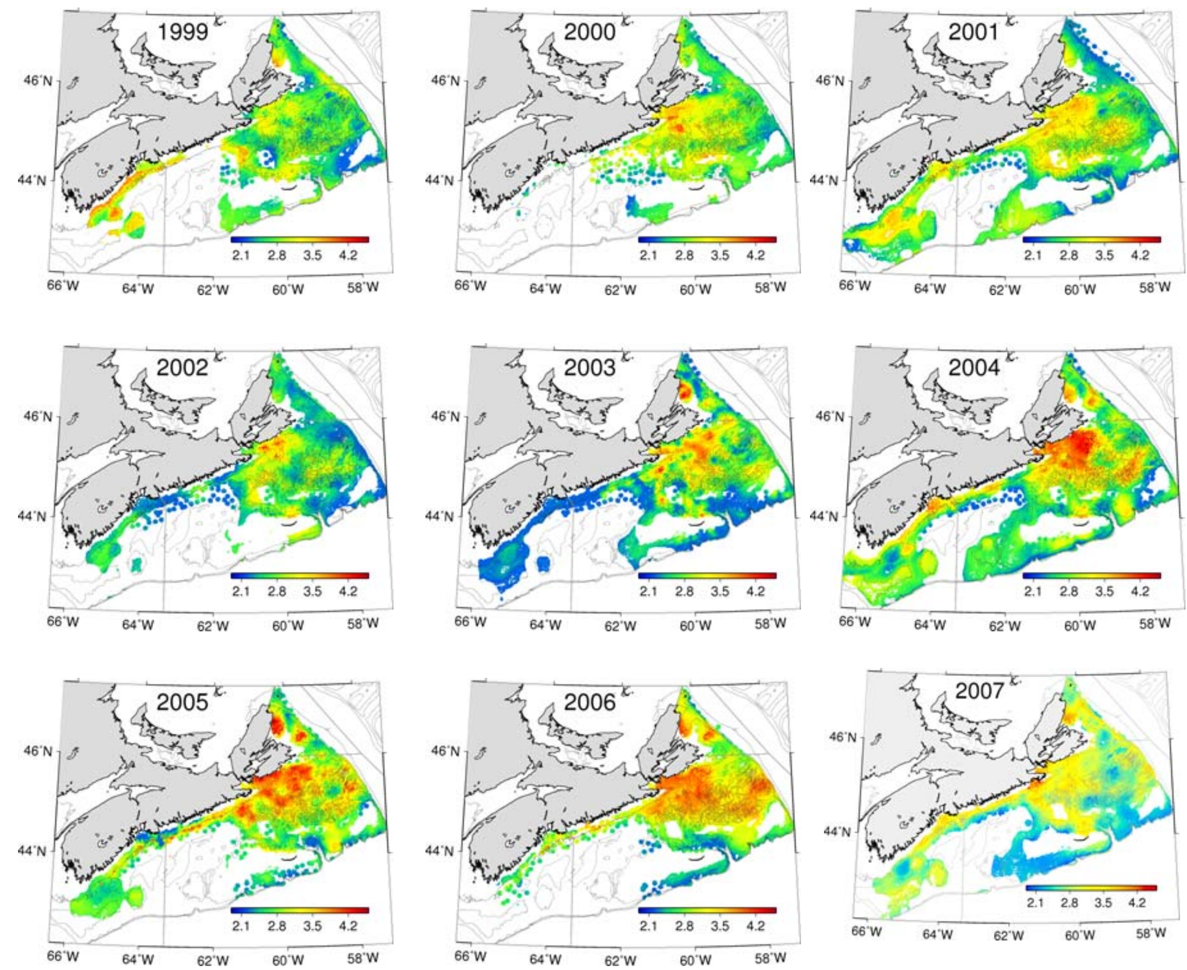


Figure 42: Numerical densities of the immature female snow crabs on the Scotian Shelf; $\log_{10}$ (number/km^2).

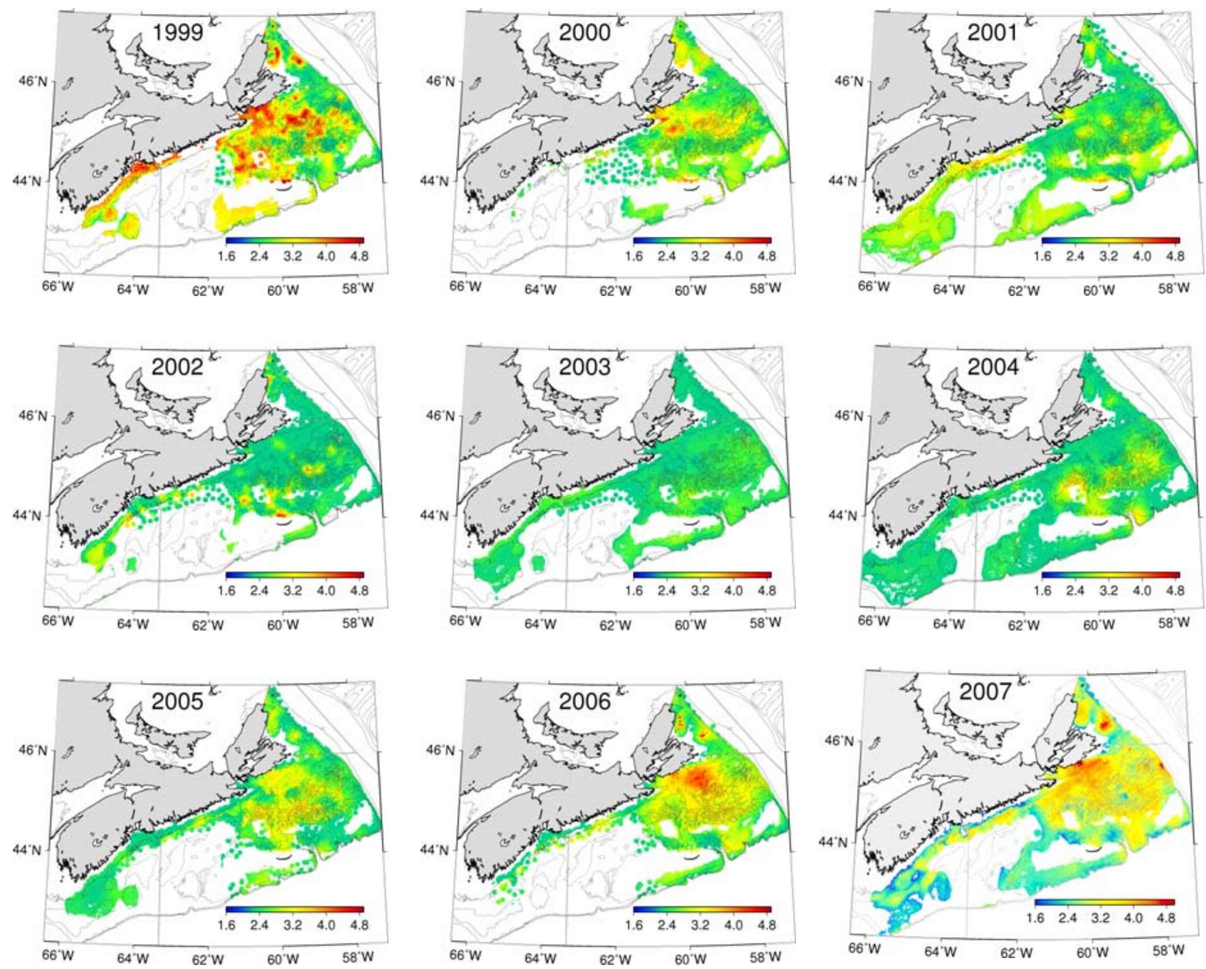


Figure 43: Numerical densities of the mature female snow crabs on the Scotian Shelf; $\log_{10}$ (number/km^2).

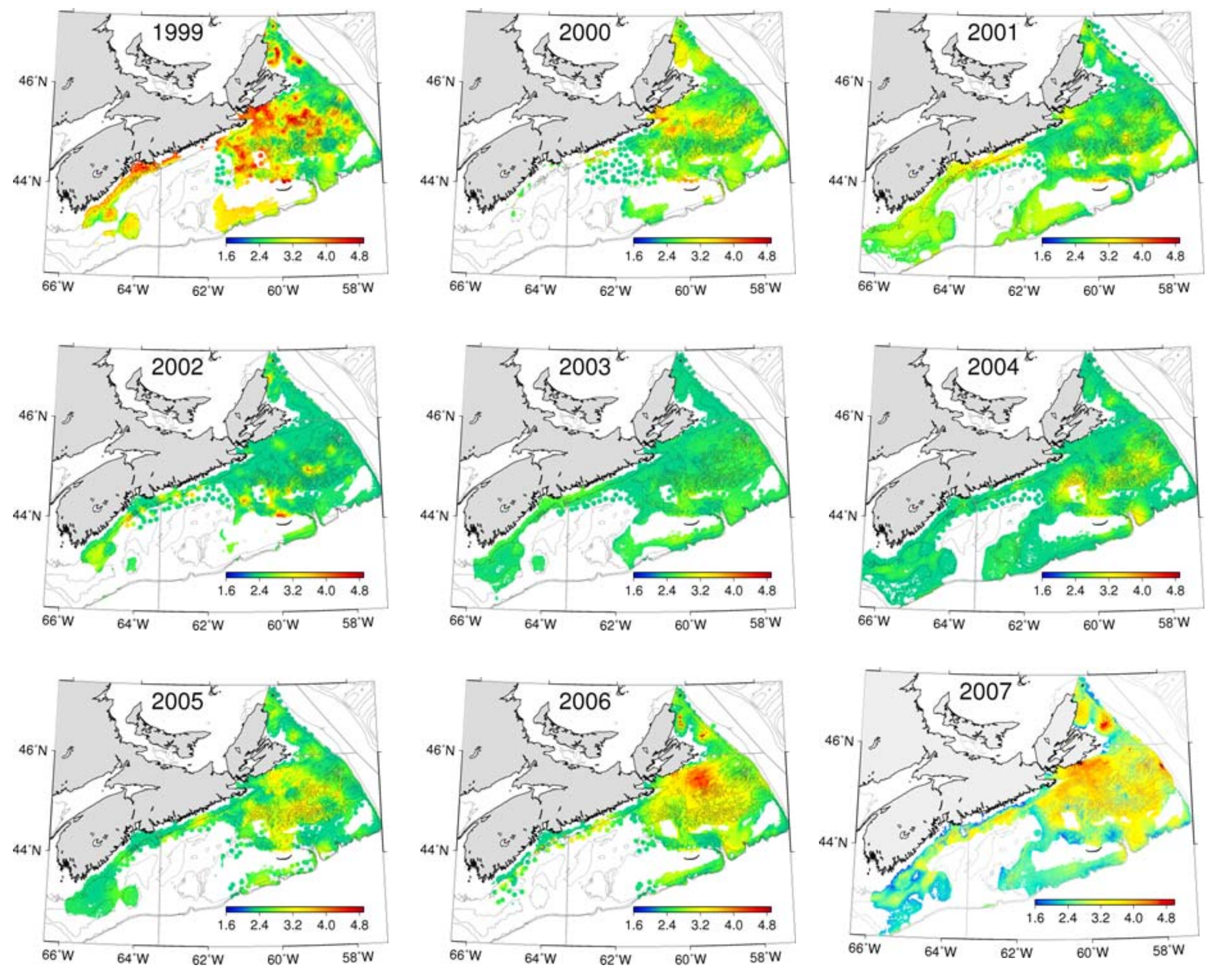


Figure 44: Numerical densities of the berried female snow crabs on the Scotian Shelf; $\log_{10}$ (number/km^2).

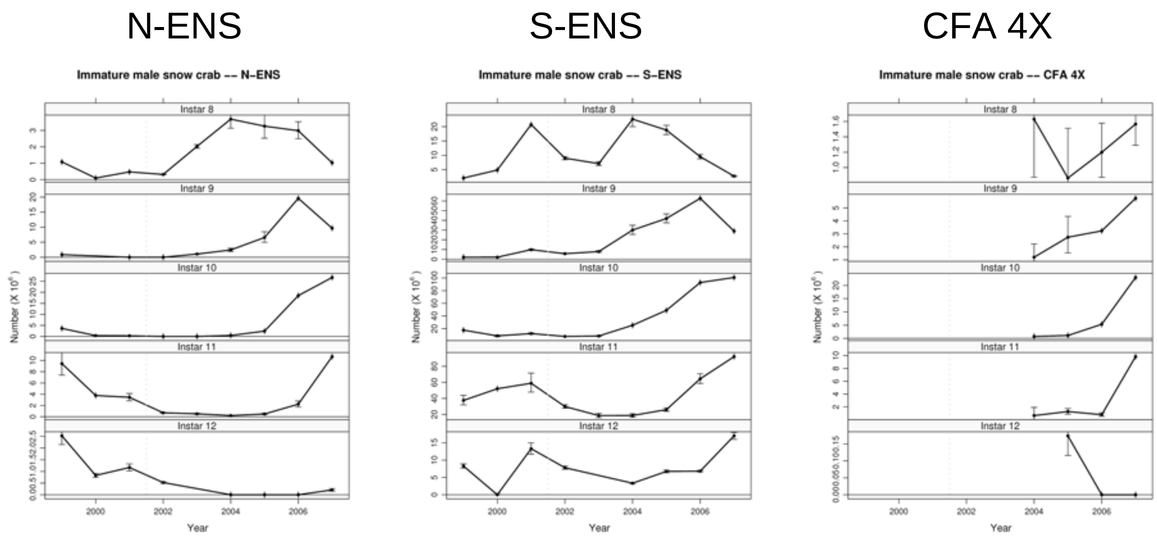


Figure 45: Temporal variations in immature instars (9 to 12) of male snow crab abundance obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

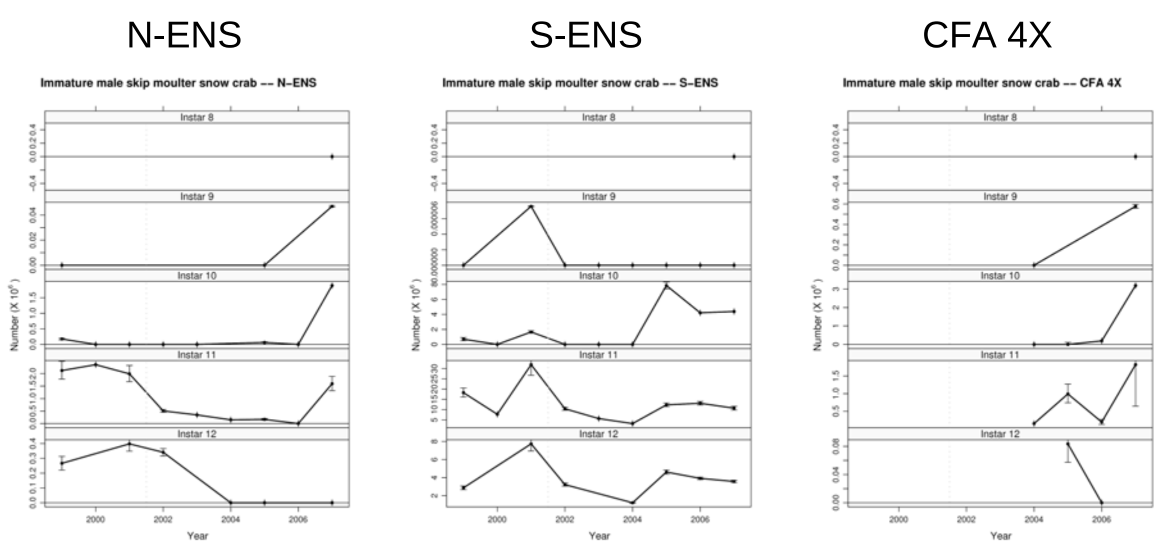


Figure 46: Temporal variations in immature skip moulting instars (9 to 12) of male snow crab abundance in N-ENS obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from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

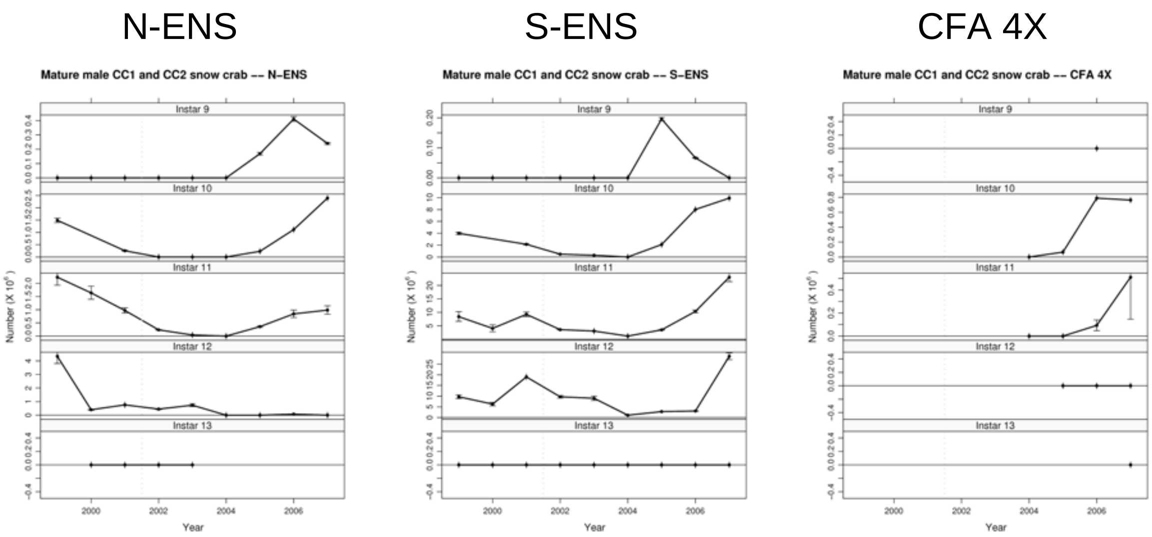


Figure 47: Temporal variations in mature CC1 and CC2 instars (9 to 13) of male snow crab abundance obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to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

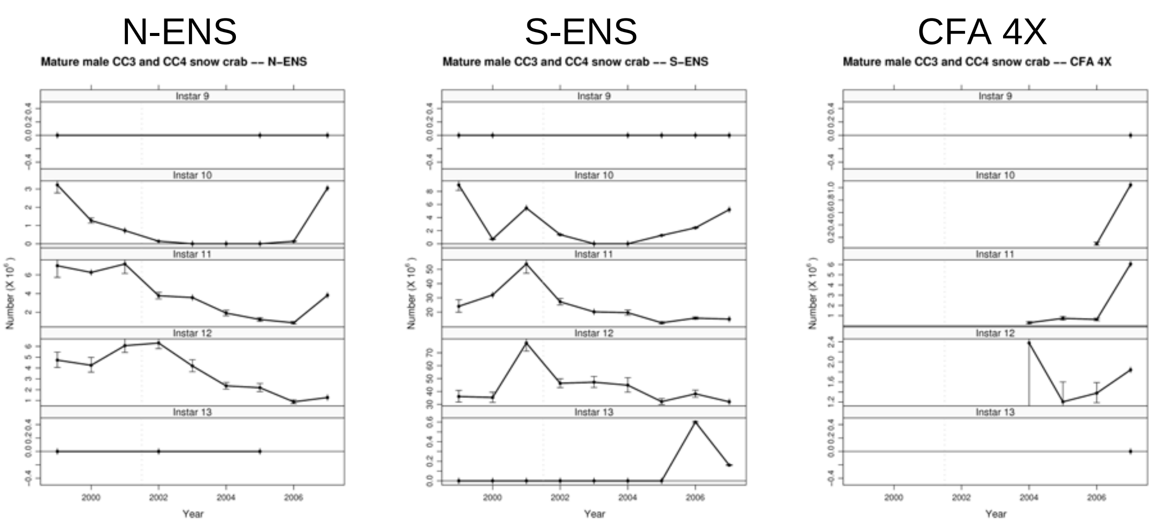


Figure 48: Temporal variations in mature CC3 and CC4 instars (9 to 13) of male snow crab abundance obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to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

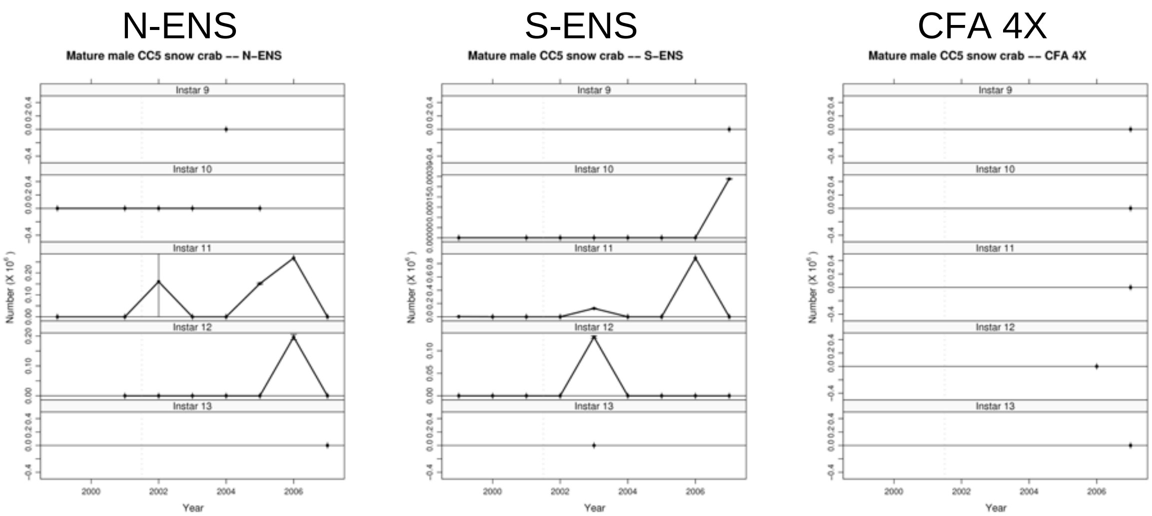


Figure 49: Temporal variations in mature CC5 instars (9 to 13) of male snow crab abundance obtained from Kriged estimates. Error bars are 95% confidence intervals about the estimated total number. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period. Note that in CFA 4X, CC5 instars are below the detection limit.

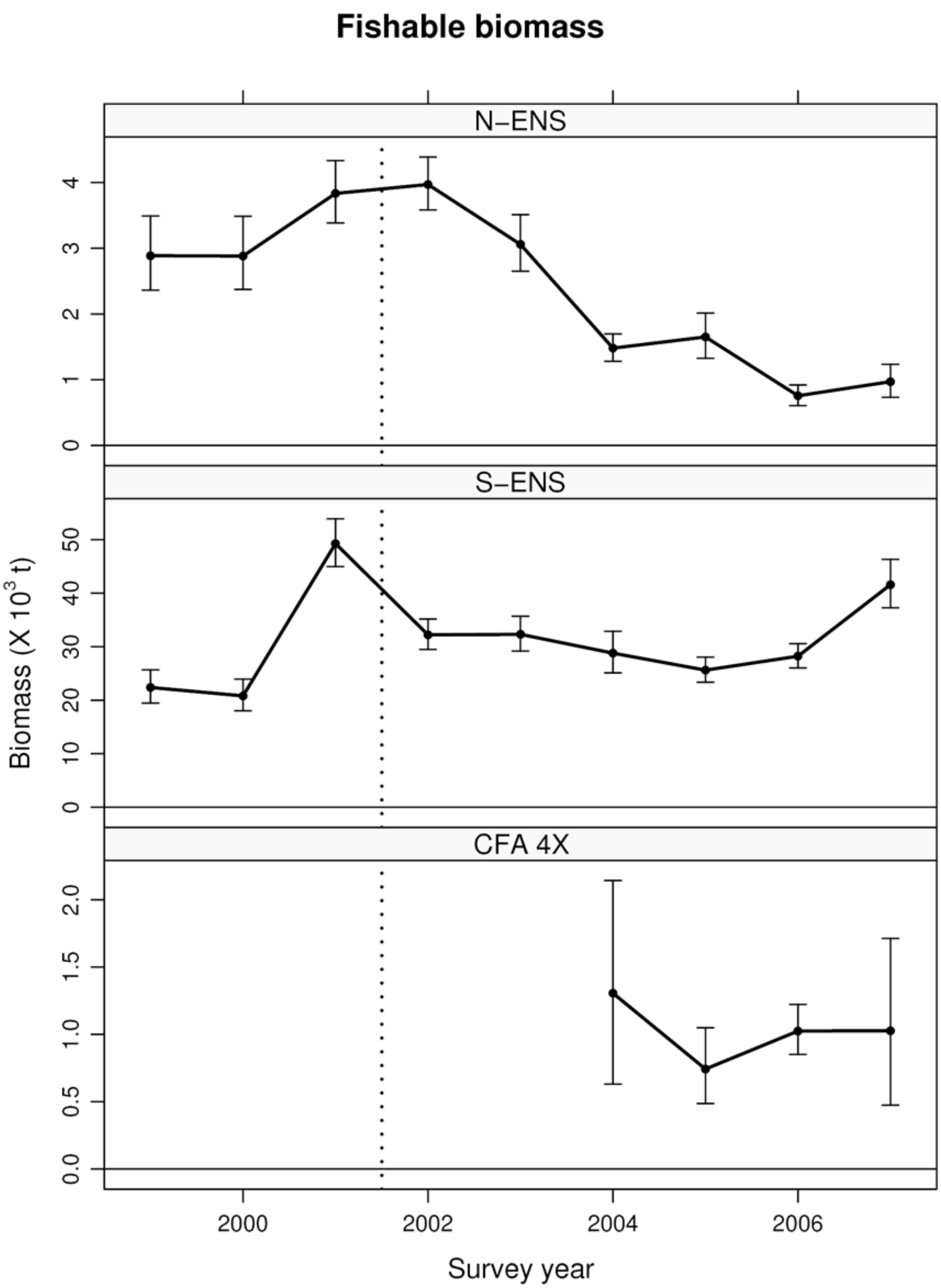


Figure 50: Temporal variations in fishable biomass estimates. Error bars are 95% confidence intervals about the estimated total biomass. The vertical line near 2002 indicates the period in which trawl surveys changed from a spring to an autumn sampling period.

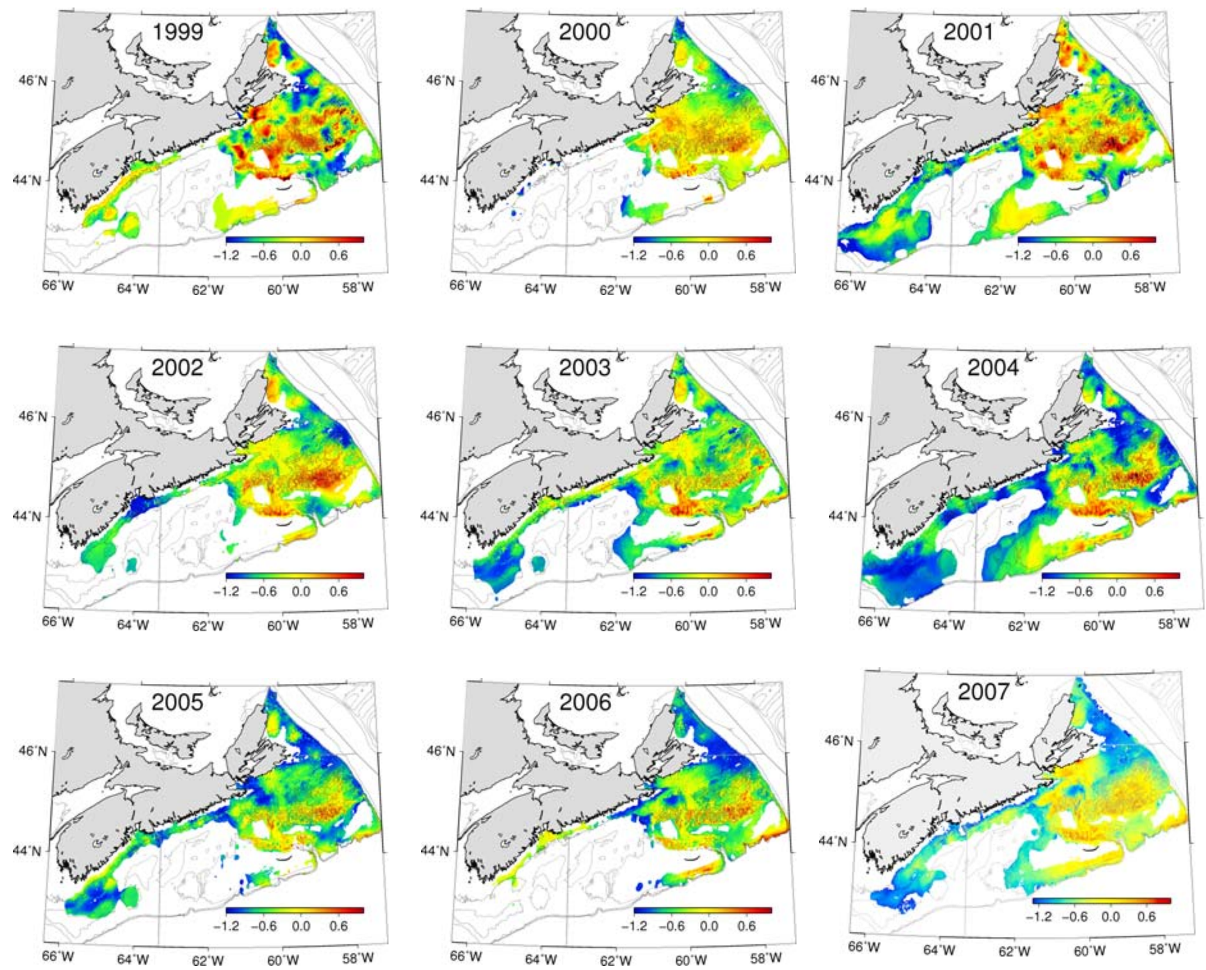


Figure 51: Fishable biomass densities on the Scotian Shelf; $\log_{10}$ (t/km^2).

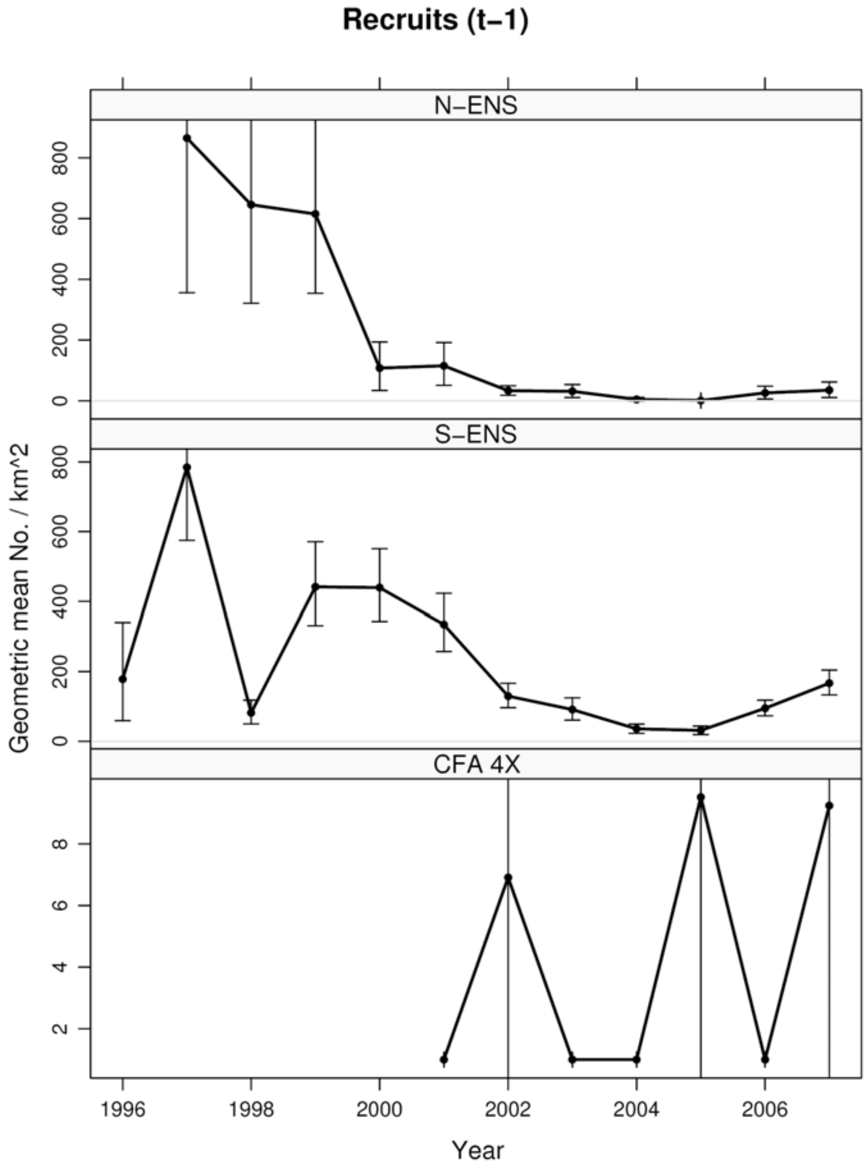


Figure 52: Temporal variations in the expected recruitment into the fishable biomass. This includes only legal sized soft crab. As surveys are conducted in the autumn (since 2002/2003), the majority of recruitment into the fishable biomass has already occurred. This figure shows the additional recruitment 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.

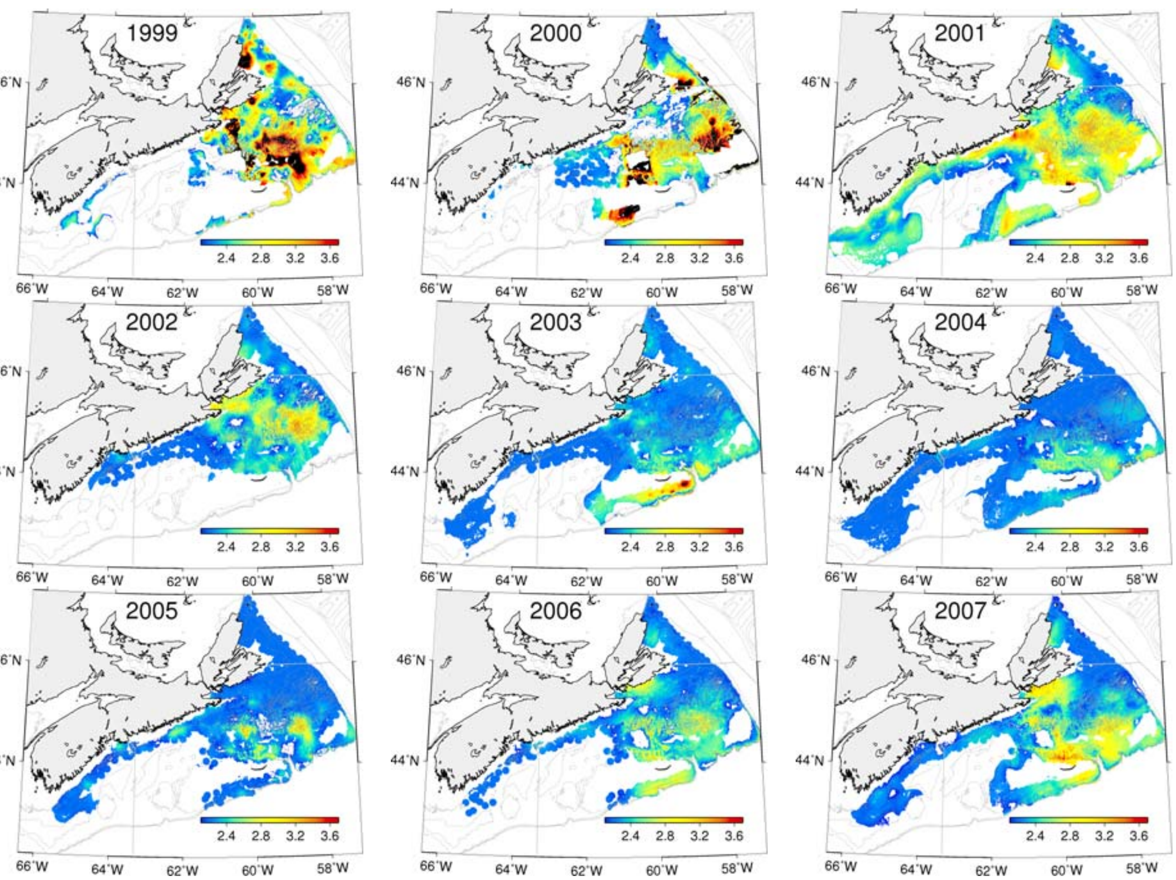


Figure 53: Numerical densities of snow crab recruiting into the next year; $\log_{10}$ (number/km^2).

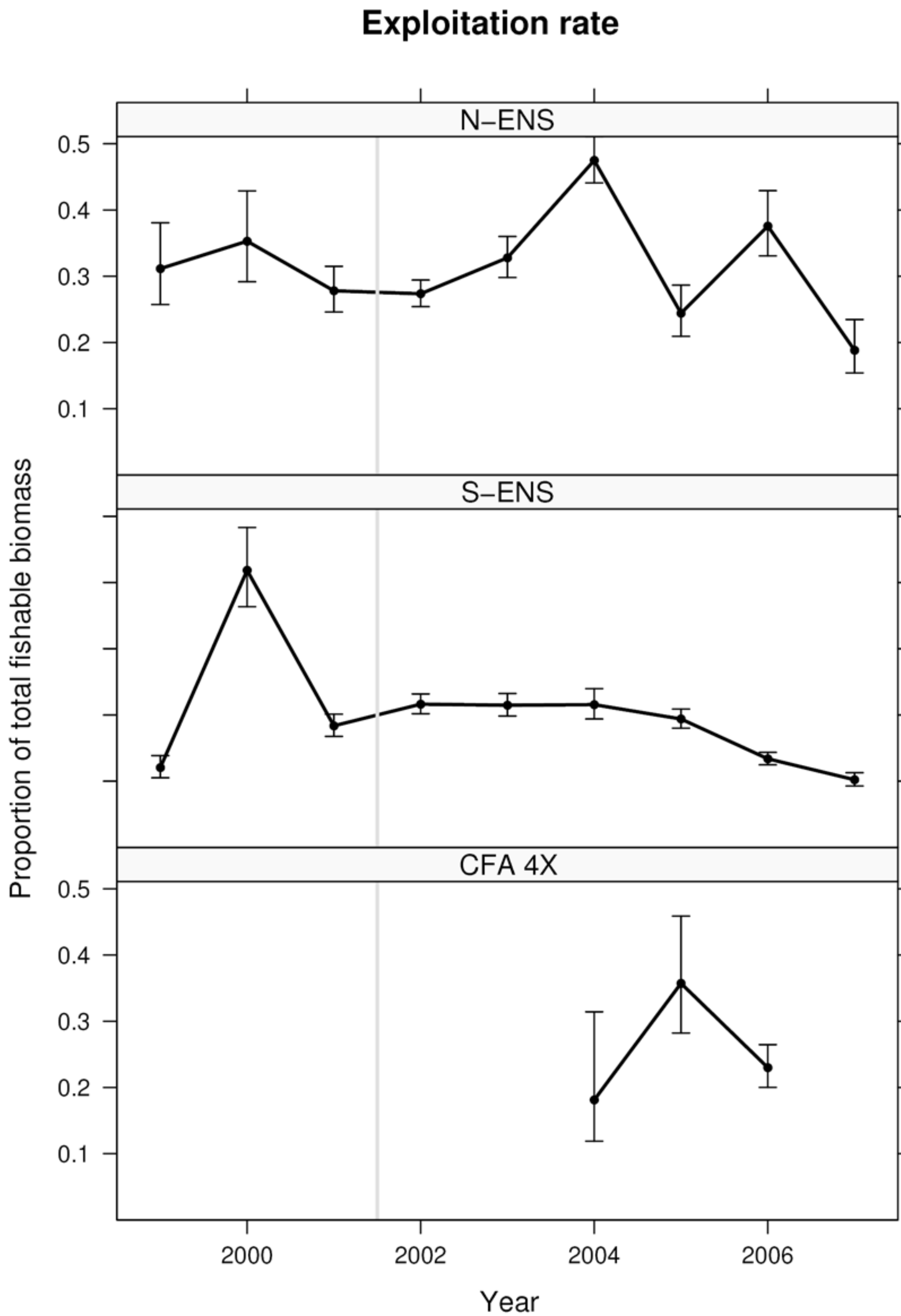


Figure 54: Relative exploitaiton rate ($Landings_{(t)}$ / [$Landings_{(t)}$ + Fishable $biomass_{(t)}$]) of snow crab. Vertical line represents the shift in survey timing from spring to autumn.

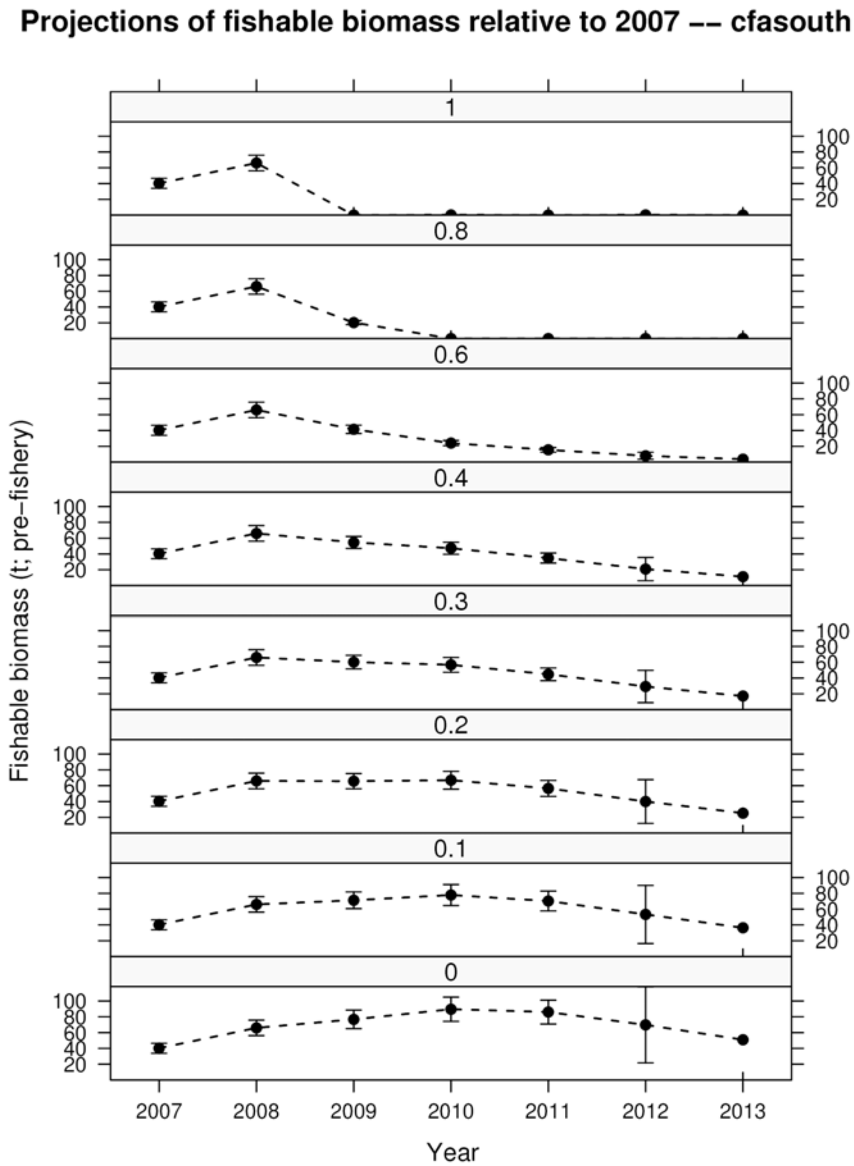


Figure 55: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for S-ENS. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.

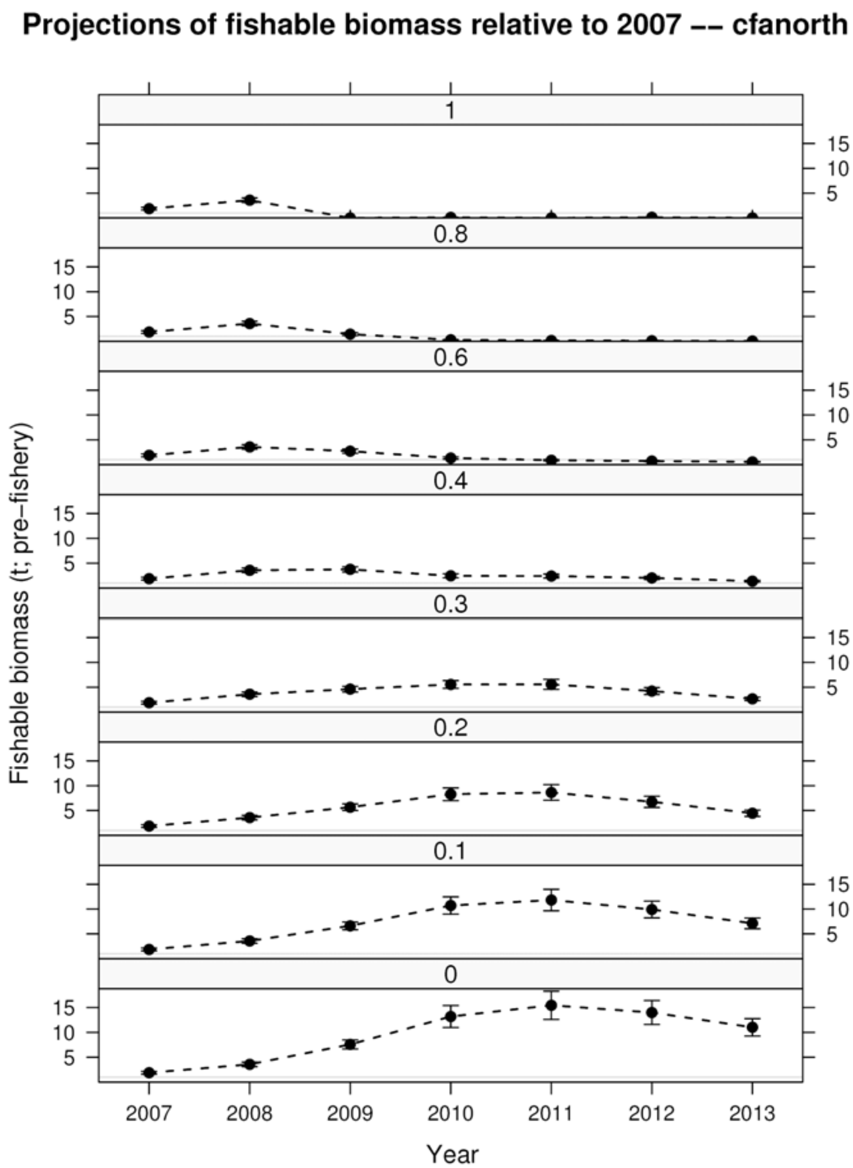


Figure 56: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for N-ENS. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.

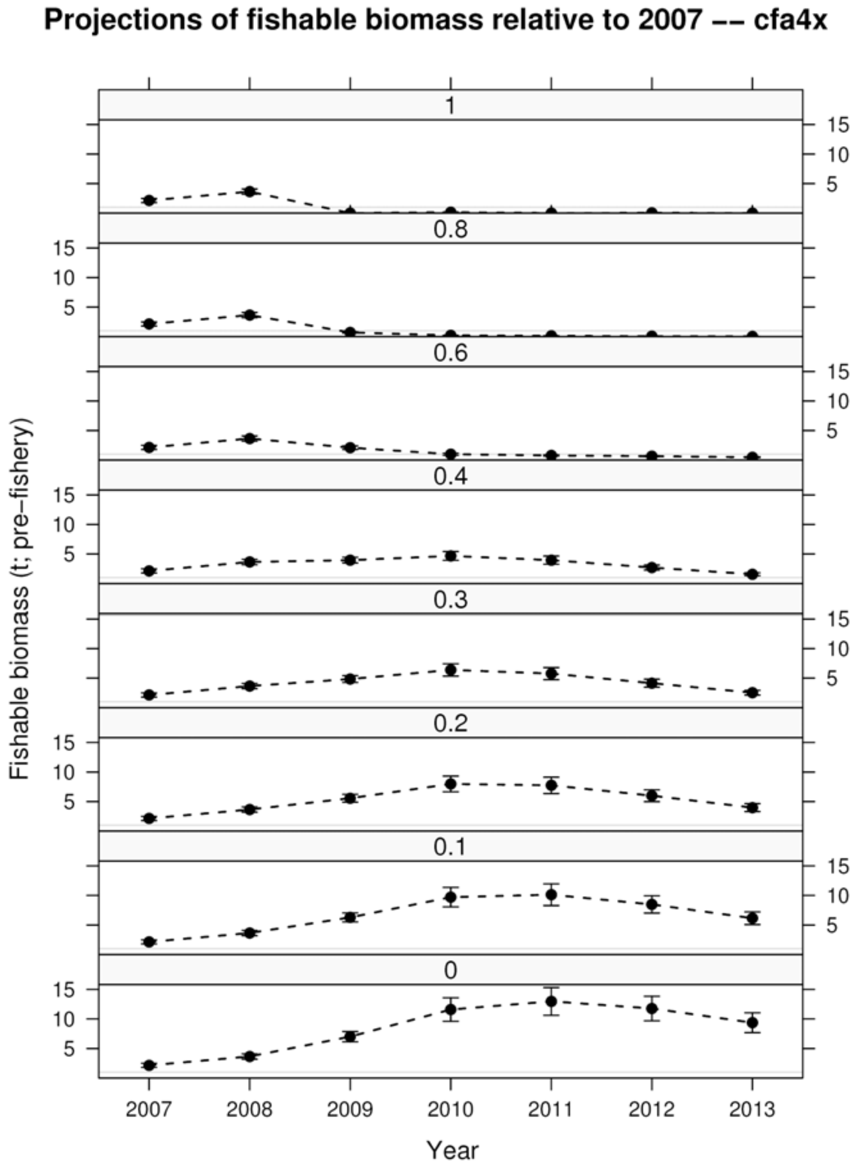


Figure 57: Temporal variations in fishable biomass relative to that of 2006 (pre-fishery; horizontal line) projected into the future based upon differing exploitation rates for CFA-4X. Error bars are 95% confidence intervals propagated by assuming all errors in parameter estimates to be independent.