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Scallop Production Areas in the Bay of Fundy: Stock Status for 2011 and Forecast for 2012

Zones de production du pétoncle dans la baie de Fundy: état du stock en 2011 et prévisions pour 2012

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ABSTRACT

This document reviews the status of scallop stocks in Scallop Production Areas (SPAs) 1, 2, 3, 4, 5, and 6 (Bay of Fundy and Approaches) for 2010/2011 with advice for 2011/2012. In this assessment, temporal patterns in condition and stock composition were used to calculate more accurate overall growth parameters for input into the population models. These new models appear to have rectified problems noted in previous assessments. In addition to these changes, the survey area for SPA 3 has been redefined.

The Full Bay fleet caught 278 t against a TAC of 300 t in SPA 1A in 2010/2011. An interim TAC of 100 t was set for the 2011/2012 season. The average catch rate in 2010/2011 was below the long term median. Population biomass estimated by the model was 1,147 t (meats) in 2011, unchanged from the 2010 estimate 2010 (1,141 t), and below the median biomass (1,251 t; 1997 to 2010). A catch of 200 t for 2011/2012 should result in an exploitation rate close to the reference exploitation rate, and an 8% decline in biomass for 2012.

In SPA 1B, the Full Bay fleet caught a total of 83.6 t against a TAC of 203 t in 2010/2011. An interim TAC of 100 t was set for the Full Bay 2011/2012 season. The Mid-Bay fleet caught 122.8 t against a TAC of 142.88 t, and Upper Bay Fleet caught 53.3 t against a TAC of 54.12 t. Full Bay and Mid Bay commercial catch rates have been relatively stable in this area for the last few years with a few exceptions. Population biomass estimated by the model was 1,745 t (meats) in 2011, a 7% decrease from the 2010 estimate (1,878 t), and below the median biomass of 1,881 t (1997 to 2010). Current recruit biomass estimates of 42.9 t are the lowest in the time series. A catch of 300 t for 2011/2012 should correspond to the reference rate and is predicted to result in a 3% decline in biomass.

The 2010/2011 TAC in SPA 3 was set at 50 t. A total of 24.2 t was landed by mid-November 2010 when the fall season closed. Approximately 49 t was caught in St. Mary's Bay and Brier/Lurcher by June 10 2011 at the close of the summer season. An interim TAC of 100 t was set for 2011/2012. The fall fishery closed October 26, 2011 with landings of 124 t. Commercial catch rates for the 2011 summer fishery indicated an increase for St. Mary's Bay from 2010, but no change for the Brier/Lurcher area. October catch rates in Brier/Lurcher were very similar to the summer catch rates in the same area, but the 2011 October catch rate increased by 15% over the 2011 summer rate. Population biomass estimated by the model was 796 t (meats) in 2011, a 37% increase from the 2010 estimate (579 t) and below the median biomass of 827 t (1996 to 2010). A catch of 150 t for 2011/2012 should result in an exploitation rate close to the reference and no appreciable change in biomass for 2012. This catch includes the 125 t already landed in the fall 2011 fishery.

In SPA 4, a total of 136.3 t was caught against a TAC of 140 t in 2010/2011. An interim TAC of 120 t was set for the 2011/2012 season. The 2010/2011 catch rate was above the long-term median. Recruitment in this area has been low but stable, with little change in recruit abundance since 2005. Population biomass estimated by the model was 656 t (meats) in 2011, a 2% increase from the estimate for 2010 (641 t), and below the median biomass of 767 t (1983 to

2010). The estimated recruitment biomass of 7.4 t in 2011 is the second lowest since 1983. Catches for 2011/2012 of 100 t should result in an exploitation rate close to the reference and is predicted to result in a 7% decline in biomass.

In SPA 5, landings were 10 t against a TAC of 10 t. The commercial catch rate in 2011 was above the long-term median. The annual survey was discontinued in this area as of 2009 at the request of industry. Catch rates have been relatively stable which would suggest a relatively stable population size at current levels of exploitation. The TAC for 2012 should not exceed the average catch of 10 t over the period 1997–2010.

A total of 104 t was landed against a TAC of 140 t in SPA 6 in 2010/2011. The Full Bay fleet reported no landings against a TAC of 21 t. Mid Bay landings for 2010 were 23.9, 26.5, 46.5, and 7.0 t for SPA 6A, B, C, and D, respectively, against a TAC of 119 t. Catch rates increased in 6B in 2011, and decreased slightly in the other areas. The distribution of commercial sized scallops decreased in 6B and 6C, and to a lesser extent in 6A. All three areas decreased in condition from 2010, and only 6C is near the long term median. Commercial catch rates suggest that commercial scallop biomass remained unchanged over recent years, while the survey indicates decreases in 2011 relative to 2010. If the condition factors continue to decline for all three areas, population biomass may decrease at the current levels of catch.

Since 2001, as part of the inshore scallop surveys, catches of commercial groundfish, lobster, squid, and octopus has been recorded. Of those species recorded during the survey, the most commonly encountered species since 2001 has been, in respective order, lobster, winter flounder, monkfish and octopus. As part of a Species-At-Risk (SARCEP) project, observer coverage was funded for the inshore scallop fishery in the Bay of Fundy and approaches in 2008 and 2009. Observer coverage occurred in SPAs 1, 4 and 5 combined in both 2008 and 2009, at a level of 2% and 3%, respectively. There was only coverage of SPA 3 in 2008 at a level of 5%, and coverage in SPA 6 only in 2009 at a level of 9%. Estimated discard rates by species group were presented.

RÉSUMÉ

Le présent document passe en revue l'état des stocks de pétoncle dans les zones de production de pétoncle (ZPP) 1, 2, 3, 4, 5 et 6 (baie de Fundy et ses environs) pour 2010-2011, et fournit des avis pour 2011-2012. Dans cette évaluation, les patrons temporels de la condition et de la composition du stock ont été utilisés pour calculer des paramètres de croissance globale plus précis qui seront utilisés dans les modèles de population. Ces nouveaux modèles semblent avoir corrigé les problèmes soulignés dans les évaluations précédentes. En plus de ces changements, la zone de relevé pour la ZPP 3 a été redéfinie.

La flottille de la totalité de la baie a capturé 278 t dans la ZPP 1A en 2010-2011, par rapport à un total admissible des captures (TAC) de 300 t. Un TAC provisoire de 100 t a été fixé pour la saison 2011-2012. Le taux de capture moyen en 2010-2011 était inférieur au taux médian à long terme. La biomasse de la population estimée par le modèle était de 1 147 t (chairs) en 2011, elle n'a pas varié par rapport à 2010 (1 141 t) et était inférieure à la biomasse médiane (1 251 t; 1997 à 2010). Une capture totale de 200 t en 2011-2012 devrait aboutir à un taux d'exploitation proche du taux de référence et à une baisse de 8 % de la biomasse en 2012.

Dans la ZPP 1B, la flottille de la totalité de la baie a capturé 83,6 t en 2010-2011, par rapport à un TAC de 203 t. Pour cette flottille, un TAC provisoire de 100 t a été fixé pour la saison 2011-2012. La flottille du milieu de la baie a capturé 122,8 t, par rapport à un TAC de 142,88 t, et la flottille de la partie supérieure de la baie a capturé 53,3 t, par rapport à un TAC de 54,12 t. Les taux de capture commerciale ont été relativement stables dans cette zone au cours des dernières années, à quelques exceptions près. La biomasse de la population estimée par le modèle était de 1 745 t (chairs) en 2011, soit une baisse de 7 % par rapport à l'estimation de 2010 (1 878 t), et était inférieure à la biomasse médiane de 1 881 t (1997 à 2010). Les estimations actuelles de la biomasse de recrue de 42,9 t sont les plus basses des séries chronologiques. Une capture totale de 300 t en 2011-2012 devrait correspondre au taux de référence et aboutir à une baisse de 3 % de la biomasse.

Le TAC de 2010-2011 dans la ZPP 3 était fixé à 50 t. Un total de 24,2 t a été débarqué avant la fermeture de la saison d'automne de la mi-novembre 2010. Environ 49 t ont été capturées dans la baie Sainte-Marie, ainsi qu'à l'île Brier et au haut-fond Lurcher, avant la fermeture de la saison d'été le 10 juin 2011. Un TAC provisoire de 100 t a été fixé pour 2011-2012. La pêche d'automne a été fermée le 26 octobre 2011, avec des débarquements de 124 t. Les taux de capture commerciale pour la pêche d'été de 2011 ont indiqué une hausse pour la baie Sainte-Marie par rapport à 2010, mais sont restés les mêmes pour l'île Brier et le haut-fond Lurcher. Les taux de capture en octobre pour l'île Brier et le haut-fond Lurcher sont très semblables à ceux observés en été dans la même zone, mais le taux de capture en octobre 2011 a augmenté de 15 % par rapport à celui de l'été 2011. La biomasse de la population estimée par le modèle était de 796 t (chairs) en 2011, soit une augmentation de 37 % par rapport à l'estimation de 2010 (579 t), et était inférieure à la biomasse médiane de 827 t (1996 à 2010). Une capture totale de 150 t en 2011-2012 devrait aboutir à un taux d'exploitation proche du taux de référence sans changement appréciable de la biomasse en 2012. Cette capture comprend les 125 t déjà débarquées pendant la pêche d'automne de 2011.

Dans la ZPP 4, un total de 136,3 t a été capturé en 2010-2011, par rapport à un TAC de 140 t. Un TAC provisoire de 120 t a été fixé pour la saison 2011-2012. Le taux de capture en 2010-2011 était supérieur au taux médian à long terme. Le recrutement dans cette zone a été faible, mais stable, avec peu de changement dans l'abondance des recrues depuis 2005. La biomasse de la population estimée par le modèle était de 656 t (chairs) en 2011, soit une augmentation

de 2 % par rapport à l'estimation de 2010 (641 t), et était inférieure à la biomasse médiane de 767 t (1983 à 2010). La biomasse de recrues estimée de 7,4 t en 2011 est la deuxième plus faible depuis 1983. Une capture totale de 100 t en 2011-2012 devrait aboutir à un taux d'exploitation proche du taux de référence et à une baisse de 7 % de la biomasse.

Dans la ZPP 5, les débarquements étaient de 10 t, par rapport à un TAC de 10 t. Le taux de capture commerciale en 2011 était supérieur au taux médian à long terme. À la demande de l'industrie, le relevé annuel n'est plus effectué dans cette zone depuis 2009. Les taux de capture ont été relativement stables, ce qui semble indiquer que la taille de la population est relativement stable au niveau d'exploitation actuel. Le TAC de 2012 ne devrait pas dépasser la quantité moyenne de capture de 10 t au cours de la période allant de 1997 à 2010.

Un total de 104 t a été débarqué dans la ZPP 6 en 2010-1011, par rapport à un TAC de 140 t. La flottille de la totalité de la baie n'a déclaré aucun débarquement, par rapport à un TAC de 21 t. Les débarquements de la flottille du milieu de la baie en 2010 étaient de 23,9 t, 26,5 t, 46,5 t et 7 t dans les ZPP 6A, 6B, 6C et 6D, respectivement, par rapport à un TAC de 119 t. Les taux de capture ont augmenté dans la ZPP 6B en 2011, et ont diminué légèrement dans les autres zones. La répartition des pétoncles de taille commerciale a diminué dans les zones 6B et 6C, et dans une moindre mesure, dans la zone 6A. La condition dans trois zones a diminué par rapport à 2010, et seule la zone 6C est près de la médiane à long terme. Les taux de capture commerciale semblent indiquer que la biomasse des pétoncles de taille commerciale n'a pas varié au cours des dernières années, tandis que les relevés indiquent des baisses en 2011 par rapport à 2010. Si les coefficients de condition continuent de baisser pour les trois zones, il est possible que la biomasse de la population diminue aux niveaux de capture actuels.

Depuis 2001, dans le cadre des relevés côtiers du pétoncle, les prises de poissons de fond commerciaux, de homard, de calmar et de pieuvre ont été consignées. De ces espèces consignées pendant le relevé, les espèces les plus présentes depuis 2001 étaient, en ordre, le homard, la plie rouge, la baudroie et la pieuvre. Dans le cadre du Programme des *espèces en péril* (SARCEP), une couverture d'observateurs a été financée pour la pêche côtière du pétoncle dans la baie de Fundy et ses environs en 2008 et 2009. Les couvertures d'observateurs, pour les ZPP 1, 4 et 5 combinées en 2008 et 2009, étaient de 2 % et 3 %, respectivement. Il y a seulement eu une présence d'observateurs dans la ZPP 3 en 2008 à un niveau de couverture de 5 %, et une couverture de 9 % en 2009 dans la ZPP 6. Les taux de rejets estimés par groupe d'espèces ont été présentés.

INTRODUCTION

The Bay of Fundy is fished by three separate scallop fishing fleets. Full Bay scallop license holders are able to fish scallops anywhere in the Bay of Fundy, Mid Bay license holders can fish for scallops on the northern side of the Mid Bay line (Fig. 1) and Upper Bay license holders fish east of the Upper Bay line. The Full Bay fleet has traditionally been based in Digby with larger vessels (> 14.5 m and < 19.8 m Length Over All (LOA)) fishing only scallops, the Mid Bay fleet consists mainly of New Brunswick based, smaller (< 14.5 m LOA) vessels with multiple licenses for different species, and the Upper Bay fleet are Nova Scotian and New Brunswick based smaller, multi-species vessels. These distinctions are diminishing as the Mid and Upper Bay fleets become more specialized, and smaller boats are replaced with larger ones. The Full Bay fleet fishes under Individual Transferable Quotas (ITQs) with a 1 October to 30 September season while the Mid and Upper Bay fleets fish a competitive quota with a 1 January to 31 December season.

Details on the Scallop Production Areas (SPA), fleet access, current TACs, landings and available data sets for stock assessment are given in the table below. No TAC has been set for SPA 2 and fishing can take place subject to special licence conditions. The Decision column indicates whether advice is provided in terms of a formal model or simply on the basis of trends in the abundance indices.

Bay of Fundy Scallops: Preliminary Results for 2011.

SPA	Fleets	TAC (meats, t)	Landings [1] (meats, t)	Survey (strata) [2]	CPUE	Decision
1A	Full Bay	300.0	278.0	1981–2011 (8–16) 1984–2011 (2–8 mile) 1997–2002, 2004–2011 (MBS)	1976–2011	Model
1B	Full Bay	203.0	83.6	1997–2011 (Cape S., MBN)	1982–2011	Model
	Mid-Bay	144.88	122.8	2002–2003, 2005–2011 (UB)	1992–2011	
	Upper Bay	54.12	53.3		1997–2011	
2	Full Bay Mid-Bay			2006		Marginal Area
3	Full Bay	50.0	73.3	1996–2011	1996–2011	Model
4	Full Bay	140.0	136.3	1981–2011	1976–2011	Model
5	Full Bay	10.0	10.0	1997–2008	1976–2011	Trends
6	Full Bay	21.0	0.0	1997–2003, 2005–2011	1976–2011	Trends
	Mid-Bay	119.0	104.4		1993–2011	
	All	1042.0	861.7			

1. As of November 8, 2011.

The last formal assessment of the stock status and scientific advice on catch levels for the Bay of Fundy and Approaches was reported in DFO (2010). Problems were identified with the results from population models being used for SPAs 1A, 1B, and 4, in addition to instability in the estimates from the model for SPA 3. A complete investigation of the models and the data inputs was recommended before the next full assessment. The stock assessment for 2009/2010 consisted of an update of the survey estimates, commercial catch rates and landings and this information was presented to a meeting of the Inshore Scallop Advisory Committee (ISAC) on January 7, 2011, along with the recommendation that catch levels for 2010/2011 remain the same as those set for 2009/2010 because survey and commercial catch rates in 2010 had indicated little change from 2009.

The performance of the delay-difference model for evaluating the impact of the fishery in the past and for the upcoming season has been evaluated by comparing successive year's estimates of biomass from previous assessments. The main problems with the results from the models for SPAs 1A, 1B, and 4 were that the current year biomass estimates were declining by a greater amount than predicted from the previous year based on estimates of growth, recruitment, natural mortality, and catch. As a result, the current models would reduce the biomass estimates for previous years to balance off the increases due to growth and recruitment with losses due to natural mortality and catch. The failure of the model for SPA 3 also appeared to be due to inconsistencies between the degree of decline in survey biomass estimates and removals from the population due to estimated natural mortality and catch. Problems may have also been related to a mismatch between the broader survey area (i.e., covering much of SPA 3) and the areas currently being fished (focused on nearshore waters).

In this assessment, annual changes in the relationship between meat weight and shell height were re-evaluated and a new growth model was developed for the population models. This new model appears to have rectified the problems with the models for SPAs 1A, 1B, and 4. The survey area for SPA 3 was redefined based on Vessel Monitoring System (VMS) data to correspond to the area being fished since 2002 and catches were lined up with the survey index allowing for the change in survey timing from an August survey before 2004 to a May/June/July survey from 2004 onwards. These changes, in addition to the new growth model, have solved the problems for the population model in SPA 3.

In previous assessments of these SPAs, catch levels for the following year had been evaluated for the modelled populations in terms of an exploitation rate target of 0.15, and whether or not the proposed catch would result in a decrease in biomass from the current year. The main goal for this approach was to promote stability in the population biomass until recruitment levels had improved. Recruitment success seems to be determined more by favourable environmental conditions than stock size for scallops in this area.

Reference points defined by Department of Fisheries and Oceans (DFO) for its implementation of the Precautionary Approach evaluate catches in terms of lowering exploitation rates and improving levels of stock status (e.g., biomass) such that the productivity of the stock increases (DFO 2006). Previous assessments of scallops in the Bay of Fundy (Smith et al. 2008, Smith et al. 2009b) had argued that the lack of a demonstrable stock/recruitment relationship for scallops did not guarantee an increase in productivity when biomass was used to indicate stock status. All fisheries managed by DFO will be adopting a full Precautionary Approach with reference points defining limits, thresholds, and targets for exploitation and stock status in the next year. While work is ongoing on developing such reference points for the inshore scallop fisheries, the results have not been discussed with the fishing industry. Until these discussions take place and the reference points undergo peer review, advice for the inshore scallop fisheries will continue to be presented in terms of a target exploitation rate of 0.15 and the likelihood of decreases in biomass.

Observer coverage has not been routinely available for the scallop fleets in the Bay of Fundy. However, as part of a Species-At-Risk (SARCEP) project, observer coverage was funded for the inshore scallop fishery in the Bay of Fundy and approaches in 2008 and 2009. Data is presented here for all species recorded by this additional observer coverage.

Scallop removals accounted for in the assessment include landings from the inshore scallop fleets and Food Social and Ceremonial (FSC) catch. Landed recreational and FSC catch by dip netting, diving, tongs, and hand is not recorded and, therefore, not available. Scallop discards by the scallop fishery are presented in the Fishery Bycatch section. For non-scallop fisheries where bycatch information is available, scallop discards were insignificant compared to discards from the inshore scallop fleet (Gavaris et al. 2010).

GROWTH AND CONDITION

The population dynamics for all SPAs (excluding 5 and 6) have been modelled using the delay-difference model (Quinn and Deriso 1999),

$$B_{t+1} = \left(\exp(-m_t)\left(\rho + \frac{\alpha}{\overline{w}_t} \right)(B_t - C_t) + R_t \right)\mu_t \tag{1}$$

where B_t, $\overline{w}_t$, and m_t are the population biomass, average weight of the portion of the population recruited to the fishery, and instantaneous natural mortality, respectively in year t. The term R_t denotes the biomass of the recruiting size classes in year t. C_t is the catch in year t. The μ_t represents random error associated with the model dynamics. The state-space structure of the model and the Bayesian methods for estimation were reviewed in Smith et al. (2008).

The $\rho + \alpha/\overline{w}_t$ term is the annual growth increment and will decrease (increase) as the average size increases (decreases) representing an older slower growing (younger, faster growing) population. The parameters α and ρ have been obtained from a regression of the weights-at-age a on the weights-at-age $a - 1$. This linear relationship is a consequence of using a von Bertalanfy growth curve for weight as a function of age (Quinn and Deriso 1999). The growth increment term assumes that growth can be modelled based on using mean meat weight of the commercial size animals as a proxy of the mean shell height. However, in many of the areas the relationship between meat weight and shell height has shown a great deal of interannual variability that has complicated the fit of the model.

Variability in growth with respect to time and space has been noted in previous assessments but incorporating this information into the assessment has presented challenges (Smith and Lundy 2002). There is also a substantial amount of variability in the shell height/meat weight relationship hereafter referred to as condition. Spatial variability in growth rates and condition are well documented in sea scallops and are likely related to both temperature and food availability (Robert et al. 1990, Kenchington et al. 1997, Smith et al. 2001). Seasonal factors such as food availability (i.e., plankton blooms) and spawning are also factors but because the surveys generally occur at similar times each year this variation should be minimized. In this assessment spatial patterns of growth and condition were examined and in the case of condition incorporated into the estimates of survey biomass. Temporal patterns in condition and stock composition were used to calculate more accurate overall growth parameters for input into the models.

To calculate condition the approach presented in Hubley et al. (2011) was applied where the meatweight/shell height model is simplified by assuming an isometric length weight relationship, i.e., the weight is divided by the cube of the shell height. This ratio is commonly referred to as the condition factor (CF).

$$CF = \frac{W}{L^3}$$

Calculating condition factor is useful because it provides a single metric that expresses the changing weight-height relationship that can be compared with various potential factors such as year, depth, and location. Decimetres (dm) were used for shell height units so that the condition factor will be relative to the meat weight of a scallop with a 100 mm shell (roughly commercial size). A linear mixed effects model was fit to meat weight (w) and shell height (h) data collected for each scallop in a given sample and the random effects are estimated for the condition factor of each sample location (l).

$$w_{il} = (A - a_l)h_{il} + \varepsilon_{il}$$

The resulting fits of this model produce a fixed effect (A) or the overall condition factor and a random effect (a_l) or the sample specific condition factor. Sample specific condition factors are used to evaluate the effect of year, depth and location so that these data may be used to predict condition factor for tows where no weight sample was taken.

Food availability and temperature are the likely factors that have the most effect on condition factor but detailed data for these variables are not available for each sample location. Depth data are available and may serve as a proxy for these other variables. Although there is a strong linear relationship between depth and condition in offshore scallop beds (Hubley et al. 2011), the relationship is more complicated in inshore areas (Figs. 2, 3). The effect also appeared to vary between areas. In the Bay of Fundy condition increased as depth decreased up to about 70 m where it levelled off (Fig. 2). In SPA 3 condition increased slightly as depth decreased until there was a sharp increase of condition for depths above 40 m (Fig. 3). For these reasons generalized additive models (GAMs) were used to predict condition as opposed to linear models. Generalized additive models use smoothing functions to fit data and are useful when explicit relationships are not clear. Despite this flexibility however, depth alone may not be sufficient to explain variability of condition for a given area in a given year. For example, in SPA 3 similar depths are found close to shore in the Brier-Lurcher areas and St. Mary's Bay, but condition in St. Mary's Bay is much higher. This prompted the use of location as a predictor in the GAM by fitting a two dimensional smooth to latitude and longitude of each sample location.

$$CF_{ly} = f_1(D_l) + f_2(Lat_l, Lon_l) + a_y + b + \varepsilon_{ly}$$

Where the condition factor for a given location (l) and year (y) is given by a smooth function (f_1) of the depth at the location (D_l), a two-dimensional smooth function (f_2) of the latitude (Lat_l) and longitude (Lon_l) at the location, an annual factor (a_y) that may represent variability in food availability and temperature, and intercept (b). More accurate estimates of biomass per tow could be estimated by using this model to predict condition factors for each tow, instead of just using the same parameters for every station. Overall annual condition factors that will be used in the models were calculated as the mean condition factor in each survey weighted by biomass.

A von Bertalanffy (VB) growth equation was fitted to available age data as a nonlinear mixed effects model with random effects assigned to each sample location (l).

$$L_t = (L_\infty - l_{\infty,l})\left(1 - e^{(K - k_l)(t - t_0)}\right)$$

where L_∞, K, and t_0 are the fixed effects model parameters and $l_{\infty,l}$, and k_l are the random effects for each sample location (l).

Although age data were available for all areas since 1996, in most cases only total age was recorded. Total ages and the associated shell heights are useful for examining spatial patterns in growth but less so for annual patterns which would be better detected using models fit to each age ring on the scallop shells. For the purposes of integrating variable annual growth rates into the delay-difference model, fixed effects parameters from the total age growth models were used while random effects parameters were used to look at spatial variability in growth.

The annually varying growth rates for the model (g_t) are simply the ratios between the observed average meat weight of commercial or recruit size scallops and the observed average meat weight of the same scallops the following year. To calculate g, the average shell height of commercial or recruit size scallops is converted to a meat weight using the annual condition factor:

$$\overline{w}_{t-1} = CF_{t-1}\overline{h}_{t-1}^{3}$$

Then the average height of those scallops a year later ($\overline{h}_t$) is calculated using the VB parameters

$$\overline{h}_t = L_\infty\left(1 - e^{-K}\right) + e^{-K}\overline{h}_{t-1}$$

and then,

$$\overline{w}_t = CF_t\overline{h}_t^{3}$$

so that

$$g_{t-1} = \frac{\overline{w}_t}{\overline{w}_{t-1}}$$

The resulting annual observed growth potential tends to be more variable than the theoretical growth potential which varies only with respect to average weight. In the models used in this assessment g_{t-1} has been substituted for the $\rho + \alpha/\overline{w}_t$ term in equation (1).

OTHER CHANGES TO THE MODELS

Information on survey catchability from efficiency studies conducted in the Quebec region was incorporated into the models in the form of a prior distribution for q_I . Various methods were used for estimating the efficiency of the Digby dredge used in the sea scallop fishery off the Magdalen Islands (Québec, Canada). The data used came from fishery or research surveys, and the methods used were DeLury's depletion, Index-Removal method, and depletion experiments. Nine independent estimates of gear efficiency were obtained using these methods. The estimates ranged between 45% and 72% (unpublished data, Hugo Bourdages, DFO).

A beta distribution was assumed for the prior with a mean equal to the mean of the efficiency estimates from the DeLury depletion experiments, and a variance equal to the variance of the estimates from all experiments mentioned above. That is,

$$q_I \sim beta(a = 10.64, b = 9.36).$$

When a uniform prior was used for the term S , corresponding to the average dissolution time as a proportion of the year for clappers as part of the “Popcorn” model used for estimating natural mortality (for details see Smith and Lundy 2002), the posteriors were not always well defined and often the variability between areas was much greater than would seem reasonable. Therefore, a beta prior was added to the models in an attempt to produce better defined posteriors and to minimize the variability between areas. The parameters of the prior were determined from the posteriors of S under a uniform prior from the model fit to SPA 1A, one of the areas where the posterior distribution of S was best defined.

$$S \sim beta(a = 8, b = 11)$$

SPA 1A: SOUTHWEST BAY OF FUNDY

Maps of fishing locations based on commercial fishing logs for the Full Bay fleet from 2003/2004 to 2010/2011 for SPAs 1A, 1B, and 4 are presented in Figs. 4 and 5.

COMMERCIAL FISHERY

The Full Bay fleet caught 278 t against a quota of 300 t in 2010/2011. Annual trends for landings and quotas are presented in Fig. 6. Landings have been similar over the last few years. An interim quota of 100 t was set for 1 October 2011 for the 2011/2012 season, and as of 8 November, 0.88 t in landings were reported.

Year	Avg. 02–06	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012
TAC (t)	600	150	216	265	300	300	100[3]
Landing (t)	465	137	226	267	297	278[2]	0.88[2]

1. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.
2. landings based on quota report dated 8 November 2011.
3. interim TAC.

Since 2006/2007, commercial catch rates (kg/h) in 1A have been around the long-term median (Fig. 7). The average catch rate in 2010/2011 (14 kg/h) declined from that in 2009/2010 (15.3 kg/h) and was below the long term median (15.7 kg/h from 1995/96 to 2009/10). Over this time period, effort was increasing, although there was little change between 2010 and 2011.

SURVEY

Density and biomass of commercial size scallops (≥ 80 mm) was most evenly distributed in the 8 to 16 mile area (Figs. 8, 9, and 10). Densities tended to be lower and more irregular in Middle Bay south. Recruit density in 1A is generally low, and concentrated mostly in the 8 to 16 mile area. Distribution of recruits is sparse in Middle Bay South (Fig. 11).

Recruitment has been low in the 8 to 16 mile area (Fig. 12) for the last number of years. In 2011 there was a slight increase in pre-recruits (< 65 mm shell height), but abundance of both recruits (65 to 79 mm) and commercial size scallops (≥ 80 mm) in the survey did not change from 2010 (Fig. 13). The mean weight per tow (kg) showed little change for either recruits or commercial sized scallops.

In the 2 to 8 mile area, abundance of recruits and pre-recruits continues to be low (Fig. 14). The survey showed little change in recruit abundance or weight, and a slight decrease in both the abundance and weight of commercial scallops (Fig. 15).

In the Middle Bay south area, there was very little change from previous years. Recruitment continues to be low, while there are more larger scallops in the population in 2011 than in recent years (Fig. 16). Abundance of recruit and commercial size scallops has been steady since 2008 (Fig. 17). There was a slight increase in weight/tow for commercial size scallops.

Survey numbers for all of SPA 1A show little change in population size of commercial or recruit size scallops, with a small increase in population biomass of commercial sizes over the last three years, and little change in recruit biomass (Fig. 18).

GROWTH AND CONDITION

The average condition factor for SPA 1A from 1996 to 2011 is 10.9 g/dm^3, so that on average a meat from a scallop of 100 mm shell height would weigh 10.9 g at the time of the survey. In Middle Bay South and the 8–16 miles area the condition factor has been near this average for the last two years, while in 2–8 miles area it appears to have increased from 11.8 g/dm^3 in 2010 to 13 g/dm^3 in 2011 (Fig. 19). The current spatial patterns of condition in SPA 1A show that condition declines in the 8–16 miles area as the depth increases the further out the Bay (Fig. 20). Patterns in the rest of SPA 1A are less discernable but condition is generally higher in the 2–8 miles area than in Middle Bay South.

The area of highest density in SPA 1A is off of Gulliver's Head (strata 12) (Fig. 9) but this is not a good condition area so that when converted to biomass using the condition factor it is similar to other areas in strata 20 and 16 (Fig. 10). Spatial variability in condition and the average shell height of the commercial scallops was used to calculate what the meat count would be for a given location assuming all scallops >80 mm were kept. This analysis shows that meat count in SPA 1A below the gut is likely higher than 45 scallops per 500 g (Fig. 21). However, other areas of SPA 1A particularly above Young's Cove (strata 6, 7, 16, 17 and Middle Bay South) have much better meat counts (10–30 scallops per 500 g). Spatial variability in VB growth parameters and the average shell height of the commercial scallops was used to calculate what the growth in biomass would be for commercial scallops for 2011/2012 in a given location, assuming no recruitment or mortality. The general pattern here is lower potential for growth in Middle Bay South than in the 2–8 and 8–16 miles area strata (Fig. 22). Knowledge of where the most growth is expected could be useful during periods when there is very little recruitment (Fig. 11).

POPULATION MODEL

The delay-difference model was fit to the survey and catch data from 1997 to 2011. Stratified survey indices from both the 8–16 and 2–8 miles area were combined with the index from Middle Bay South. The index for Middle Bay South in 1997 was assumed to be the same as it was in 1998 and other missing years (2003 and 2004) were filled in using simple interpolation. Two chains were generated, each 80,000 samples long with the first 40,000 discarded for burn-in. Retained samples were thinned by 10 to give 8000 samples to estimate the posterior distribution. Trace plots indicated full mixing of chains and convergence. The model fit the survey mean estimates quite closely for both commercial size and recruit size scallops but did allow for a high amount of uncertainty for the estimates of recruits in 2001 (Fig. 23). The comparison of posterior distributions with the priors indicated that the prior for the S term was highly influential, but this is not surprising since the posteriors of this model using an uninformative prior were used to create the informative prior of this parameter used for all other areas (Fig. 24). The prior for the survey catchability q_I also appears influential but when this model was fit using an annually varying q_I with a uniform prior the overall median q_I was very similar to the median of the final beta prior. The problem with an annually varying q_I was that it would vary greatly from one year to the next allowing the model to overfit to the data.

STOCK STATUS AND FORECAST

Exploitation and survival estimates (i.e., $\exp(-m)$) are presented in Fig. 25. Natural mortality has been quite low since 2008, while exploitation had increased from 2007 to 2008 and then levelled off in the last three years at around 0.2. Biomass posterior medians along with 95% credible intervals indicate very little change in the biomass of commercial and recruit size scallops in the last 3 years (Fig. 26). Population biomass estimated by the model was 1,147 t (meats) in 2011, unchanged from the estimate for 2010 (1,141 t) and below the median biomass of 1,251 t (1997 to 2010). Biomass is projected to increase only slightly (2.35%) under the interim TAC of 100 t which would correspond to an exploitation rate of 0.08. Other catch scenarios for 2011/2012 as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2012/2013) are presented in Table 1.

A catch of 200 t for 2011/2012 should result in an exploitation rate (0.16) close to the reference (0.15) and an 8% decline in biomass for 2012. If this catch was realized in the 2011/2012 season then a catch of 181 t next year (2012/2013) would be expected to have a 50% chance of exceeding an exploitation rate of 0.15.

The performance of the model's prediction of biomass in the following year was evaluated by comparing predictions from fits to the data up to year $t-1$ (e.g., 2005) to year t (e.g., 2006) with the estimates of biomass from fitting the model to data up to year t (Fig. 27). All of the model estimates fall within the 50% credible interval of the prediction from the previous year.

SPA 1B: NORTHERN/UPPER BAY OF FUNDY

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 83.6 t against a quota of 203 t in 2010/2011. Full Bay landings from 1B have been decreasing annually since 2006/2007 (Fig. 30). Economic reasons were reported as being responsible for the reduction of Full Bay effort in SPA 1B. An interim quota of 100 t was set on 1 October 2011 for the Full Bay 2011/2012 season, as of 8 November, 0.37 t had been landed. The Mid-Bay fleet caught 122.8 t against a quota of 142.88 t, and Upper Bay caught 53.3 t against a quota of 54.12 t. Landings have decreased slightly in the last few years for Mid-Bay fleet, and have been stable for Upper Bay fleet.

Full Bay

Year	Avg. 02–06	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012
TAC (t)	181	200	206.25	195.4	205.54	203	100 [3]
Landing (t)	154	213	210	192.7	151.98	83.6 [2]	0.37 [2]

1. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.
2. Landings based on quota report dated 9 November 2011.
3. Interim TAC.

Maps of fishing location based on commercial fishing logs from 2008 to 2011 for the Mid-Bay and Upper-Bay fleets are presented in Figs. 28 and 29.

Mid and Upper Bay

Year	Avg. 02–06	2007	2008	2009	2010	2011 [1]
TAC (t) [2]	156.3	200	148.28	137.5	144.7	142.88
MB: Landing (t)	145.8	93	120	142.5	137.1	122.8
TAC (t)			85.47	52.1	54.8	54.12
UB: Landing (t)	66.4	79.5	87.4	54.4	53.9	53.3

1. Landings based on quota report dated 8 November 2011.
2. TAC in 1B for 2002/2003 to 2006-2007 was from MB and UB combined.

Full Bay commercial catch rates in 1B have been relatively stable over the last few years, with the most fluctuation, and a recent increase, in SFA28D (Fig. 31). Mid-Bay catch rates are also stable, with very little change since 2006 in SFA28B, and a recent small increase in catch rate in SFA28C. Catch rates for the Upper Bay fleet have shown a very slow decline since 2007 in SFA28C. The catch rate for this fleet has been decreasing in SFA28D as well, but the decrease in 2011 was minimal relative to 2010.

SURVEY

The 2011 survey in 1B covered all areas except the Inner portion of SFA28D, and the southern portion of the Outer SFA28D stratum (Fig. 8). In 2008, these areas were determined to be marginal for scallops and were not included in estimating biomass (Smith et al. 2009b).

The highest densities of commercial size scallops observed in 1B were concentrated in the area divided by the Middle Bay North and SFA 28C border, as well as in Advocate Harbour and in the Spencer's Island strata (Fig. 32). These same areas correspond to higher densities of recruits as well (Fig. 33), and comparable recruit densities were found in parts of the Cape Spencer stratum. The distribution of biomass for commercial size scallops is similar to the density distribution (Fig. 34).

Shell height distributions in the Cape Spencer area show regular recruitment (Fig. 35). Survey indices for this area indicate a decrease in the mean number per tow for commercial size scallops from 2010 to 2011, but only a slight decrease in mean weight per tow over this time (Fig. 36). There was little change in recruit abundance or weight per tow from 2010 to 2011.

The average shell size for commercial size scallops in Middle Bay North are getting larger as recruitment has been low for the last few years (Fig. 37). Abundance in the survey tows has decreased slightly for both recruit and commercial size scallops since 2010, but with a small decrease in weight per tow (Fig. 38).

Trends in 28C (Upper Bay) show a steady abundance of commercial size scallops over the past few years supported by recent strong recruitment (Fig. 39). There was a trend of decreasing weight per tow over this time period, but from 2010 to 2011 there was no change (Fig. 40). The number of recruits in the survey tows has been decreasing since 2009, while there has been little change in weight per tow of recruits.

Advocate Harbour has shown good recruitment in the past (Fig. 41) and in 2011 there was a slight increase in abundance of recruits (Fig. 42). Commercial size scallops show patterns similar to other areas in 1B, with a decrease in abundance since 2010, but little change in weight per tow over that time. Abundances are much lower in the Outer area of 28D. In 2010 abundance for all size classes in the Outer area was very low and rebounded in 2011 to 2009 levels (Fig. 43) although the abundance of recruits remains low (Fig. 44).

In the two remaining strata, abundance of commercial size scallops has been increasing in the Spencer's Island stratum, and decreasing in Scots Bay since 2009 (Figs. 45 and 46). Recruit abundance has decreased in Spencer's Island (Fig. 47), but it still high relative to other areas, while recruit abundance is slowly decreasing over time in Scots Bay (Figs. 46 and 48).

Biomass of commercial size scallops in 1B is greatest, and most variable over time, in SFA28B (Cape Spencer and Middle Bay North). Biomass in the other areas is less variable and relatively steady over the last few years (Fig. 49). Recruit biomass is highest in SFA28B as well, but there is a trend of decreasing recruit biomass over the last three years in all areas (Fig. 49, lower panel).

GROWTH AND CONDITION

The average condition factor for SPA 1B from 1996 to 2011 was 10.7 g/dm^3, that is, on average a meat from a scallop of 100 mm would weigh 10.7 g. Recently, condition has been declining in all areas since 2008 and has remained below average for the last two years (Fig. 50).

The current spatial patterns of condition in SPA 1B show that condition varies within areas but was generally similar among the areas with perhaps slightly better condition in Middle Bay North (Fig. 51). However upon closer comparison of condition and density, many areas of higher condition had lower densities (Figs. 51 and 32). The meat count analysis shows that meat count in SPA 1B during the survey was higher than 45 scallops per 500 g in several areas including Advocate, Scots Bay, Spencer's Island, Upper Bay 28C, and the north-east portion of Middle Bay North (Fig. 52). The few areas of Middle Bay North with lower meat counts were also low biomass areas (Figs. 34 and 52). Expected growth of commercial biomass was highest in the high density area straddling the border between Middle Bay North and Upper Bay 28C indicating an abundance of recently recruited scallops (Fig. 53). A small portion of these scallops remain in the recruit size class but overall there are very few recruits in SPA 1B underscoring the importance of growth for maintaining the current level of biomass (Fig. 33).

POPULATION MODEL

Survey indices for each stratum in SPA 1B (Cape Spencer, Middle Bay North, Upper Bay 28C, 28D outer, Advocate, Spencer's Island, and Scots Bay) were combined to form a time series from 1997 to 2011. Middle Bay North was divided into two strata by a line from (Lat. 45.237°, Long. -65.197°) to (Lat. 45.459°, Long. -65.264°) in order to compensate for variable coverage in early years. The 28D outer strata was modified so that it only included the area north of a line from (Lat. 45.145°, Long. -65.032°) to (Lat. 45.292°, Long. -64.775°). Missing data in early years was dealt with by assuming the densities in Upper Bay 28C, 28D outer, Advocate, Spencer's Island, and Scots Bay were the same as Middle Bay North from 1997 to 2000, and from 2001 to 2004 the densities of Spencer's Island and Scots Bay were assumed to be the same as the modified 28D outer strata. Other missing data that occurred in 2004 were estimated by interpolation.

As with SPA 1A two chains were generated each 80,000 samples long with the first 40,000 discarded for burn-in. Retained samples were thinned by 10 to give 8000 samples to estimate the posterior distribution. Trace plots indicated full mixing of chains and convergence. The model fit the survey mean estimates quite closely for both commercial size and recruits despite a relatively high amount of uncertainty for the estimates (Fig. 54). The posterior distributions show well defined posteriors for these parameters and that the prior for the survey catchability q_I was fairly influential (Fig. 55).

STOCK STATUS AND FORECAST

Exploitation and survival estimates (i.e., $\exp(-m)$) show natural mortality and exploitation rates being less variable than in other areas (Fig. 56). The estimated exploitation rate for 2011 was 0.19. Wide 95% credible intervals for biomass indicate a high degree of uncertainty that perhaps reflects the incomplete survey index of the early years in the time series. (Fig. 57). Population biomass estimated by the model was 1,745 t (meats) in 2011, a decrease of 7% from the estimate for 2010 (1,878 t) and below the median biomass of 1,881 t (1997 to 2010). Current estimates of recruit biomass are the lowest in the time series at 42.9 t. Biomass is projected to increase to 1941 t under the interim TAC of 100 t which would correspond to an exploitation rate of 0.05. Other catch scenarios for 2011/2012 as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2012/2013) are presented in Table 2. A catch of 300 t for 2011/2012 should correspond to the reference exploitation rate (0.15) and is predicted to result in a 3% decline in biomass. If this catch was realized in the current season then a catch of 309 t next year would be expected to have a 50% chance of resulting in an exploitation rate greater than 0.15 for 2012/2013.

The performance of the model's prediction of biomass in the next year was evaluated by comparing predictions from fits to the data up to year $t-1$ (e.g., 2005) to year t (e.g., 2006) with the estimates of biomass from fitting the model to data up to year t (Fig. 58). All of the model estimates fall within the 50% credible interval of the prediction from the previous year.

SPA 3: BRIER, LURCHER AND ST. MARY'S BAY

COMMERCIAL FISHERY

Annual trends for quotas and landings are presented in Fig. 59. The 2010/2011 quota for this area was set at 50 t based on survey trends and commercial catch rates to 2010. A total of 24.2 t was landed by mid-November 2010 when the fall season closed. Industry asked for an increase in quota for the 2011 summer portion of the fishery. However, catch rates in the fall season were very similar to those in the summer fishery (19.2 vs. 18.9 kg/h) and there would be no new information until the survey in June 2011. An increase was not granted and the fishery started June 1, 2011, with the remaining 25.8 t of quota. Approximately 34 t was caught in St. Mary's Bay and 15 t in the Brier/Lurcher area by the time the fishery ended on June 10. The catch for St. Mary's was the highest since 2005 and the second highest since 2002.

An interim quota of 100 t was set for October 1, 2011, for the 2011/2012 season. The fall opening was set to end mid-November and was limited to the Brier/Lurcher area. The rationale for the interim included the fact that this area had not been heavily fished over the last 5 years and the science advice was problematic due to model and survey issues. Catch rates from this opening would provide information towards the assessment. The fishery closed October 26 with a total of 124 t.

Year	Avg. 02–06	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012
TAC (t)	250	200	70	60	50	50.0	100[2]
Landing (t)	194	109	80.2	63	56	73.3[1]	124.5[1]

1. Landings based on quota report dated 8 November 2011.
2. Interim TAC.

Commercial catch rates for the 2011 summer fishery indicated an increase for St. Mary's Bay from 2010 (26.8 vs. 19.6 kg/h) but no change for the Brier/Lurcher area (19.0 vs. 18.9 kg/h) (Fig. 60). Generally, October catch rates in Brier/Lurcher are very similar to the summer catch rates in the same area, but the 2011 October catch rate (22.2 kg/hr) increased by 15% over the 2011 summer rate (and October 2010).

SURVEY

In previous assessments (e.g., Smith et al. 2009b), survey indices (numbers and weights per tow) were presented separately for the St. Mary's Bay area and the Brier/Lurcher area. The decrease in area being fished in the areas outside of St. Mary's over time as noted above led to concerns over whether the survey was adequately representing the area being fished.

Recent work has indicated that productivity of scallops is closely tied to habitat suitability and in the absence of habitat information, the spatial distribution of fishing effort can be a good indicator for habitat associations (e.g., Smith et al. 2009a). Vessel Monitoring System (VMS) data provides information on the spatial distribution of fishing activity and have been available for this fishery since 2002. Analysis of the VMS data indicated that the main area of concentration for the fishery was significantly smaller than that for the survey area (Fig. 61). This finding was used in two ways: 1) the 2011 survey was redesigned to concentrate higher sampling effort in the “fished” area according to the VMS data (see Fig. 61 for details), and 2) separate survey indices were calculated for inside and outside of the VMS area. The sampling with partial replacement (or double sampling) design has been used for these surveys since 2007 (Smith et al. 2008).

The spatial distribution of numbers per tow of commercial size scallops (shell heights ≥80 mm; Fig. 62) reflects the pattern in Fig. 61 with the higher densities occurring in the inside VMS areas. Numbers per tow for recruit size scallops (65 to 79 mm) scallops exhibited a similar spatial distribution (Fig. 63).

Annual trends for survey numbers per tow are presented for both St. Mary's Bay area and the Brier/Lurcher area as well as for inside (BILU-Inside) and outside (Outside) of the VMS area for the the Brier/Lurcher area (Fig. 64). The lower sampling intensity in St. Mary's Bay complicates presenting estimates for inside and outside of the VMS area over the time series but the recent increase of sampling inside the VMS area should allow for such estimates in the future. Note that starting in 2004 the surveys were conducted in May/June instead of August to accommodate the change of the Bay of Fundy surveys from June to August because of the increasing distribution of lobsters traps in June. Surveys in August in SPA 3 occurred at the end of the fishery while May/June surveys (July in 2010) could be before most of the fishery, during the fishery, or in the case of 2011, after the fishery.

The survey indices for the BILU-Inside and Outside areas indicate very different trends with the inside area having higher numbers per tow. The last major year-class to recruit to the fishery (in 2002) only occurred in the BILU-Inside area. Survey indices for both St. Mary's Bay and the BILU-Inside area indicate an increase in numbers per tow for 2011 while there was no change in the estimate for the Outside area from 2010.

There is evidence of a larger than average year-class in St. Mary's Bay (mode of 35–37 mm shell height, probably 2 years old) which should recruit to the fishery in 2013 (Fig. 65). Shell height frequencies for BILU-Inside (Fig. 66) and Outside areas (Fig. 67) do not indicate a similar large year class.

GROWTH AND CONDITION

The relationship between meat weight and shell height was used to convert numbers per tow from the survey to weight per tow to estimate the survey biomass index for the stocks. The methods used to estimate condition factor (CF) were discussed above. The spatial distribution of CF in 2011 corresponds to the VMS areas having higher condition with St. Mary's Bay having the highest CF for the whole area (Fig. 68).

Comparison of annual trends indicate that St. Mary's Bay consistently had the highest CF (equivalent to the meat weight of a scallop with 100 mm = 1 dm shell height), followed by BILU-Inner and Outer (Fig. 69). Condition factor declined in 2011 for St. Mary's while it increased in the other two areas after a two-year decline.

The spatial distribution of survey estimates of biomass for the 2011 survey is a combination of the condition factor and the numbers per tow (Fig. 70). Annuals trends for survey mean weight per tow are very similar to those for mean number per tow (Fig. 71).

POPULATION MODEL

The delay-difference model was fit to the survey and catch data. The catch data was partitioned as occurring either before or after the survey each year to deal with the survey timing changes that have occurred. Given that the 2011 survey occurred after the fishery in June the catch in October 2011 was included in predicting the biomass for next June to correspond to the 2012 survey. Survey indices from both St. Mary's Bay and BILU-Inside were used, combined with the missing years in the former series filled in using simple interpolation. Separate growth functions for each series were combined, weighted by survey biomass. While separate models for St. Mary's Bay and BILU-Inside may be more useful for the way this fishery is conducted, it is difficult to allocate catches to the two areas based on log books prior to 2002 due to database changes and changes to editing methods. This option could be explored in the future but will require considerable work to go through the log files from 1996 to 2001.

Two chains were generated, each 160,000 samples long with the first 80,000 discarded for burn-in. Retained samples were thinned by 10 to give 8000 samples to estimate the posterior distribution. Trace plots indicated full mixing of chains and convergence.

The model fit the survey mean estimates quite closely for both commercial size and recruit size scallops but did allow for a high amount of uncertainty for the estimates of recruits in 2001 (Fig. 72). The comparison of posterior distributions with the priors indicated that the priors were not highly influential except for the term S corresponding to the average dissolution time as a proportion of the year for clappers as part of the Popcorn model used for estimating natural mortality (for details see, Smith and Lundy 2002) (Fig. 73).

STOCK STATUS AND FORECAST

Exploitation and survival estimates (i.e., $\exp(-m)$) are presented in Fig. 74. Survival has declined (natural mortality increasing) since 2008 while exploitation has mainly decreased. The catch of 73.3 t as of June 2011 corresponded to an exploitation rate of 0.09.

Biomass posterior medians for commercial and recruit size scallops along with 95% credible intervals not surprisingly strongly resemble the survey fits (Fig. 75). Population biomass estimated by the model was 796 t (meats) in 2011, an increase of 37% from the estimate for

2010 (579 t) and below the median biomass of 827 t (1996 to 2010). This seems to be in agreement with the trend for the commercial catch rate estimates in Fig. 60.

The performance of the model's prediction of biomass in the next year was evaluated by comparing predictions from fits to the data up to year $t-1$ (e.g., 2005) to year t (e.g., 2006) with the estimates of biomass from fitting the model to data up to year t (Fig. 76). All of the model estimates fall within the 50% credible interval of the prediction from the previous year.

A catch of 150 t for 2011/2012 should result in an exploitation rate (0.16) close to the reference (0.15) and no appreciable change in biomass for 2012. This catch includes the 125 t already landed in the fall 2011 fishery (Table 3). Projections for the 2012/2013 are also presented in the table.

SPA 4: DIGBY

COMMERCIAL FISHERY

Full Bay fleet caught a total of 136.3 t against a quota of 140 t in 2010/2011 (Fig. 77). Landings in this area have been increasing since 2006/2007. An interim TAC of 120 t was set for 1 October 2011 for the 2011/2012 season. As of 08 November, 17.4 t had been reported.

Year	Avg. 02–06	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012
TAC (t)	710	100	100	100	120	140	120[2]
Landing (t)	656	42[3]	79	98	114	136.3[1]	17.4[1]

1. Landings based on quota report dated 8 November 2011.
2. Interim TAC.
3. Landings reported as 68 t in 2007.

The 2010/2011 catch rate (18.7 kg/h) changed little from the 2010 catch rate (18.6 kg/hr) and is above the long-term median (16.4 kg/hr, 1983/1984 to 2009/2010). Effort in this area has been slowly increasing since 2006/2007 (Fig. 78).

The location of fishing effort in SPA 4 has been changing over the last few years based on locations from fishing logs as seen in Fig. 5. Since 2007/2008 fishing has shifted more to the area above Digby Gut. This change was clearly evident in the 2010/2011 season when most records were from above the Gut and relatively little fishing took place in other parts of SPA 4.

SURVEY

Recruitment in this area has been generally low but stable since the larger than average 1998 year-class entered the fishery (Fig. 79), and there has been little change in recruit abundance or weight per tow since 2005 (Fig. 80). In 2011, recruit density was highest above Digby Gut (stratum 3) in strata 6 and 7 (see Fig. 8), and below the Gut in stratum 1 near the Mid Bay Line (Fig. 81). Density of commercial size scallops were lowest in the center of SPA 4, in strata 3, 9, and 2. Densities above Digby Gut in strata 5, 4, and 10 are comparable to densities below the Gut in stratum 1 (Fig. 82). The spatial distribution of biomass was similar to that for density (Fig. 83).

GROWTH AND CONDITION

The average condition factor for scallops in SPA 4 from 1996 to 2011 was 12.0 g/dm^3, resulting in scallops of 100 mm shell height having an average meat weight of 12.0 g at the time of the survey. Condition has increased from 10.9 g/dm^3 in 2010 to 12.5 g/dm^3 in 2011 (Fig. 84). Condition in SPA 4 tends to be higher above Digby Gut than below, but condition was especially low in strata 1 and 8 (Fig. 85).

Densities in SPA 4 are fairly low overall with relatively higher densities in strata 1, 8, 10, 4, and 5 than in strata 2, 9, and 3 (Fig. 82) while the distribution of biomass is fairly uniform throughout the area (Fig. 83). The spatial pattern of stock composition for SPA 4 was that near Digby Gut the stock consists mainly of few large scallops and further from the Gut scallops are smaller and more numerous. As a consequence of this, meat count and expected growth near the Gut is low, while further from the Gut meat count and expected growth increase (Figs. 86 and 87). This pattern is altered somewhat by the difference in condition such that above the Gut meat count is lower than below the Gut and expected growth somewhat higher. There is very little recruitment present in SPA 4 (Fig. 81).

POPULATION MODEL

For SPA 4 the delay-difference model was fit to the stratified survey index and catch data from 1983 to 2011. In previous assessments annual estimates of survey catchabilities were introduced to correct a problem where a large index of commercial size scallops appeared in 2001 but were not represented in the recruit index in 2000 (Smith et al. 2005). This caused the model to underestimate catchability and consequently overestimate biomass. At the time a decline in the ratio of the estimates of the mean number of commercial size scallops from the lined and unlined gear was identified as an indication of a trend in catchability. Annual estimates of q_I allowed for a shift in catchability from 2000 to 2001 that explained the apparent difference between recruits in 2000 and commercial scallops in 2001, while maintaining an overall average q_I that was more consistent with previous assessments and did not bias the predictions. However, annual estimates of q_I can cause the model to overfit the data by absorbing all uncertainty that might better be described as process error. A closer examination of the issue indicated that in 2000 scallops at a size that were smaller than what are considered recruits (<65 mm) actually did grow to commercial size the following year because of abnormally favourable growth conditions that year (Smith and Lundy 2002). In another attempt to correct this problem, without introducing annual estimates of q_I and the potential to overfit the data, three adjustments were made to the model. First the recruit index was adjusted in 2000 so that scallops between 40–79 mm were considered recruits. Second, the new growth model was introduced and accounts for some of the increased growth at this period, and third, the informative prior for q_I prevents q_I from being drastically underestimated.

As with the other models two chains were generated each 80,000 samples long with the first 40,000 discarded for burn-in. Retained samples were thinned by 10 to give 8000 samples to estimate the posterior distribution. Trace plots indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Fig. 88). The posterior distribution of q_I suggests information in the data points to q_I as being somewhat lower in SPA 4 than other areas[1]. The model fits the survey mean estimates quite closely for most years while allowing for uncertainty in estimates of recruitment events in 1987 and 2001 (Fig. 89).

[1]This area has a high incidence of the bryozoan *Flustra foliacea* which may cause problems with gear efficiency.

STOCK STATUS AND FORECAST

Estimates of survival (i.e., $\exp(-m)$) show the very high levels of natural mortality that occurred 1989–91 as the result of a catastrophic mortality event. Natural mortality has been very low in the past 5 years as exploitation has been increasing from 0.07 in 2007 to 0.17 in 2011 (Fig. 90). Biomass posterior medians along with 95% credible intervals indicate very little change in the biomass of commercial and recruit size scallops in the last 3 years (Fig. 91). Population biomass estimated by the model was 656 t (meats) in 2011, an increase of 2% from the estimate for 2010 (641 t) and below the median biomass of 767 t (1983 to 2010). Estimated recruitment of 7.4 t in 2011 is the second lowest since 1983, second only to an estimated 4.2 t in 2010. Catches for 2011/2012 of 100 t should result in an exploitation rate (0.14) close to the reference (0.15) and is predicted to result in an 7% decline in biomass. Other catch scenarios for 2011/2012 as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2012/2013) are presented in Table 4. If the interim TAC was set as the final TAC for this season then a TAC of 98 t in 2012/2013 would be expected to have a 50% chance of corresponding to an exploitation rate greater than 0.15.

The performance of the model's prediction of biomass in the next year was evaluated by comparing predictions from fits to the data up to year $t-1$ (e.g., 2005) to year t (e.g., 2006) with the estimates of biomass from fitting the model to data up to year t (Fig. 92). All of the model estimates fall within the 50% credible interval of the prediction from the previous year.

SPA 5: ANNAPOLIS BASIN

COMMERCIAL FISHERY

The fishery in the Annapolis Basin is only open to the Full Bay fleet with a season running from 1 January to 31 March. In recent years, landings have varied between 2 and 20 t (Fig. 93). Landings in 2011 were 10 t against a TAC of 10 t. The increase of landings in 2010 and 2011 may have been due to the good signs of pre-recruits observed in the 2008 survey (Smith et al. 2009b).

Year	Avg. 02–06	2006/ 2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011
TAC (t)	14	10	10	10	10	10
Landing (t)	10.8	4	7	6	8	10

The average commercial catch rate in 2011 (19 kg/h) increased from 2010 (14.6 kg/h) and was above the long-term median (18.6 kg/h, 1977–2010) (Fig. 94). The effort increased in 2010 and 2011 and is now above the long-term median level.

SURVEY

The annual survey was discontinued as of 2009 in SPA 5 at the request of industry and the sampling effort was redirected to the other areas in Bay of Fundy.

STOCK STATUS AND FORECAST

The commercial catch rate in SPA 5 is influenced positively by strong recruitment episodes. Over the last twenty years, the catch rate was higher than the long-term median level during the years 2002–2005, due to the larger than average 1999 and 2000 year-classes. Outside of the periods influenced by the strong recruitment, the catch rate has been relatively stable which would suggest a relatively stable population size at this level of exploitation. The TAC for 2012 should not exceed the average catch of 10 t over the period 1997–2010 (excluding the high catch in 2004). The anticipated medium-term recruitment prospects are unknown without a survey.

SPA 6: GRAND MANAN AND SOUTHWEST NEW BRUNSWICK

COMMERCIAL FISHERY

A total of 104 t was landed against a quota of 140 t in SPA 6 in 2010/2011. The Full Bay fleet reported no landings against a TAC of 21 t (Fig. 95). The Full Bay fleet has not caught its quota for the last 7 years as it has directed its effort to the other scallop fishing areas

Mid Bay landings for 2010/2011 were 23.9, 26.5, 46.5, and 7.0 t for SPAs 6A, B, C, and D, respectively, against a quota of 119 t. A more complete breakdown of catches by fleet and subarea over time is given in Table 5. Fishing locations from logbooks for both fleets are presented in Fig. 96 for 2008–2011.

Year	Avg. 02–06	2007	2008	2009	2010	2011
TAC (t)	171	140	140	140	140	140
FB: Landing (t)	10	5	7.4	1.3	0.07	0
MB: Landing (t)	85	64	61	88	103	104[1]

1. Landings to 8 November 2011.

Catch has increased for Mid-Bay fleet over the last few years. Catch rates increased between 2009 and 2010 in all areas, and continued to increase in 6B in 2011, and decreased slightly in the other areas (Fig. 97). There is a trend of increasing effort for the Mid Bay fleet in this area (Fig. 98).

SURVEY

A partial replacement survey design was used to deal with the patchiness of the distribution of scallops in SPA 6. This design was used in all subareas in the survey, with 92 survey stations chosen randomly and 27 stations chosen randomly from 2010 survey locations. The survey was conducted in August using the F/V Royal Fundy. The number of tows was greater than in 2010 (102 vs. 119) and similar to 2009 (120). The reduction of the number of tows in 2010 was due to conflicts with fixed gear in the survey areas.

Pre-recruit (40 to 64 mm) distribution was similar to that seen in 2010 (Fig. 99). In 2011 they were more concentrated in area 6B mainly around White Head Island, and in Duck Island Sound, and there were fewer in area 6C. Recruits (65 to 79 mm) were found in more areas in 2011 than 2010. The 2010 pre-recruits appeared as recruits in the 2011 survey. The greatest recruit density was observed in 6A (253 scallops/tow). The distribution of commercial sized (≥80 mm) scallops decreased in 6B and 6C, and to a lesser extent in 6A (Fig. 100). These changes are reflected in the survey indices (see below).

A total of 12, 12, and 3 stations from the 2010 survey were resampled for the 2011 survey in SPAs 6A, 6B, and 6C, respectively. Correlation coefficients were calculated between catches of commercial size scallops (≥80 mm) in the two years as well as between numbers per tow of commercial size plus recruits in 2010 with commercial size scallops in 2011 for each of the areas (Figs. 101 and 102). The correlations were highest for 6A and 6C. The paired tows in 6B indicated that densities in the repeated stations were reduced from 2010 while densities did not appear to change in the other two areas.

The differences between the mean number per tow for 2010 and 2011 for each of the three areas were evaluated in Table 6. The means were significantly different between years for 6B and 6C, showing a decrease in mean number per tow in areas 6B and 6C. There was no difference between years for 6A.

Survey index for abundance and weight decreased in all subareas of SPA 6 between 2010 and 2011 (Figs. 103–105). Shell height frequencies suggest that recruitment will be low for the next few years (Figs. 106–108). There were a large number of pre-recruits in 6B in Duck Island Sound, probably two-year olds (2009 year-class, Fig. 107).

GROWTH AND CONDITION

The average condition factor for SPA 6 from 1997 to 2011 was 11.3 g/dm^3, corresponding to average a meat weight of 11.3 g for scallops with 100 mm shell height. All three areas show a drop in condition from 2010 so that only 6C, which is generally higher condition than 6A and 6B, is near the overall average (Fig. 109). Condition in SPA 6C is highly variable spatially. Areas of high condition were similar in 2010 and 2011, and are found in 6C near Deer Island and in 6B east of Grand Manan, while very low condition factors were found in the surveyed areas of 6A (Figs. 110 and 111). Timing of the survey could account for part of the decrease seen between 2010 and 2011. The 2011 survey was in August, when we could expect to see the effects of spawning on condition. The survey in 2010 was in September, when we would expect to see a recovery from spawning reflected in a higher condition. However, past surveys conducted in August (1998–2000) show a range of condition between 10 to 14 g/dm^3, which is greater than what was seen for 6A and 6B in 2011 (7.4 and 8.5 g/dm^3, respectively). As well, condition is not always higher in September, as seen in the low condition in SPAs 6B and 6C in the 2001 and 2002 September surveys.

STOCK STATUS AND FORECAST

For all areas, recruitment is expected to be low for the next couple of years. In 6A, evidence from the Mid Bay commercial catch rates and survey suggest that the abundance of commercial size scallops is similar to previous years, although condition is down from the previous year and is well below the historic average. In SPA 6C, there was some decline in commercial density and decreases in average weight relative to 2009 and 2010, and condition is highest in this area, and near the long-term average. In SPA 6B there was a significant decline in commercial density as seen in both the survey abundance data and the direct comparison of repeated tows. There was also a decrease in average weight, and the condition factor was below the long-term average. There were a large number of pre-recruits concentrated in Duck Island Sound, but it will be at least two of years before they recruit to the fishery.

The Mid Bay commercial catch rates suggest that the biomass of commercial size scallops remains unchanged over recent years, while the surveys are indicating decreases in 2011 relative to 2010. If the condition factors continue to decline for all three areas, population biomass may decrease at the current levels of catch.

ECOSYSTEM CONSIDERATIONS

SURVEY BYCATCH

Since 2001, commercial groundfish has been recorded as part of the inshore scallop surveys in addition to lobster, squid, and octopus. The survey data presented here is therefore not an exhaustive inventory of other species encountered during the survey. Surveys occur between May and October and use 4 gang Digby gear. Data was standardized to a 800 m tow length and 5.3 m drag width, and summarized for each area (SPAs 1,4 and 5 combined, SPA 3, SPA 6) by year as the number per standard tow. Since 2001, the number of survey tows has varied between 266 and 497 in SPAs 1,4 and 5 combined, has been between 109 and 162 in SPA 3, and between 45 and 180 in SPA 6, for those years with a survey (Table 7). In 2004 there was no survey in SPA 6 (Table 6). In addition to sea scallop, of those species recorded by the survey, the most commonly encountered species since 2001 have been, in respective order, lobster, winter flounder, monkfish and octopus (Tables 8, 9 and 10). Sea scallop per tow includes all live size ranges recorded by the survey.

FISHERY BYCATCH

As part of a Species-At-Risk (SARCEP) project, observer coverage was funded for the inshore scallop fishery in the Bay of Fundy and approaches in 2008 and 2009. Data presented here is for all species recorded by this additional observer coverage. The incidental capture of non-target species can be affected by the nature of the fishery, the time of year, and the location fished. To account for some of these effects discard calculations were done by year and for the following areas: SPAs 1, 4, and 5 combined, SPA 3, and SPA 6. SPAs 1, 4, and 5 were combined due to limited observed coverage, however they represent a similar geographic area (Fig. 1). It is possible that there is within year temporal variability of discards, however limited observer coverage restricted this analysis from any temporal resolution finer than a year. Observed trips were assumed to be representative of the rest of the scallop fishery for the given year and area.

The discard rates for the inshore scallop fishery were estimated from the information from at-sea observers coupled with information from fishery monitoring as per the methodology described in Gavaris et al. (2010)

$$DiscardRate_{ijk} = \left(\frac{discards_{ijk}}{all\ species\ landings_{jk}} \right)$$

where the indices of i, j, k are species, year and area, respectively. Information on *discards* were obtained from the ISDB whereas *all species landings* were obtained from MARFIS. For each year and area *all species landings* was the sum of all landings (i.e. scallop and monkfish) for all inshore scallop observed trips.

Estimated discard rates of bycatch species are approximate as the observers generally record the lowest weights as one kilogram and therefore the catch weights of smaller animals can be overestimated because of this practice. In addition, some species that may remain attached to rocks when caught (e.g., sponges, lemonweed) may be over estimated.

Observer coverage occurred in SPAs 1, 4 and 5 combined in both 2008 and 2009, at a level of 2% and 3%, respectively. There was only coverage of SPA 3 in 2008 at a level of 5%, and coverage in SPA 6 only in 2009 at a level of 9% (Table 11). Estimated discard rates by species group are presented in Tables 12 through 14. Further details on the methods and estimates of discards can be found in Sameoto and Glass (2012).

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Table 1. Decision table to evaluate catch levels in SPA 1A for 2011/2012 in terms of expected changes in biomass (percent). Posterior median exploitation rates given in column labelled e. Potential catches in 2012/2013 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2011/2012			$Pr(e_{2012/2013} \geq 0.15)$					
Catch (t)	e	% Change	0.1	0.2	0.3	0.4	0.5	0.6
100	0.08	2.4	64	95	126	161	205	256
150	0.12	-1.7	59	90	119	152	191	241
200	0.16	-7.9	55	83	113	144	181	229
250	0.20	-12.7	51	78	107	137	173	221
300	0.24	-16.6	48	74	100	131	165	209
350	0.28	-21.8	45	70	95	124	157	199

Table 2. Decision table to evaluate catch levels in SPA 1B for 2011/2012 in terms of expected changes in biomass (percent). Posterior median exploitation rates given in column labelled e. Potential catches in 2012/2013 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2011/2012			$Pr(e_{2012/2013} \geq 0.15)$					
Catch (t)	e	% Change	0.1	0.2	0.3	0.4	0.5	0.6
200	0.10	3.8	100	150	200	256	325	412
250	0.12	1.6	98	147	195	249	315	399
300	0.15	-3.0	91	139	190	244	309	388
350	0.17	-6.9	87	134	180	230	292	373
400	0.20	-9.0	85	130	174	223	281	355
450	0.23	13.5	81	122	165	214	268	342

Table 3. Decision table to evaluate catch levels in SPA 3 for 2011/2012 in terms of expected changes in biomass (percent). Posterior median exploitation rates given in column labelled e. Potential catches in 2012/2013 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2011/2012			$Pr(e_{2012/2013} \geq 0.15)$					
Catch (t)	e	% Change	0.1	0.2	0.3	0.4	0.5	0.6
100	0.10	7.9	49	75	100	128	160	200
125	0.13	4.7	46	71	95	123	155	196
150	0.16	0.2	46	68	91	117	149	188
175	0.18	-2.9	43	65	88	114	146	184
200	0.21	-7.3	41	63	85	109	140	177
225	0.24	-10.9	39	61	82	106	135	170
250	0.26	-14.3	38	58	79	102	130	165

Table 4. Decision table to evaluate catch levels in SPA 4 for 2011/2012 in terms of expected changes in biomass (percent). Posterior median exploitation rates given in column labelled e. Potential catches in 2012/2013 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2011/2012			$Pr(e_{2012/2013} \geq 0.15)$					
Catch (t)	e	% Change	0.1	0.2	0.3	0.4	0.5	0.6
100	0.14	-6.7	36	50	66	82	101	124
120	0.17	-11.3	34	49	64	79	98	118
140	0.20	-14.0	32	46	60	76	93	115
160	0.23	-17.8	30	44	58	73	90	110
180	0.26	-20.2	29	43	56	70	87	108
200	0.29	-25.9	27	40	52	66	81	101

Table 5. Catch by fleet and subarea for Scallop Production Area 6. 2011 landings as of 8 November, 2011.

Subarea	Catch (meats, t)							
	2004	2005	2006	2007	2008	2009	2010	2011
Full Bay								
TAC	50	25	25	35	21	21	21	21
6A	1.1	0.3	0.9	2.3	1.7	0.3	0.07	0
6B	0.6	3.2	1.7	1.7	1.9	0.8	0	0
6C	3.74	0.2	0.3	0.1	2.7	0.2	0	0
6D	2.8	1.2	1.4	0.8	1.1	0.05	0	0
Total	8.1	4.9	4.4	4.9	7.4	1.3	0.07	0
Mid Bay								
TAC	145	145	75	105	119	119	119	119
6A	13.1	38.0	25.2	22.2	15.8	25.5	32.3	23.9
6B	14.5	18.1	23.7	11.3	10.8	23.1	23.2	26.5
6C	23.9	16.7	19.8	23.8	27.6	34.8	46.7	46.5
6D	22.4	7.9	18.0	6.7	6.3	5.4	0.3	7.0
Total	74.0	80.7	86.7	64.0	60.6	88.8	102.5	103.9

Table 6. Double sample estimates of the mean number per tow, difference between mean number per tow for 2010 and 2011 and standard error (SE) of the difference for SPA 6. Test statistic tested using a Student's t distribution.

Estimate	Mean/tow				Test-Statistic (p -value)
	2010	2011	Difference	SE(Diff)	
Commercial size in 2010					
6A	93.11	86.21	-6.9	13.84	-0.49 ($p = 0.6$)
6B	129.0	52.84	-76.16	16.39	-4.65 ($p < 0.001$))
6C	25.17	10.5	-14.67	7.32	-2.00 ($p = 0.04$)
Commercial+recruits in 2010					
6A	119.0	93.57	-25.42	16.15	-1.57 ($p = 0.11$)
6B	140.3	52.71	-87.55	16.81	-5.21 ($p < 0.001$)
6C	31.39	10.47	-20.92	9.31	-2.25 ($p = 0.02$)

Table 7. Number of tows by survey. NS = no survey.

Area	Year										
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
SPAs 1, 4 and 5	349	346	298	266	421	497	384	456	440	376	380
SPA 3	148	111	123	109	162	147	150	151	150	152	160
SPA 6	93	105	102	NS	45	180	169	145	120	102	119

Table 8. SPAs 1, 4 and 5 survey bycatch numbers per standard tow by species.

Common Species Name	Year										
	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
American Lobster	0.273	0.121	0.179	0.249	0.090	0.302	0.253	0.572	0.566	0.670	0.524
American Plaice	0	0.010	0	0	0.021	0	0.009	0.004	0	0	0
Black Sea Bass	0	0.004	0	0	0	0	0	0	0	0	0
Brill/Windowpane Flounder	0.037		0.018	0.032	0.053	0.119	0.052	0.217	0.078	0.212	0.150
Cod (Atlantic)	0.006	0.040	0.006	0.044	0	0.004	0.014	0.029	0.008	0.012	0.031
Cusk	0	0	0	0	0	0.025	0	0.020	0.004	0.032	0.133
Fourspot Flounder	0	0	0	0	0	0.004	0	0	0	0	0
Haddock	0	0	0.006	0	0	0	0	0	0	0.005	0
Halibut (Atlantic)	0	0	0	0	0.004	0	0	0	0	0	0
Herring	0	0	0	0	0	0	0	0	0	0.005	0.005
Lesser Bobtail Squid	0.022	0.030	0.005	0.059	0.017	0.047	0.063	0.012	0.013	0.016	0.040
Monkfish	0.434	0.569	0.247	0.293	0.083	0.065	0.123	0.130	0.095	0.079	0.046
Octopus	0.381	0.474	0.169	0.147	0.147	0.479	0.519	0.508	0.909	0.860	0.584
Redfish	0	0.006	0	0	0	0.004	0.005	0	0	0	0.005
Sea Scallop	679.053	665.786	423.021	221.388	138.657	171.886	175.052	166.480	124.005	143.849	122.315
Short-Fin Squid	0	0	0	0	0	0	0	0	0	0.005	0
Silver Hake	0	0.004	0.006	0.006	0	0.004	0.015	0.004	0.048	0.112	0.021
Smelts, Capelin	0	0	0	0	0	0	0.010	0.004	0.009	0	0
Spiny Dogfish	0	0	0	0	0.004	0.004	0	0	0	0.005	0
Squirrel Or Red Hake	0	0.005	0.012	0	0	0	0	0	0.053	0.030	0.153
Summer Flounder	0	0	0	0	0.046	0.003	0.104	0.046	0.096	0.036	0
White Hake	0	0	0	0.092	0.043	0.211	0.258	0.226	0.425	0.248	0.117
Winter Flounder	0	0.047	0.046	0.392	0.005	0.101	0.087	0.357	0.235	0.339	0.290
Witch Flounder	0.006	0.051	0.028	0.019	0.004	0.007	0.044	0.012	0.089	0.055	0.026
Yellowtail Flounder	0.130	0.068	0.013	0.007	0	0	0.004	0	0	0	0

Table 9. SPA 3 survey bycatch numbers per standard tow by species.

Common Species Name	**Year**										
	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*
American Lobster	2.282	2.866	2.300	2.523	2.863	2.562	1.997	3.118	4.083	3.636	6.056
American Plaice	0.026	0	0	0	0.342	0	0	0.039	0.026	0	0.213
Brill/Windowpane Flounder	0	0	0	0	0.065	0.013	0.013	0	0.050	0.012	0.051
Cod (Atlantic)	0	0	0	0.093	0.058	0.012	0.037	0.039	0.013	0	0.012
Cusk	0	0	0	0	0	0	0	0	0	0.077	0
Haddock	0	0	0	0.031	0	0	0	0	0	0.013	0.013
Halibut (Atlantic)	0	0	0	0	0.011	0	0	0	0	0	0
Lesser Bobtail Squid	0.055	0.076	0.096	0.048	0.047	0.080	0.113	0.012	0.013	0.063	0.088
Monkfish	1.481	1.854	1.610	0.173	0.253	0.090	0.153	0.154	0.066	0.141	0.073
Octopus	0.104	0.052	0.077	0.092	0.107	0.179	0.189	0.674	0.253	0.598	0.178
Redfish	0	0.019	0.014	0.255	0.139	0.027	0.012	0.051	0.039	0.177	0
Sea Scallop	198.305	224.638	109.900	235.708	141.917	83.599	312.969	222.924	129.511	109.580	160.544
Short-Fin Squid	0	0.016	0	0	0	0	0	0	0	0	0
Silver Hake	0	0	0.033	0	0	0	0	0	0	0.203	0.085
Squirrel Or Red Hake	0	0	0	0	0	0	0	0	0	0.193	0.013
Striped Atlantic Wolffish	0	0	0	0	0.011	0	0	0	0	0	0
Summer Flounder	0.054	0.034	0.031	0.654	0	0.104	0.375	0.062	0.344	0	0
White Hake	0.087	0	0	0.063	0.092	0.054	0.027	0	0.233	0.052	0.134
Winter Flounder	0.012	0	0.090	0.923	0.411	0.359	0.297	0.857	0.733	1.033	0.777
Witch Flounder	0.348	0.140	0.016	0.102	0.077	0.097	0.065	0.263	0.320	0.340	0.252
Yellowtail Flounder	0.012	0.018	0.052	0.028	0.046	0.126	0.064	0	0.066	0.013	0

Table 10. SPA 6 survey bycatch numbers per standard tow. There was no survey in this area in 2004.

Common Species Name	**Year**										
	2001	2002	2003	2004 *	2005	2006	2007	2008	2009	2010	2011
American Lobster	4.325	2.507	5.020		2.098	3.404	1.671	2.504	7.164	6.788	4.987
American Plaice	0	0.017	0		0	0.010	0.057	0	0	0.039	0
Brill/Windowpane Flounder	0.020	0	0.017		0	0	0	0.013	0.017	0	0
Cod (Atlantic)	0	0.019	0		0	0	0	0.013	0	0.059	0.017
Cusk	0	0	0		0	0	0	0	0.052	0.022	0.034
Haddock	0	0	0		0	0	0	0	0	0	0.016
Halibut (Atlantic)	0	0	0		0	0.021	0	0	0	0	0
Lesser Bobtail Squid	0	0	0		0	0	0	0	0.017	0	0.054
Monkfish	1.052	0.204	0.073		0.122	0	0.125	0.014	0.033	0	0
Octopus	0.023	0.142	0		0	0.042	0.042	0.254	0.243	0.420	0.294
Redfish	0	0	0		0	0.011	0	0.013	0	0	0
Sea Scallop	119.568	84.060	116.055		124.002	84.134	85.381	450.606	181.800	168.926	177.541
Short-Fin Squid	0	0	0		0	0	0	0	0	0	0.019
Silver Hake	0	0	0		0	0	0.011	0	0	0	0
Squirrel Or Red Hake	0	0	0		0	0	0	0	0	0.041	0.018
Summer Flounder	0.020	0	0		0.161	0.021	0	0.026	0.035	0	0
White Hake	0	0	0		0	0.031	0.023	0.052	0.064	0	0.053
Winter Flounder	0	0.355	0.393		0.041	1.267	0.877	1.143	0.993	1.455	0.820
Witch Flounder	0	0	0		0.080	0.032	0	0.025	0.224	0.083	0
Yellowtail Flounder	0.569	0	0		0	0	0.011	0	0	0	0

Table 11. Observed and total landings (mt), and observed and total number of trips, by area and year. The percent observed coverage is also indicated. Scallop weight used is in meat weight.

	2008		2009	
Area	Trips	Landings	Trips	Landings
SPAs 1,4,5	31/1798 2%	13.7/705.0 2%	62/2080 3%	27/797.9 3%
SPA 3	8/158 5%	3.8/79.6 5%	0/123 0%	0/65.0 0%
SPA 6	0/587 0%	0/69.0 0%	58/715 8%	8.5/90.4 9%

Table 12. Inshore Scallop Discard Rates (kg discard per kg landed) in SPAs 1, 4, 5 by Year. Scallop discards are in round weight.

Species	2008	2009
American Eel	0.010	0.004
American Lobster	0.031	0.031
American Plaice	0.009	0.029
Arctic Staghorn Sculpin	0.000	0.003
Atlantic Moonfish	0.000	0.114
Atlantic Rock Crab	0.258	0.196
Brill/Windowpane Flounder	0.088	0.007
Brittle Star	0.020	0.000
Cod (Atlantic)	0.004	0.004
Cusk	0.017	0.006
Eelpouts	0.000	0.006
Halibut (Atlantic)	0.004	0.028
Hermit Crabs	0.078	0.041
Herring	0.000	0.003
Jonah Crab	0.103	0.131
Lemonweed	3.742	3.875
Little And Winter Skate	0.212	0.083
Longhorn Sculpin	0.035	0.055
Monkfish	0.039	0.000
Mussels	0.051	0.349
Ocean Pout	0.012	0.007
Octopus	0.021	0.000
Rock Gunnel	0.000	0.005
Round Skate	0.527	0.101
Sand Dollars And Sea Urchins	0.085	0.088
Sea Cucumbers	0.007	0.024
Sea Raven	0.027	0.015
Sea Scallop	0.720	0.455
Searobin	0.003	0.002
Shrimp	0.034	0.009
Silver Hake	0.010	0.000
Smooth Skate	0.064	0.027
Spiny Dogfish	0.005	0.000
Sponges	8.317	6.661
Squirrel Or Red Hake	0.005	0.000
Starfish	0.448	0.596
Stickleback	0.000	0.012
Striped Atlantic Wolffish	0.000	0.003
Summer Flounder	0.036	0.025
Thorny Skate	0.170	0.063
Unident. Bivalves	0.000	0.168
Unident. Crustaceans	0.000	0.691

Table 12 (cont'd). Inshore Scallop Discard Rates (kg discard per kg landed) in SPAs 1, 4, 5 by Year. Scallop discards are in round weight.

Species	2008	2009
Unident. Sculpins	0.000	0.016
Unident. Skates	0.000	0.028
White Hake	0.008	0.011
Winter Flounder	0.030	0.025
Witch Flounder	0.010	0.011
Worms	0.028	0.000
Yellowtail Flounder	0.008	0.003

Table 13. Inshore Scallop Discard Rates (kg discard per kg landed) in SPA 3 by Year. Scallop discards are in round weight.Note there was no observer coverage in 2009 for this area.

Species	***2008***
American Lobster	0.096
Atlantic Rock Crab	0.324
Cancer Sp. (Crab)	0.118
Clam	0.087
Cunner	0.004
Hermit Crabs	0.049
Jonah Crab	0.233
Little And Winter Skate	0.049
Longhorn Sculpin	0.055
Monkfish	0.025
Mussels	0.285
Sand Dollars And Sea Urchins	0.008
Sea Raven	0.041
Sea Scallop	0.147
Smooth Skate	0.025
Sponges	0.189
Starfish	0.079
Thorny Skate	0.061
Winter Flounder	0.020
Witch Flounder	0.017
Yellowtail Flounder	0.009

Table 14. Inshore Scallop Discard Rates (kg discard per kg landed) in SPA 6 by Year. Scallop discards are in round weight. Note there was no observer coverage in 2008 for this area.

Species	***2009***
American Lobster	0.085
Atlantic Rock Crab	0.544
Cephalopoda (Class)	0.015
Fourhorn Sculpin	0.006
Hermit Crabs	0.128
Herring	0.031
Jonah Crab	0.396
Lemonweed	2.873
Little And Winter Skate	0.121
Longhorn Sculpin	0.043
Lumpfish	0.016
Monkfish	0.024
Mussels	2.857
Ocean Quahaug	0.132
Redfish	0.001
Sand Dollars And Sea Urchins	1.458
Sea Cucumbers	1.700
Sea Potato	0.145
Sea Raven	0.054
Sea Scallop	0.649
Sea Urchins	0.048
Shrimp	0.012
Silver Hake	0.014
Smooth Skate	0.004
Snails And Slugs	3.614
Spider Crab	0.140
Sponges	0.024
Starfish	0.882
Striped Atlantic Wolffish	0.009
Summer Flounder	0.007
Thorny Skate	0.028
Toad Crab	0.010
Unident. Sculpins	0.072
Unident. Skates	0.058
Whelks	0.016
Winter Flounder	0.063
Yellowtail Flounder	0.001

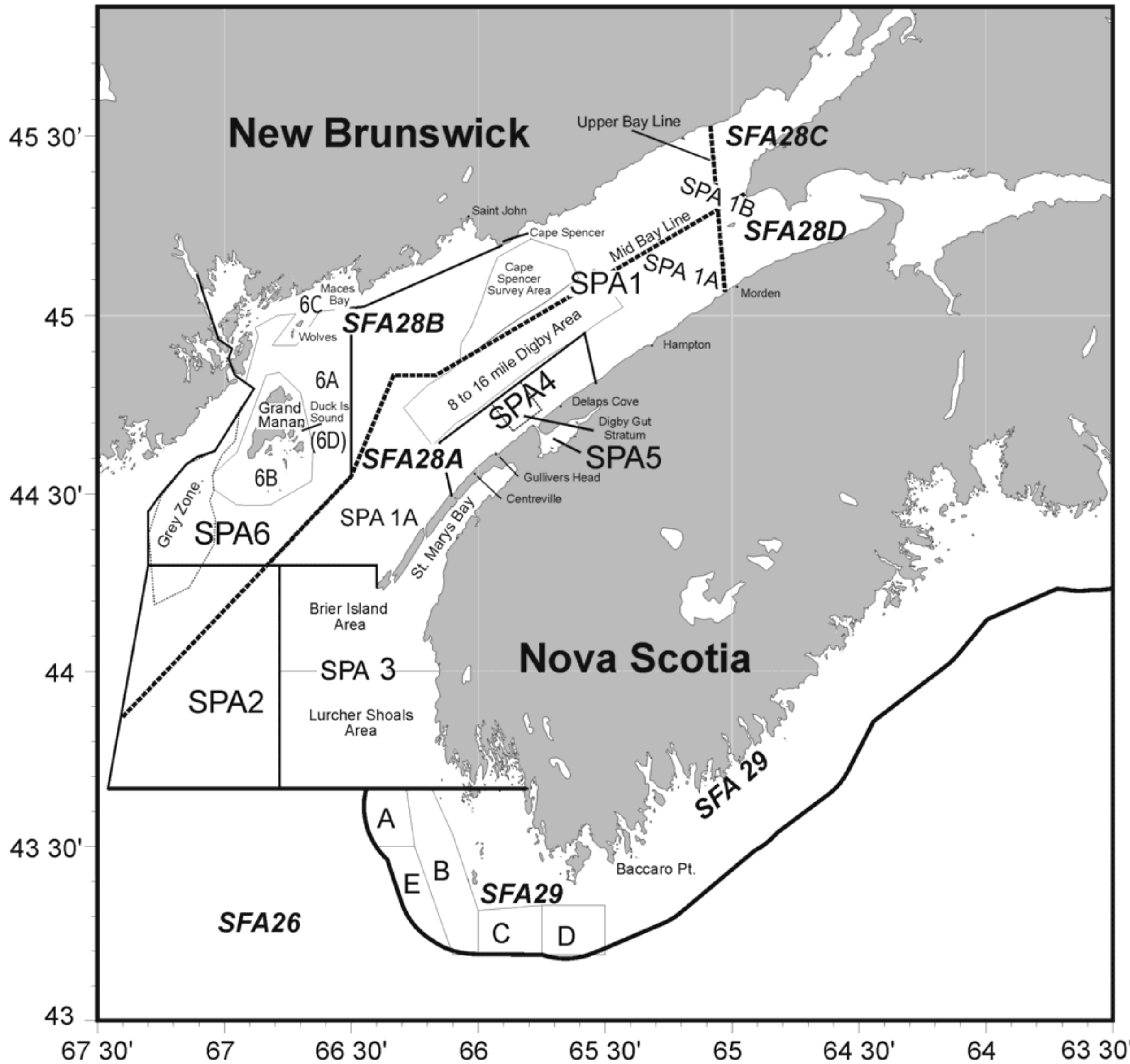

Figure 1. Scallop Production Areas and Scallop Fishing Areas in the Bay of Fundy.

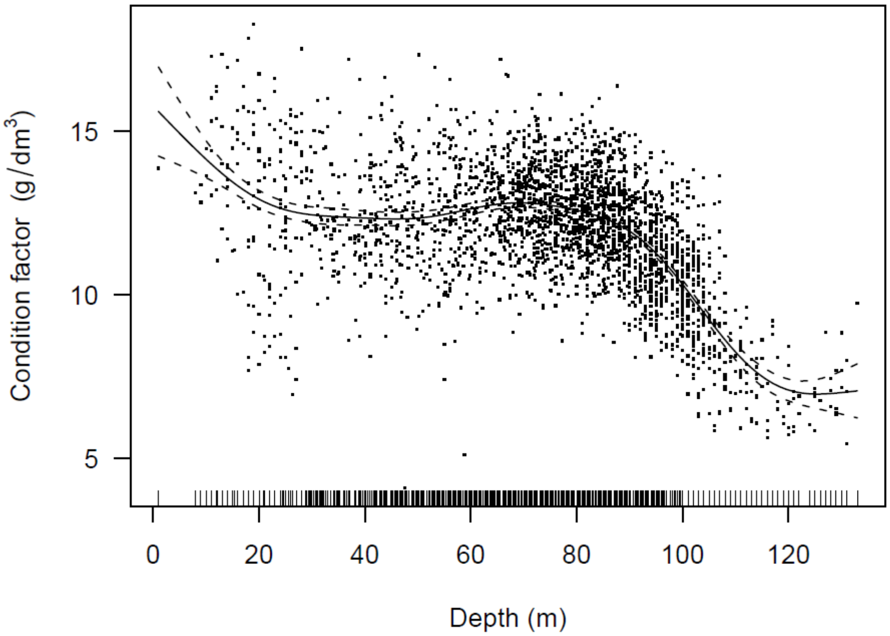

Figure 2. Fit of condition factor as a function of depth from a generalized additive model. Data from Scallop Production Areas 1, 4 and 5.

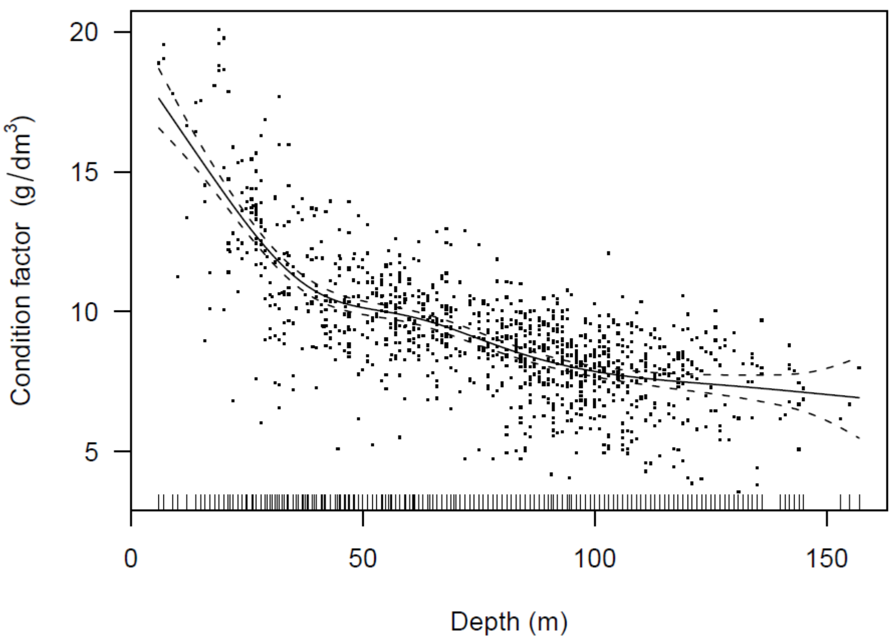

Figure 3. Fit of condition factor as a function of depth from a generalized additive model. Data from Scallop Production Area 3.

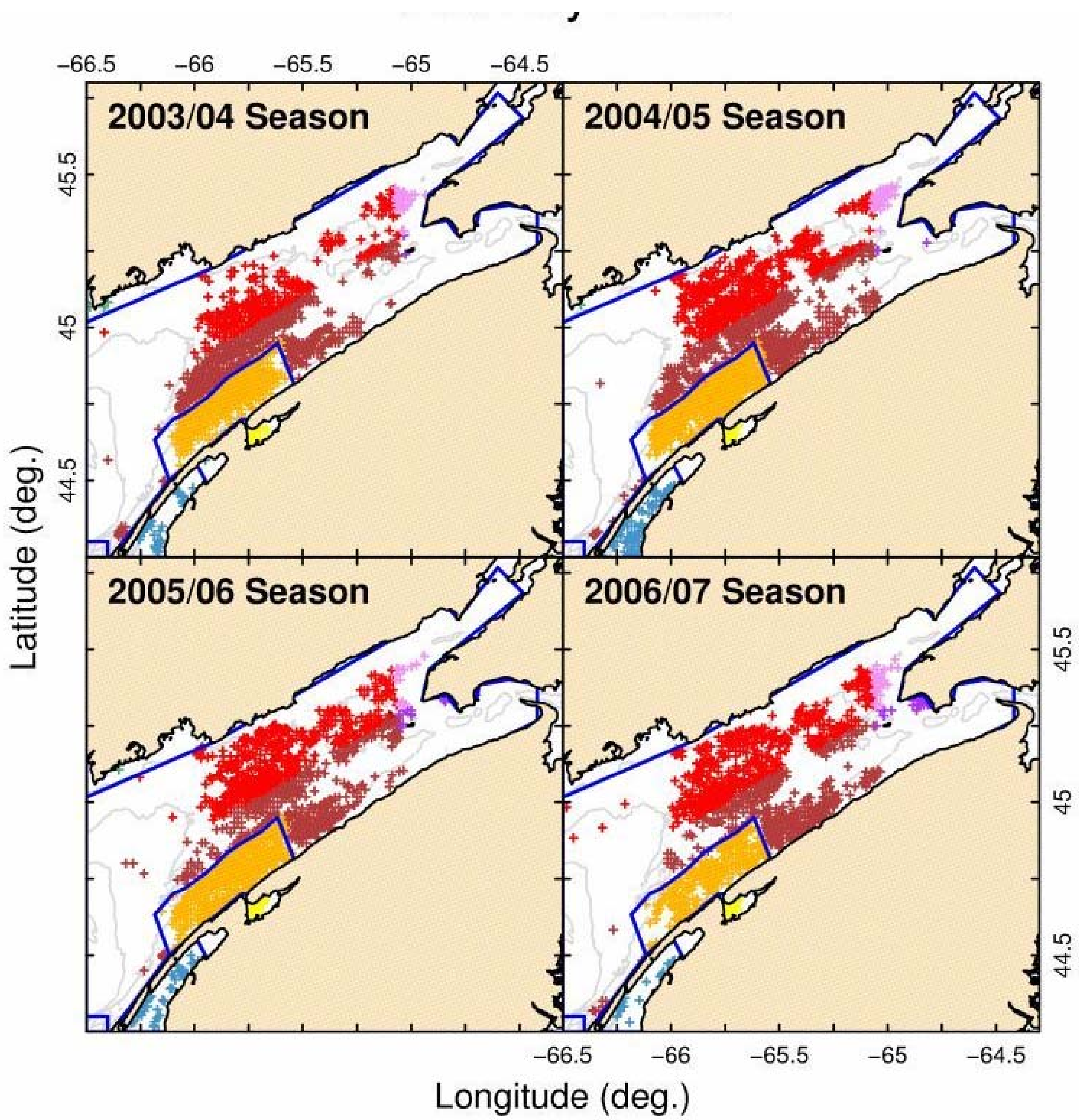

Figure 4. Fishing locations for 2003/2004 to 2006/2007 seasons based upon commercial fishing logs from the Full Bay Fleet in Scallop Production Areas 1A, 1B and 4. The positions are colour-coded to correspond to fishing in the different management areas.

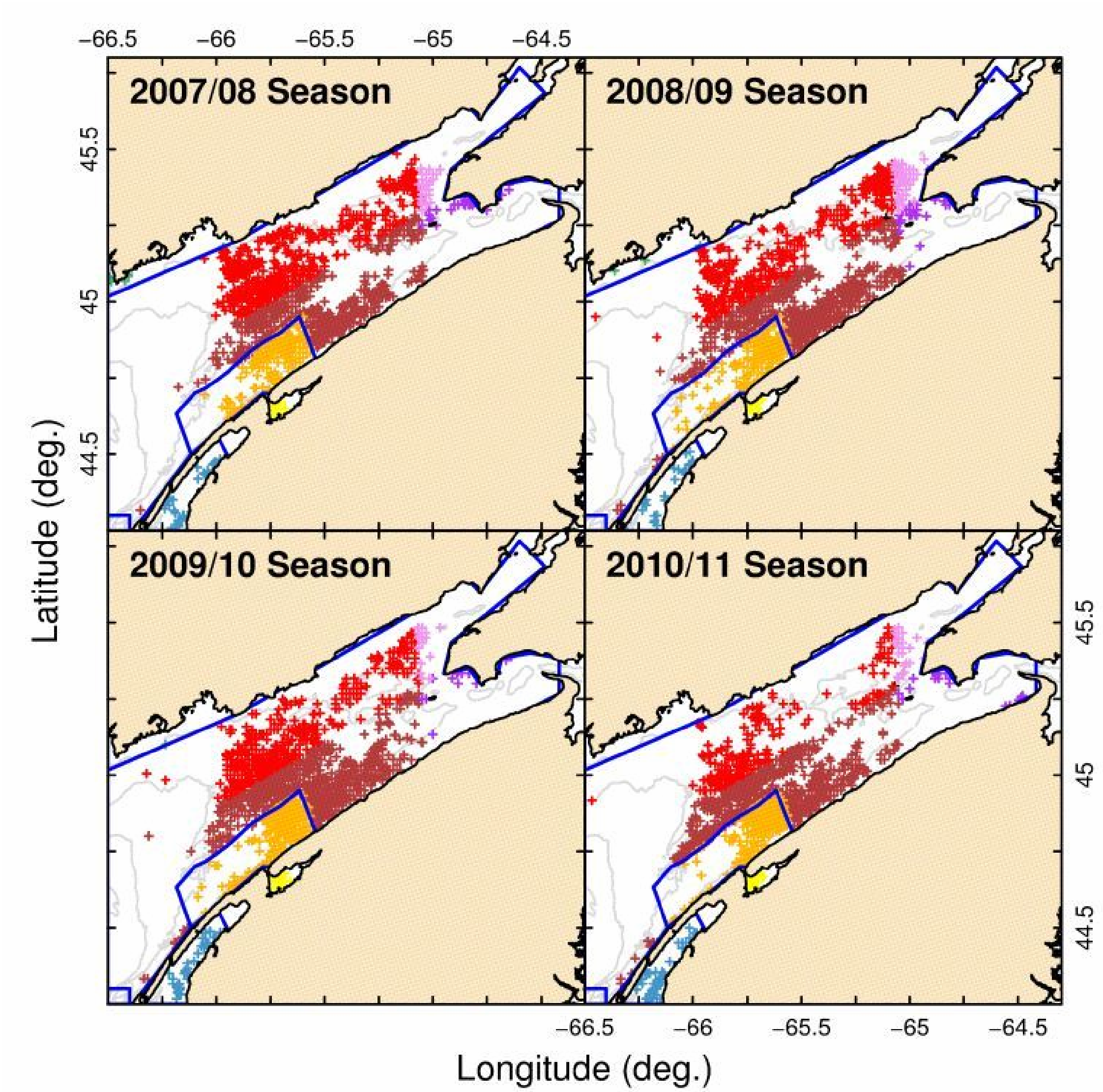

Figure 5. Fishing locations for 2007/2008 to 2010/2011 seasons based upon commercial fishing logs from the Full Bay Fleet in Scallop Production Areas 1A, 1B and 4. The positions are colour-coded to correspond to fishing in the different management areas.

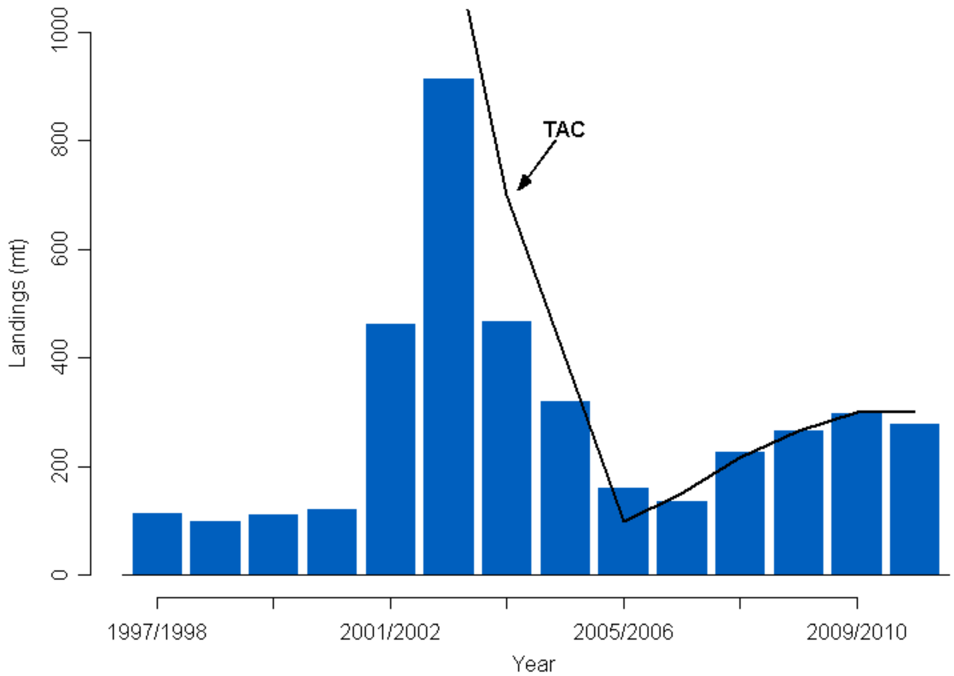

Figure 6. Scallop landings (meats, t) in Scallop Production Area 1A by the Full Bay Fleet.

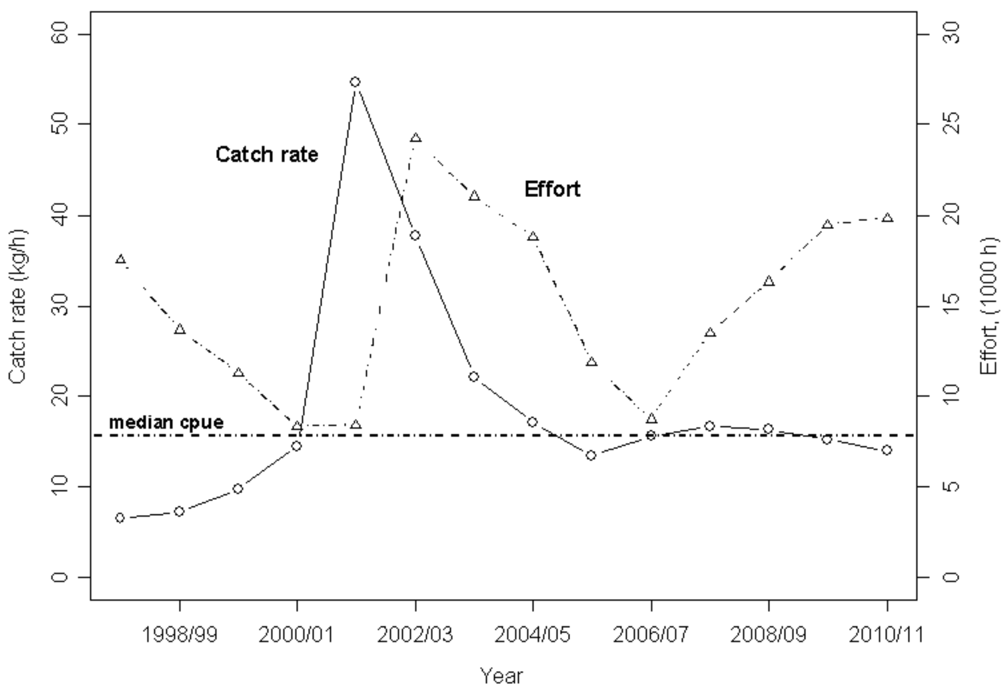

Figure 7. Trends in scallop catch rate (kg/h) and effort (1000 h) from SPA 1A. Median catch rate over the 1995-1996 to 2009-2010 period indicated.

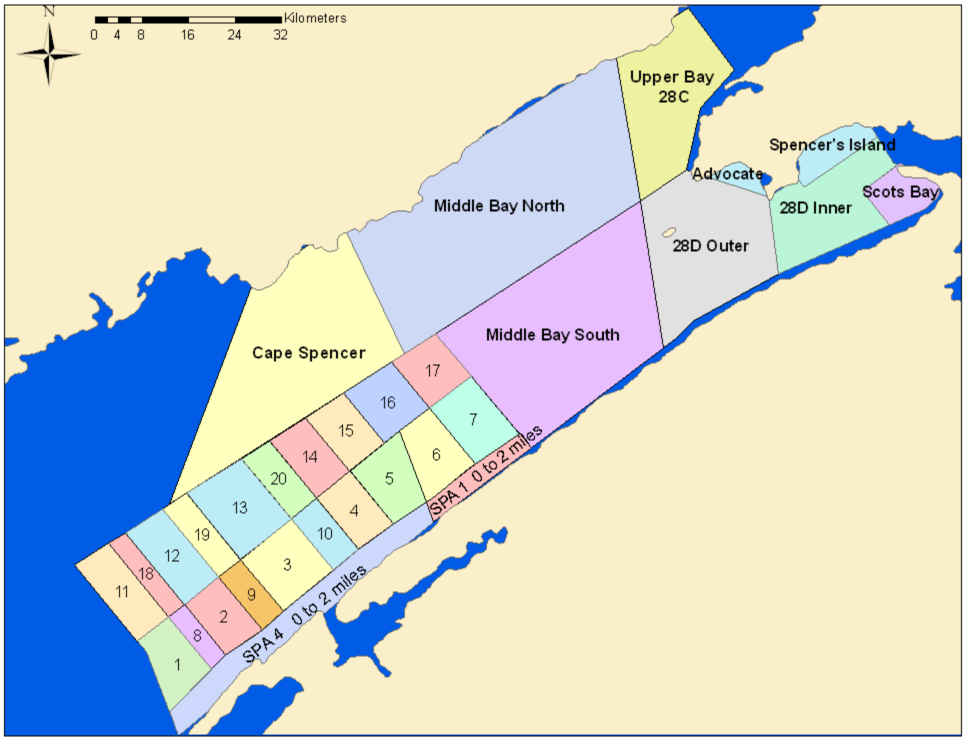

Figure 8. Map of survey strata for the Bay of Fundy scallop survey.

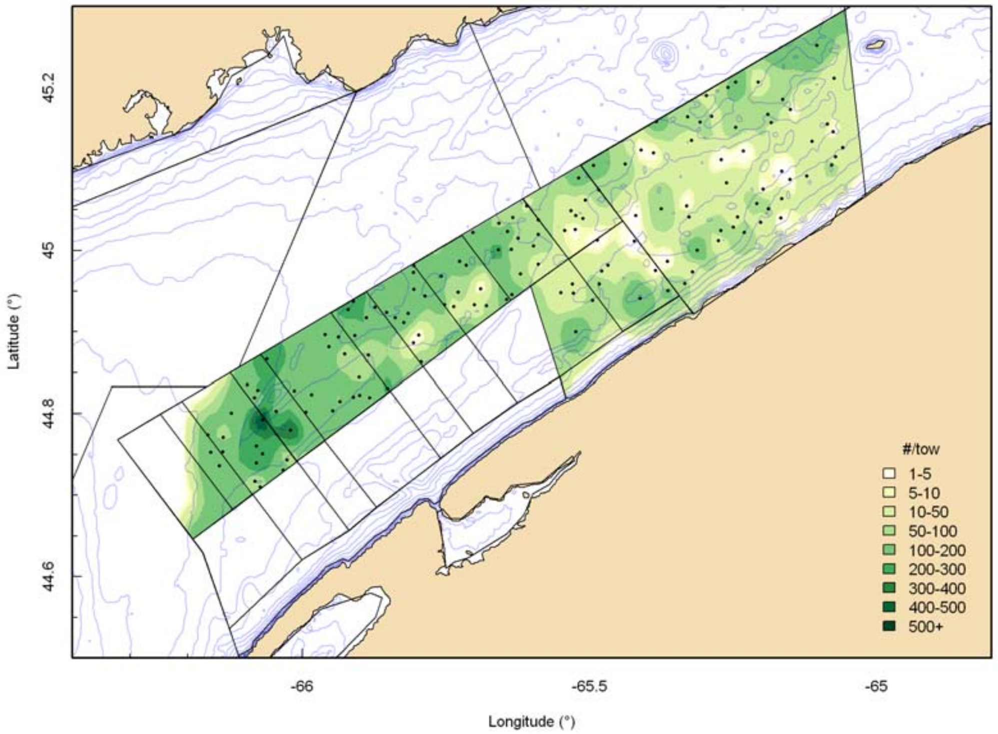

Figure 9. Spatial density (no./tow) distribution for commercial size scallops in Scallop Production Area 1A.

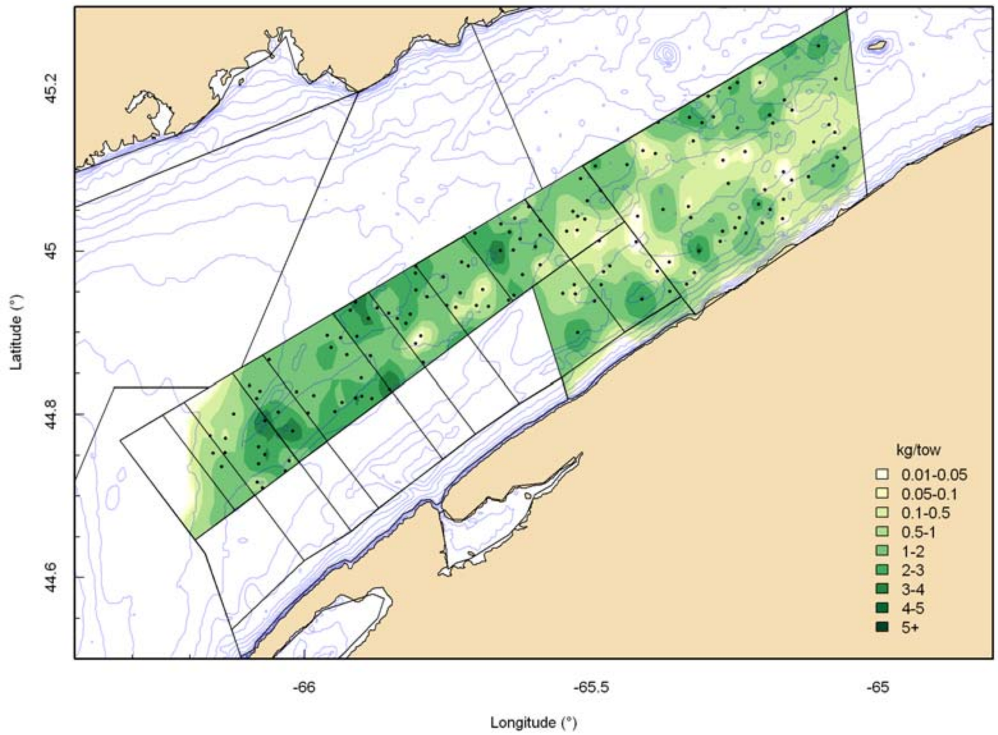

Figure 10. Spatial density (kg/tow) distribution of commerical biomass from the 2011 survey data for Scallop Production Area 1A.

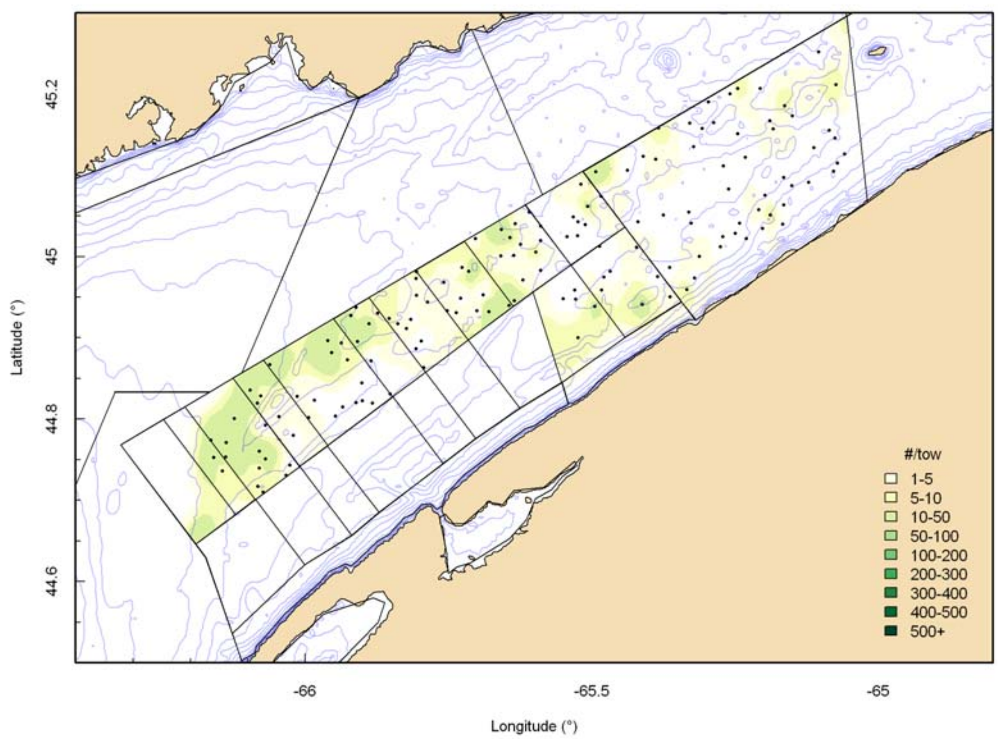

Figure 11. Spatial density (no./tow) distribution for recruit size scallops in Scallop Production Area 1A.

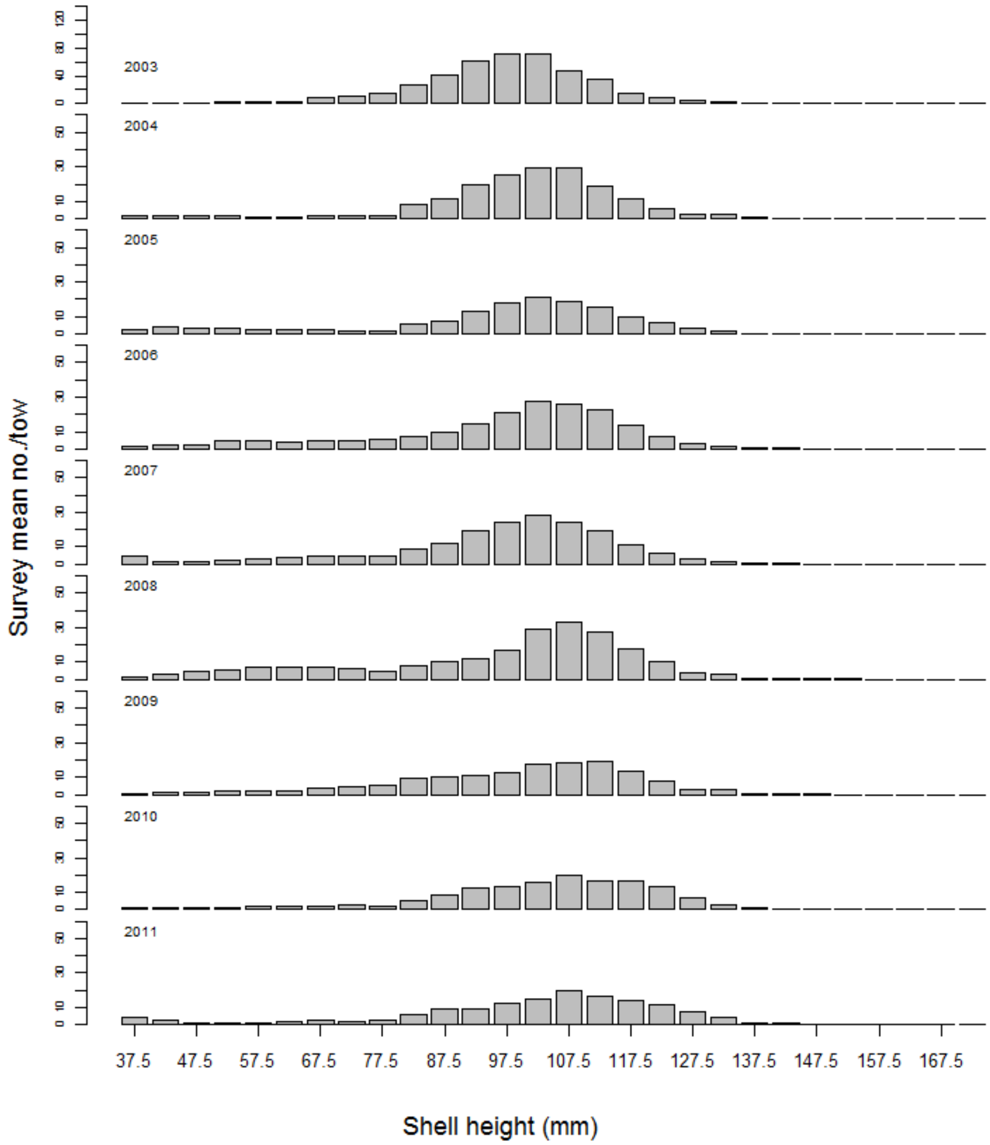

Figure 12. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1A, 8 to 16 mile zone. Note the change in scale on the y-axis between 2003 and 2004.

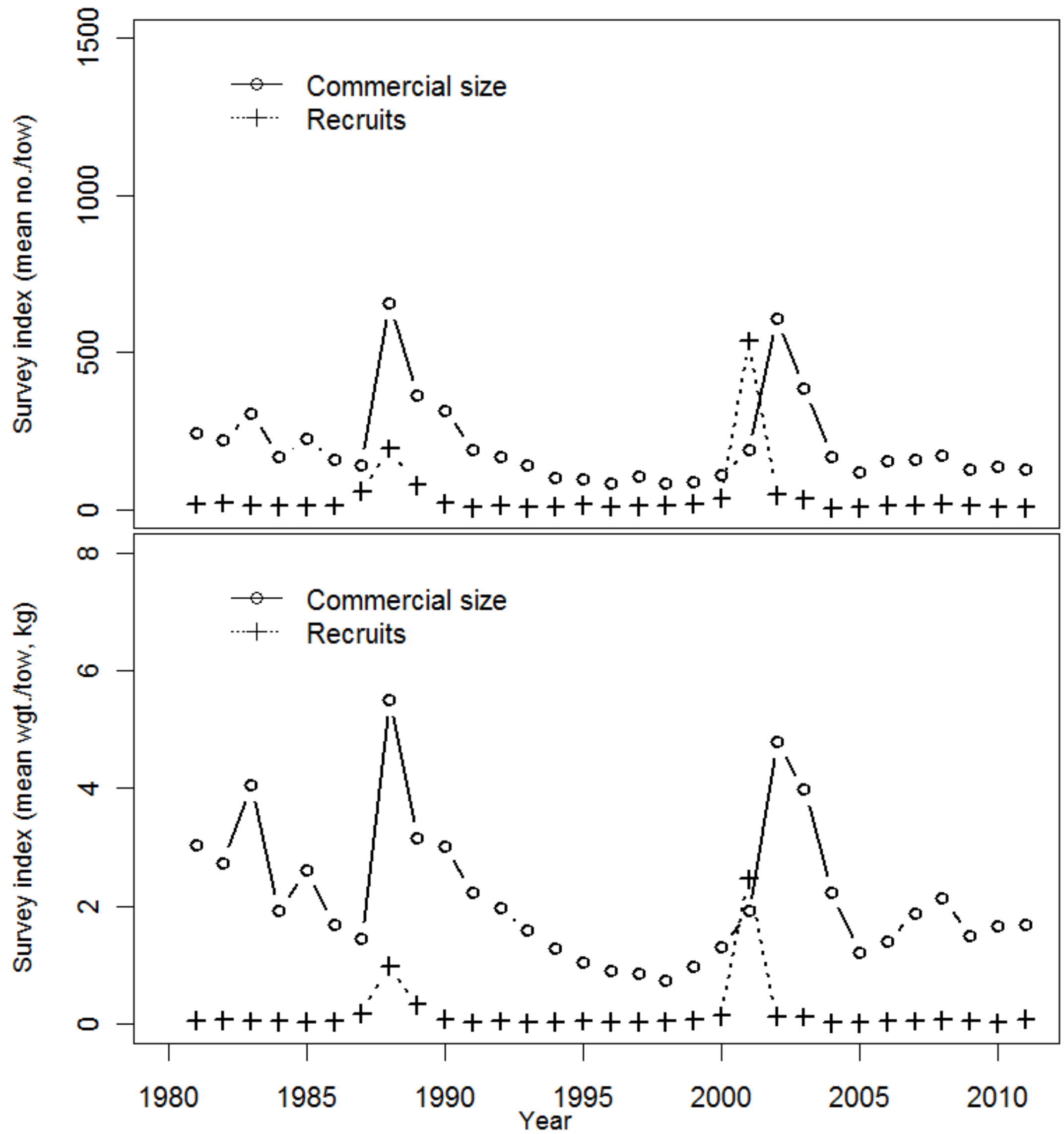

Figure 13. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the 8 to 16 mile zone of Scallop Production Area 1A.

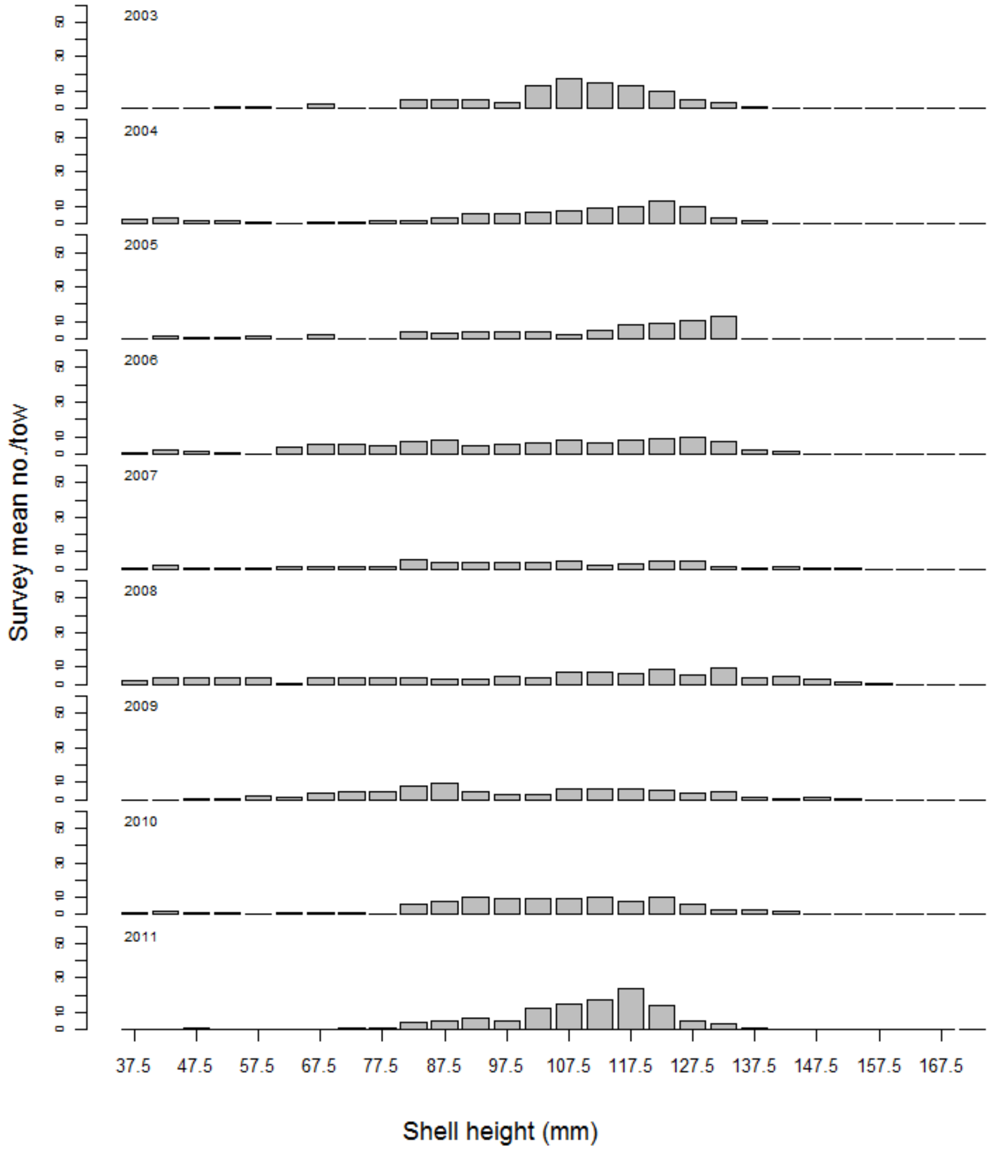

Figure 14. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1A, 2 to 8 mile zone.

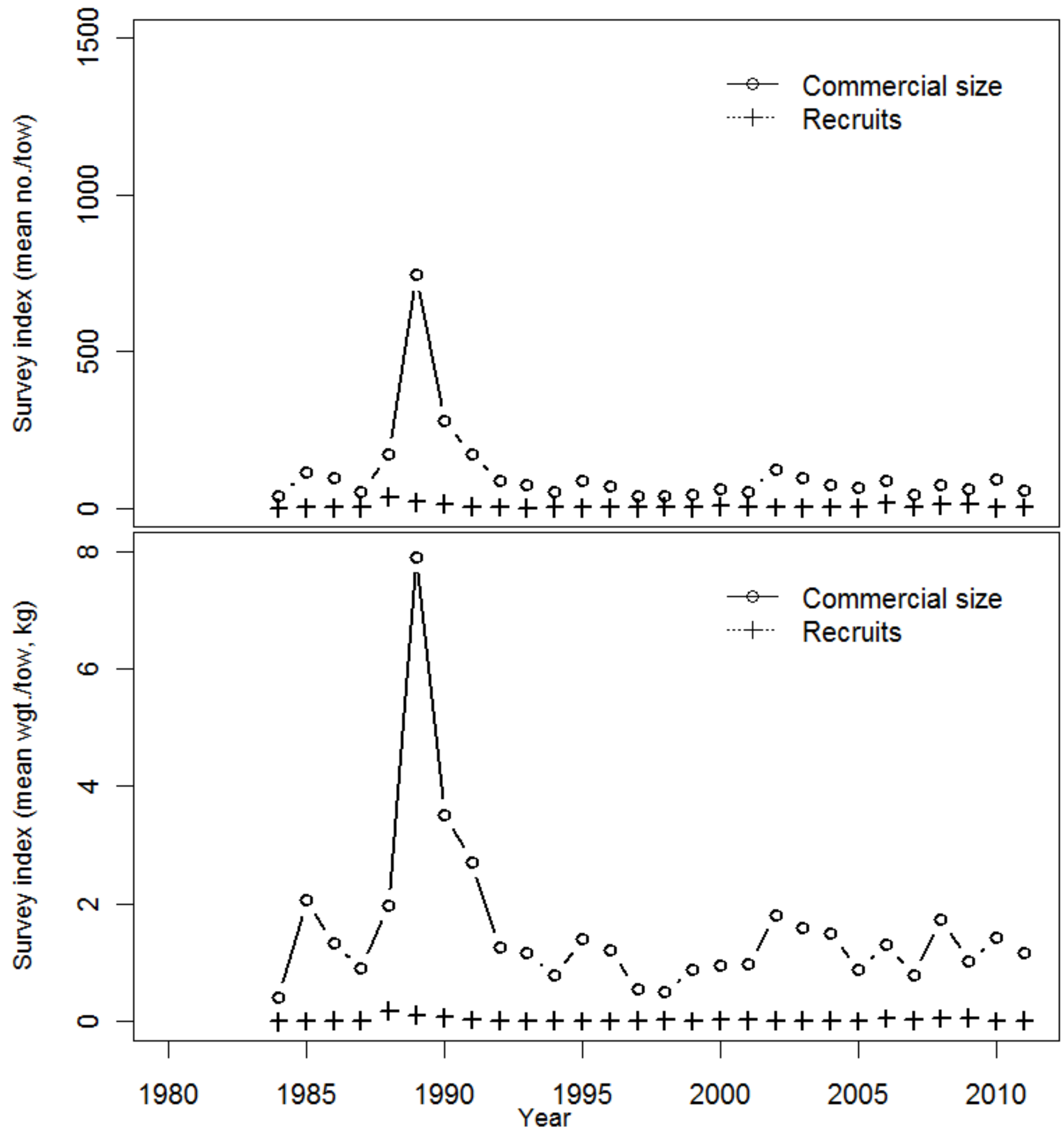

Figure 15. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the 2 to 8 mile zone of Scallop Production Area 1A.

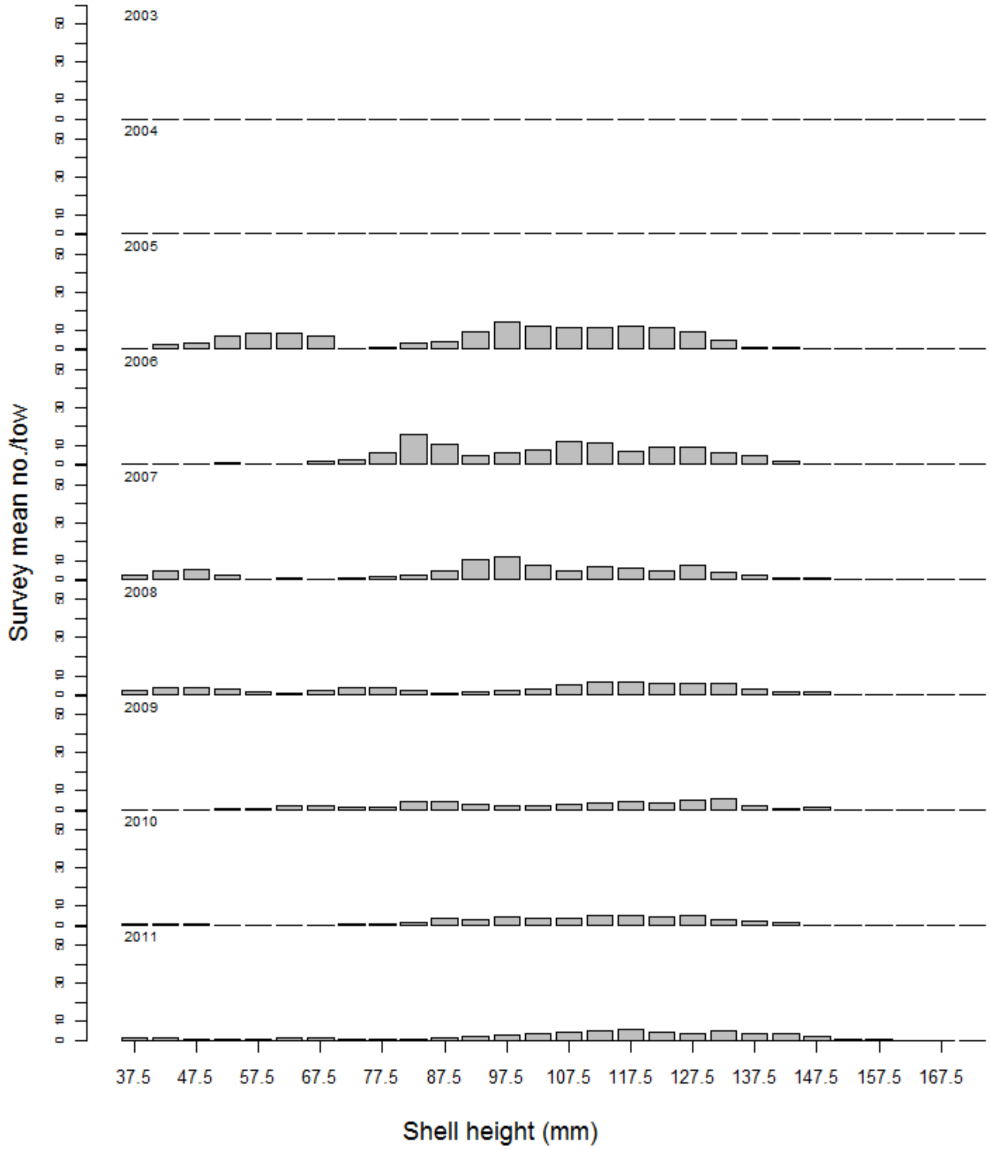

Figure 16. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1A, Middle Bay South zone.

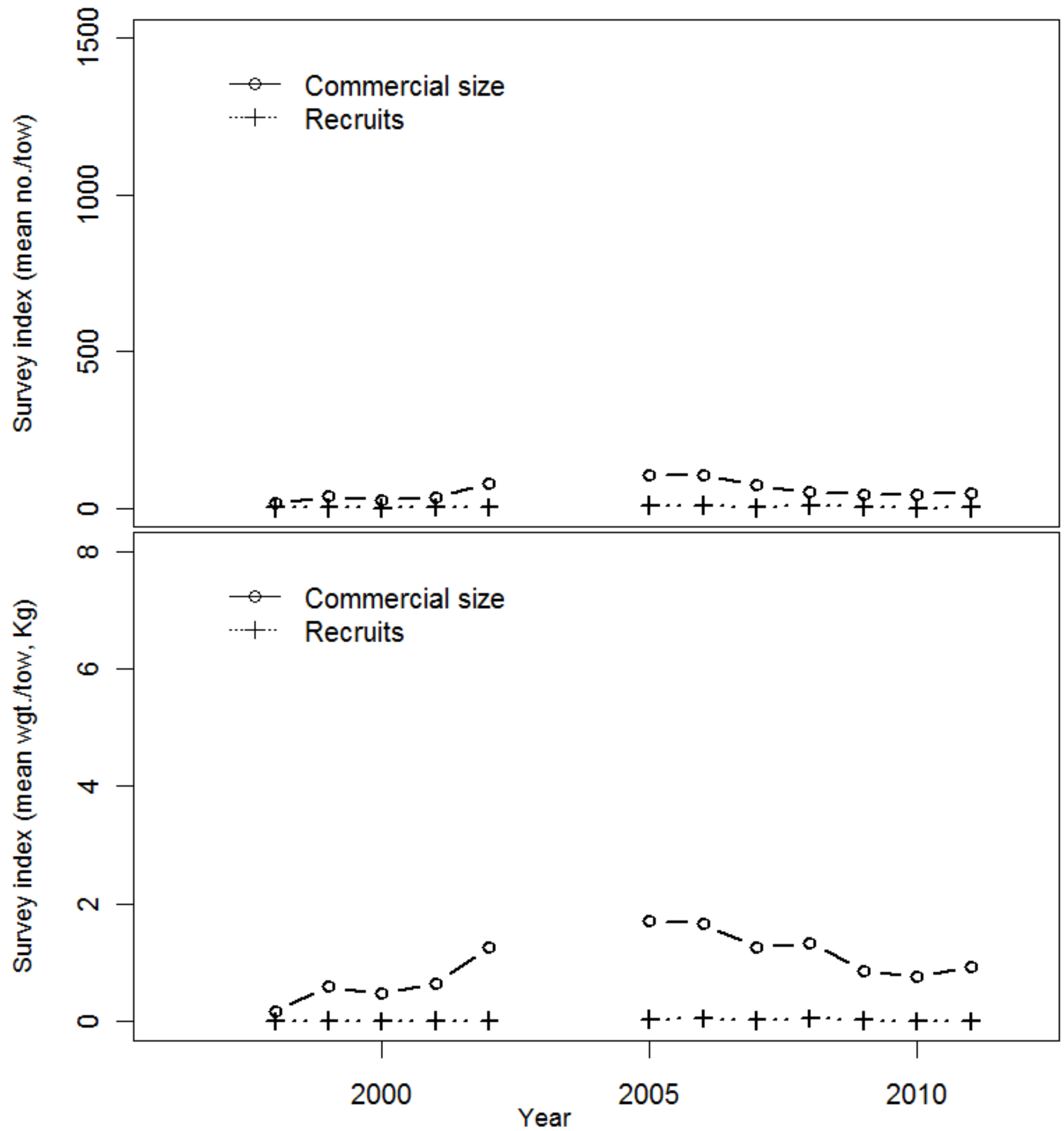

Figure 17. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Middle Bay south zone of Scallop Production Area 1A.

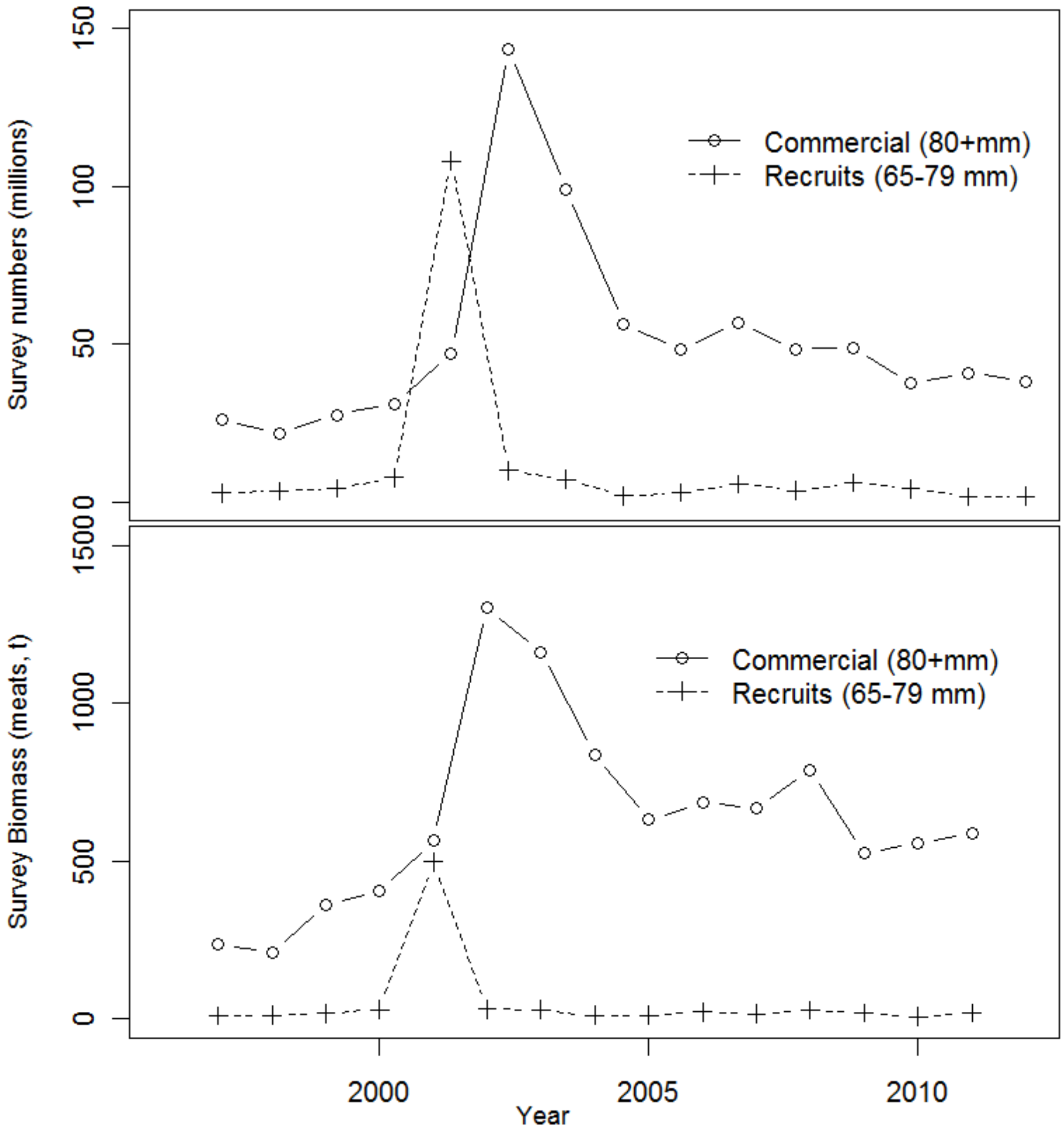

Figure 18. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in Scallop Production Area 1A.

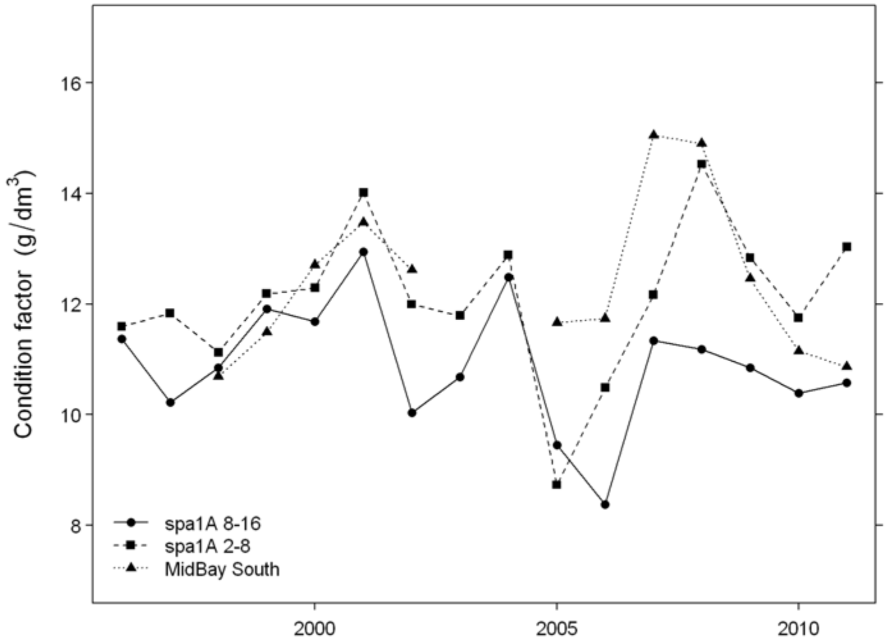

Figure 19. Annual trend in condition factor (CF) for scallops from the annual surveys of Scallop Production Area 1A.

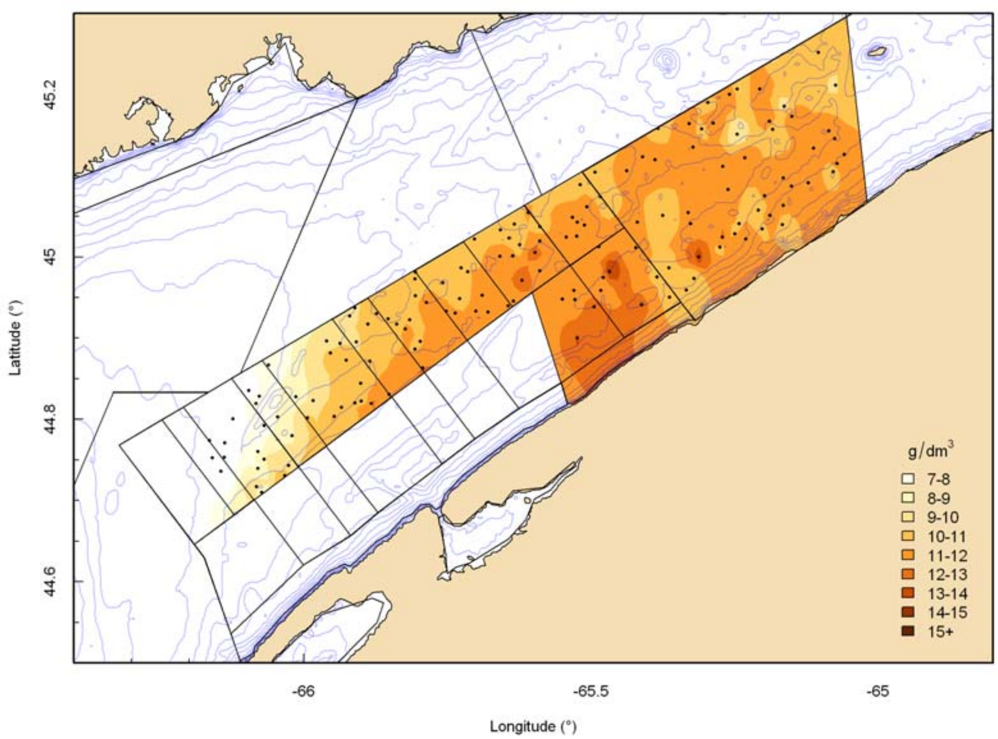

Figure 20. Spatial distribution of condition factor (g/dm^3) from the 2011 survey data for Scallop Production Area 1A.

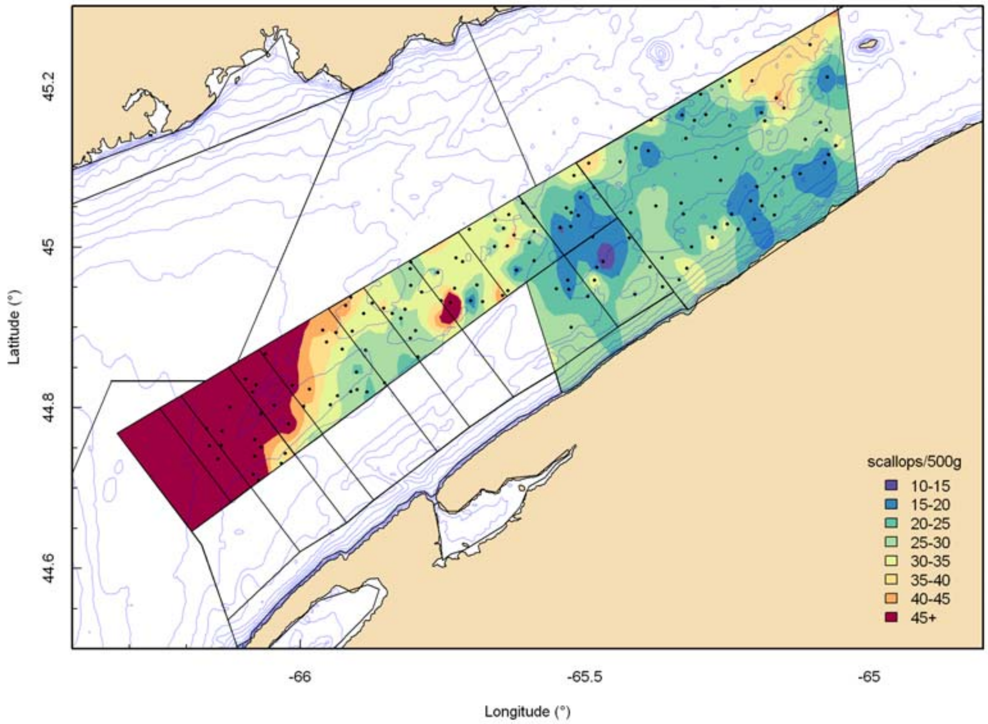

Figure 21. Spatial distribution of estimated meat count of commercial size (≥80 mm shell height) scallops from the survey of SPA 1A in 2011. Inverse distance weighted interpolation was used with the average meat weight of fully-recruited scallops for each tow to produce a contoured color image.

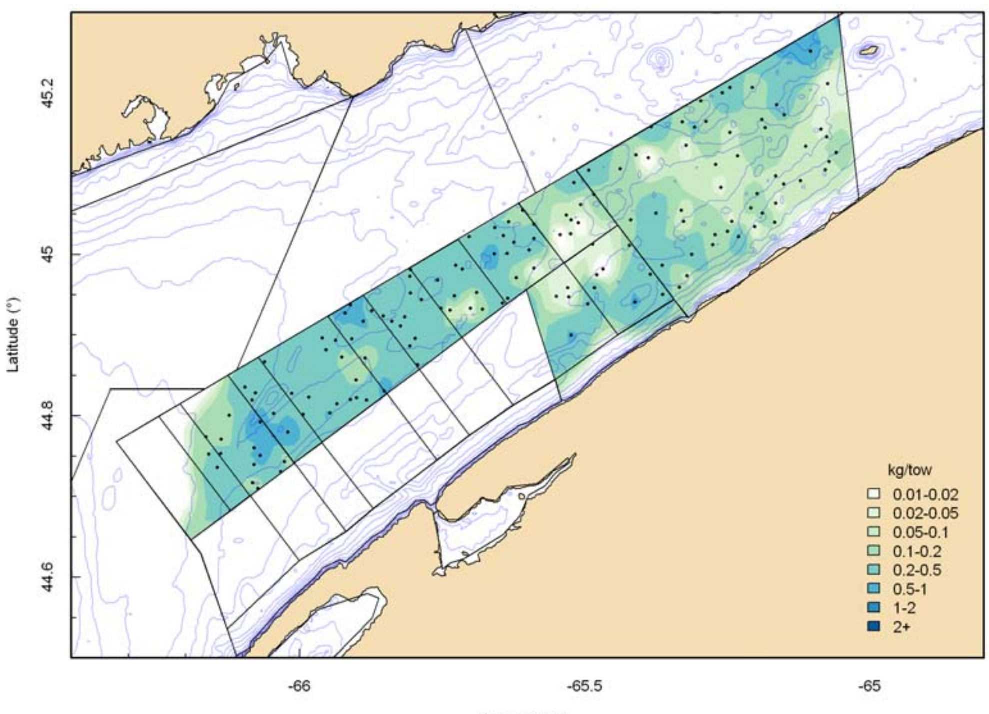

Figure 22. Spatial distribution of expected growth for 2011/2012 in biomass (meats) of commercial size (≥80 mm shell height) scallops from the survey of SPA 1A in 2011. Inverse distance weighted interpolation was used with the average expected growth of fully-recruited scallops for each tow to produce a contoured color image.

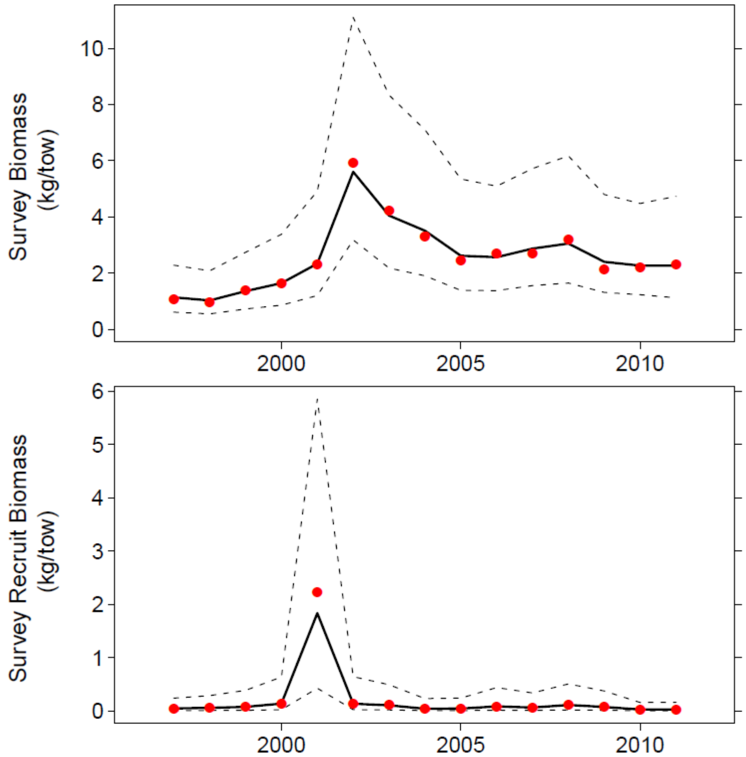

Figure 23. Posterior median fit to survey series for commercial size and recruit size scallops. Bayesian state-space delay-difference model for scallops in SPA 1A.

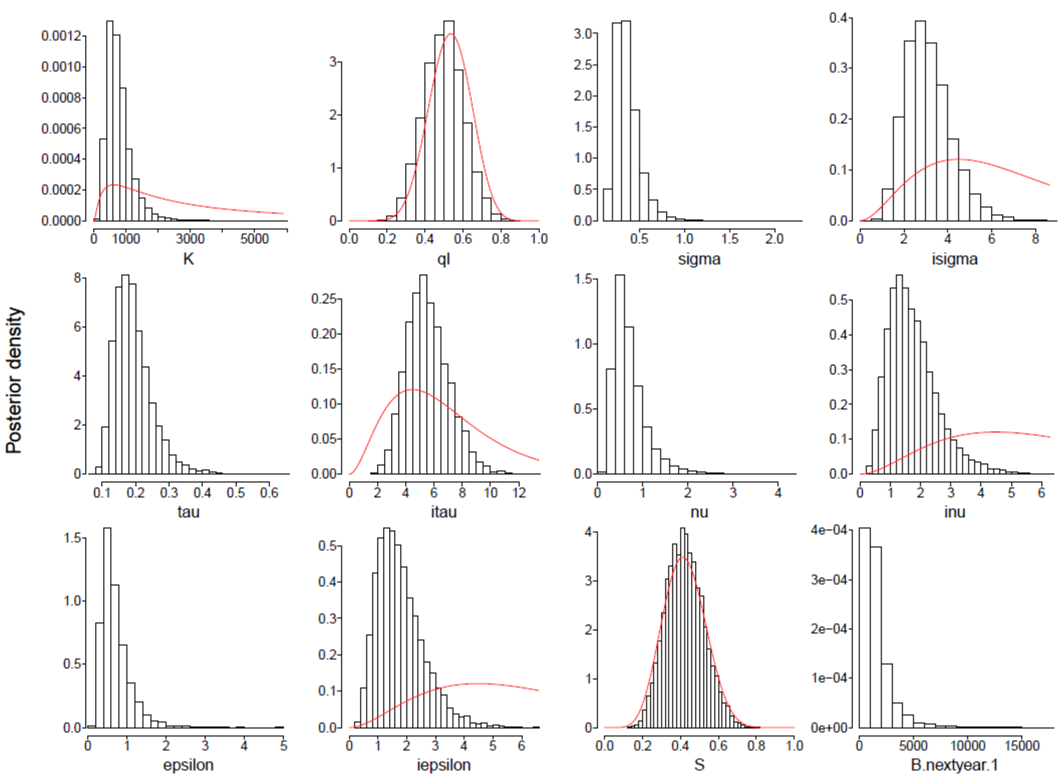

Figure 24. Comparison of prior and posterior densities. Bayesian state-space delay-difference model for scallops in SPA 1A.

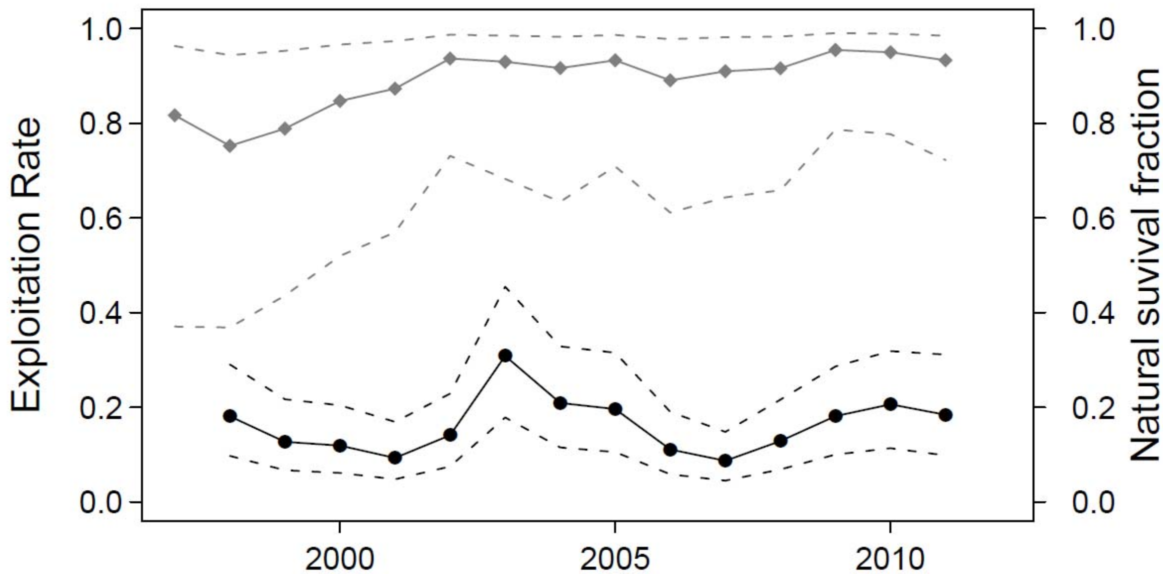

Figure 25. Annual trends in exploitation (solid line with filled circle) and survival estimates ($exp(-m)$), where m is natural mortality; solid line with filled triangles). Bayesian state-space delay-difference model for scallops in SPA 1A.

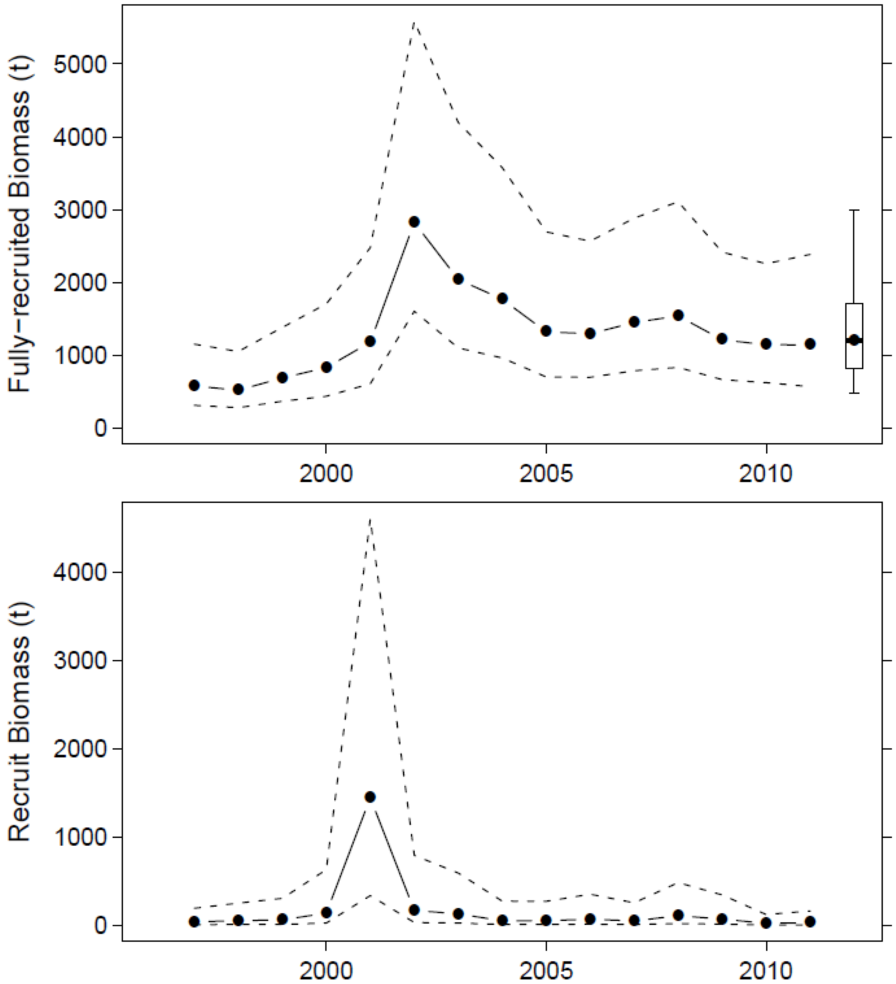

Figure 26. Biomass estimates for fully recruited scallops from the delay-difference model fit to the SPA 1A survey and commercial data. Dashed lines are the upper and lower 95% credible limits on the estimates and the dotted line represents the 25 year median. The predicted commercial size biomass for 2012, assuming the interim TAC, is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers).

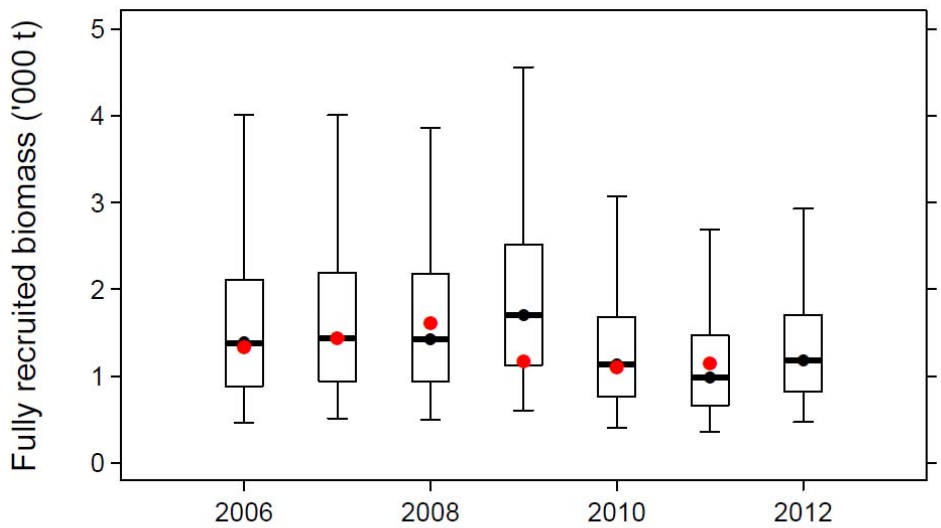

Figure 27. Evaluation of model projection performance. Box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year $t-1$ (e.g., 2006 prediction based on data up to 2005). Red dot represents the estimate of the biomass in year t using data up to and including year t. Bayesian state-space delay-difference model for scallops in SPA 1A

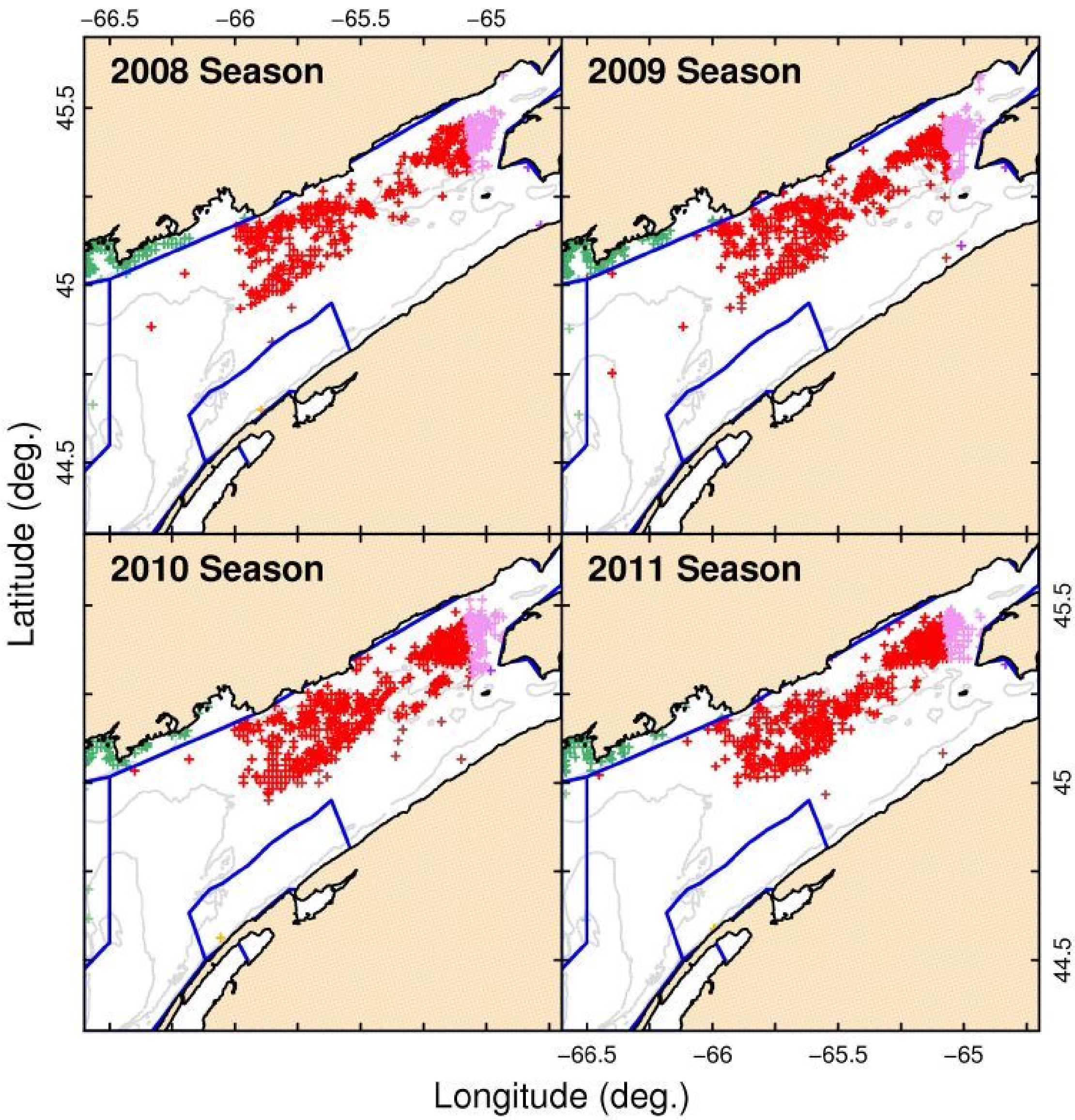

Figure 28. Fishing locations for 2008 to 2011 seasons based upon commercial fishing logs from the Mid-Bay Fleet in Scallop Production Areas 1B (28B, 28C). The positions are colour-coded to correspond to fishing in the different management areas.

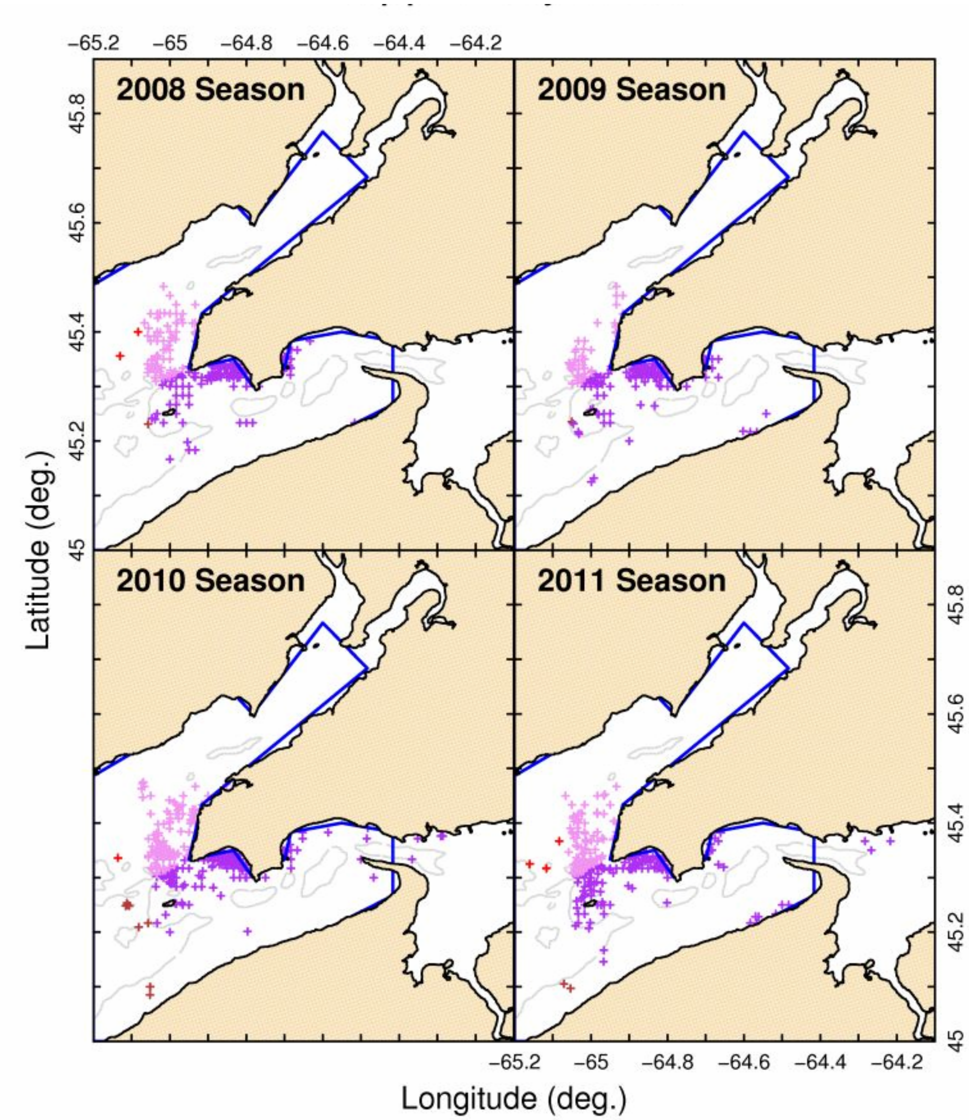

Figure 29. Fishing locations for 2008 to 2011 seasons based upon commercial fishing logs from the Upper Bay Fleet in Scallop Production Areas 1B (28C, 28D). The positions are colour-coded to correspond to fishing in the different management areas.

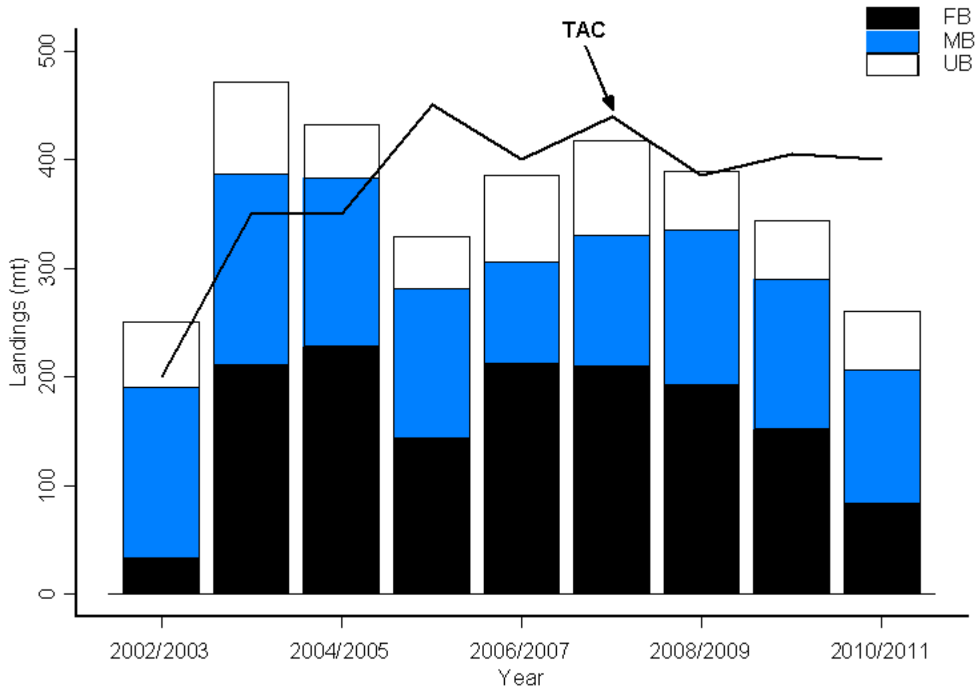

Figure 30. Scallop landings (meats, t) in Scallop Production Area 1B by each fleet.

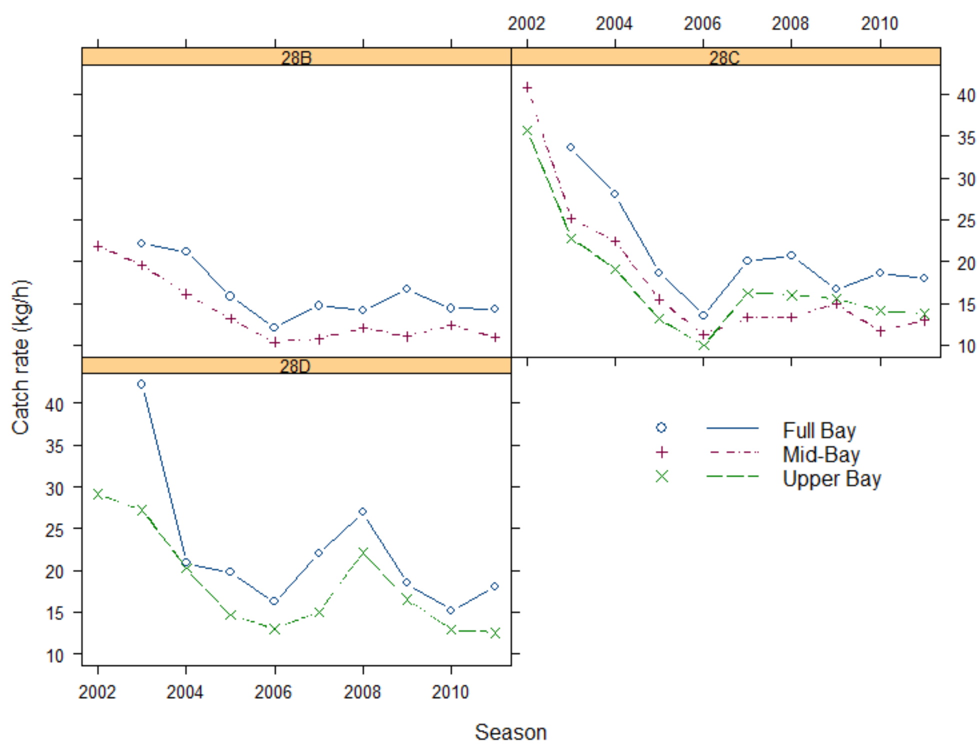

Figure 31. Commercial catch rate (kg/h) for each fleet and subarea in Scallop Production Area 1B.

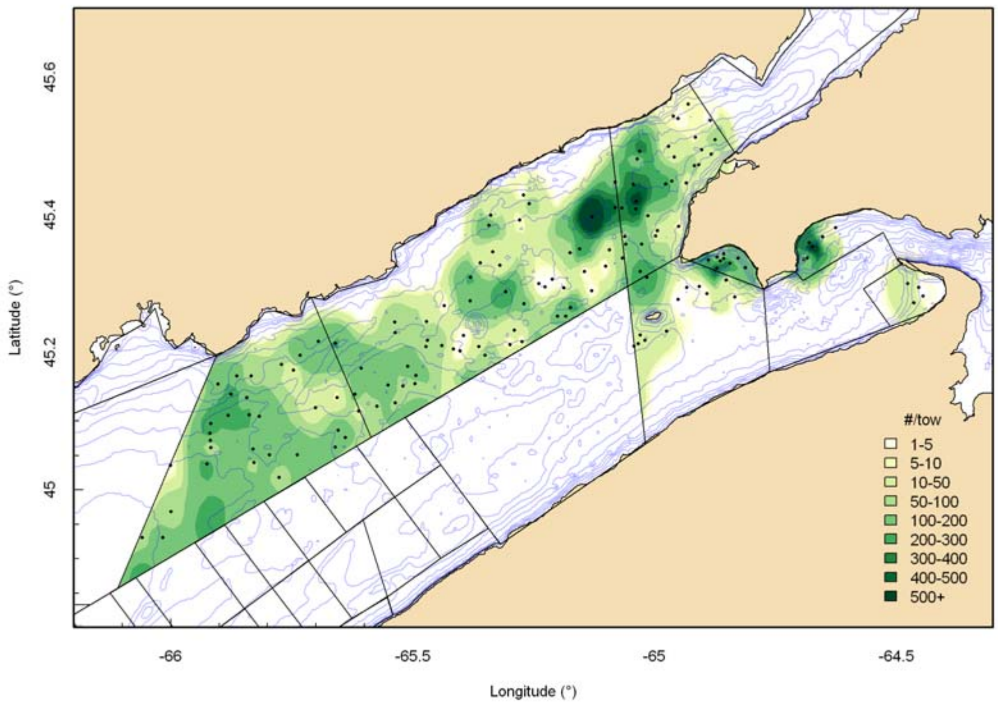

Figure 32. Spatial density (no./tow) distribution for commercial size scallops in Scallop Production Area 1B.

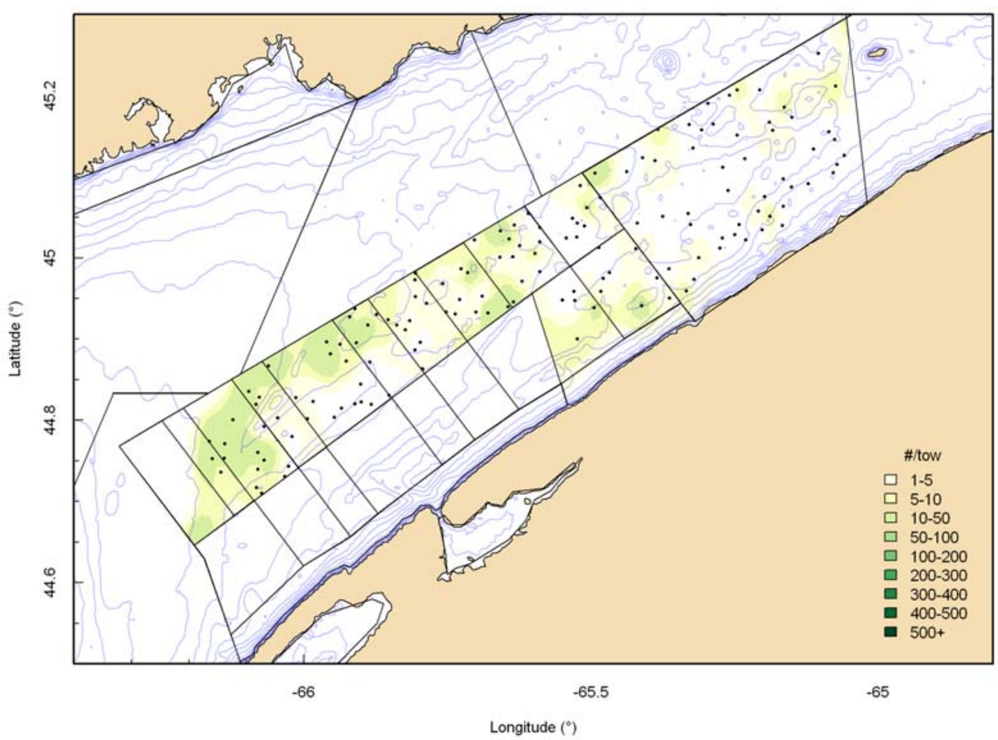

Figure 33. Spatial density (no./tow) distribution for recruit size scallops in Scallop Production Area 1B.

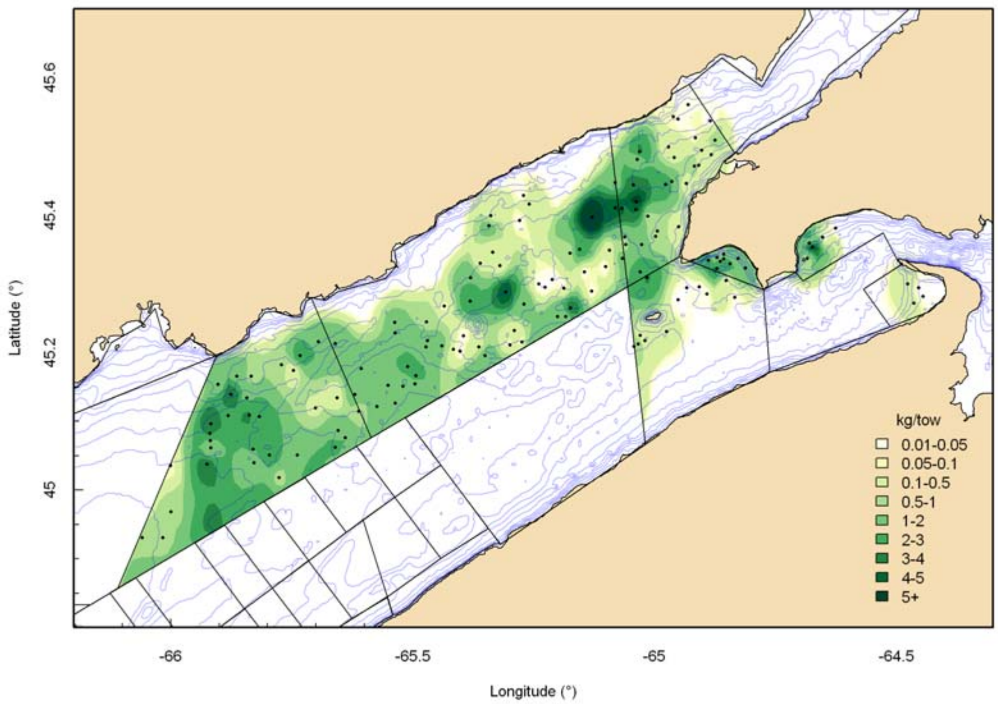

Figure 34. Spatial density (kg/tow) distribution of commercial biomass from the 2011 survey data for Scallop Production Area 1B.

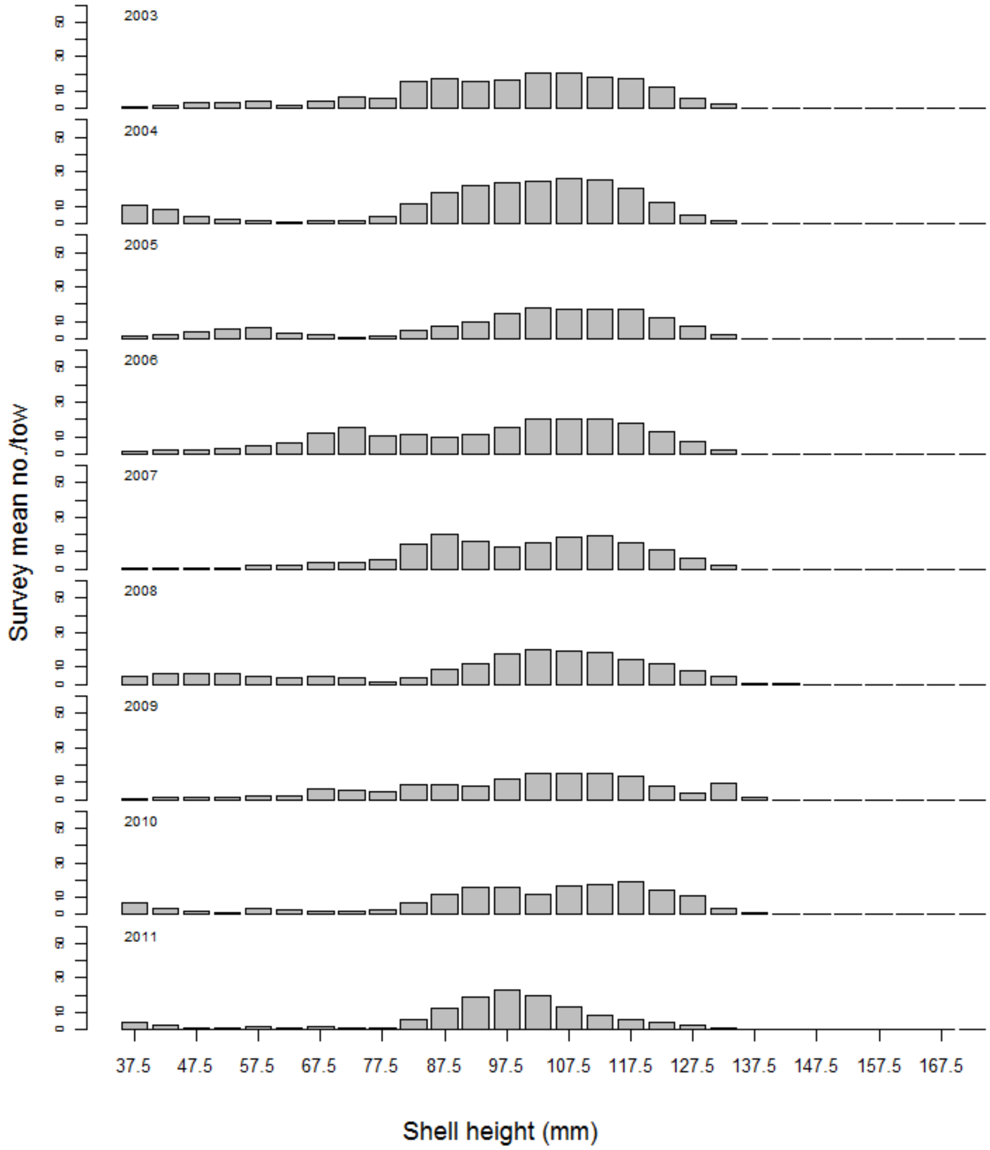

Figure 35. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Cape Spencer zone.

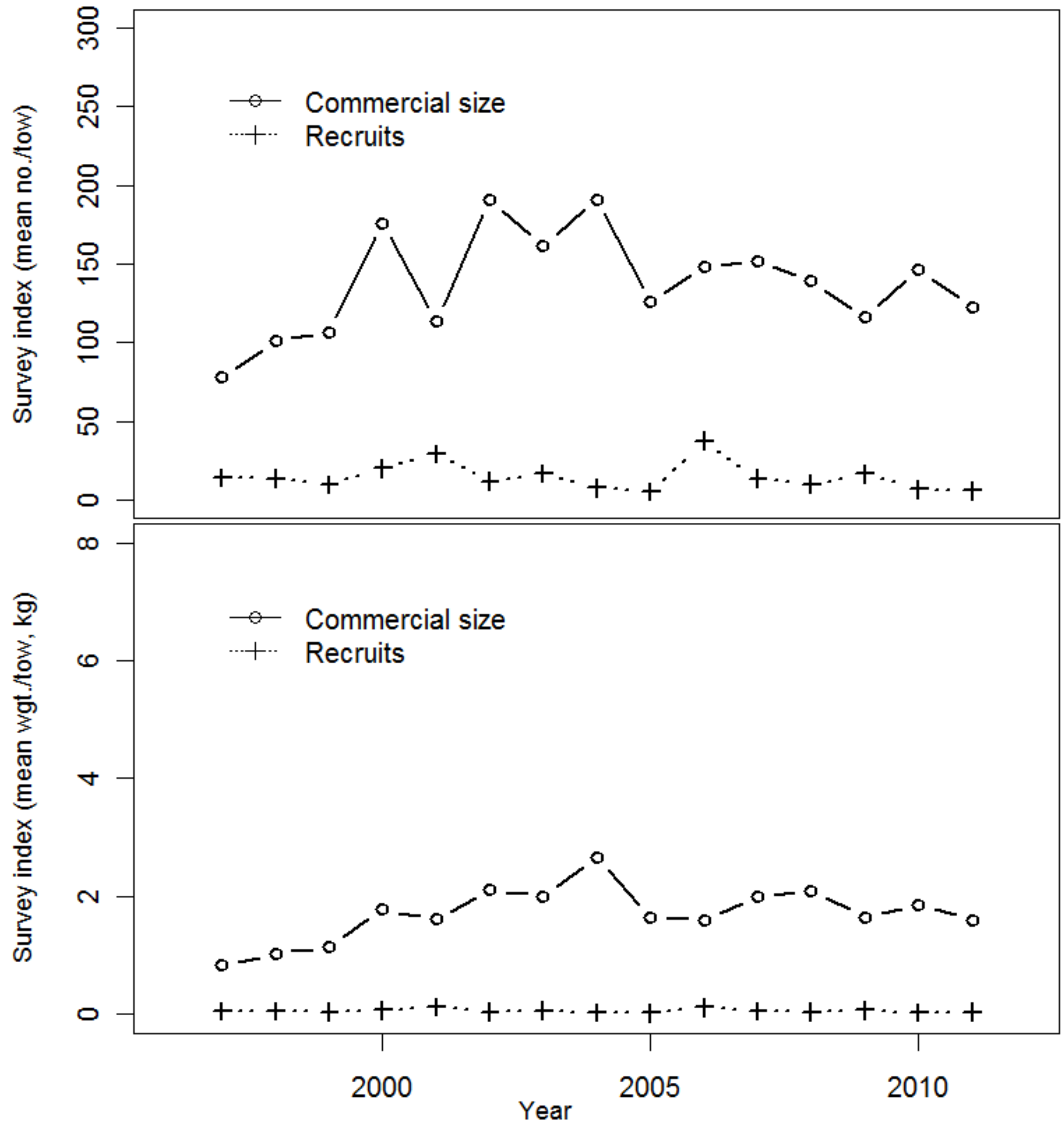

Figure 36. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Cape Spencer zone of Scallop Production Area 1B.

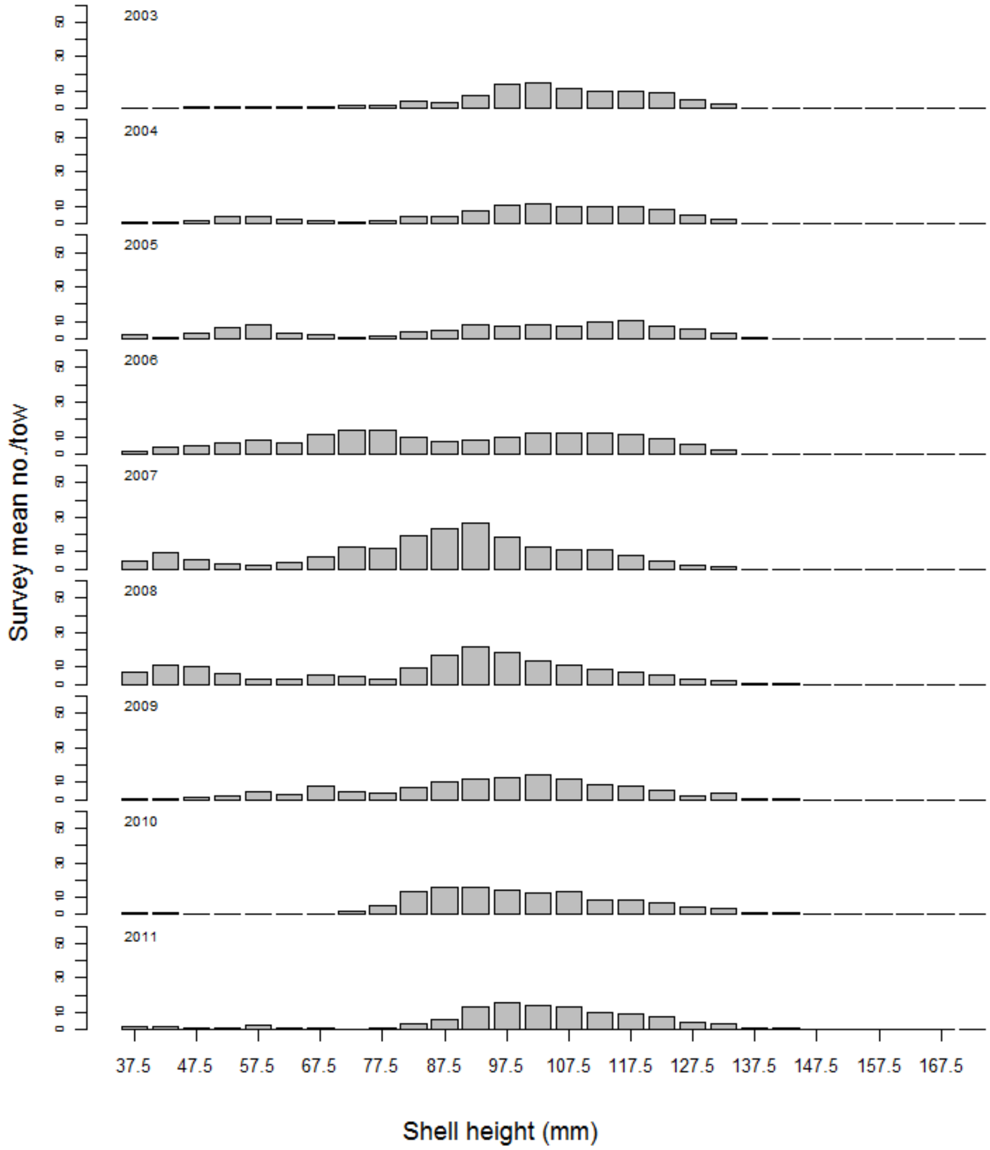

Figure 37. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Middle Bay North zone.

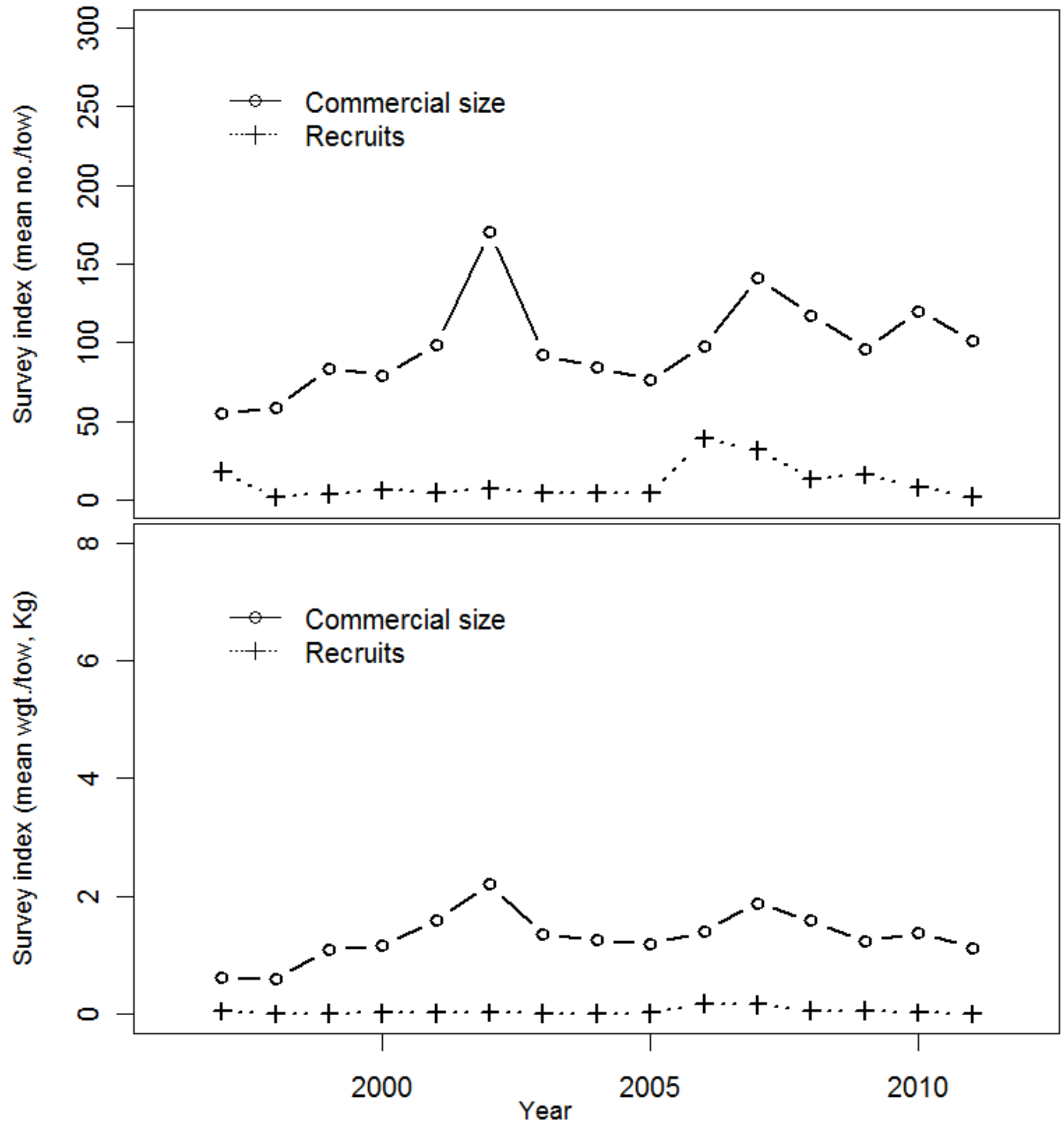

Figure 38. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Middle Bay North zone of Scallop Production Area 1B.

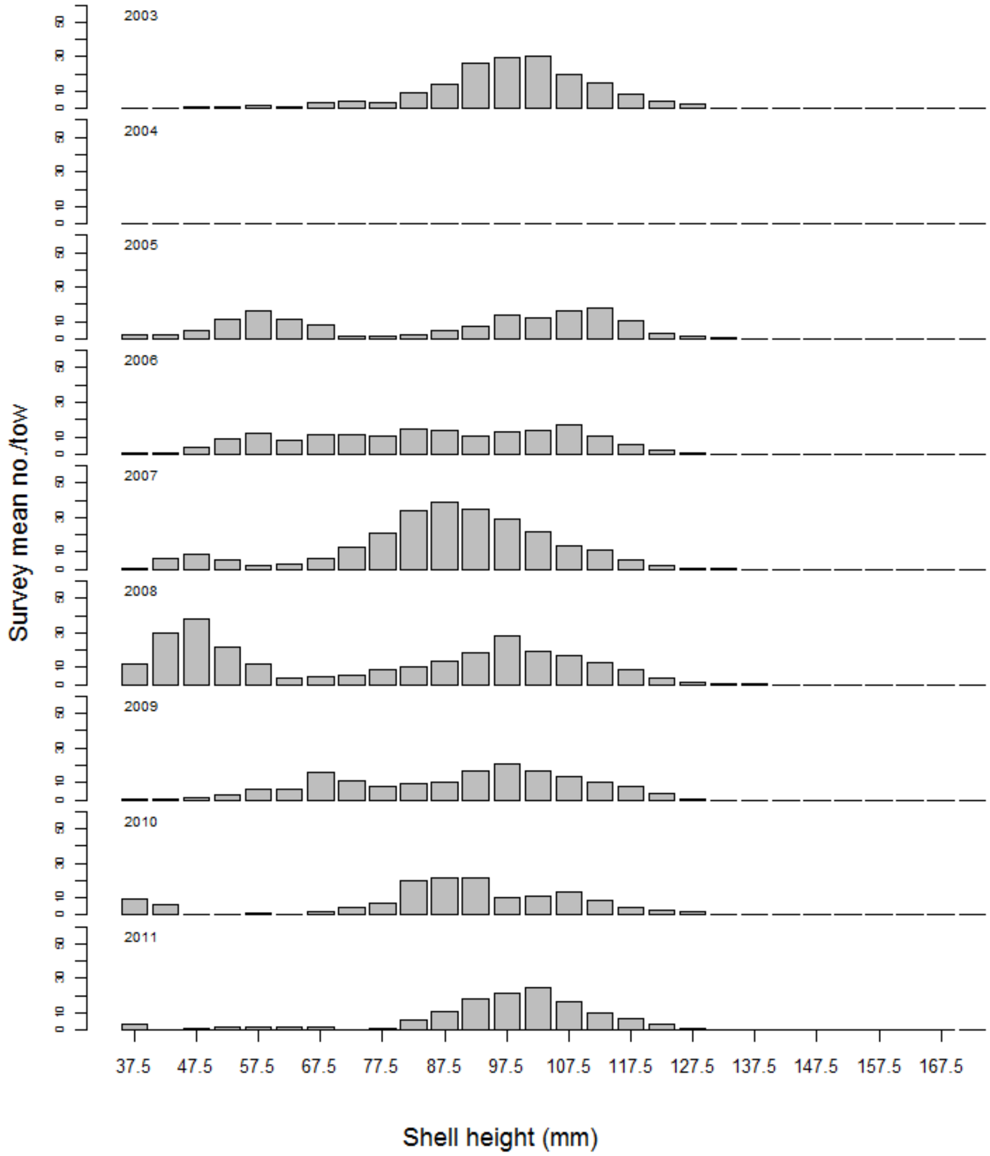

Figure 39. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, 28C zone.

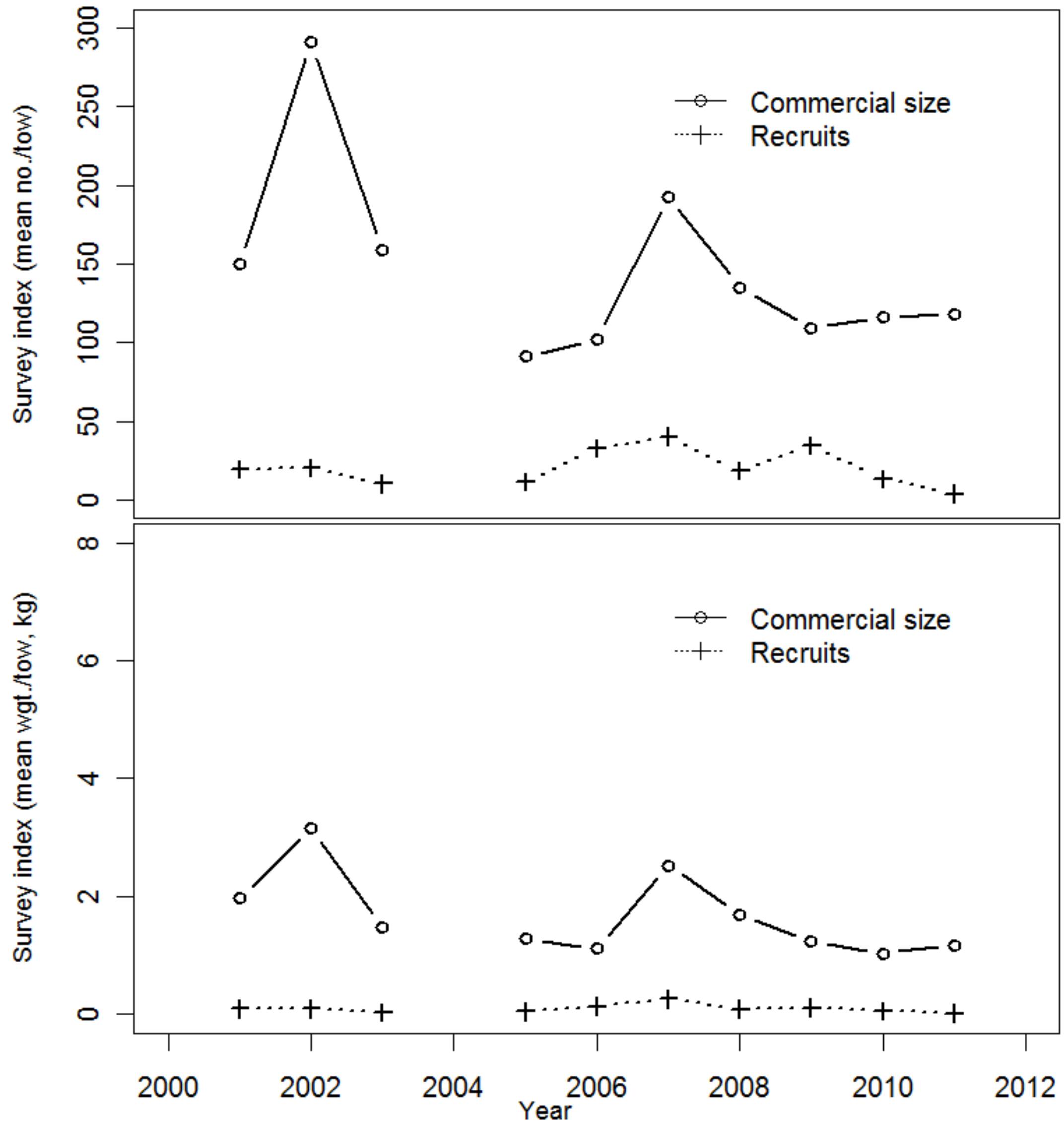

Figure 40. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the 28C zone of Scallop Production Area 1B.

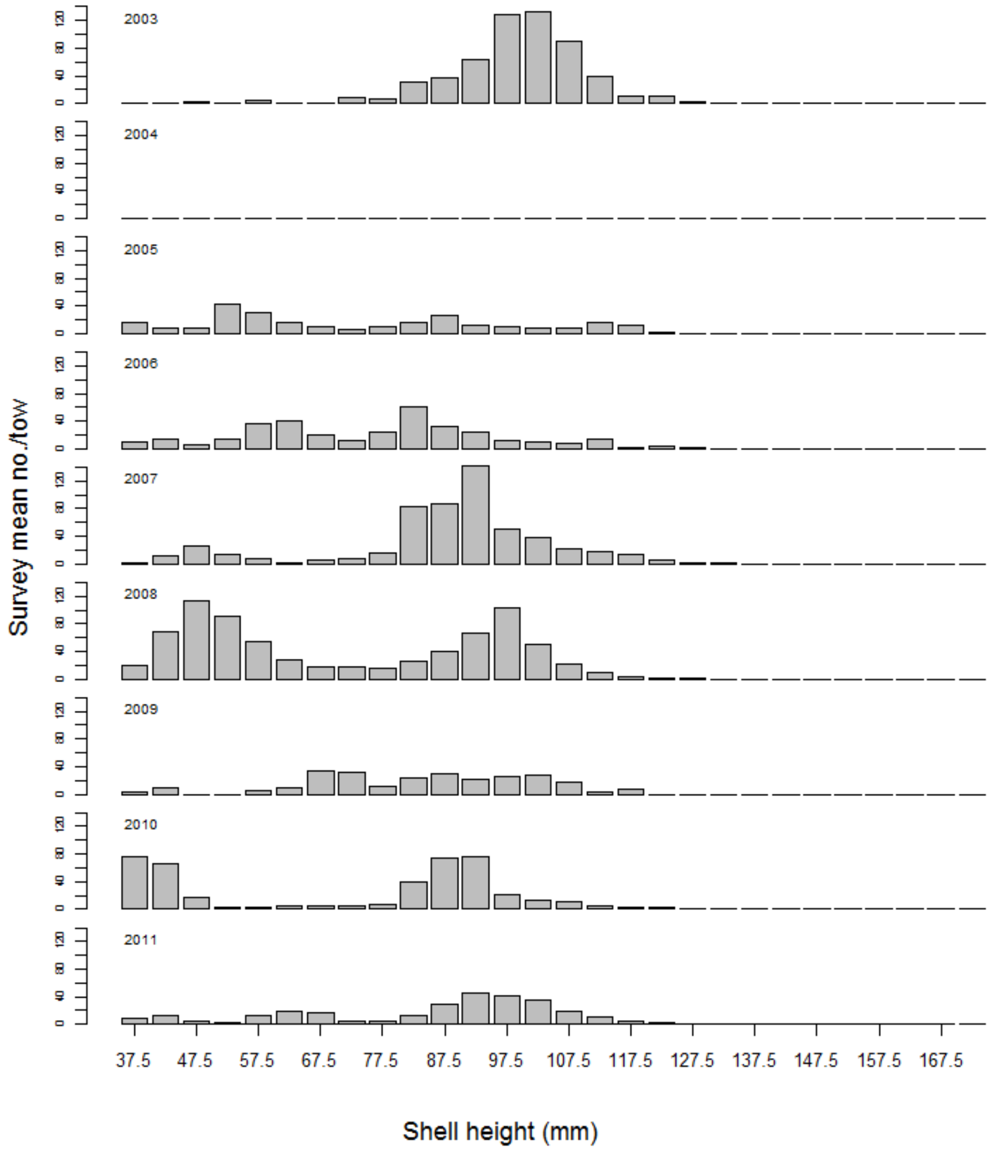

Figure 41. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Advocate zone.

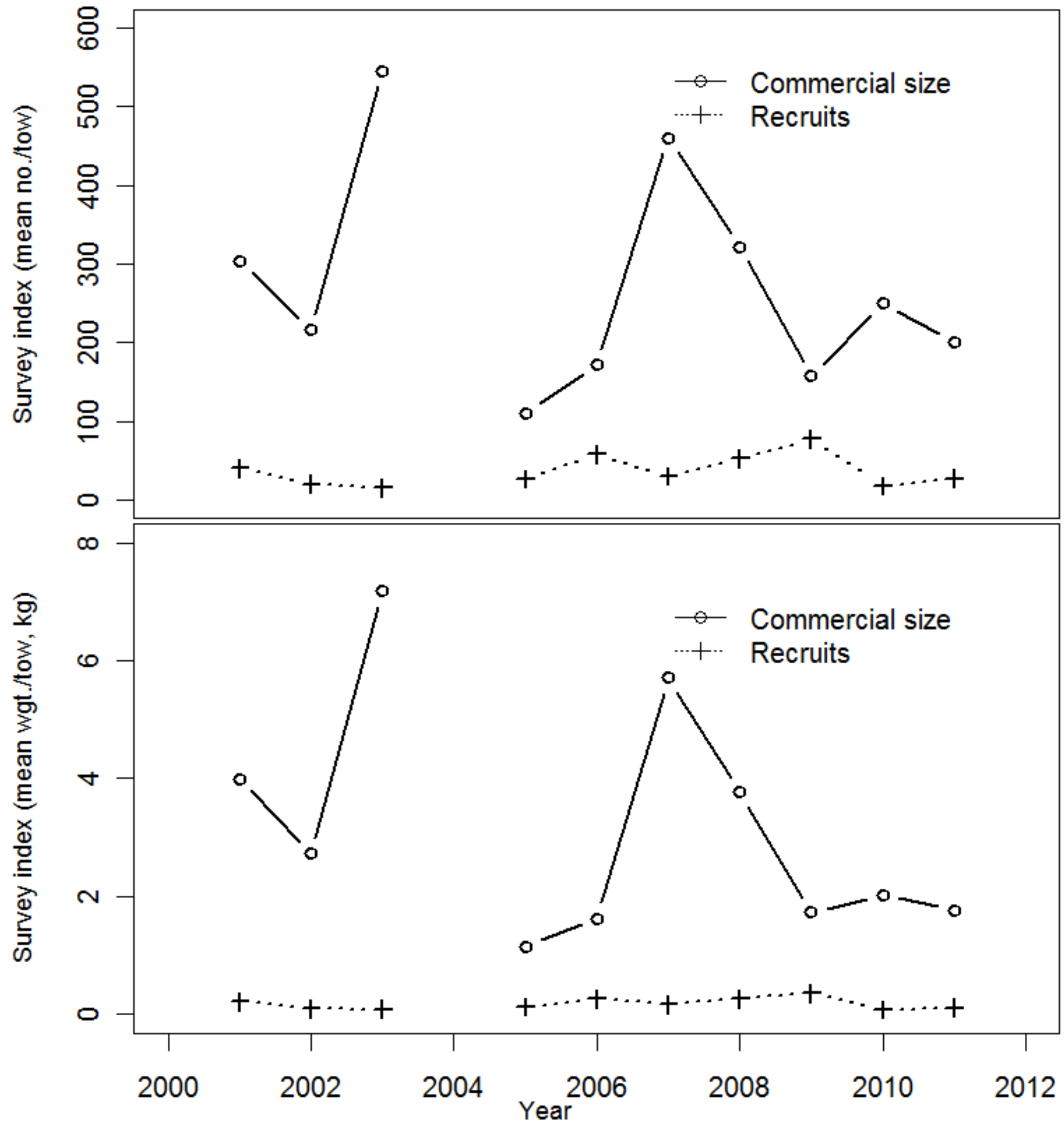

Figure 42. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Advocate zone of Scallop Production Area 1B.

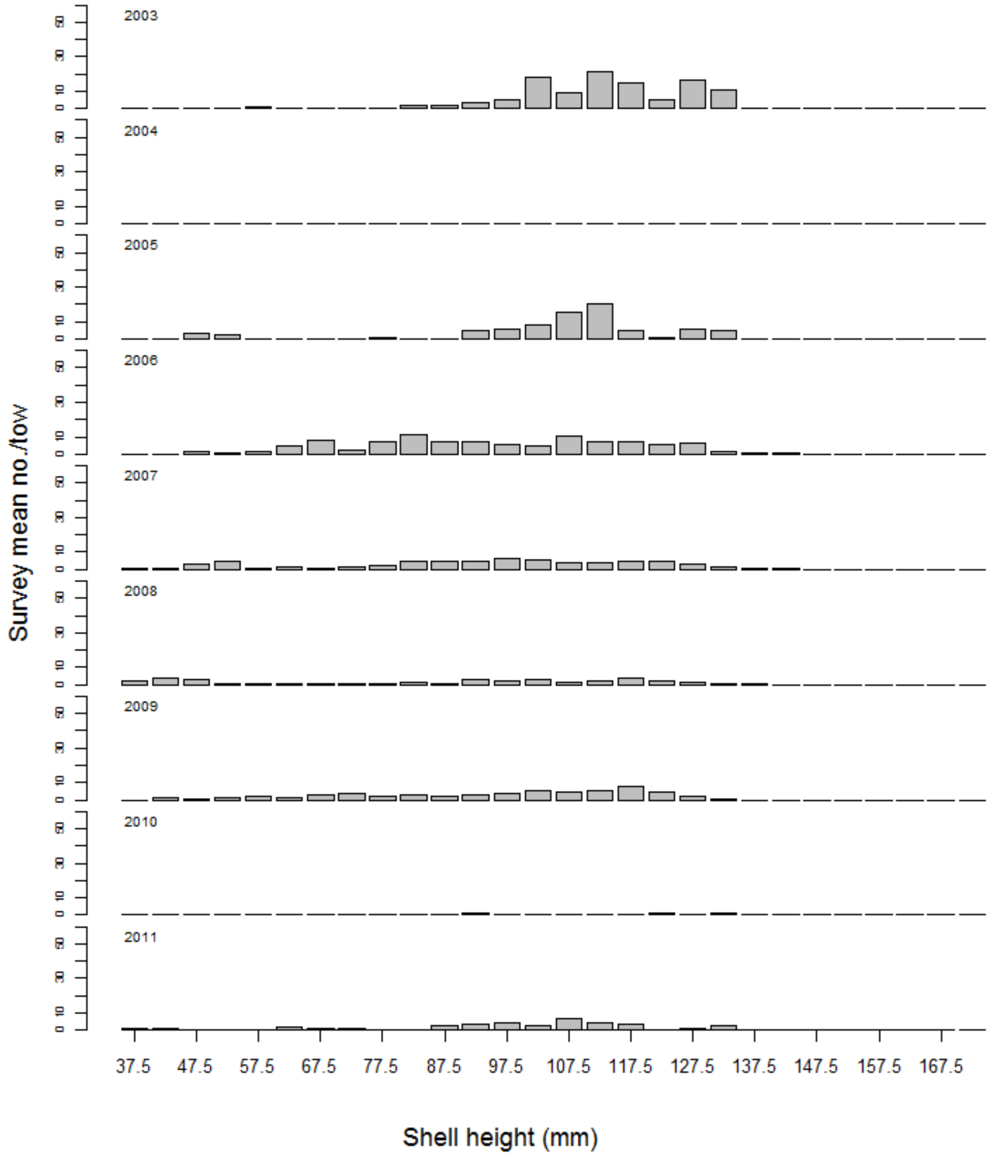

Figure 43. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Outer zone.

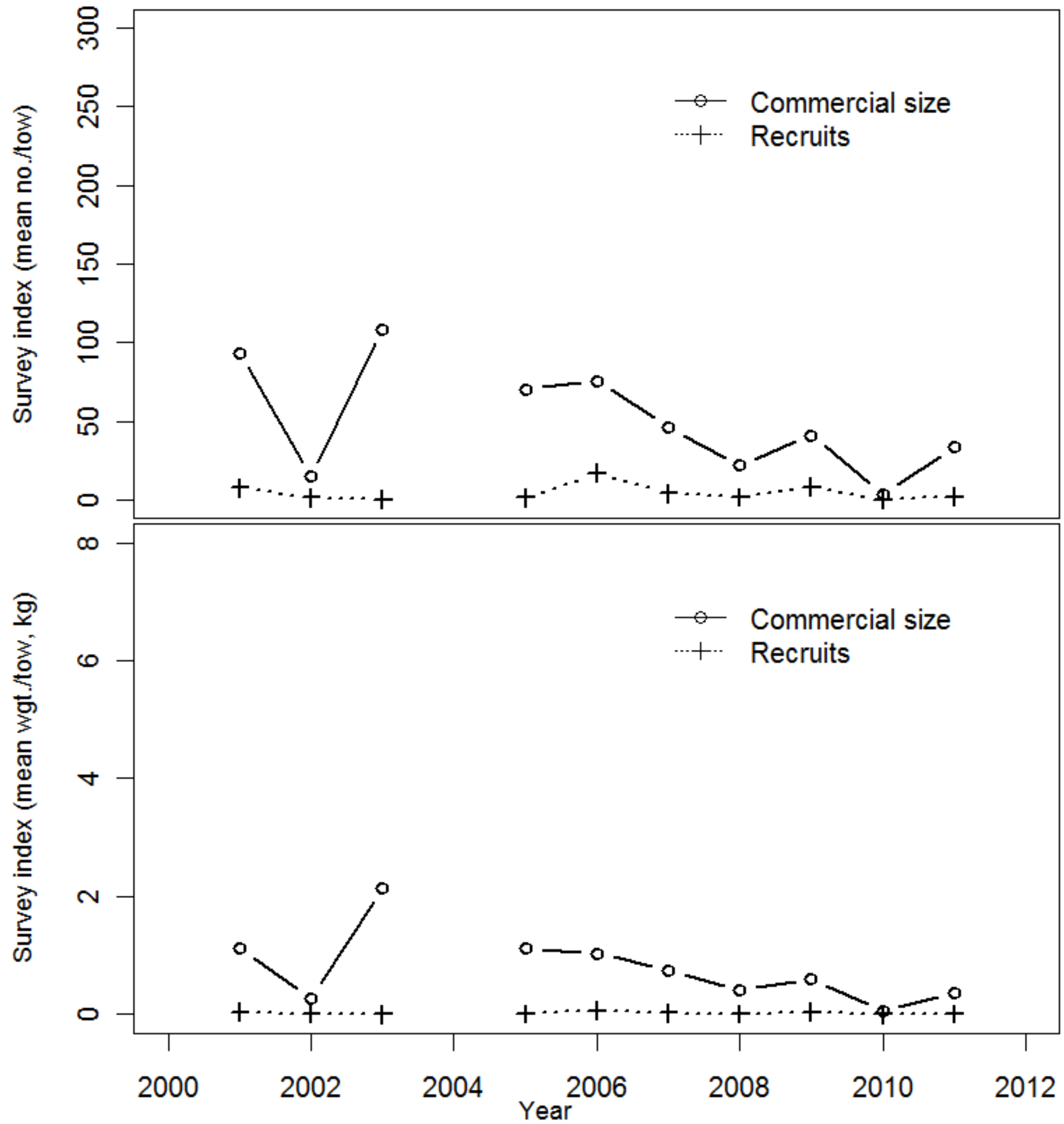

Figure 44. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Outer zone of Scallop Production Area 1B.

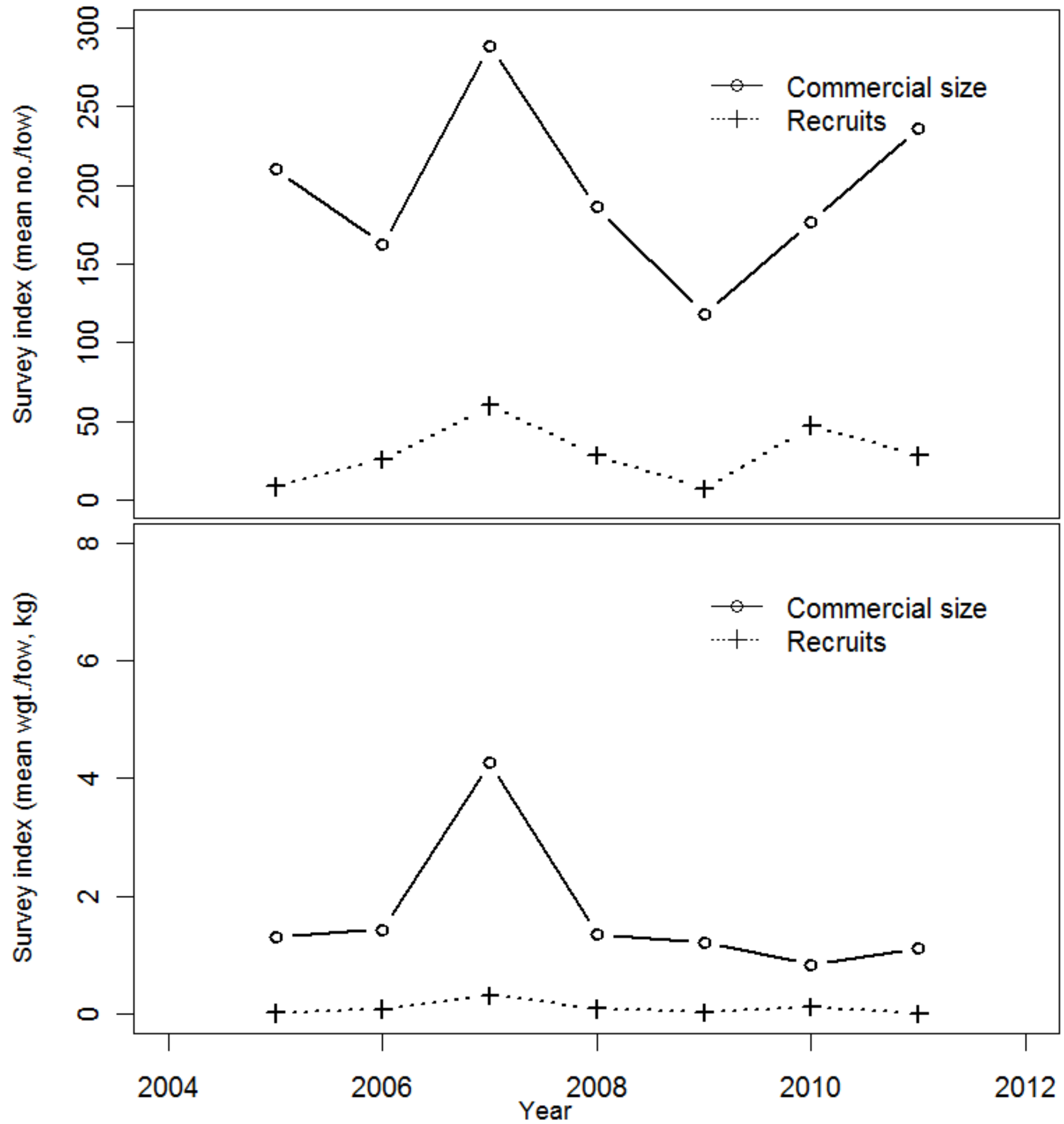

Figure 45. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Spencer Island zone of Scallop Production Area 1B.

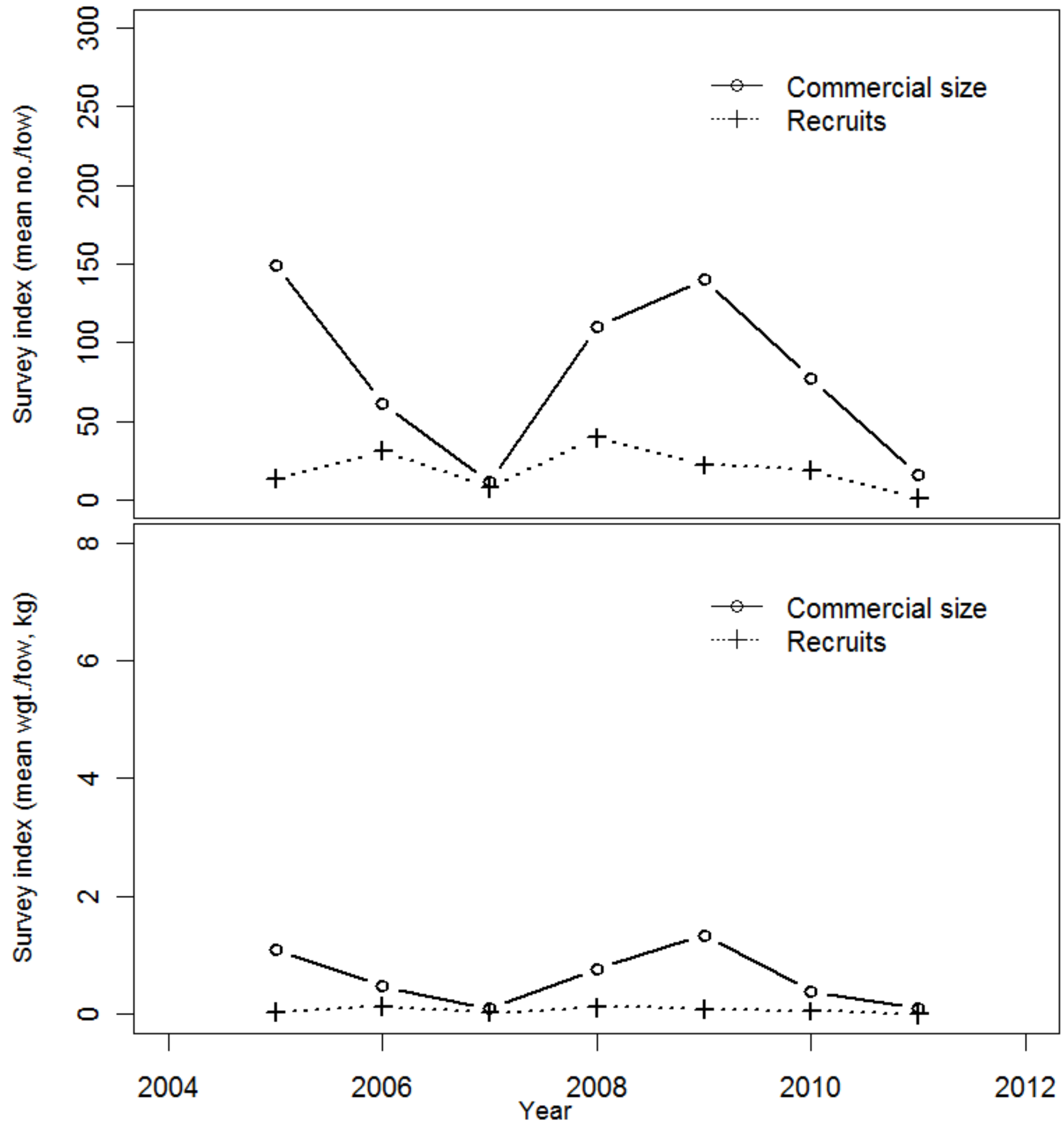

Figure 46. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Scots Bay zone of Scallop Production Area 1B.

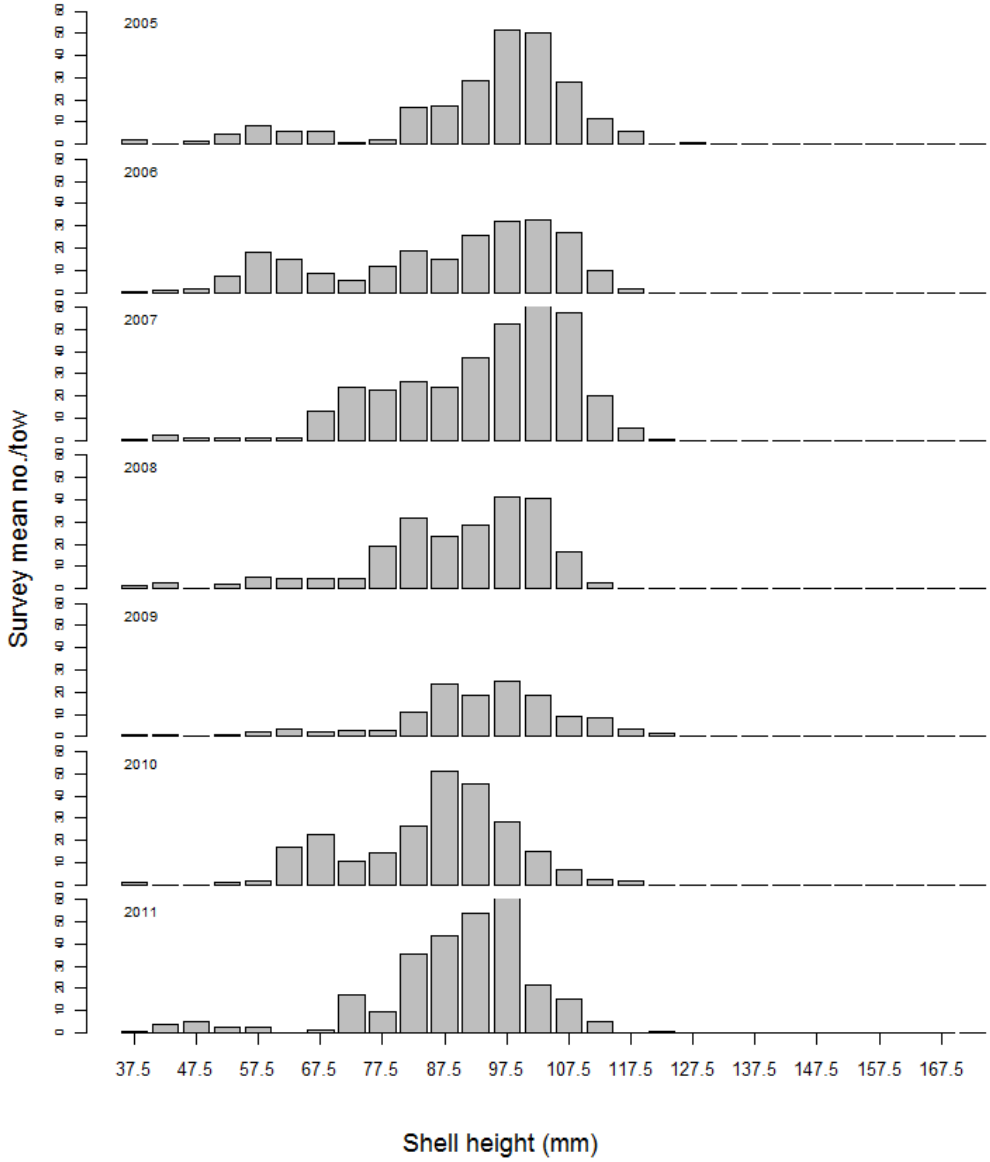

Figure 47. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Spencer Island zone.

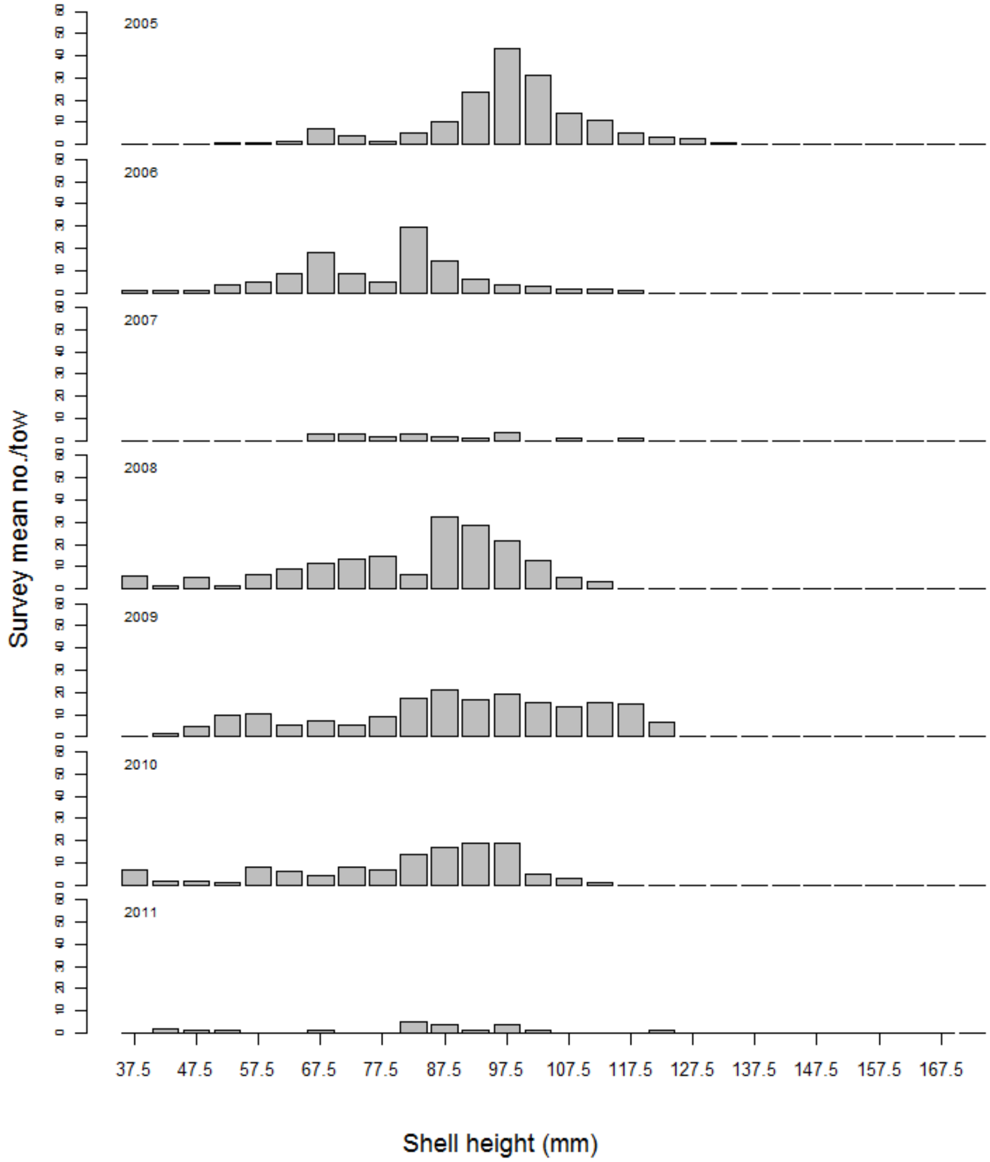

Figure 48. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 1B, Scots Bay zone.

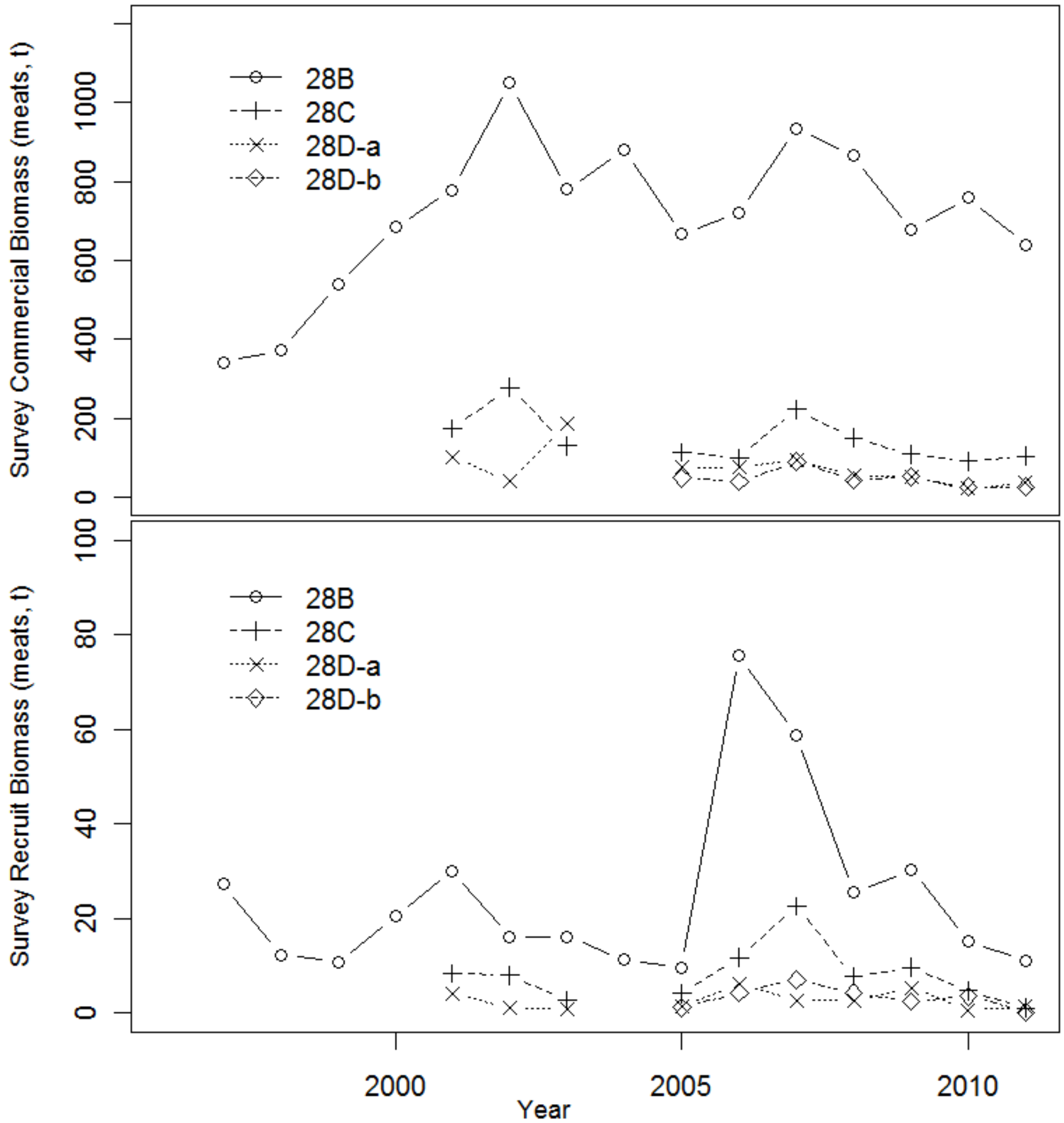

Figure 49. Survey biomass index (meats (t)) for Upper: commercial size (≥80 mm shell height) and Lower: recruit (65-79 mm), scallops in the Areas 28B (Cape Spencer+Middle Bay North), 28C, 28D-a (Advocate+Outer) and 28D-b (Spencers Island and Scots Bay) of Scallop Production Area 1B.

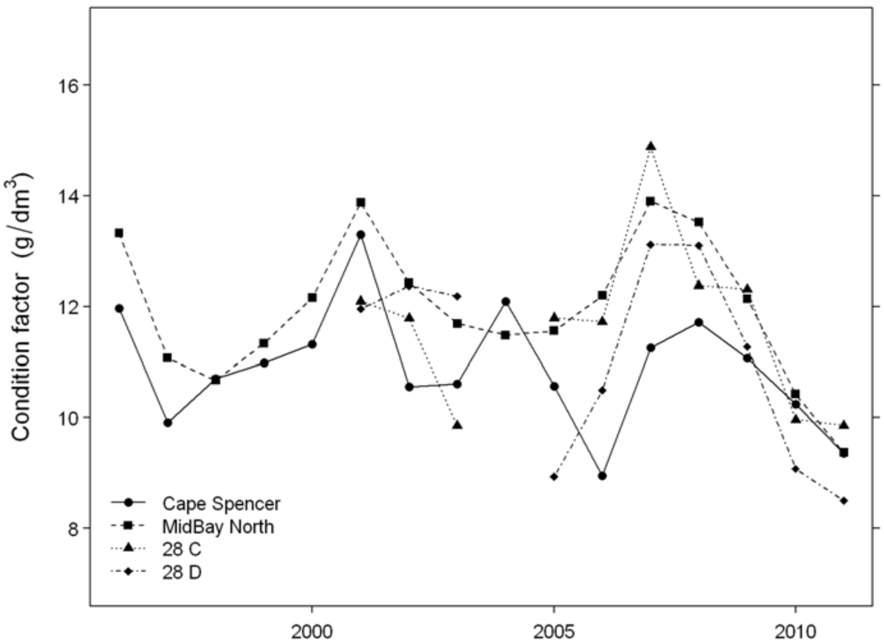

Figure 50. Annual trend in condition factor (CF) for scallops from the annual surveys of Scallop Production Area 1B.

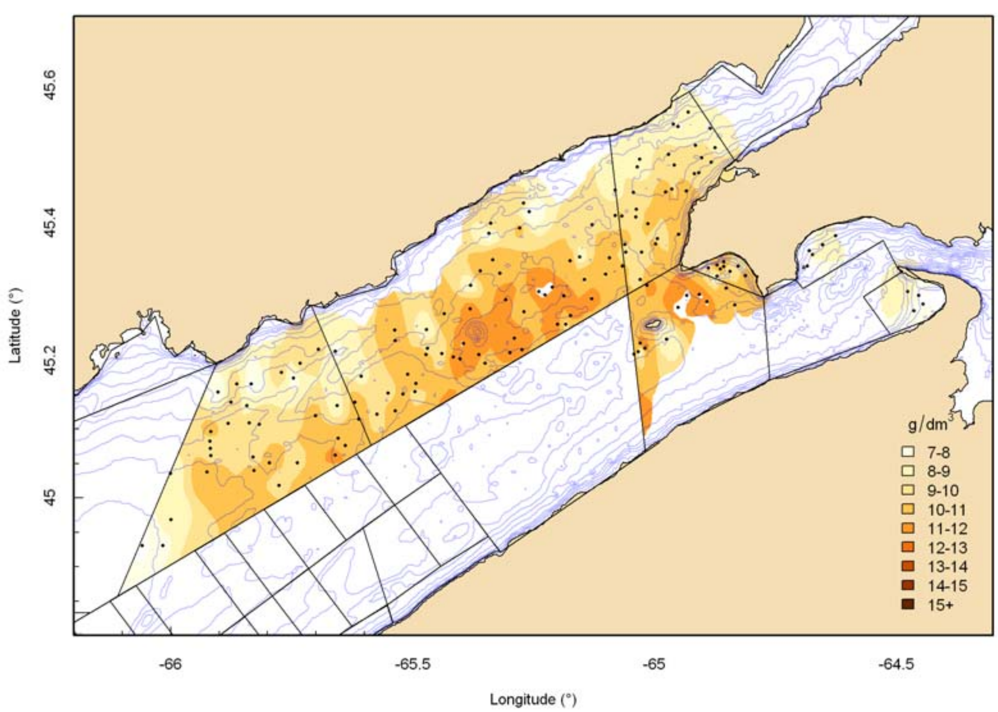

Figure 51. Spatial distribution of condition factor (g/dm^3) from the 2011 survey data for Scallop Production Area 1B.

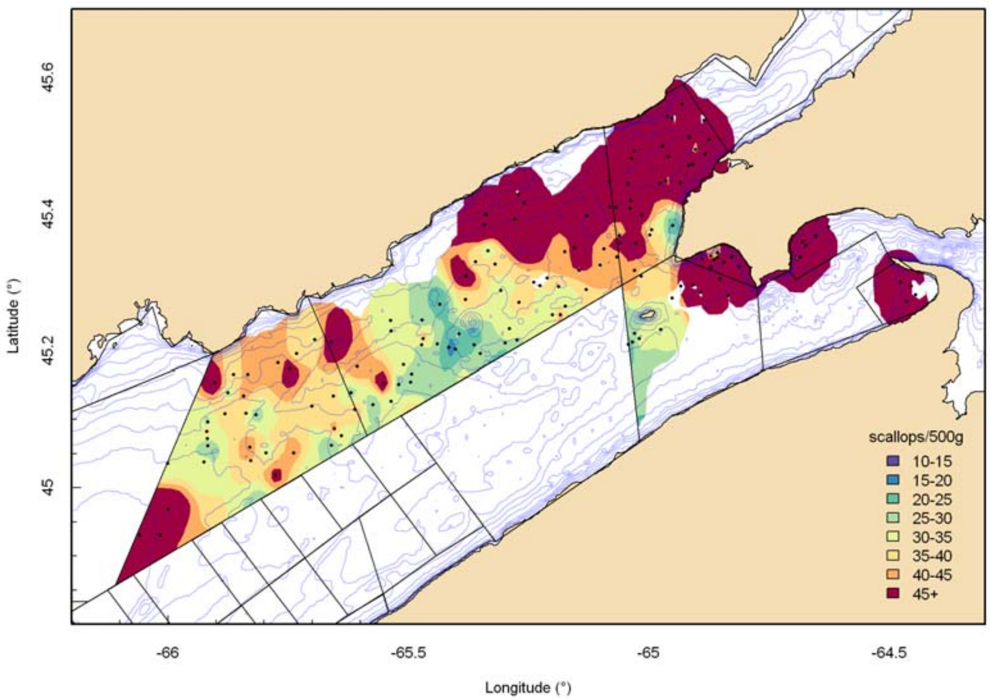

Figure 52. Spatial distribution of estimated meat count of commercial size (≥80 mm shell height) scallops from the survey of SPA 1B in 2011. Inverse distance weighted interpolation was used with the average meat weight of fully-recruited scallops for each tow to produce a contoured color image.

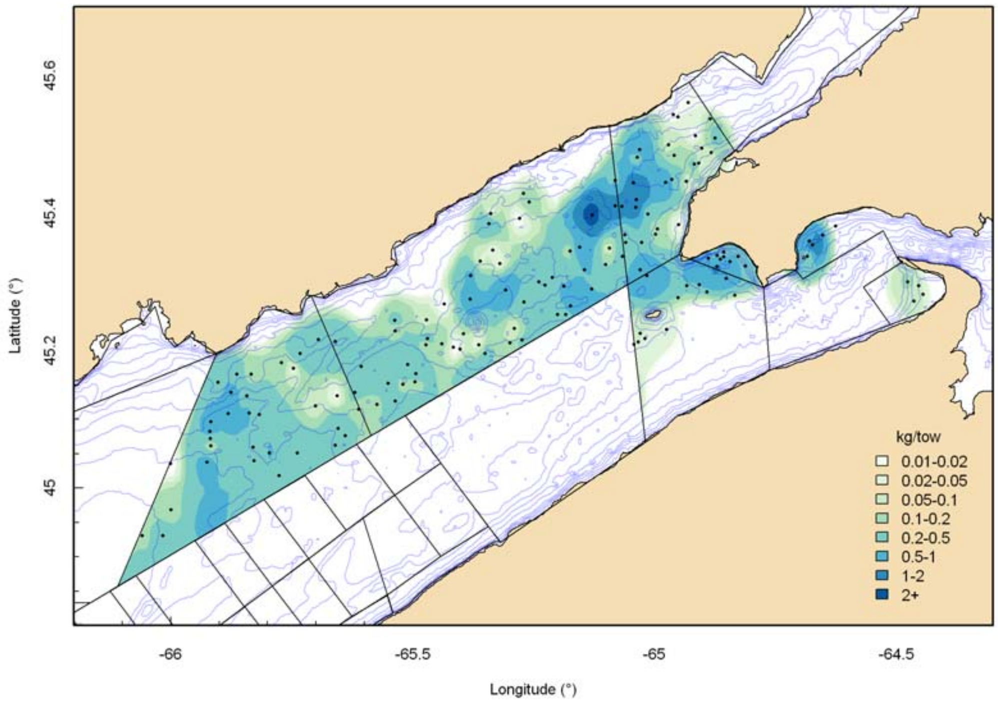

Figure 53. Spatial distribution of expected growth for 2011/2012 in biomass (meats) of commercial size (≥80 mm shell height) scallops from the survey of SPA 1B in 2011. Inverse distance weighted interpolation was used with the average expected growth of fully-recruited scallops for each tow to produce a contoured color image.

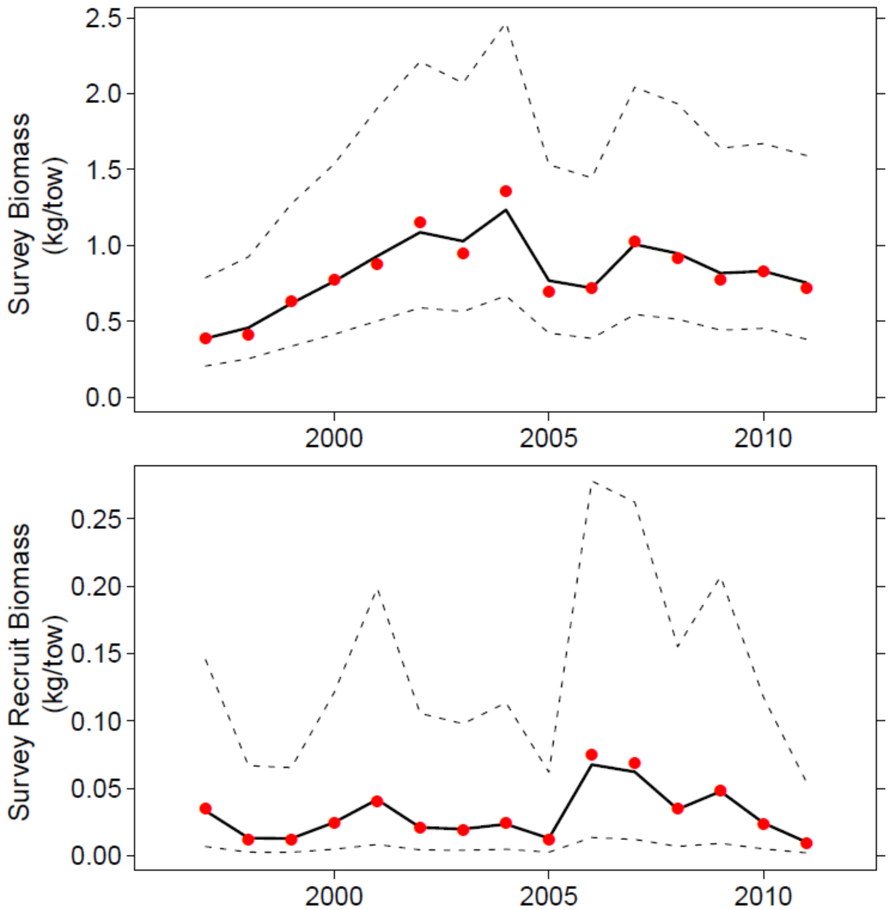

Figure 54. Posterior median fit to survey series for commercial size and recruit size scallops. Bayesian state-space delay-difference model for scallops in SPA 1B.

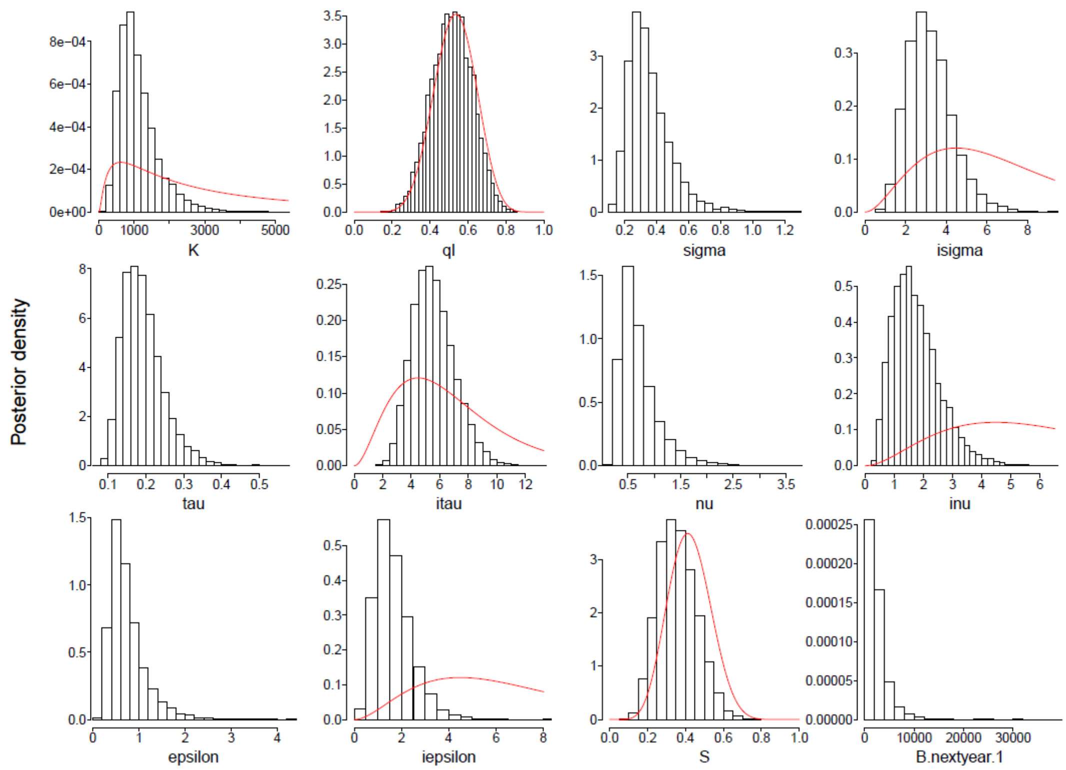

Figure 55. Comparison of prior and posterior densities. Bayesian state-space delay-difference model for scallops in SPA 1B.

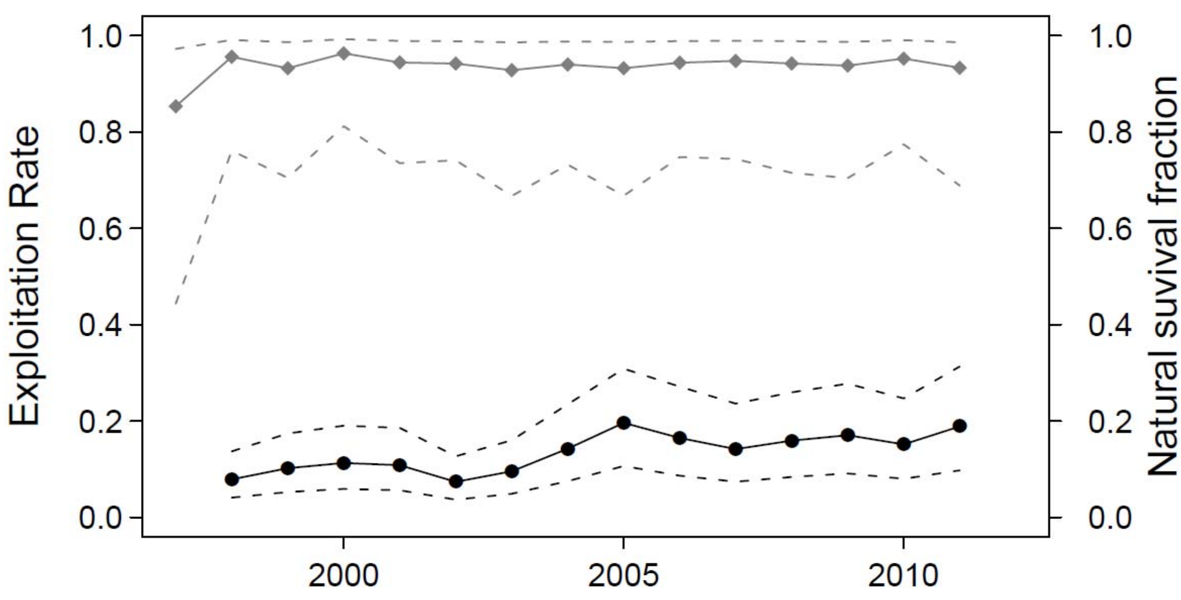

Figure 56. Annual trends in exploitation (solid line with filled circle) and survival estimates ($exp(-m)$), where m is natural mortality; solid line with filled triangles). Bayesian state-space delay-difference model for scallops in SPA 1B.

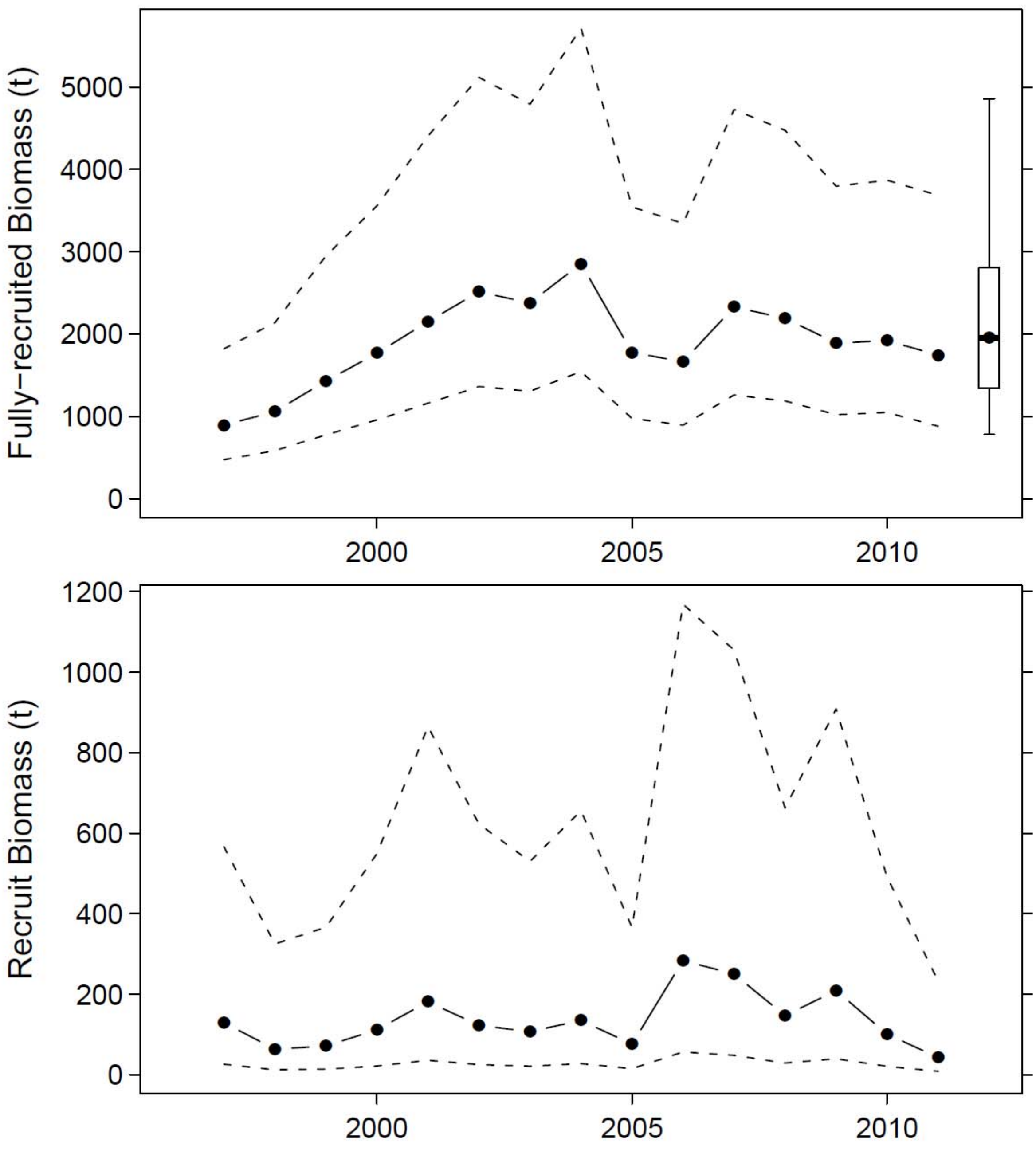

Figure 57. Biomass estimates for fully recruited scallops from the delay-difference model fit to the SPA 1B survey and commercial data. Dashed lines are the upper and lower 95% credible limits on the estimates and the dotted line represents the 25 year median. The predicted commercial size biomass for 2012, assuming the interim TAC, is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers).

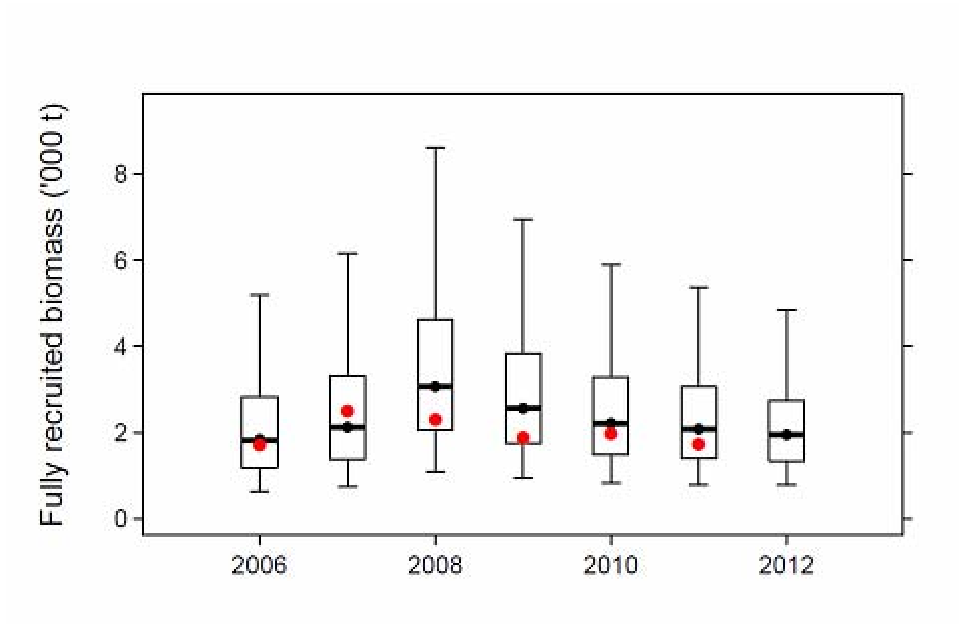

Figure 58. Evaluation of model projection performance. Box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year $t-1$ (e.g., 2006 prediction based on data up to 2005). Red dot represents the estimate of the biomass in year t using data up to and including year t. Bayesian state-space delay-difference model for scallops in SPA 1B

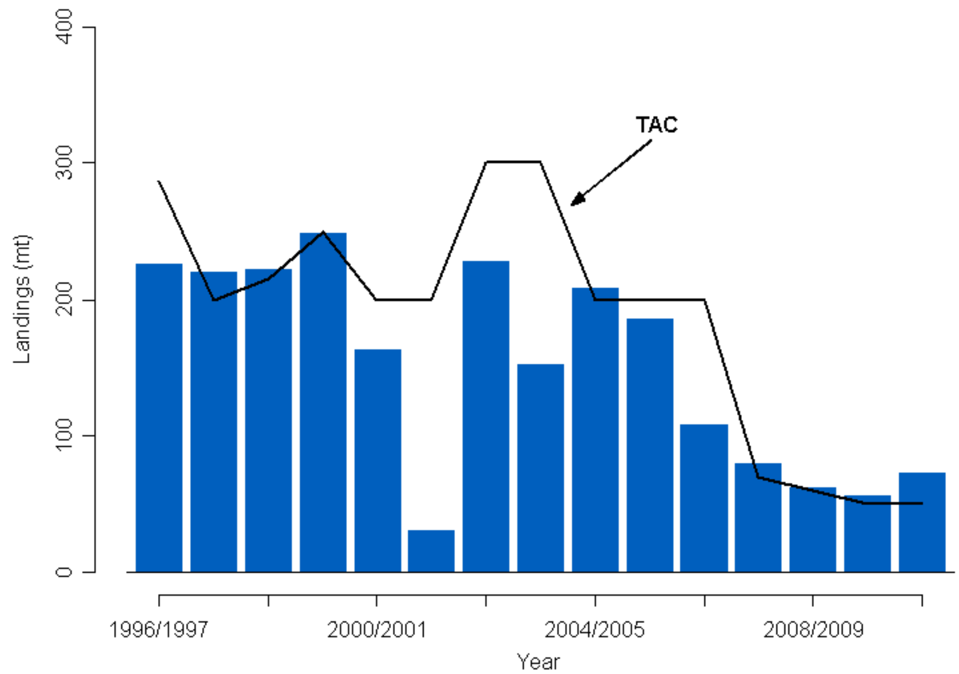

Figure 59. Scallop landings (meats, t) in Scallop Production Area 3 by the Full Bay Fleet.

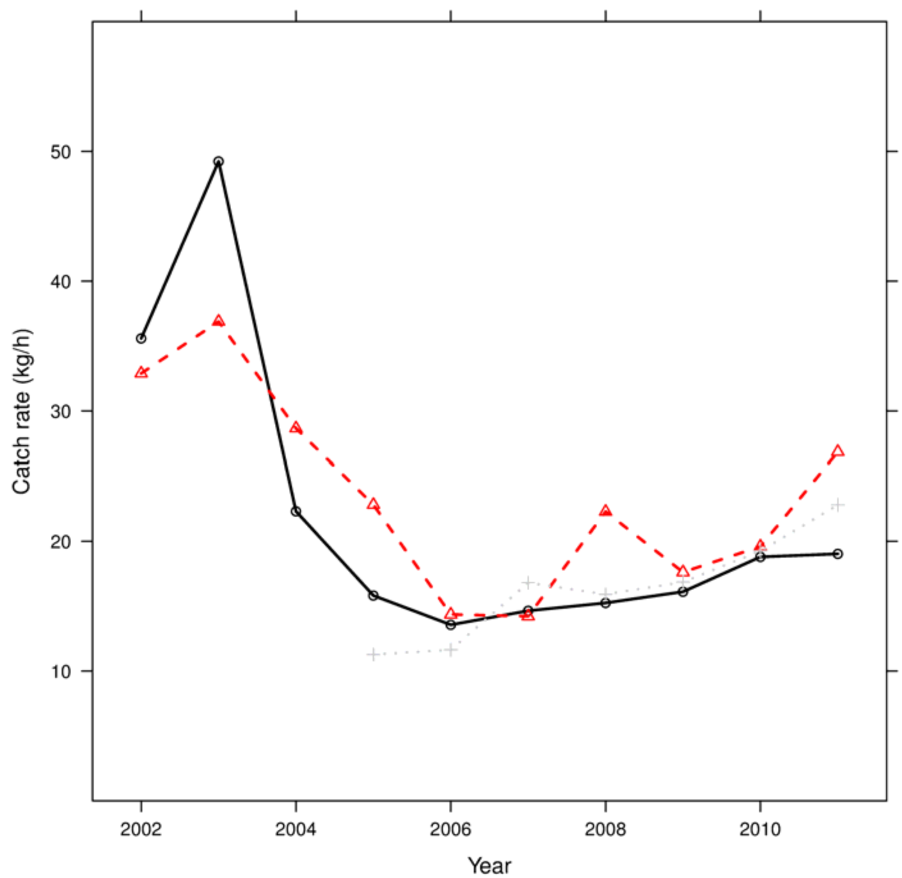

Figure 60. Commercial catch rates (kg/h) in Scallop Production Area 3 by the Full Bay Fleet. Catch rates given as Brier/Lurcher for summer fishery (black line, solid points), St. Mary's Bay (red dashed line, triangles) and October fishery in Brier/Lurcher (grey dotted line, crosses).

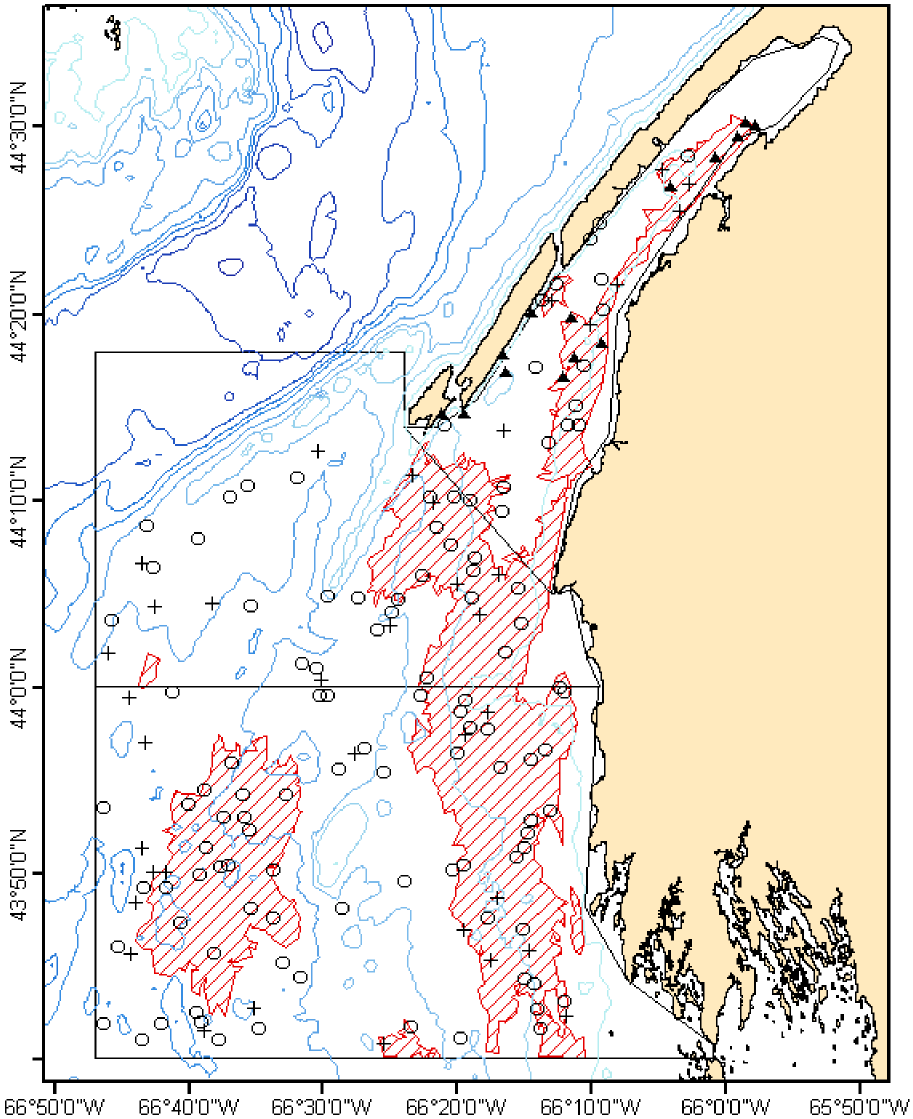

Figure 61. Polygon boundaries (red) are from the mean VMS “fishing” intensity from 2002 to 2010 for SPA 3, with a threshold of above 2 km per km^2. Survey positions for 2011 indicated. Circles represent random stations, crosses represent positions from the 2010 survey that were sampled again in 2011 and triangles indicate exploratory stations.

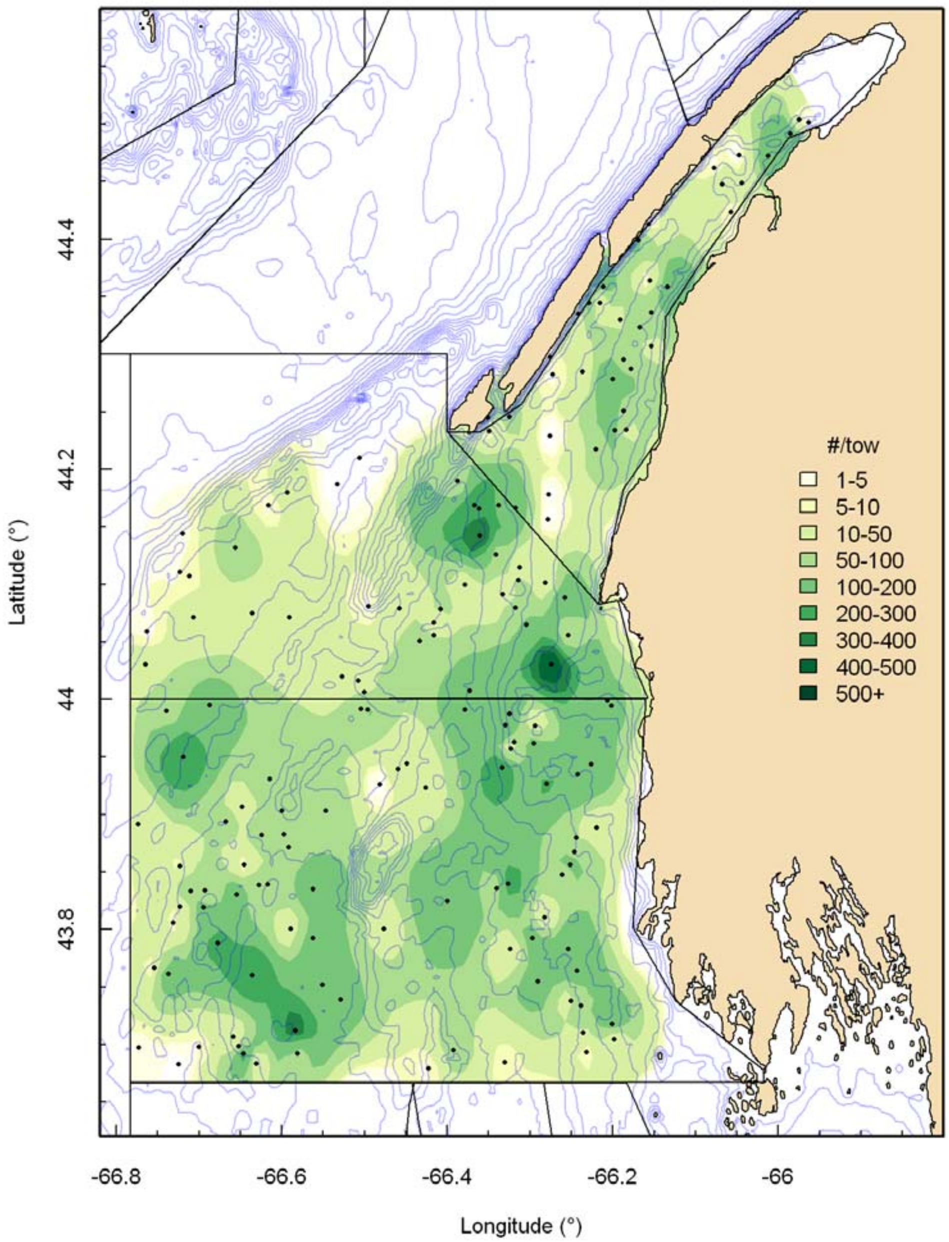

Figure 62. Spatial density (no./tow) distribution for commercial size scallops in Scallop Production Area (SPA) 3 from 2011 survey data.

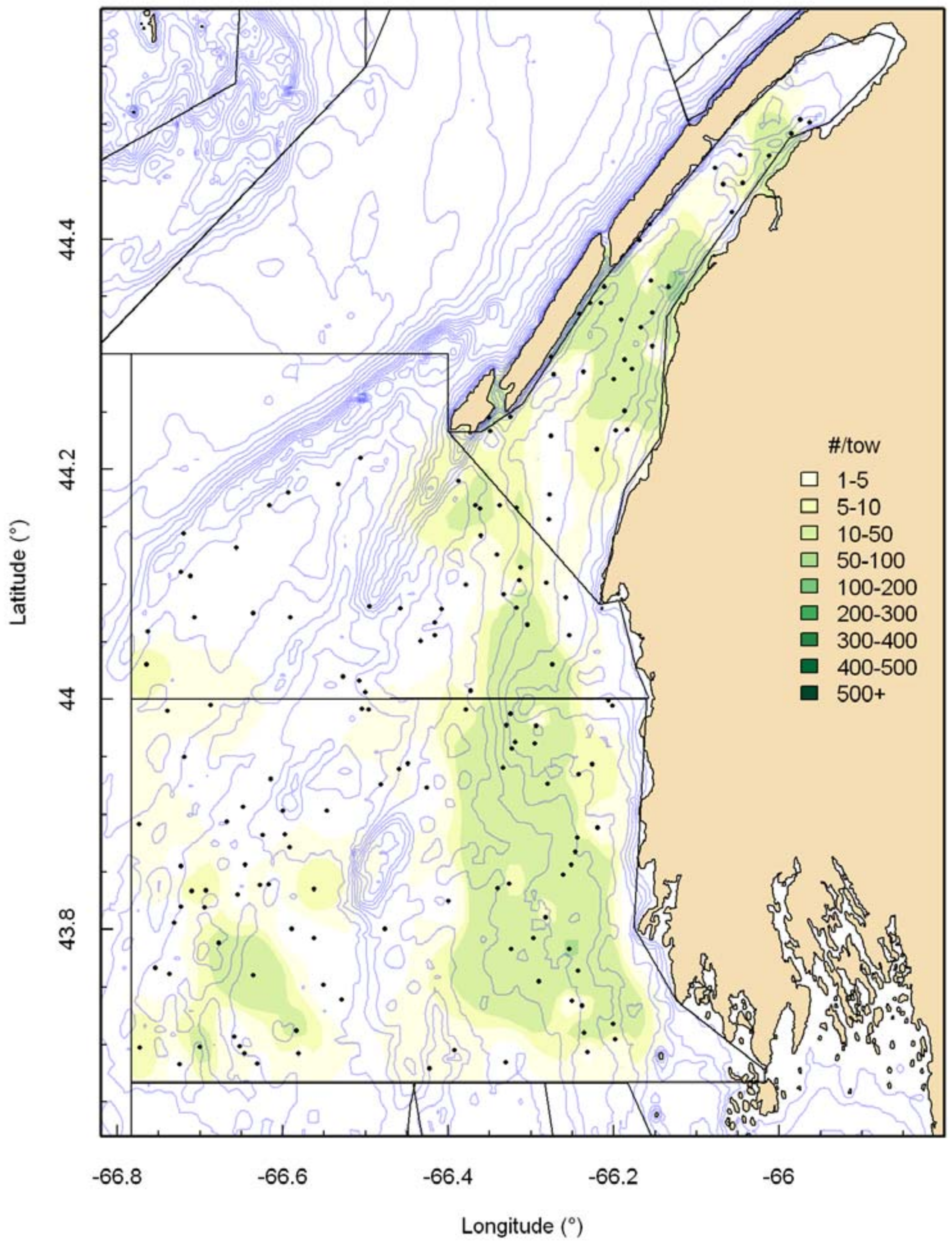

Figure 63. Spatial density (no./tow) distribution for recruit size scallops in Scallop Production Area (SPA) 3 from 2011 survey data.

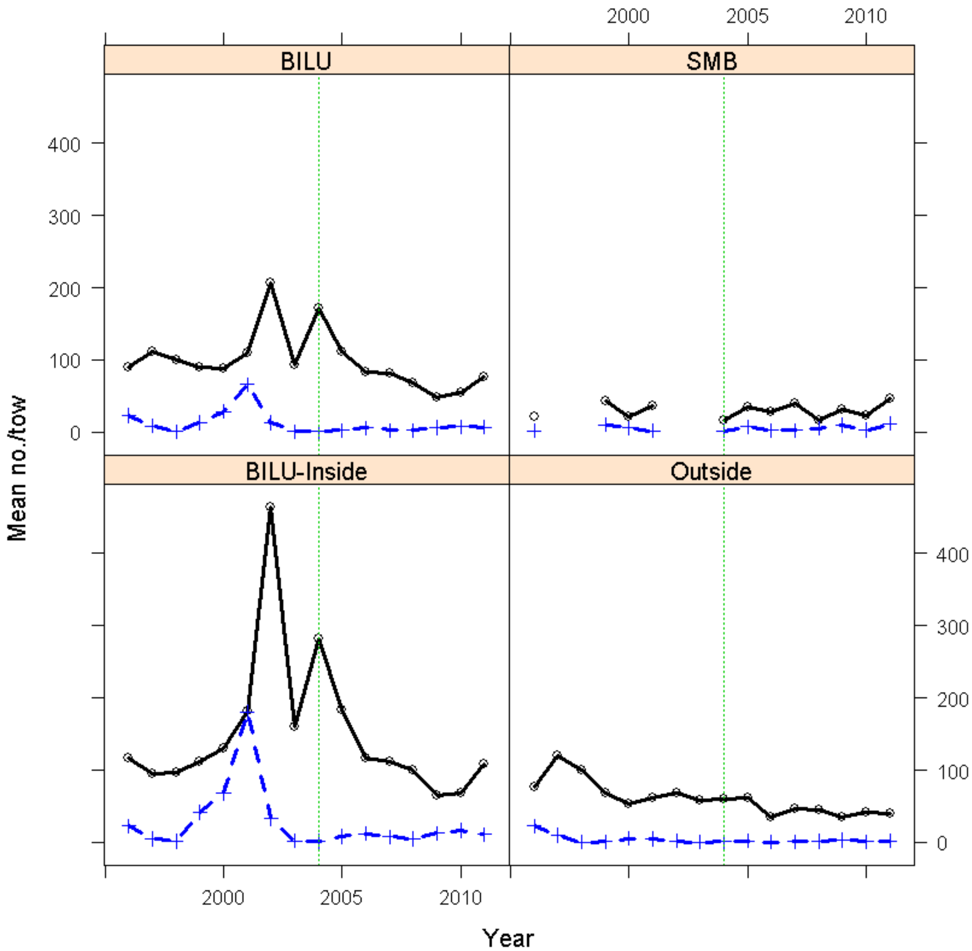

Figure 64. Survey trends for commercial size (≥80 mm shell height, black solid line) and recruits (65-79 mm, blue dashed line) mean number per tow for scallops from annual survey in SPA 3. SMB = St. Marys Bay, BILU = Brier/Lurcher area outside of St. Marys Bay, BILU-Inside = area within red polygons in Fig. 60 in the Brier/Lurcher area, Outside = area outside of red polygons in Fig. 60. Vertical dotted line indicates survey in 2004. Previous to 2004 surveys were conducted in August and have been in June from 2004 to the present.

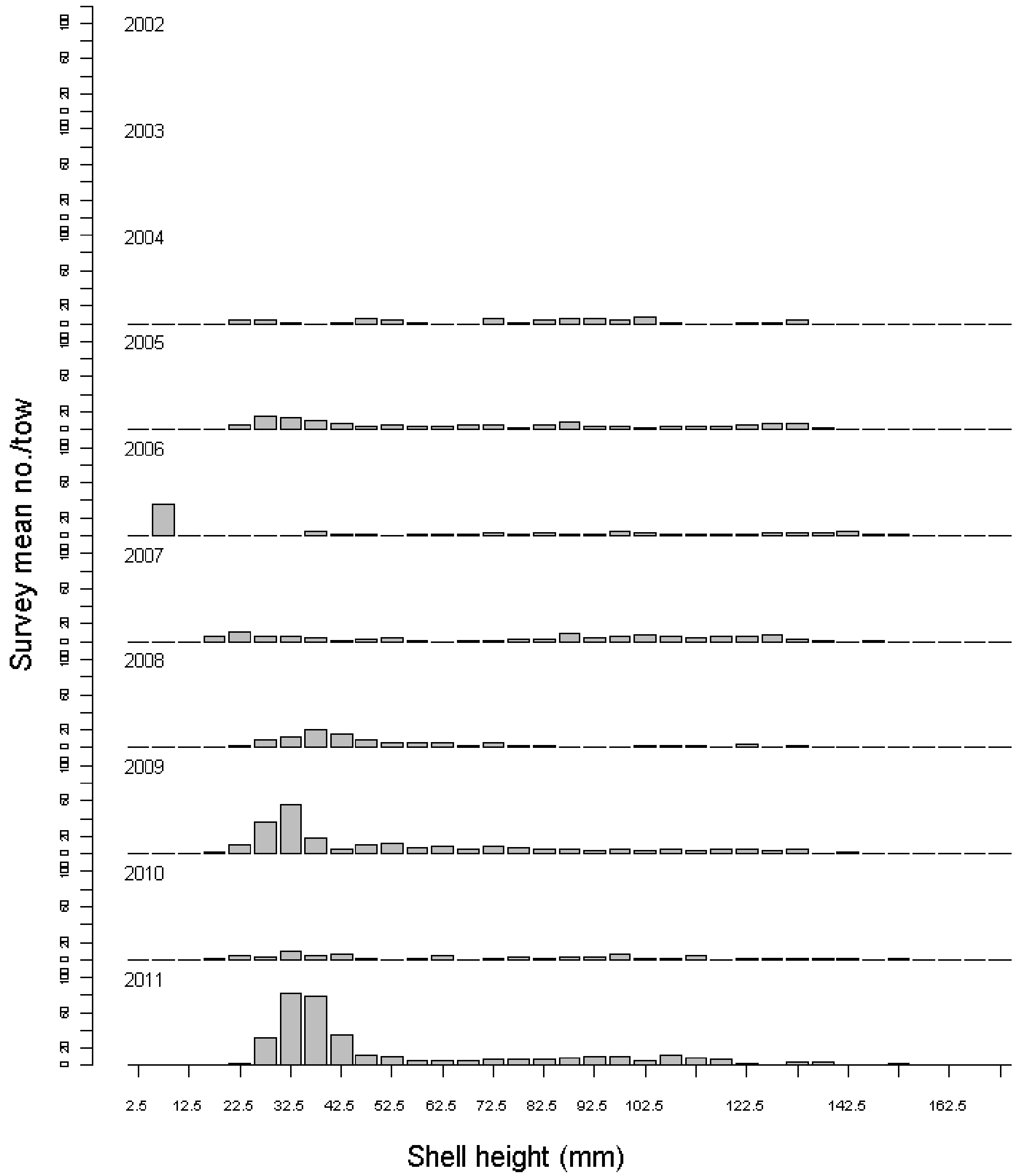

Figure 65. Scallop shell height frequencies (mean number/tow) from the annual surveys of Scallop Production Area 3. Estimates for tows within St. Marys Bay.

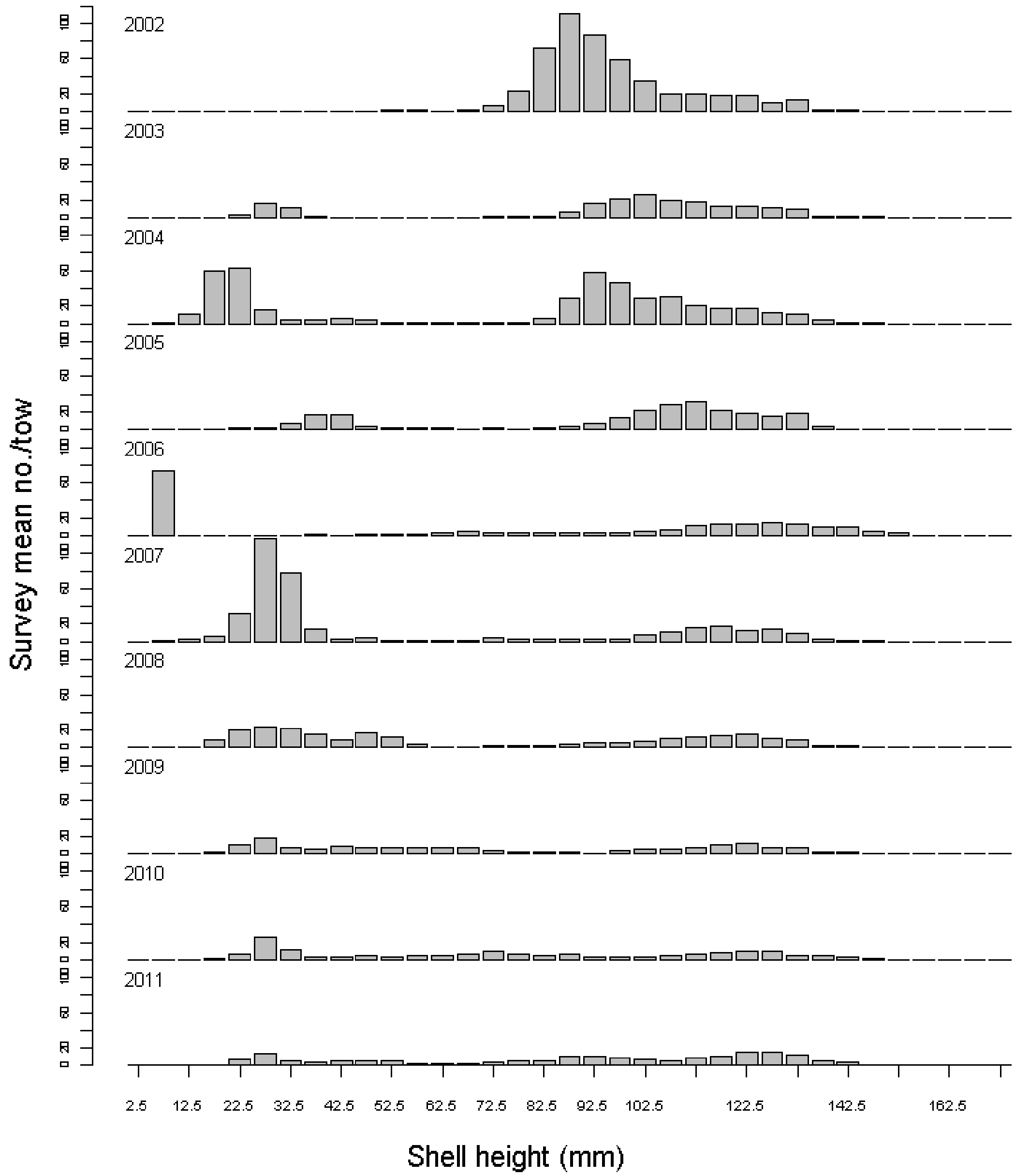

Figure 66. Scallop shell height frequencies (mean number/tow) from the annual surveys of Scallop Production Area 3. Estimates for tows within the VMS area (Fig. 60) in the Brier/Lurcher area.

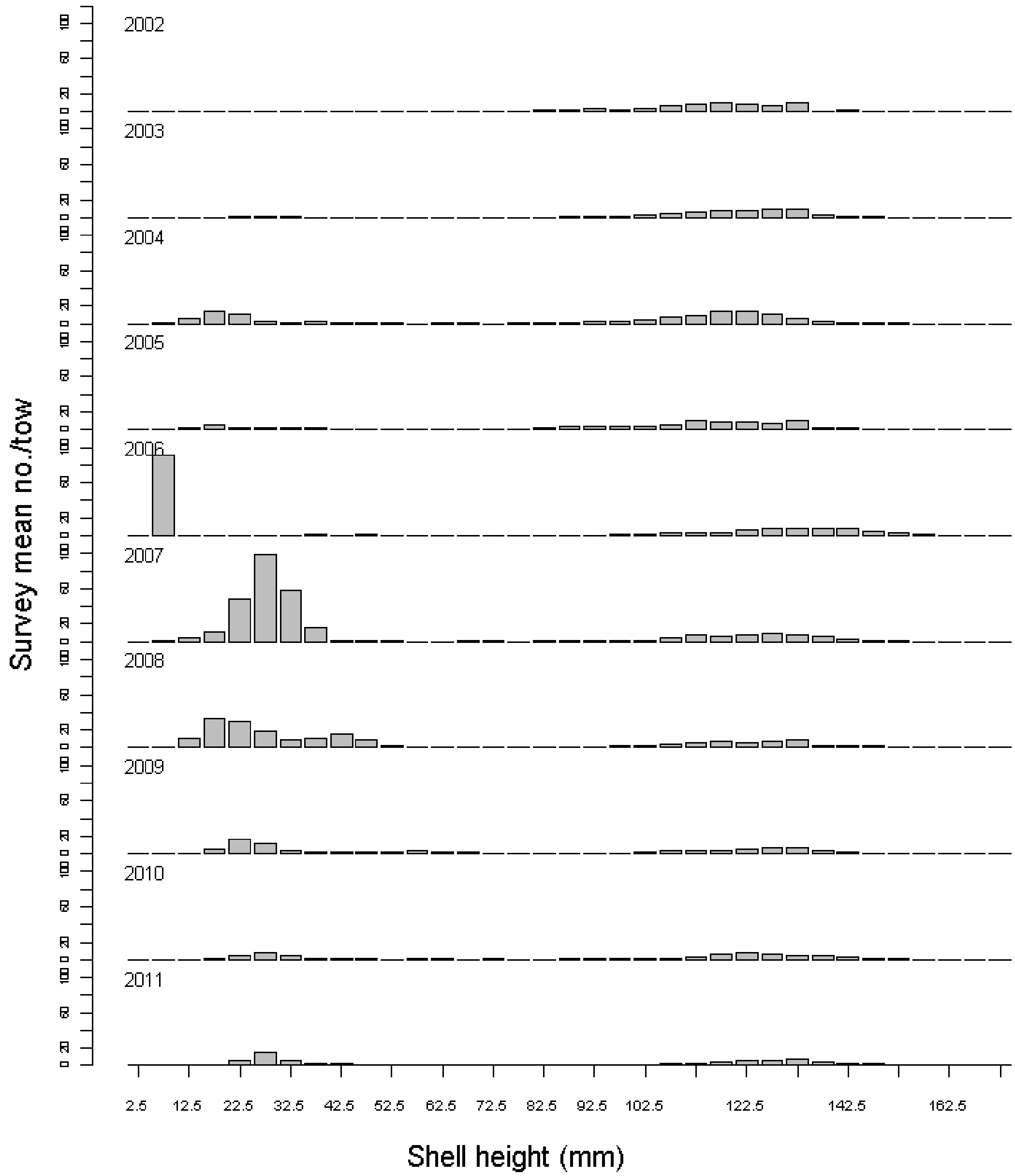

Figure 67. Scallop shell height frequencies (mean number/tow) from the annual surveys of Scallop Production Area 3. Estimates for tows outside the VMS area (Fig. 60) in the Brier/Lurcher area.

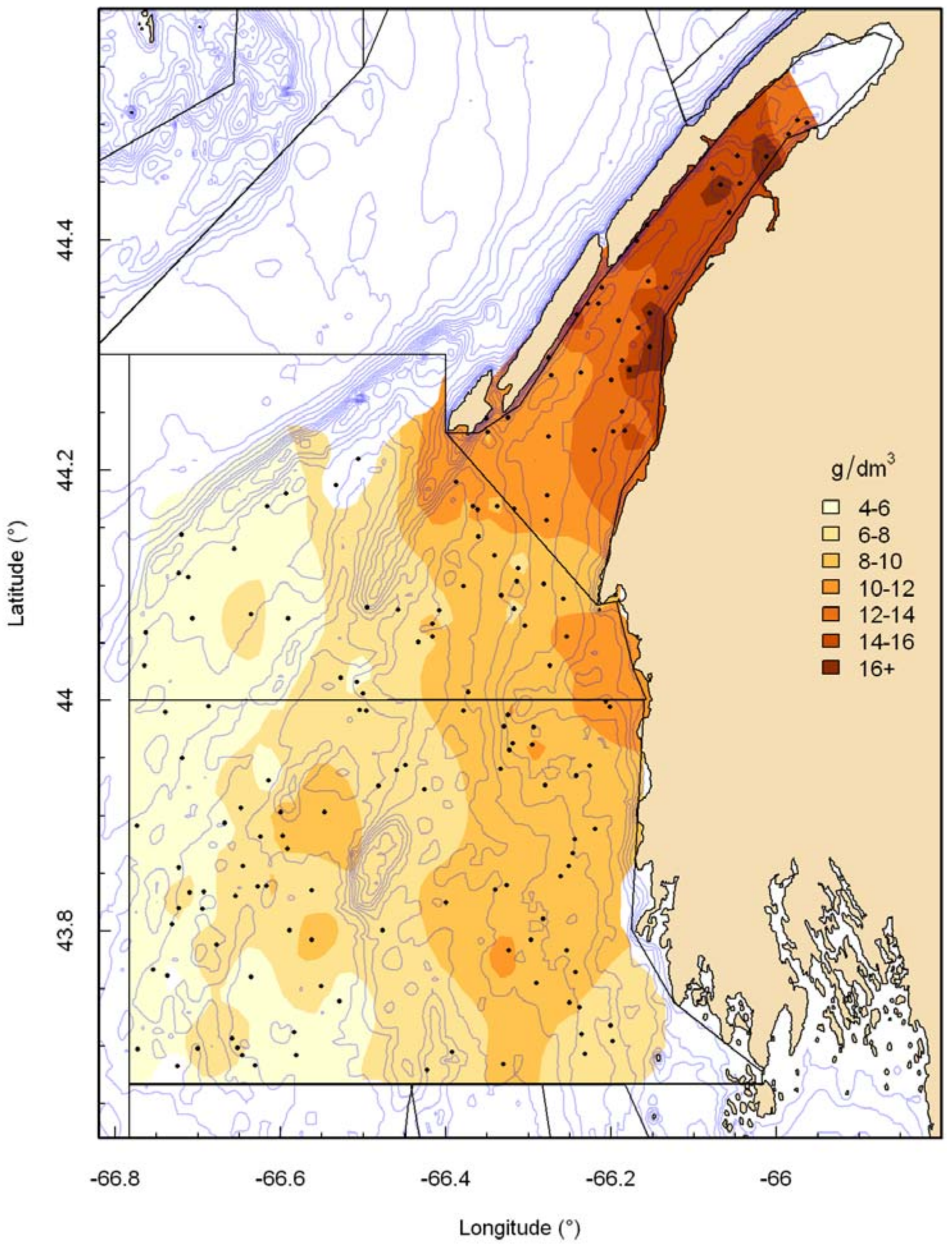

Figure 68. Spatial distribution of condition factor (g/dm^3) from the 2011 survey data for Scallop Production Area (SPA) 3.

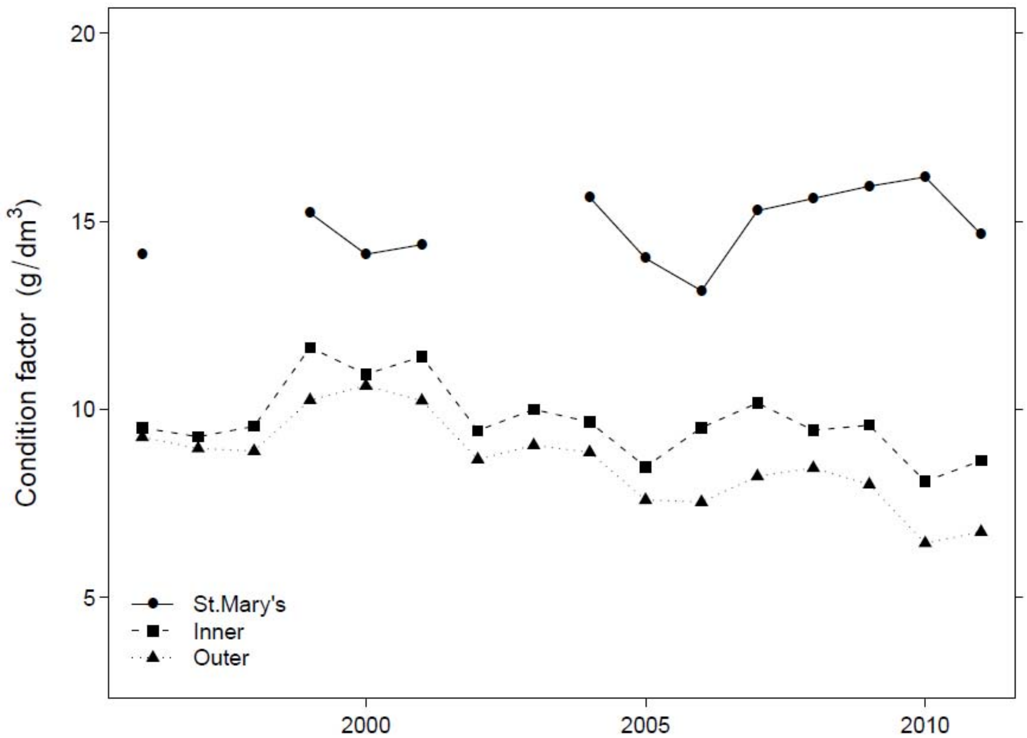

Figure 69. Annual trend in condition factor (CF) for scallops from the annual surveys of Scallop Production Area 3. Estimates for tows in St. Mary's Bay, within and outside of the VMS area (Fig. 60) in the Brier/Lurcher area. Y-axis gives condition factor relative to the meat weight of a scallop with shell height of 100 mm.

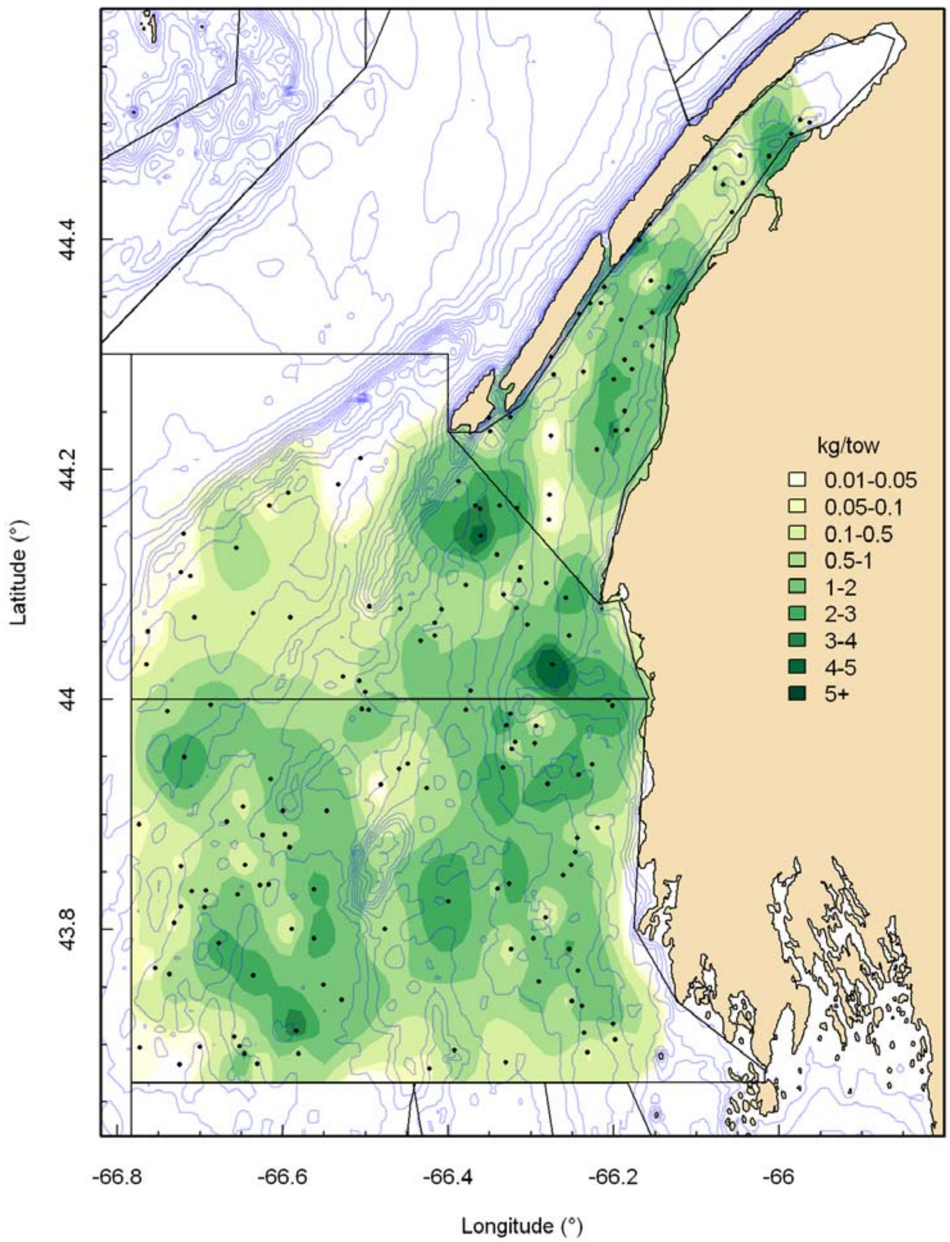

Figure 70. Spatial density (kg/tow) distribution of biomass from the 2011 survey data for Scallop Production Area 3.

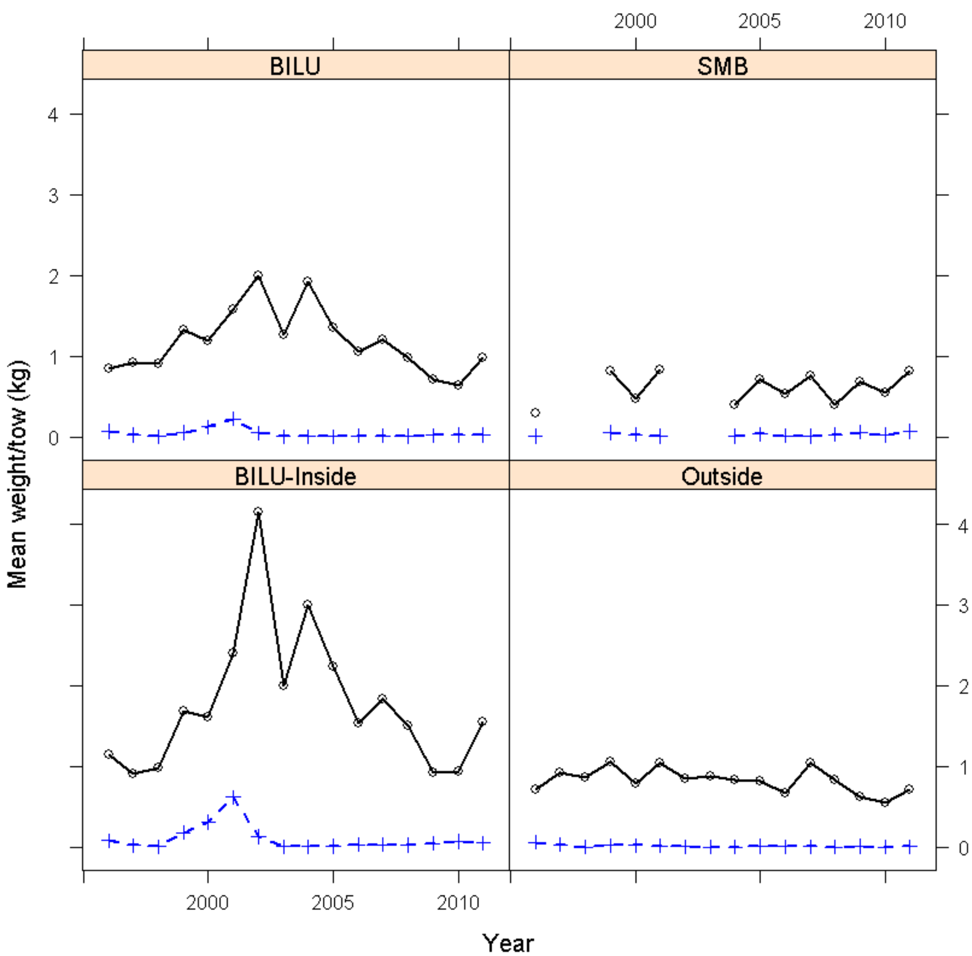

Figure 71. Survey trends for commercial size (≥80 mm shell height, black solid line) and recruits (65-79 mm, blue dashed line) mean weight per tow for scallops from annual survey in SPA 3. SMB = St. Marys Bay, BILU = Brier/Lurcher area outside of St. Marys Bay, BILU-Inside = area within red polygons in Fig. 60 in the Brier/Lurcher area, Outside = area outside of red polygons in Fig. 60. Vertical dotted line indicates survey in 2004. Previous to 2004 surveys were conducted in August and have been in June from 2004 to the present.

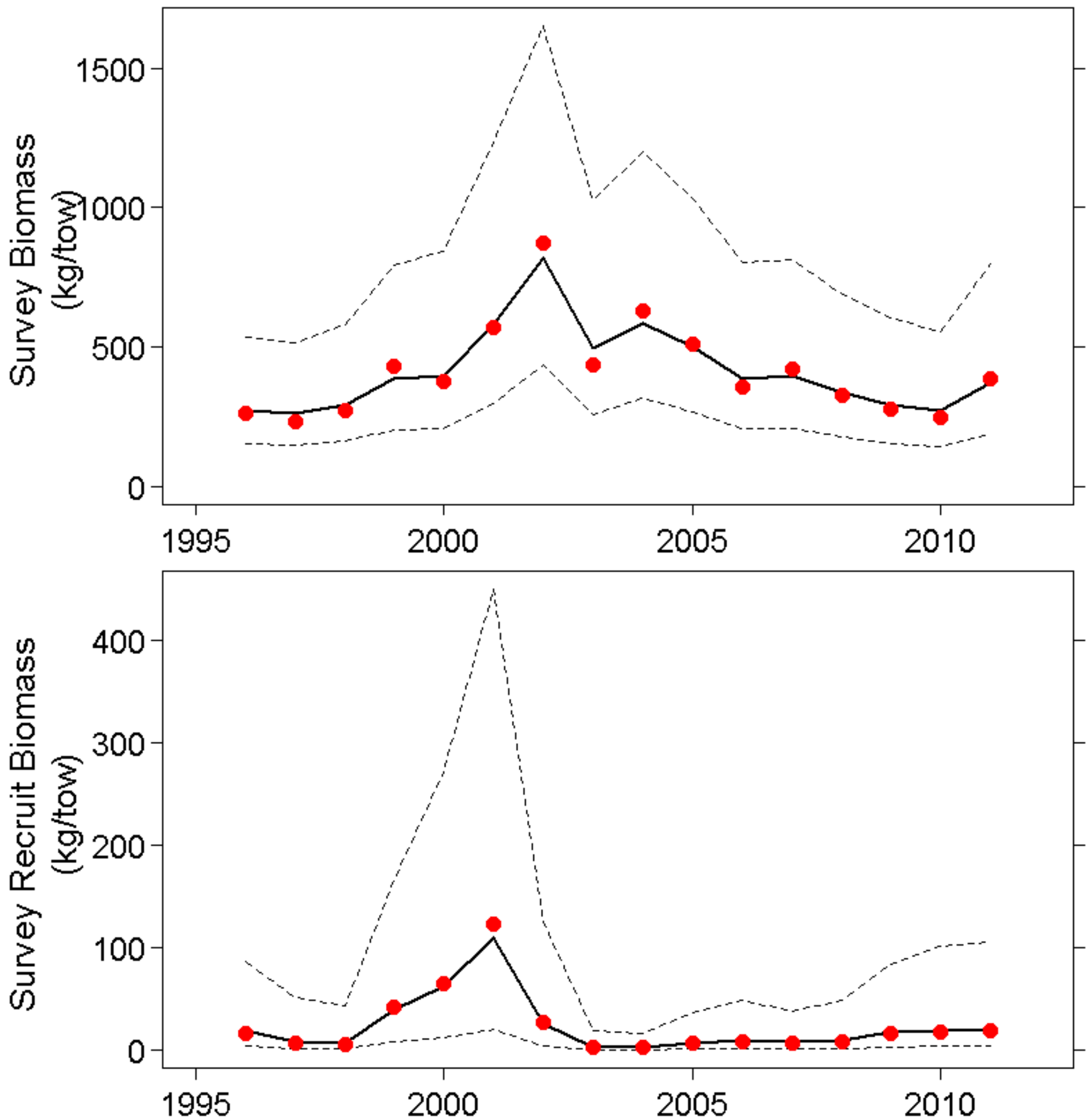

Figure 72. Posterior median fit to survey series for commercial size and recruit size scallops. Bayesian state-space delay-difference model for scallops in SPA 3.

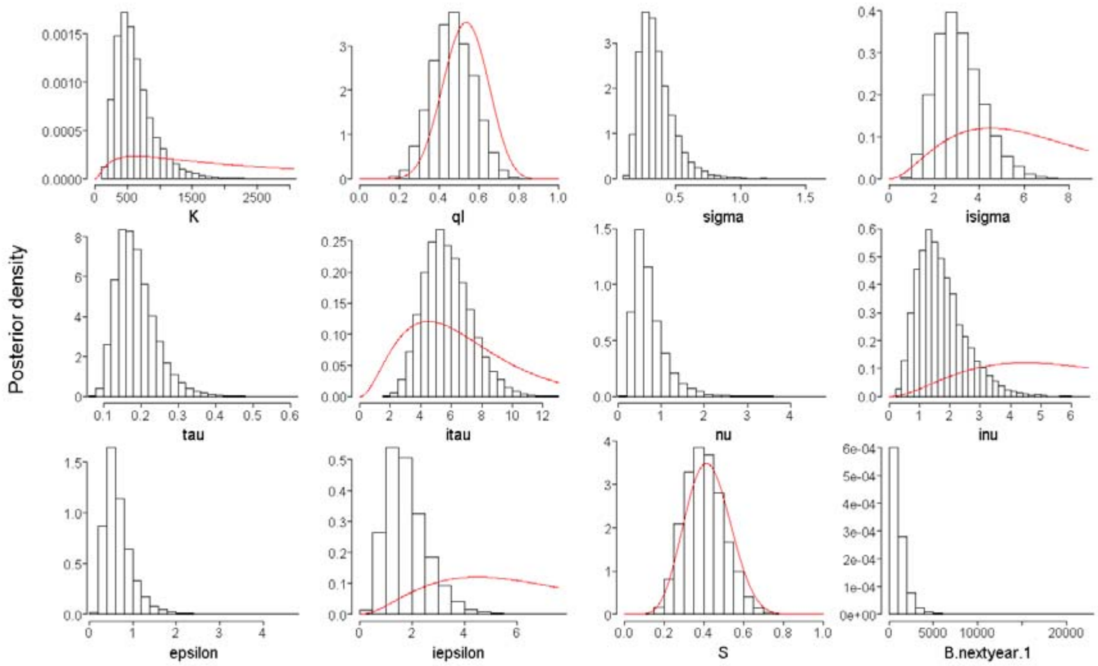

Figure 73. Comparison of prior and posterior densities. Bayesian state-space delay-difference model for scallops in SPA 3.

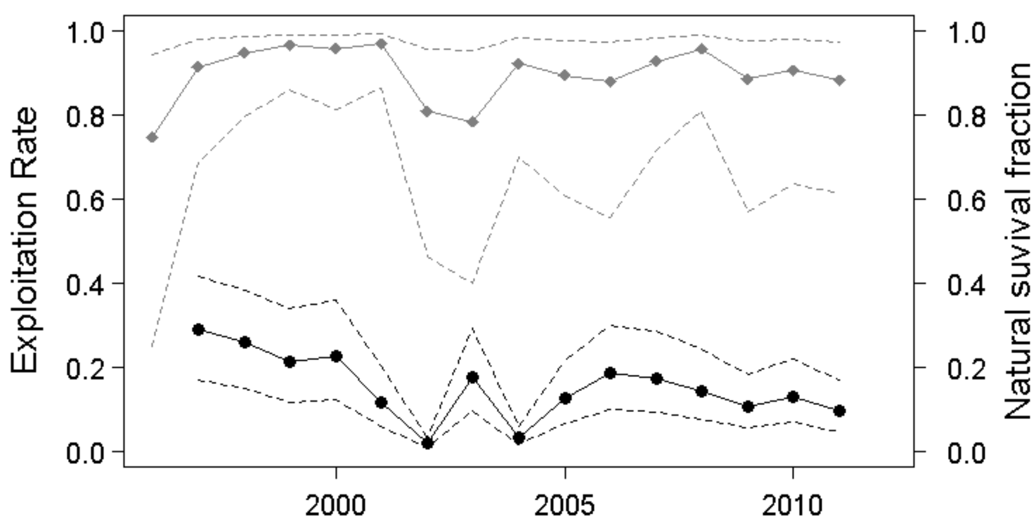

Figure 74. Annual trends in exploitation (solid line with filled circle) and survival estimates (exp(–m)), where m is natural mortality; solid line with filled triangles). Bayesian state-space delay-difference model for scallops in SPA 3.

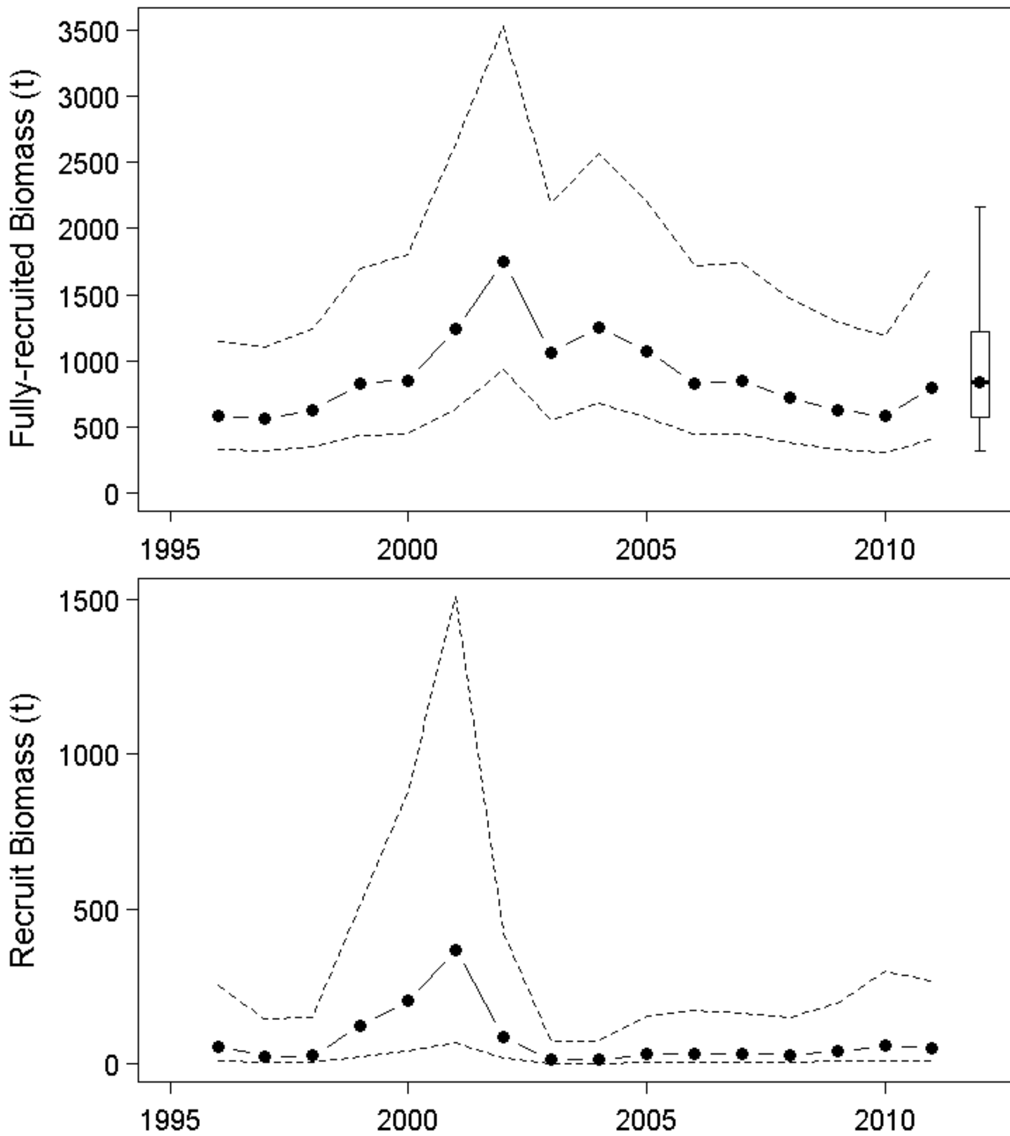

Figure 75. Biomass estimates for fully recruited scallops from the delay-difference model fit to the SPA 3 survey and commercial data. Dashed lines are the upper and lower 95% credible limits on the estimates and the dotted line represents the 25 year median. The predicted commercial size biomass for 2012, assuming the interim TAC, is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers).

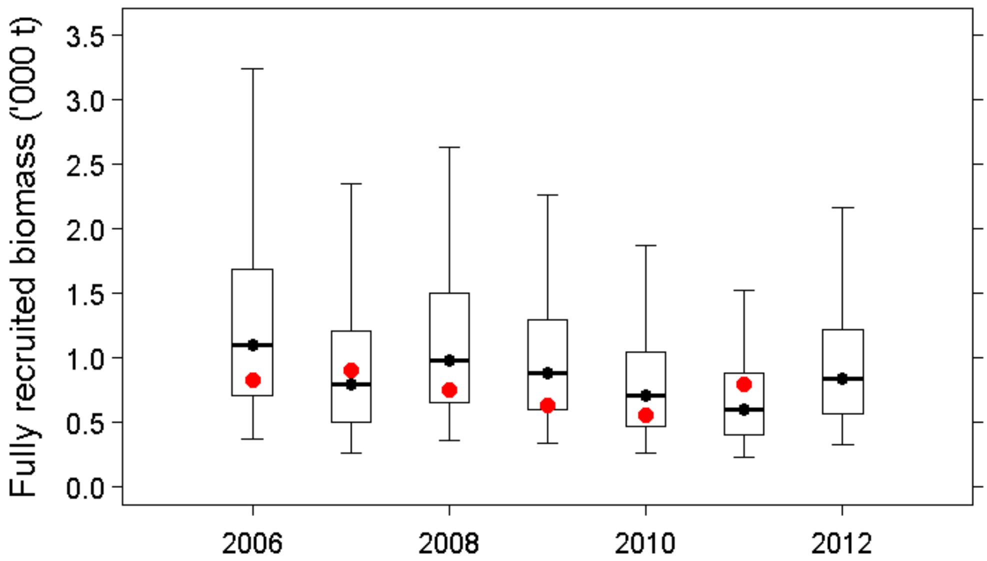

Figure 76. Evaluation of model projection performance. Box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year $t-1$ (e.g., 2006 prediction based on data up to 2005). Red dot represents the estimate of the biomass in year t using data up to and including year t. Bayesian state-space delay-difference model for scallops in SPA 3

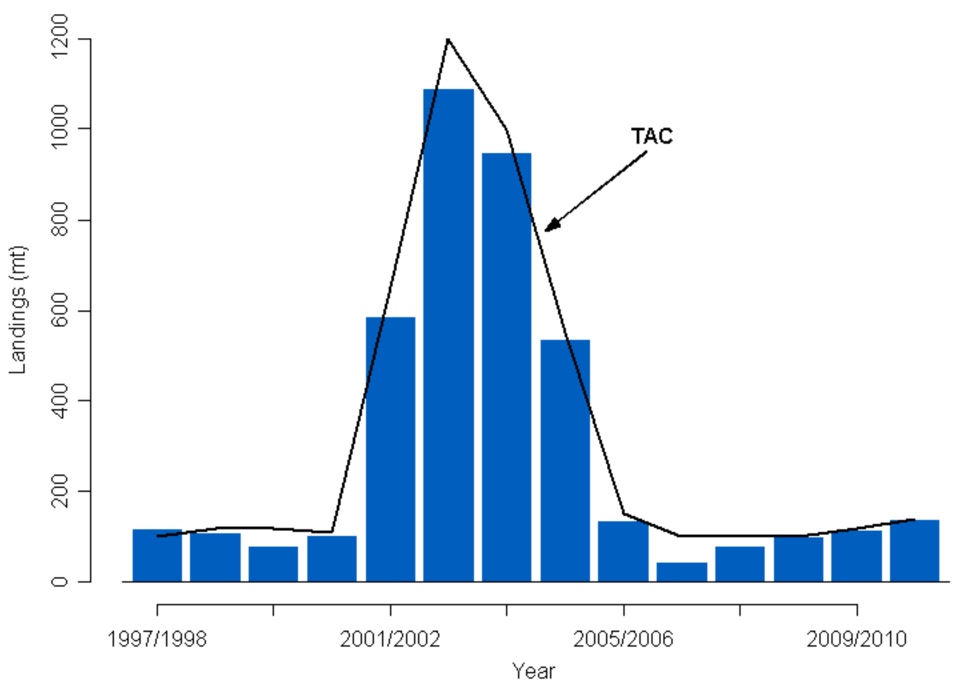

Figure 77. Trends in scallop catch (meats, t) from SPA 4. TACs were initiated in 1997.

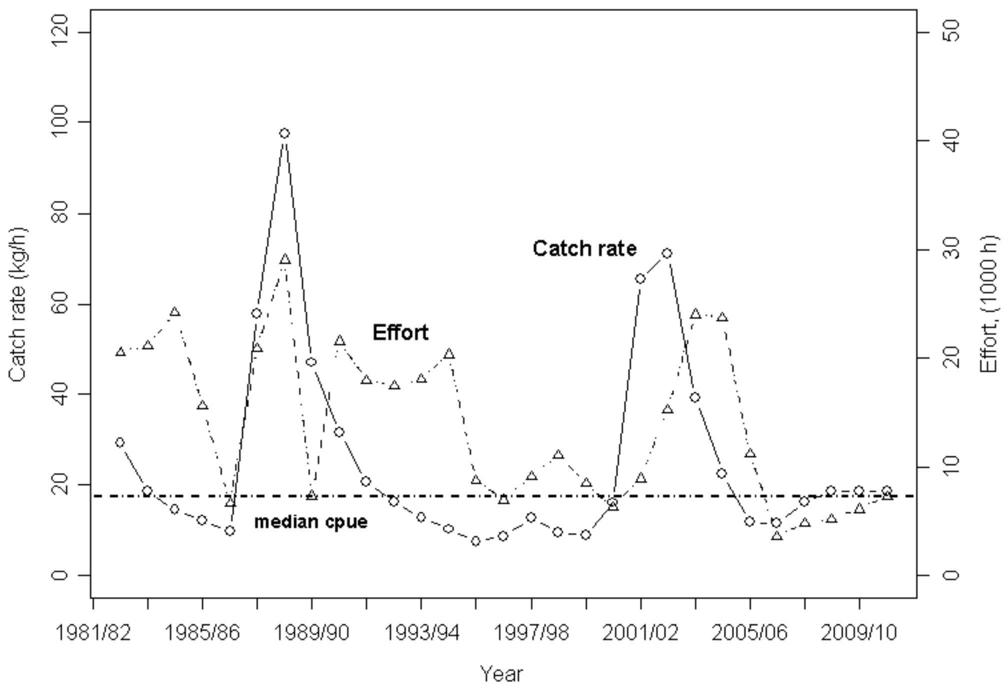

Figure 78. Trends in scallop catch rate (kg/h) and fishing effort (1000's hours) from SPA 4. Median levels over the 1976-1977 to 2009-2010 period indicated.

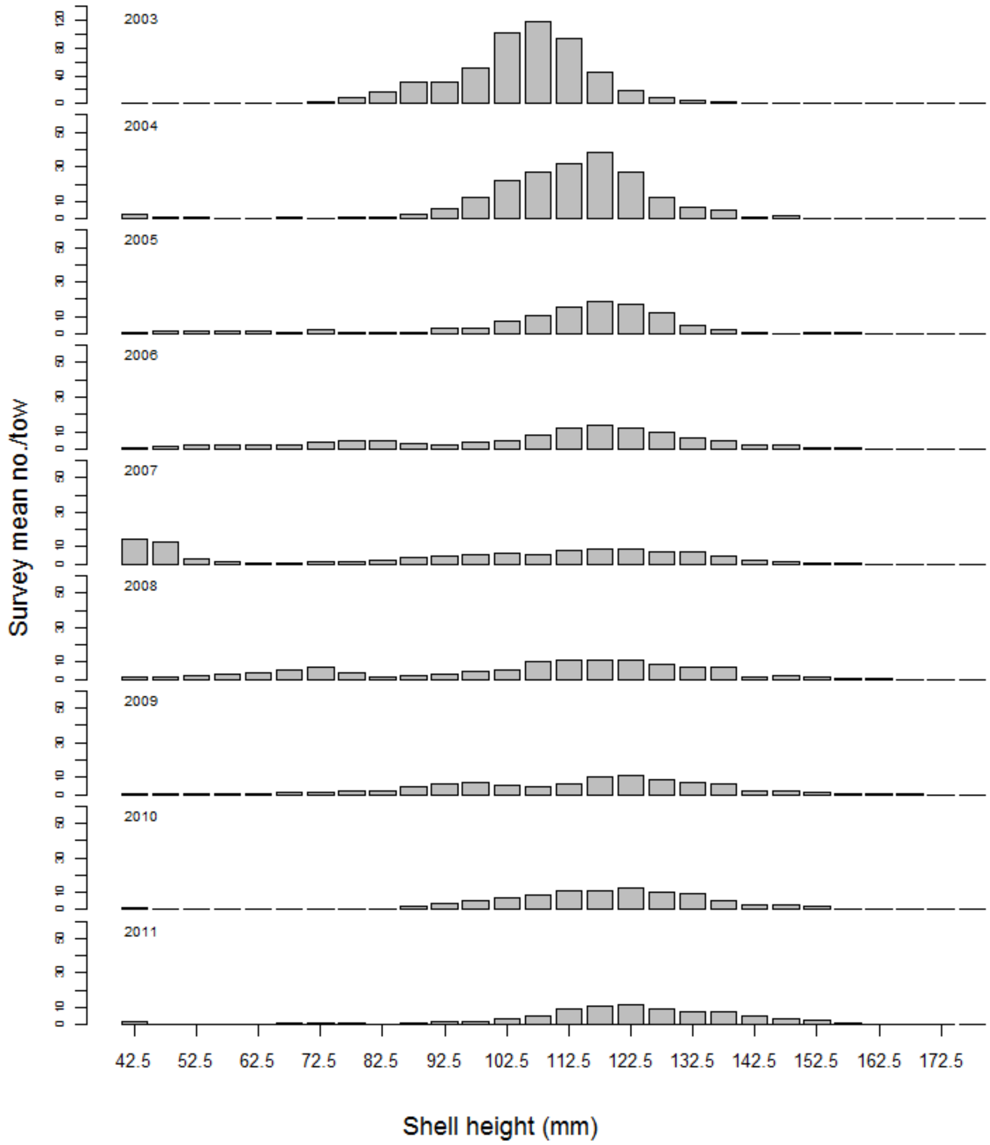

Figure 79. Scallop shell height frequencies (mean number/tow) from the surveys of the Scallop Production Area 4.

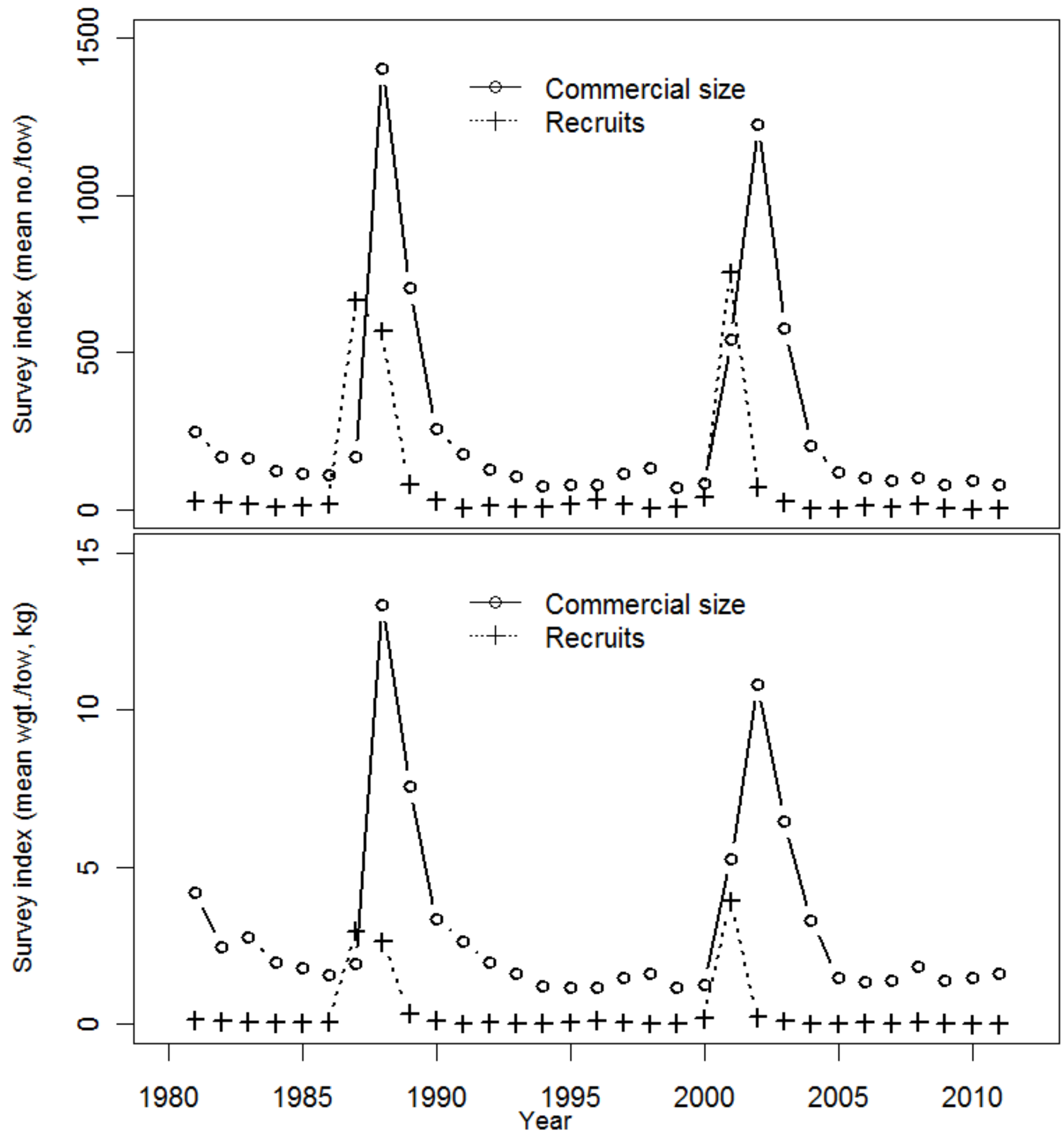

Figure 80. Upper: Survey abundance index (mean number/tow), Lower: Survey biomass index (mean meat weight/tow (g)) for commercial size (≥80 mm shell height) and recruit (65-79 mm), scallops in the Scallop Production Area 4.

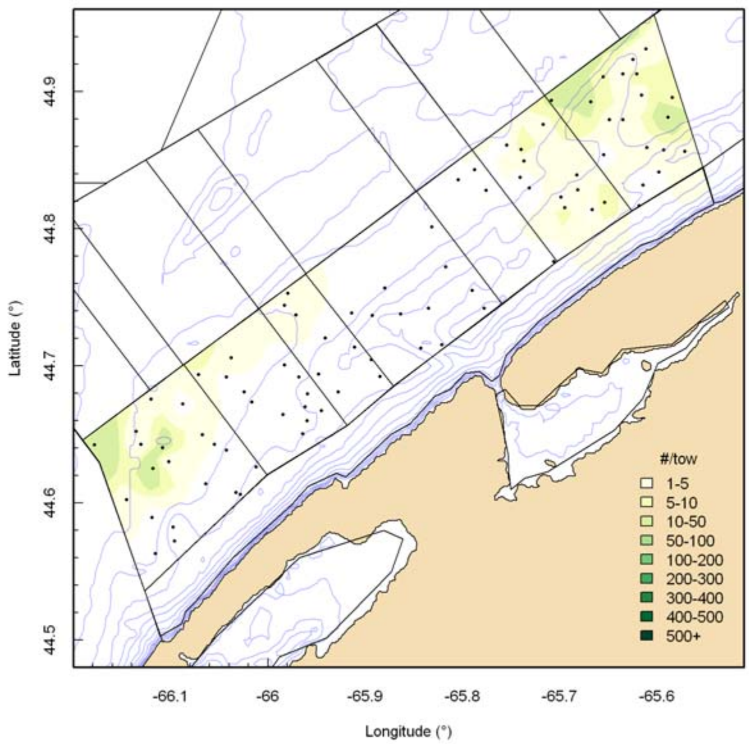

Figure 81. Spatial density (no./tow) distribution for recruit size scallops in Scallop Production Areas 4.

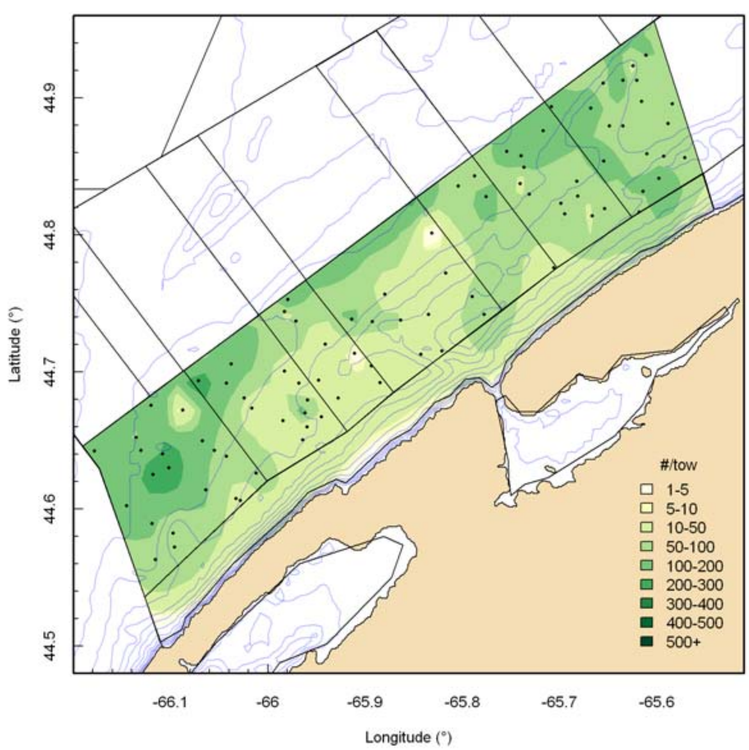

Figure 82. Spatial density (no./tow) distribution for commercial size scallops in Scallop Production Areas 4.

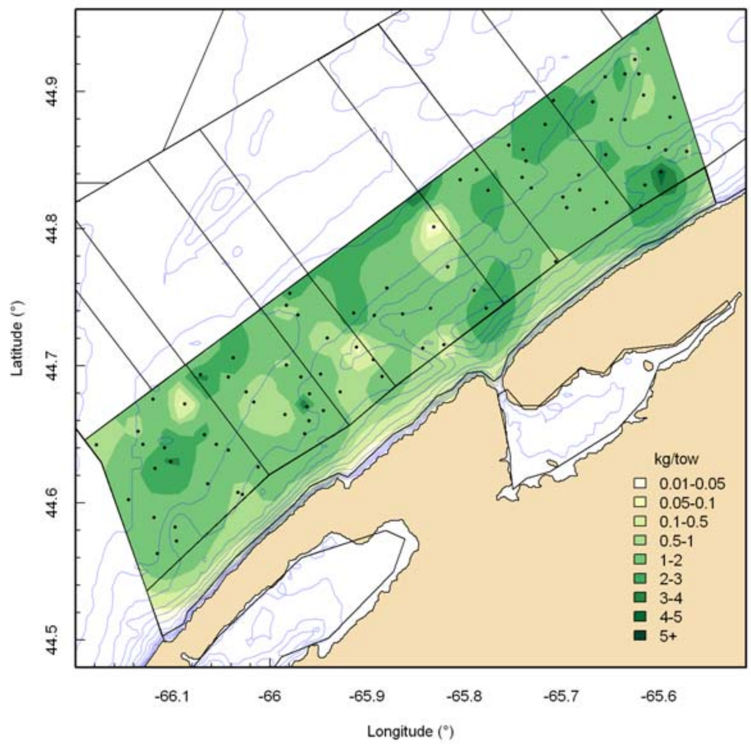

Figure 83. Spatial density (kg/tow) distribution of commercial size biomass from the 2011 survey data for Scallop Production Area

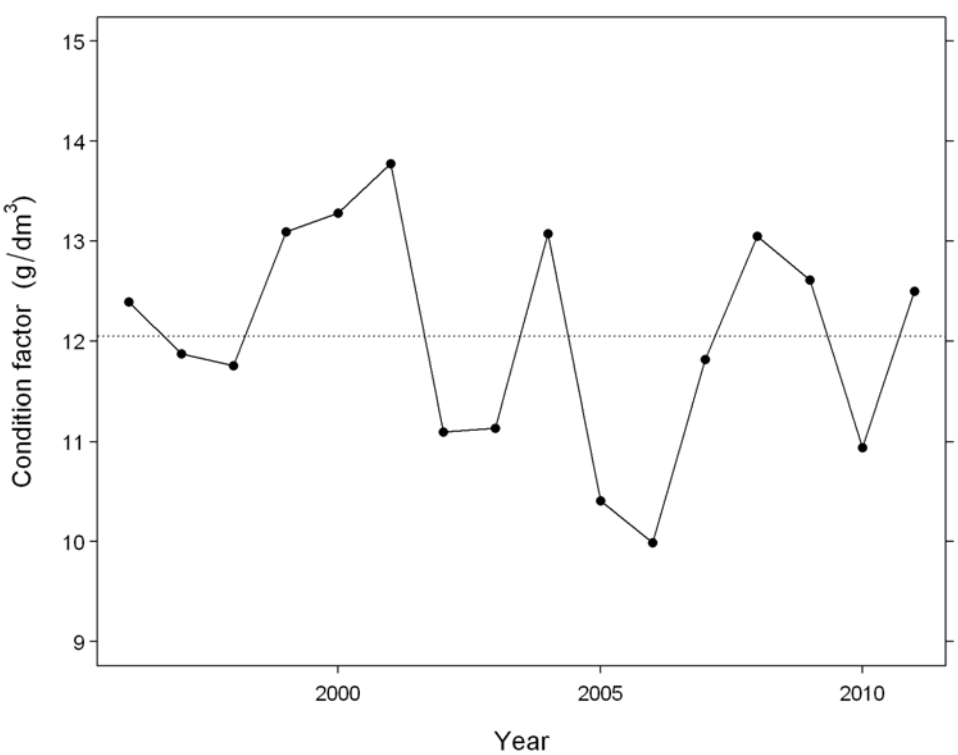

Figure 84. Annual trend in condition factor (CF) for scallops from the annual surveys of Scallop Production Area 4.

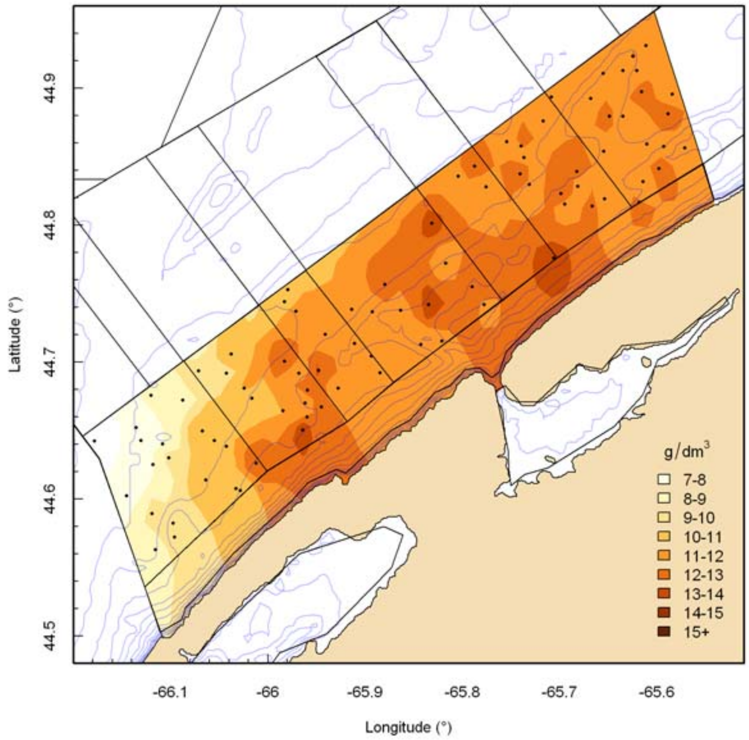

Figure 85. Spatial distribution of condition factor (g/dm^3) from the 2011 survey data for Scallop Production Area 4.

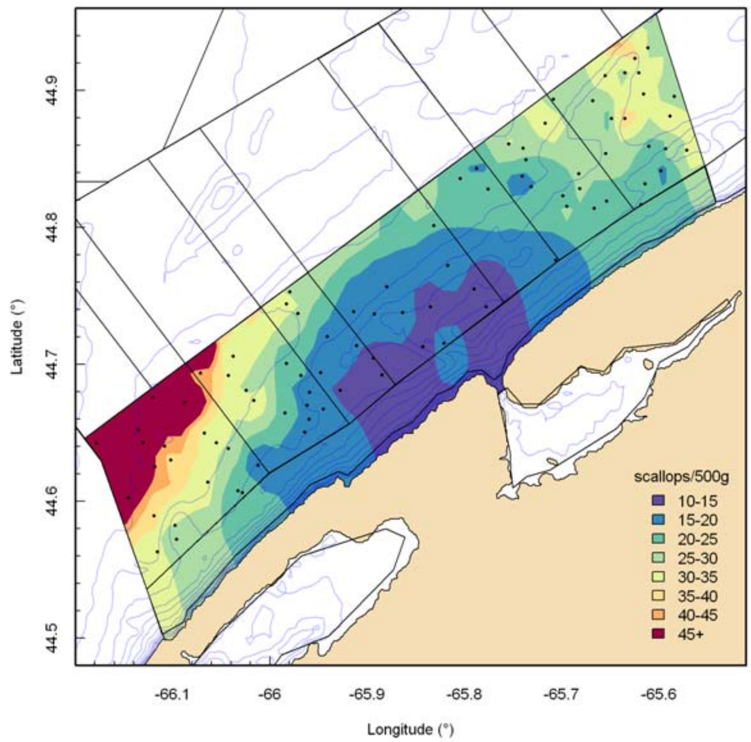

Figure 86. Spatial distribution of estimated meat count of commercial size (≥80 mm shell height) scallops from the survey of SPA 4 in 2011. Inverse distance weighted interpolation was used with the average meat weight of fully-recruited scallops for each tow to produce a contoured color image.

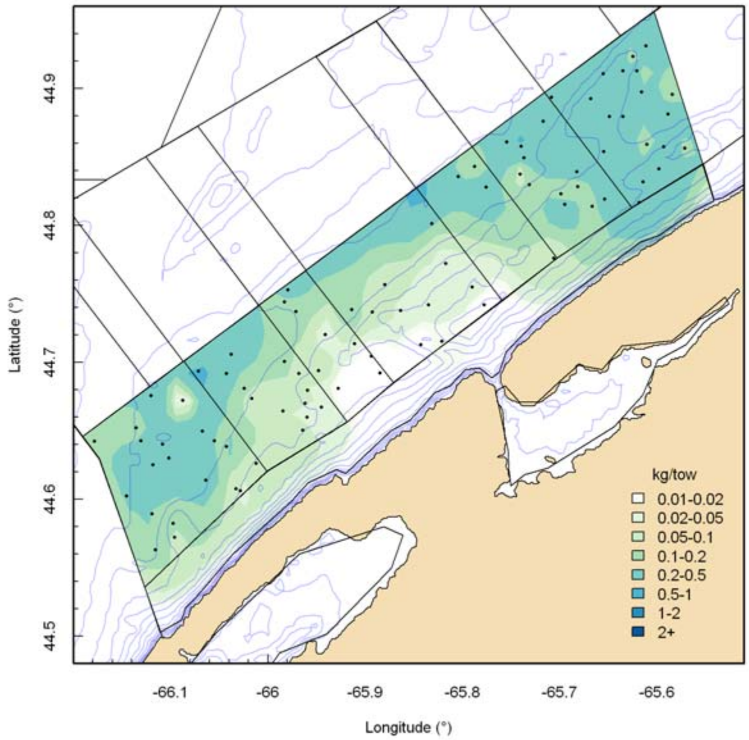

Figure 87. Spatial distribution of expected growth for 2011/2012 in biomass (meats) of commercial size (≥80 mm shell height) scallops from the survey of SPA 4 in 2011. Inverse distance weighted interpolation was used with the average expected growth of fully-recruited scallops for each tow to produce a contoured color image.

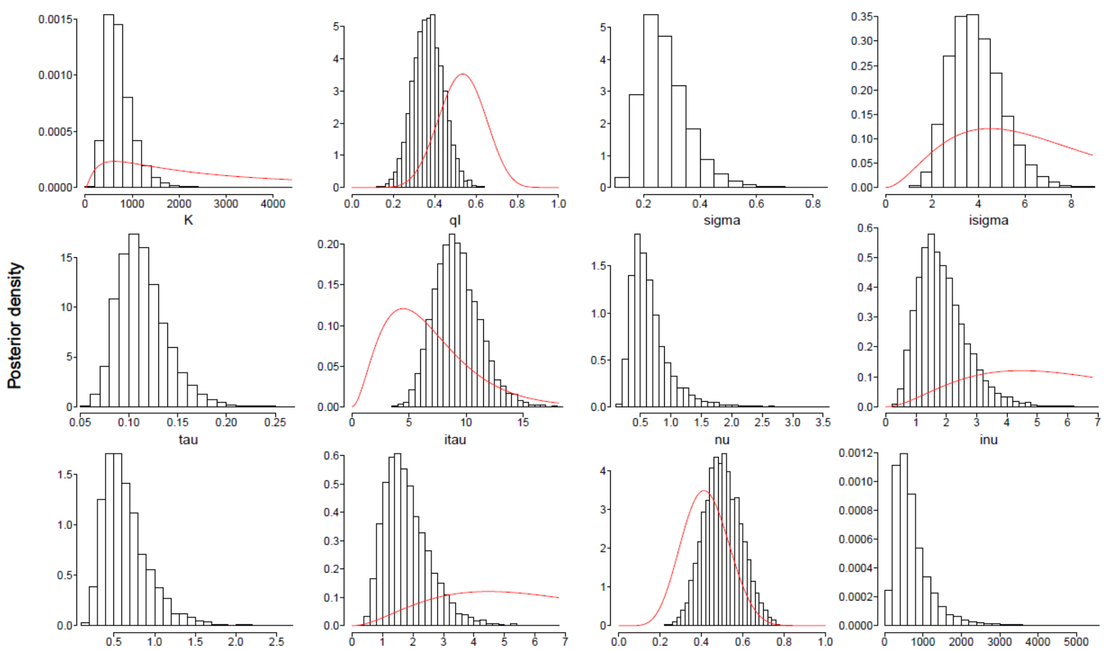

Figure 88. Comparison of prior and posterior densities. Bayesian state-space delay-difference model for scallops in SPA 4.

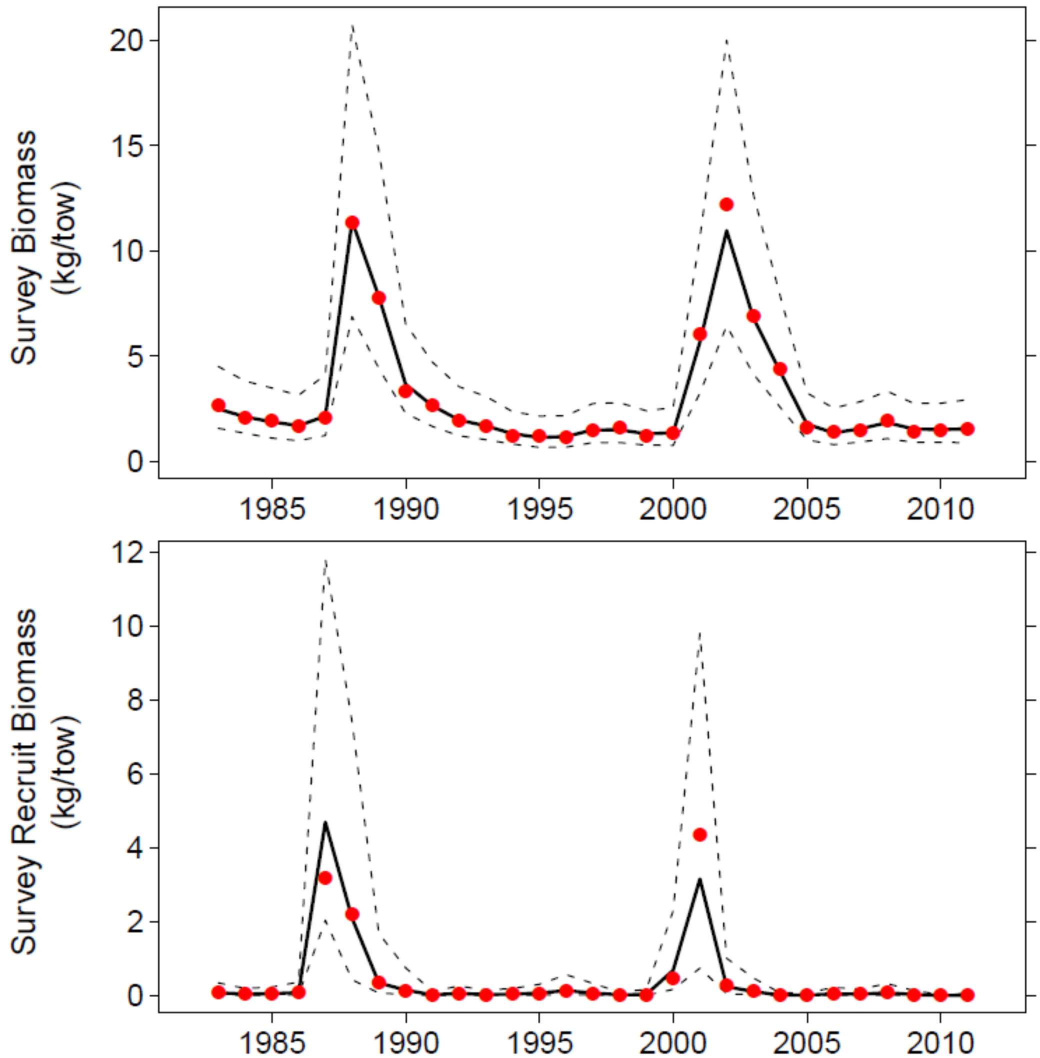

Figure 89. Posterior median fit to survey series for commercial size and recruit size scallops. Bayesian state-space delay-difference model for scallops in SPA 4.

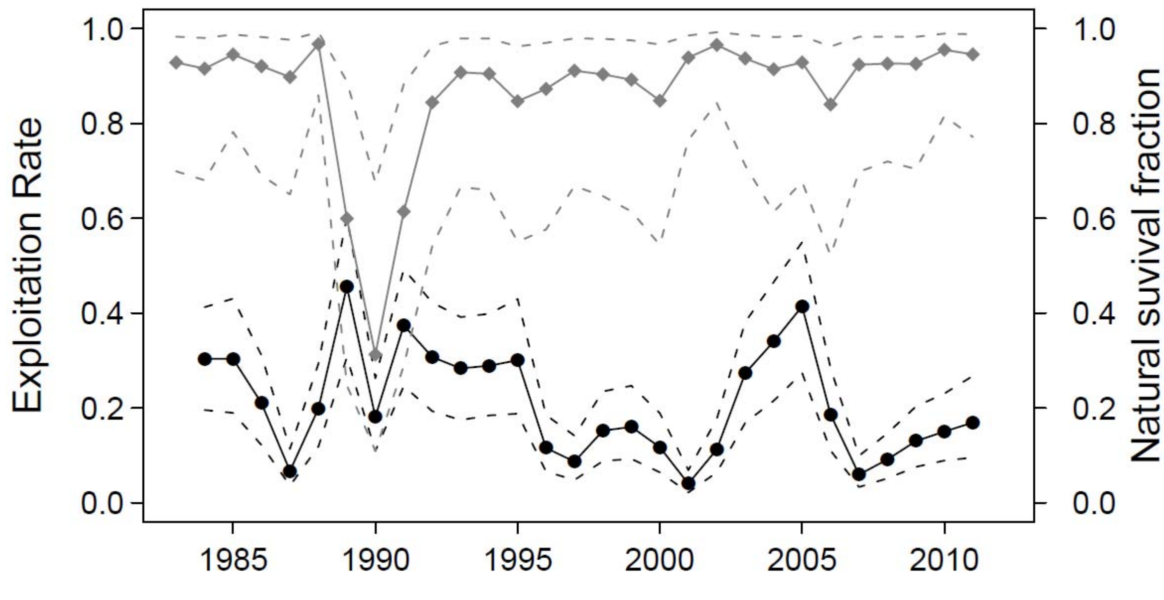

Figure 90. Annual trends in exploitation (solid line with filled circle) and survival estimates ($exp(-m)$), where m is natural mortality; solid line with filled triangles). Bayesian state-space delay-difference model for scallops in SPA 4.

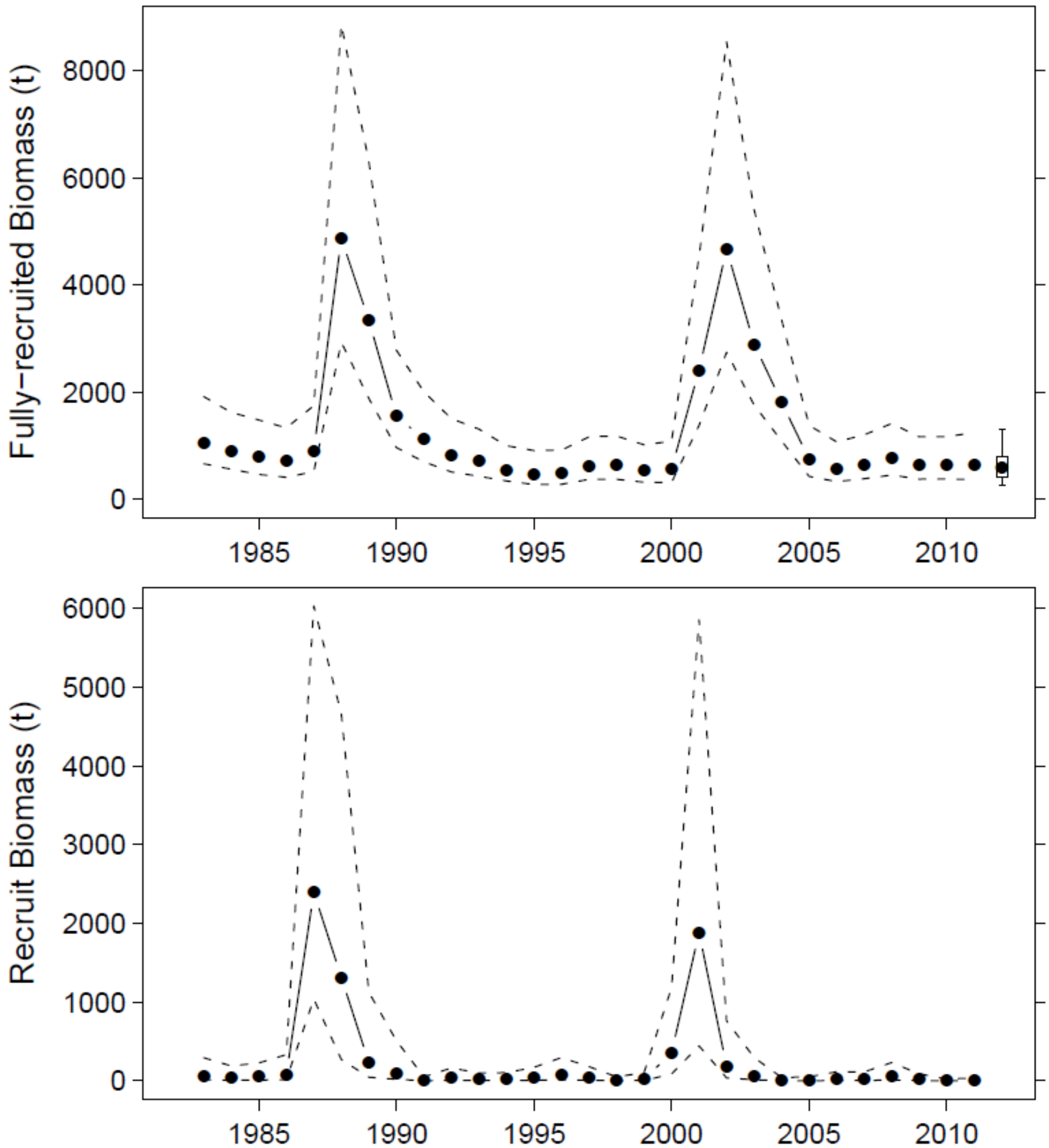

Figure 91. Biomass estimates for fully recruited scallops from the delay-difference model fit to the SPA 4 survey and commercial data. Dashed lines are the upper and lower 95% credible limits on the estimates and the dotted line represents the 25 year median. The predicted commercial size biomass for 2012, assuming the interim TAC, is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers).

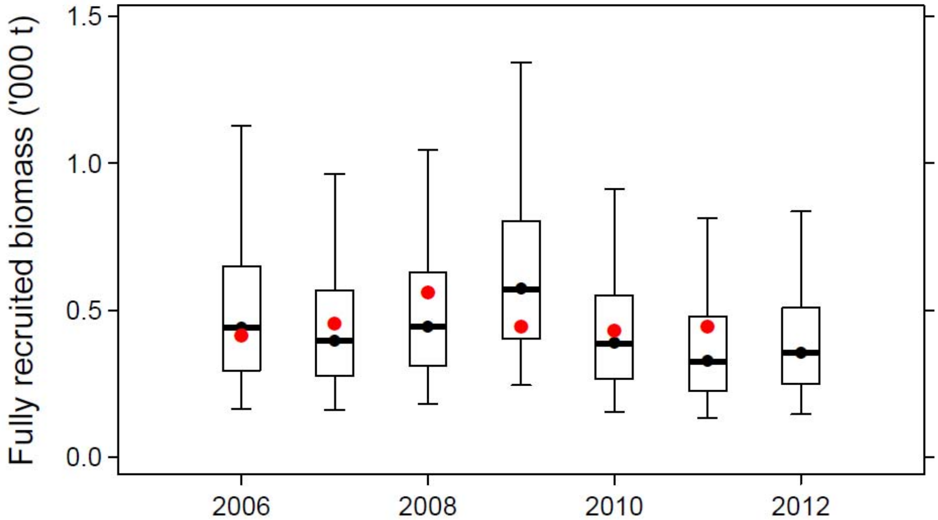

Figure 92. Evaluation of model projection performance. Box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year $t-1$ (e.g., 2006 prediction based on data up to 2005). Red dot represents the estimate of the biomass in year t using data up to and including year t. Bayesian state-space delay-difference model for scallops in SPA 4

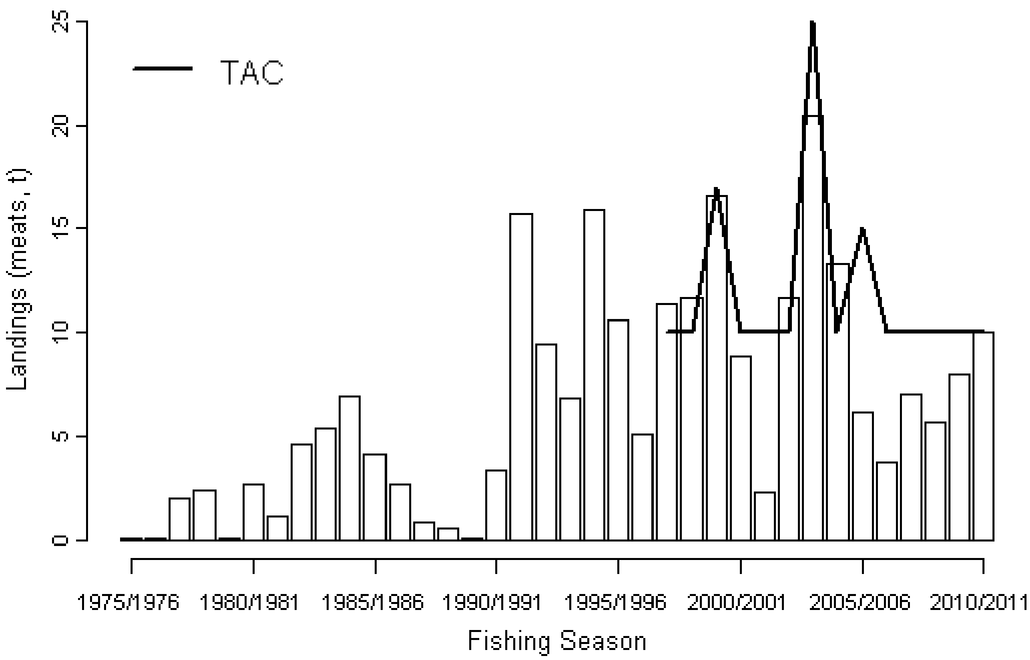

Figure 93. Trends in scallop catch (meats, t) from SPA 5. TACs were initiated in 1997.

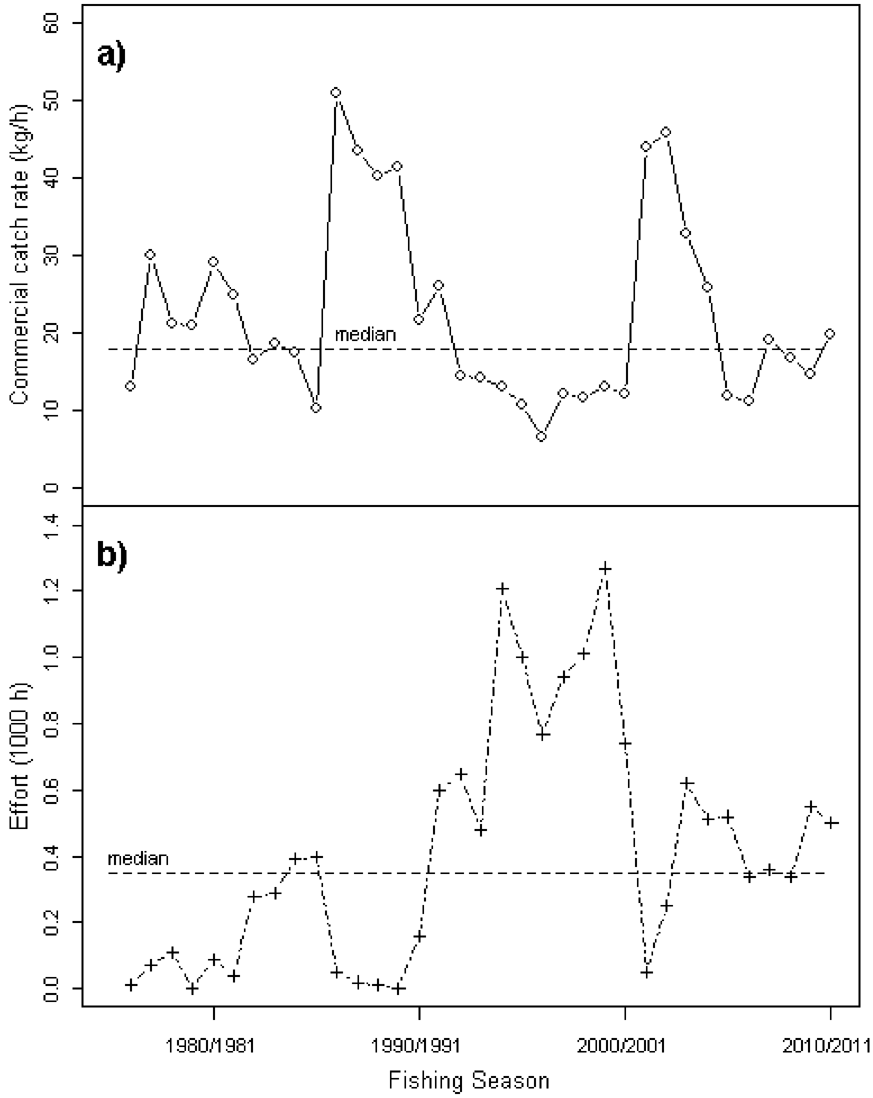

Figure 94. Trends in a) commercial catch rate (kg/h) and b) commercial fishing effort (hours) from SPA 5. Median levels over the 1975/1976 to 2009/2010 fishing seasons indicated.

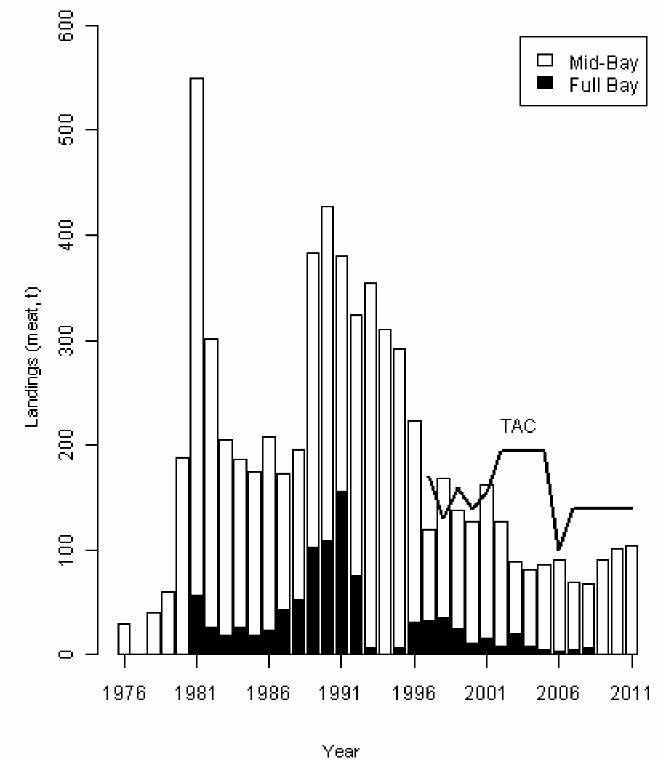

Figure 95. Scallop landings (meats, t) in Scallop Production Area 6 by fleet.

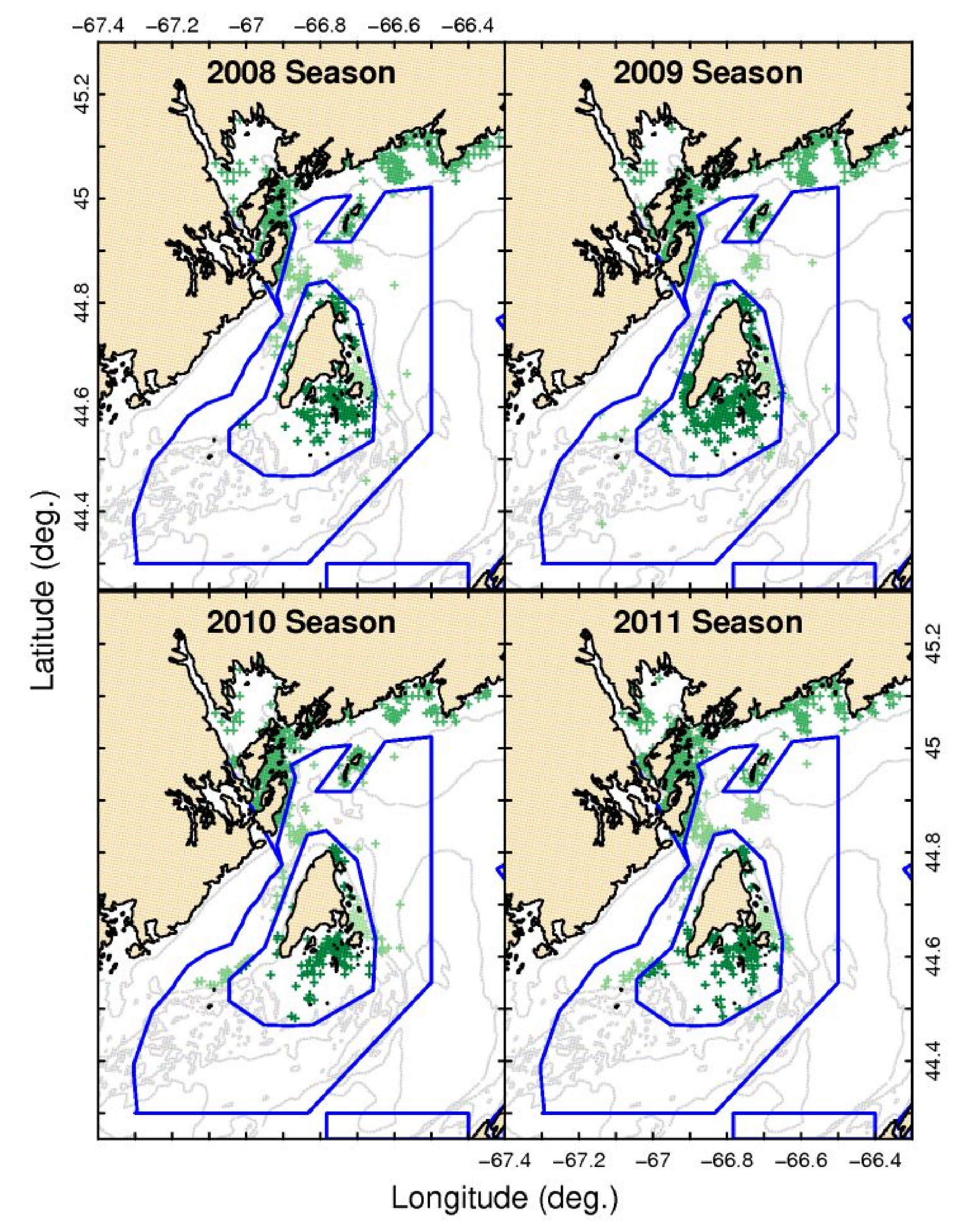

Figure 96. Fishing locations based upon commercial fishing logs from the Full Bay and Mid-Bay Fleets in Scallop Production Area 6.

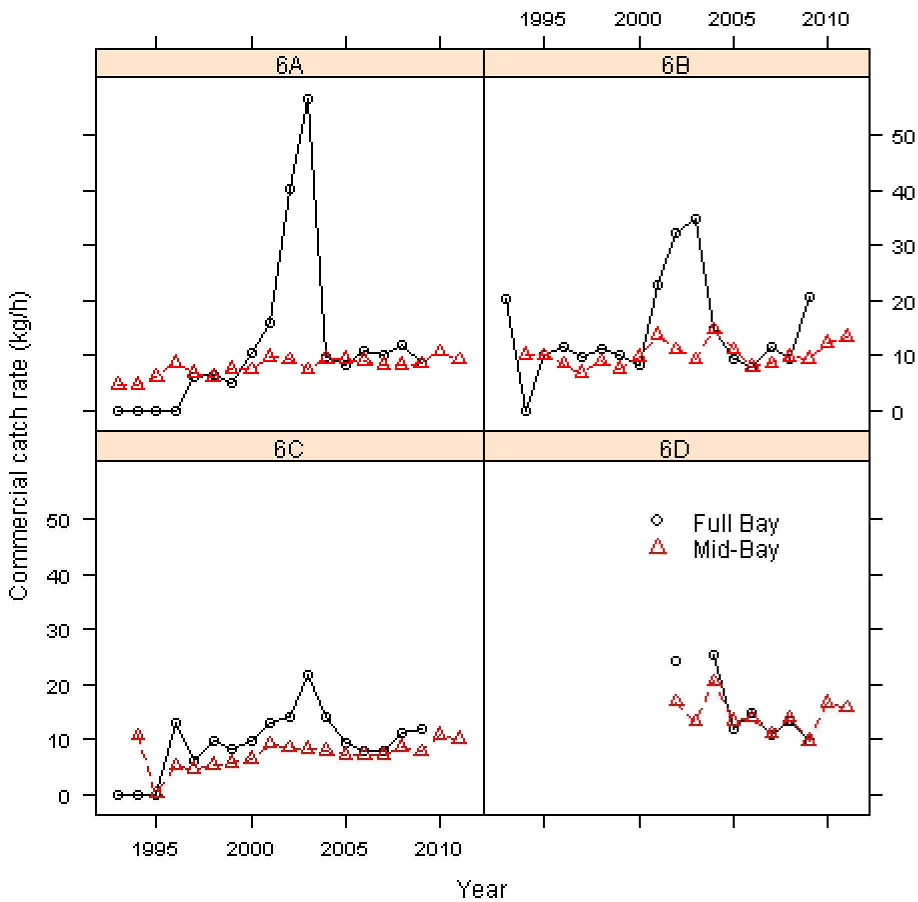

Figure 97. Commercial catch rate (kg/h) for scallops in Scallop Production Area 6. Top left: SPA 6A, Top right: 6B, Bottom left: 6C, Bottom right 6D (Duck Island Sound).

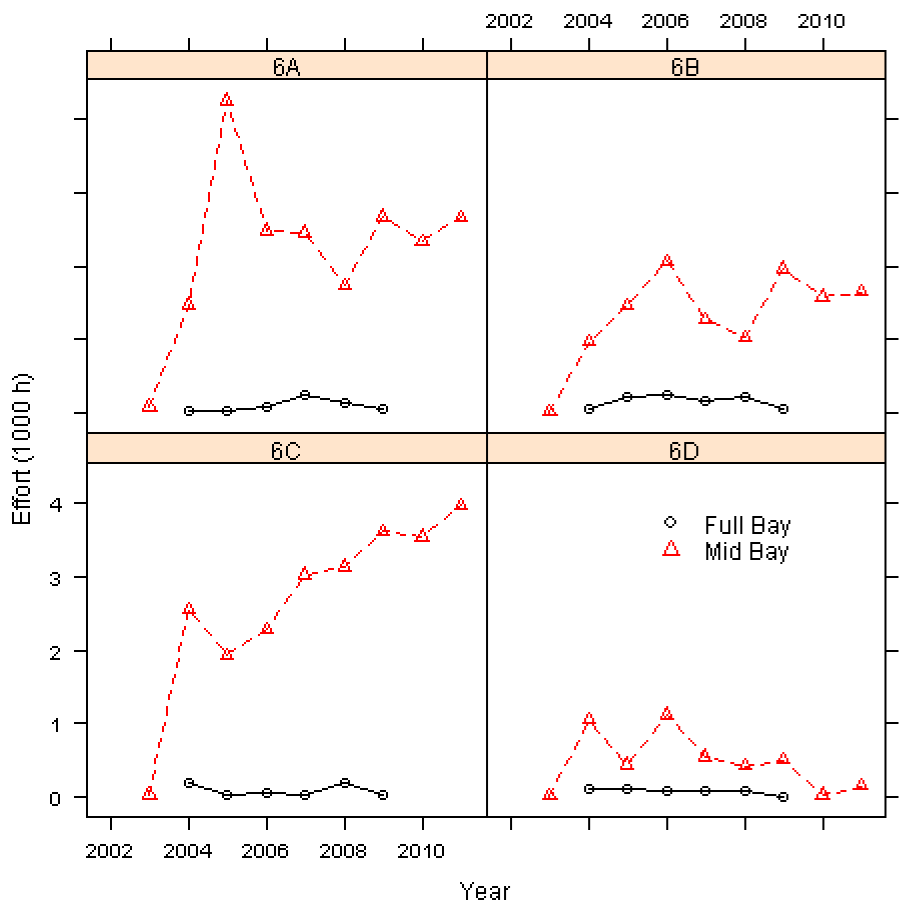

Figure 98. Commercial effort (1000 h) for scallops in Scallop Production Area 6. Top left: SPA 6A, Top right: 6B, Bottom left: 6C, Bottom right 6D (Duck Island Sound).

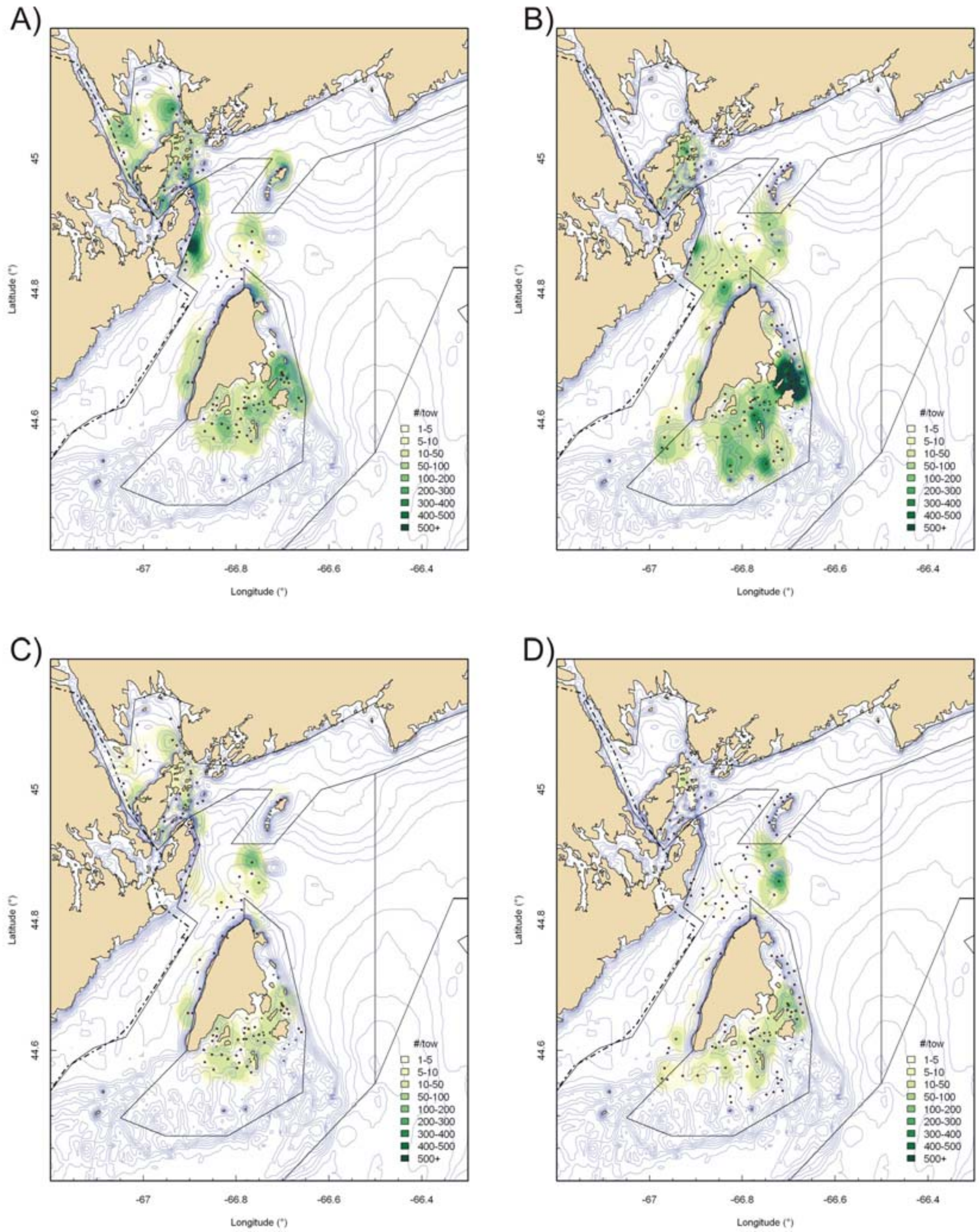

Figure 99. Spatial distribution of scallop survey catches from the 2010 (left column) and 2011 (right column) surveys of Scallop Production Area 6. A-B: 40-64 cm shell height; C-D: 65-79.

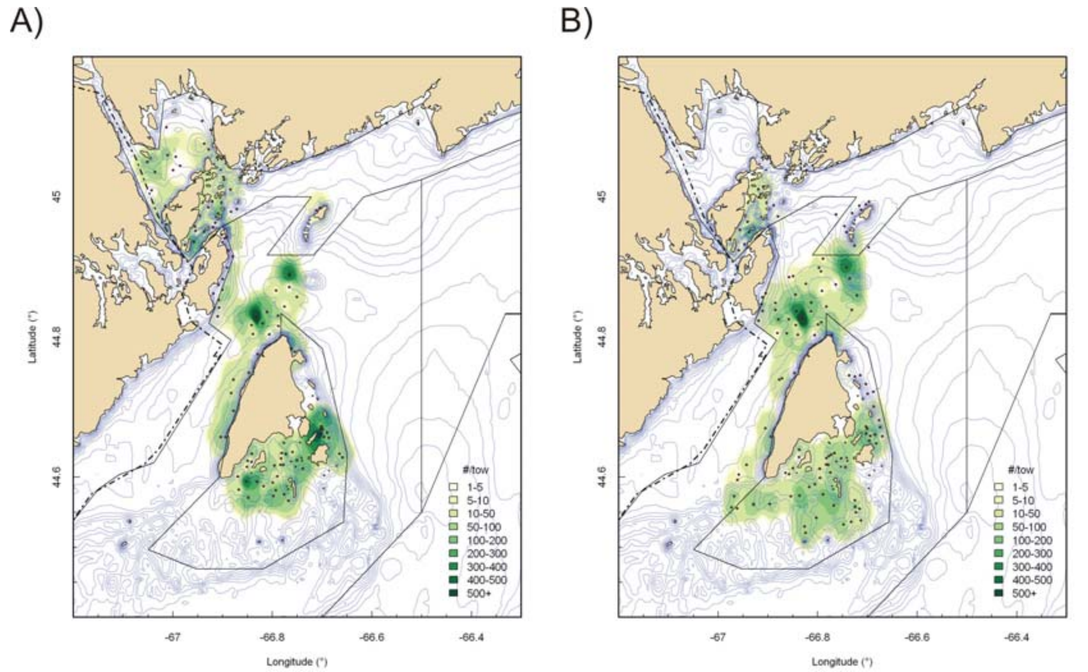

Figure 100. Spatial distribution of scallop survey catches from the 2010 (left column) and 2011 (right column) surveys of Scallop Production Area 6. A-B: ≥80 mm.

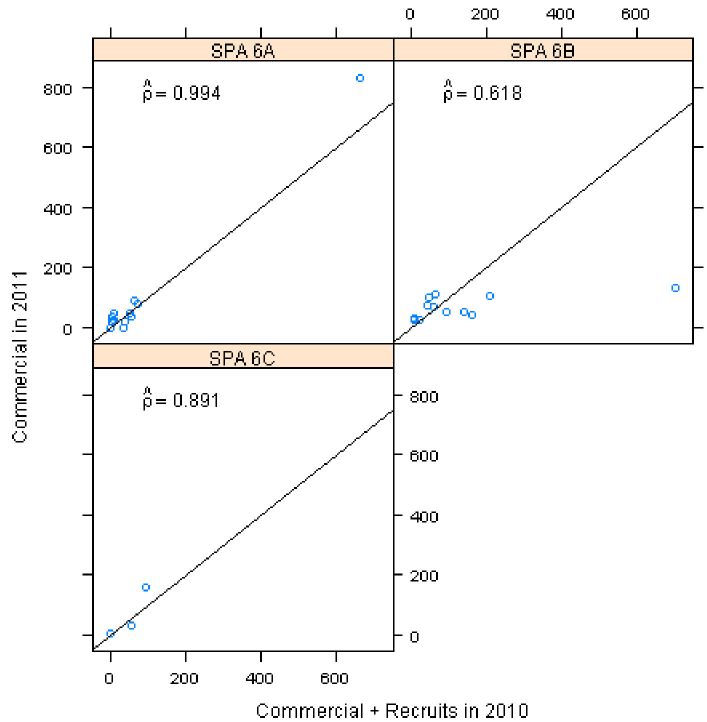

Figure 101. Comparing numbers of commercial size scallops (≥80 mm shell height) caught in 2010 and 2011 in the survey stations common to both of the surveys in SPA 6. Solid line indicates 1:1 line.

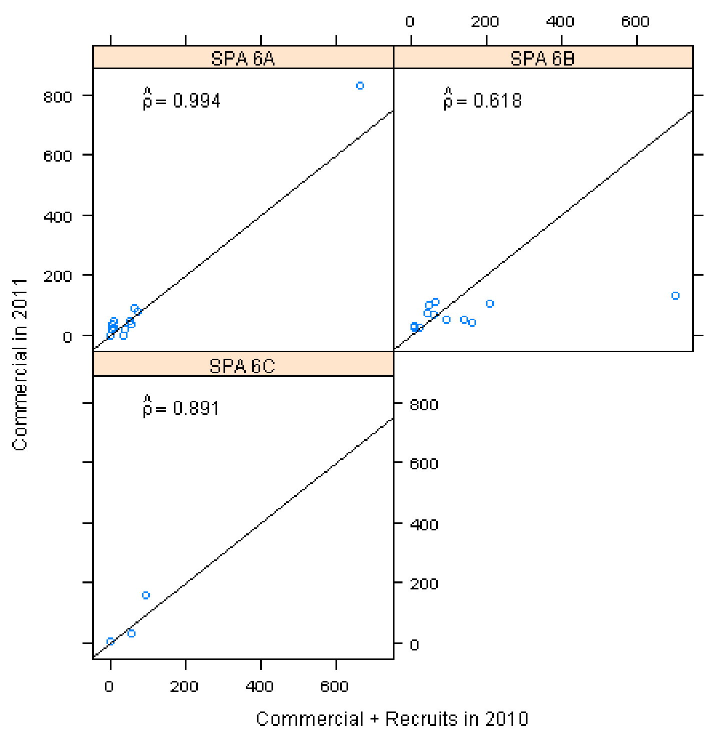

Figure 102. Comparing numbers of commercial size scallops (≥80 mm shell height) and recruits (65 to 79 mm shell height) caught in 2010 and commercial size scallops 2011 in the survey stations common to both of the surveys in SPA 6. Solid line indicates 1:1 line.

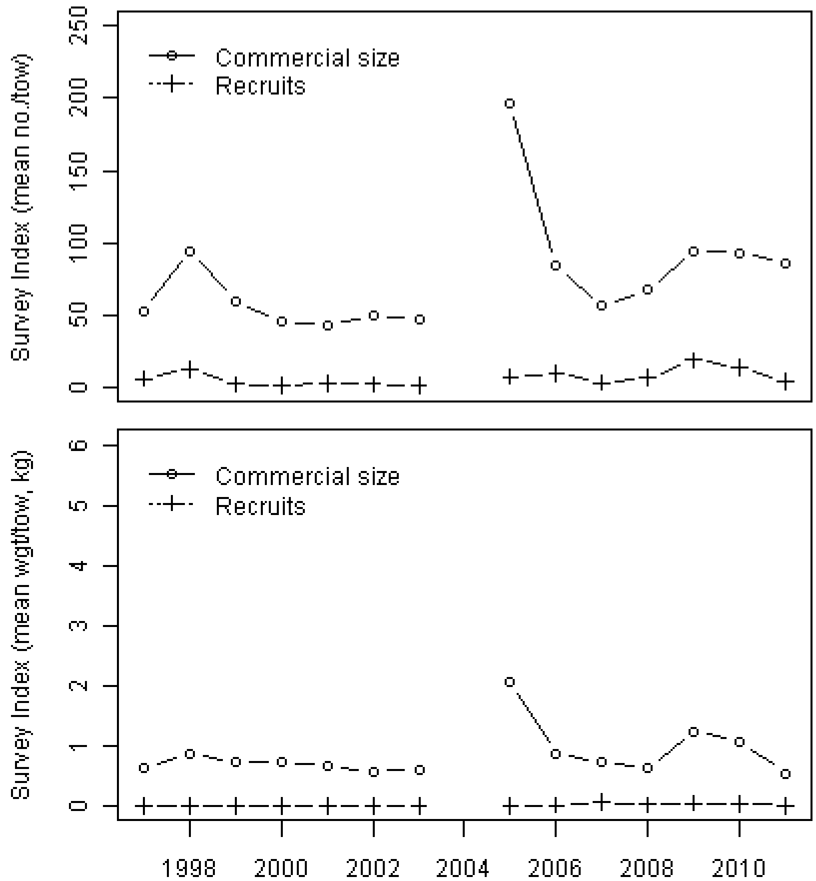

Figure 103. Trends in survey estimates of mean number (upper panel) and mean weight (lower panel) per tow of commercial size scallops (shell height ≥80 mm) and recruits (see text for definition) from research vessel surveys of Scallop Production Area 6A.

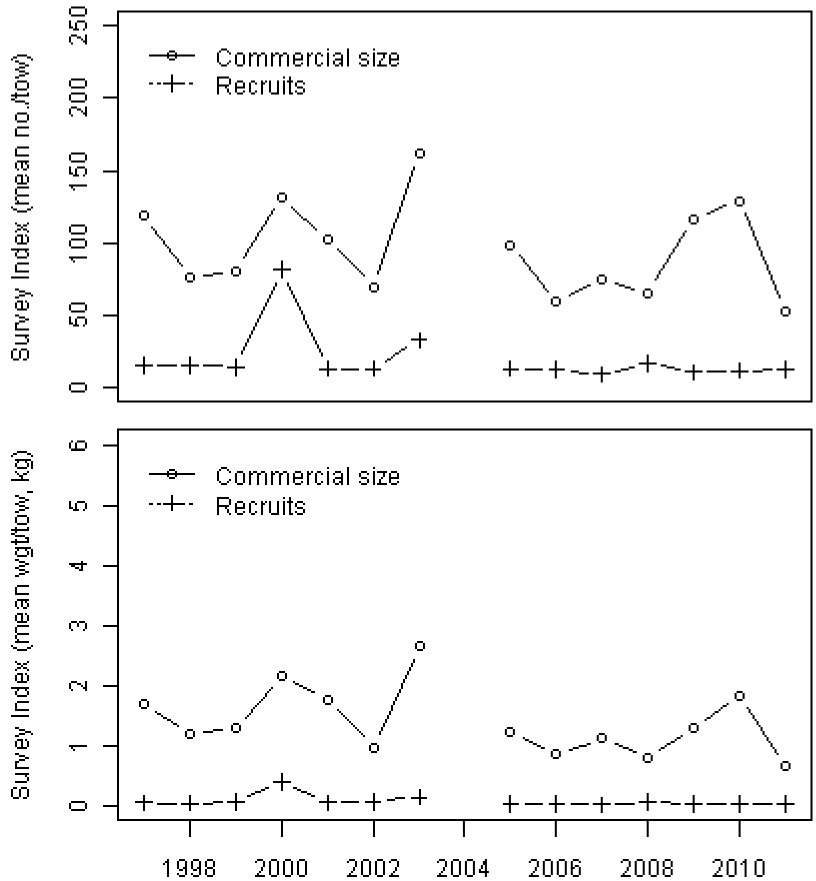

Figure 104. Trends in survey estimates of mean number (upper panel) and mean weight (lower panel) per tow of commercial size scallops (shell height ≥80 mm) and recruits (see text for definition) from research vessel surveys of Scallop Production Area 6B.

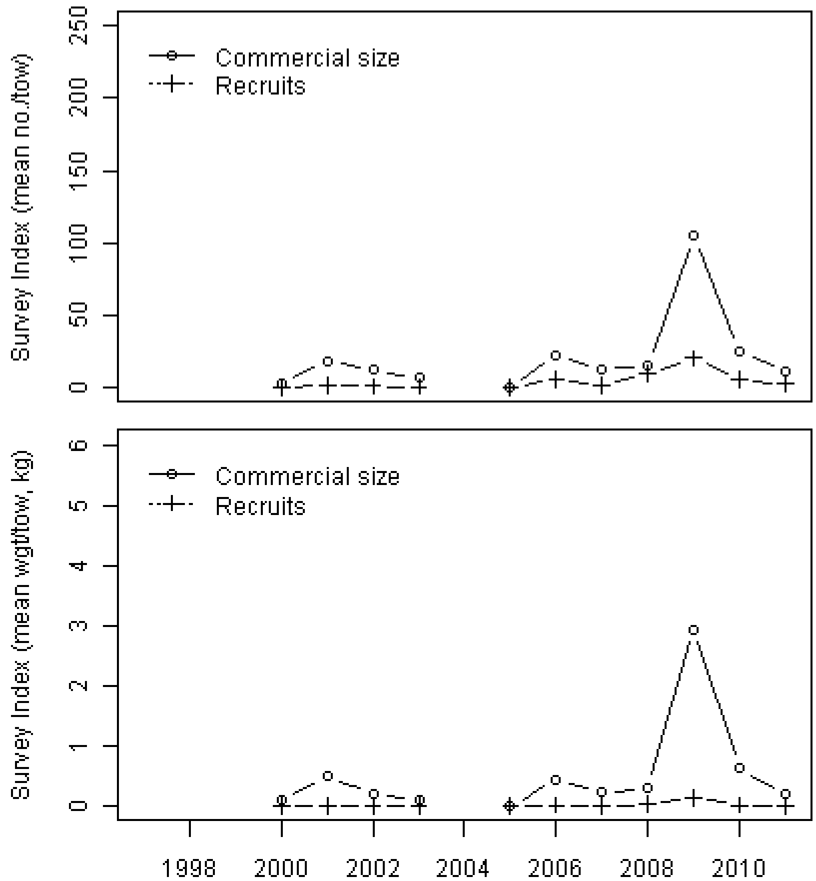

Figure 105. Trends in survey estimates of mean number (upper panel) and mean weight (lower panel) per tow of commercial size scallops (shell height ≥80 mm) and recruits (see text for definition) from research vessel surveys of Scallop Production Area 6C.

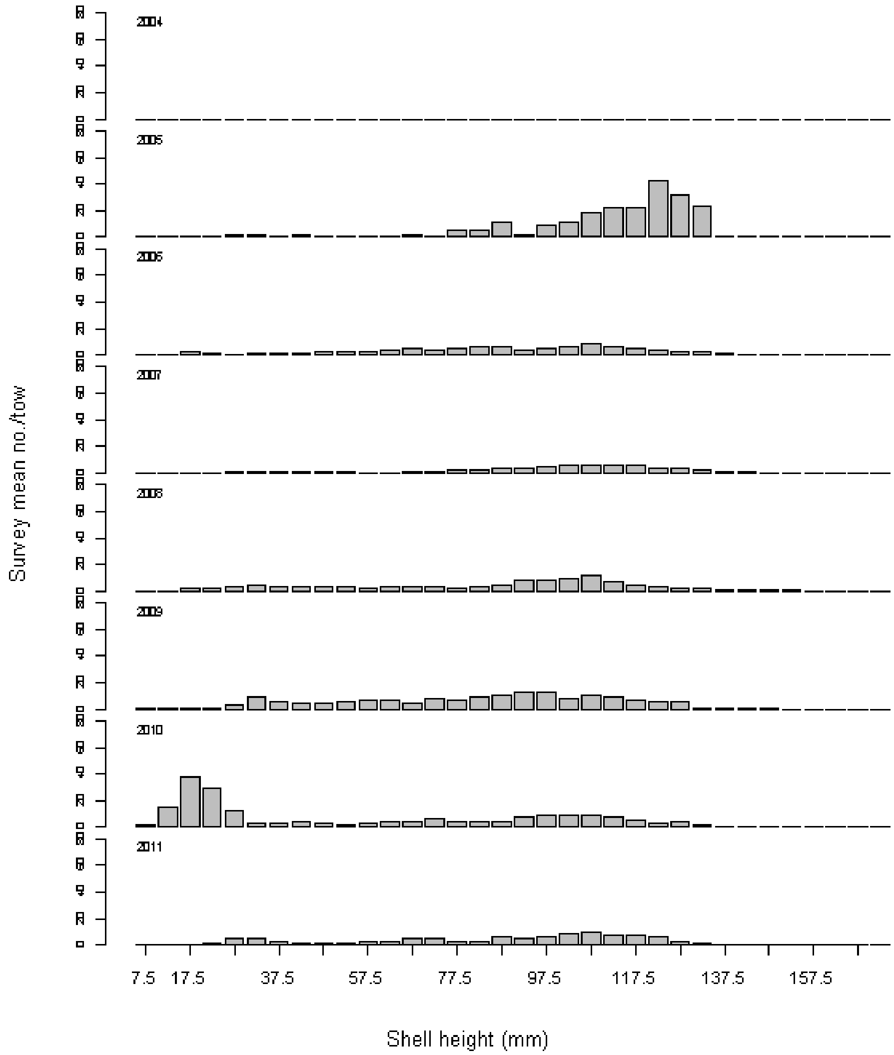

Figure 106. Comparison of shell height frequencies from the 2004 to 2011 surveys of SPA 6A. No survey was conducted in 2004 and the 2005 survey consisted of only 2 tows.

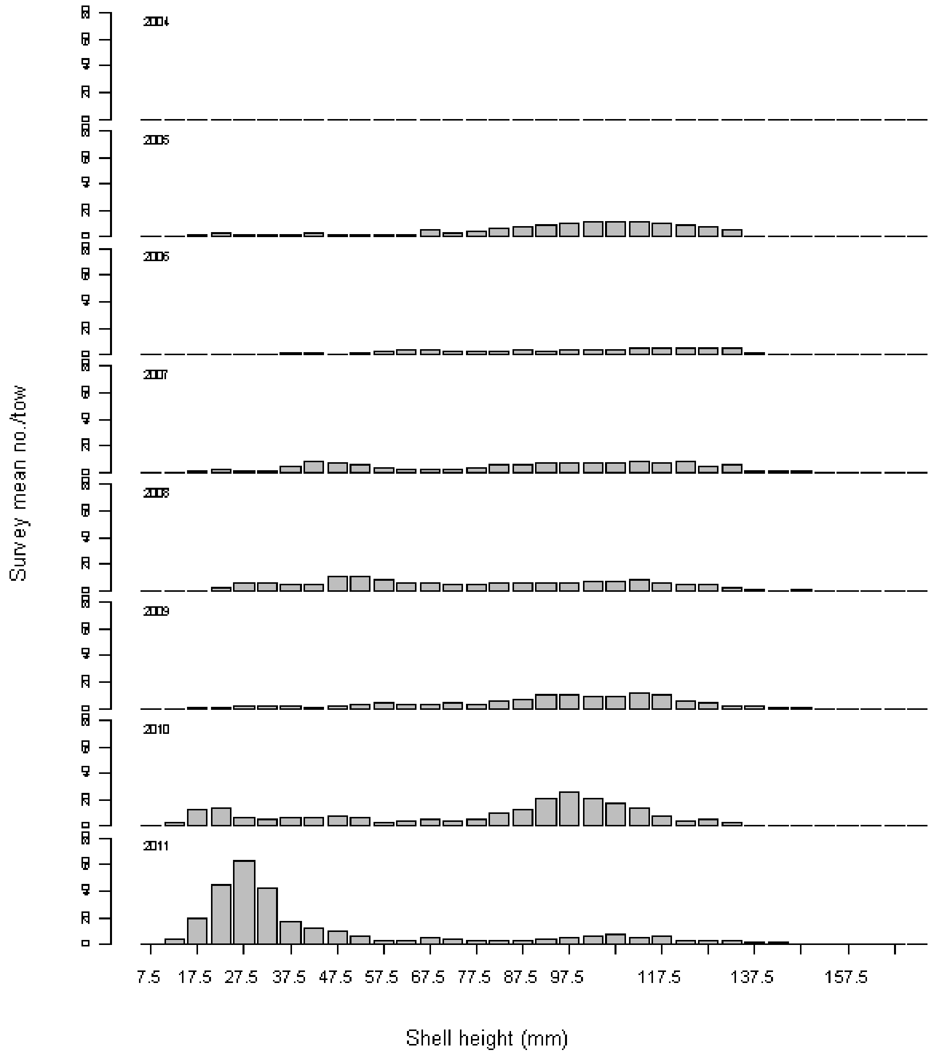

Figure 107. Comparison of shell height frequencies from the 2004 to 2011 surveys of SPA 6B. No survey was conducted in 2004.

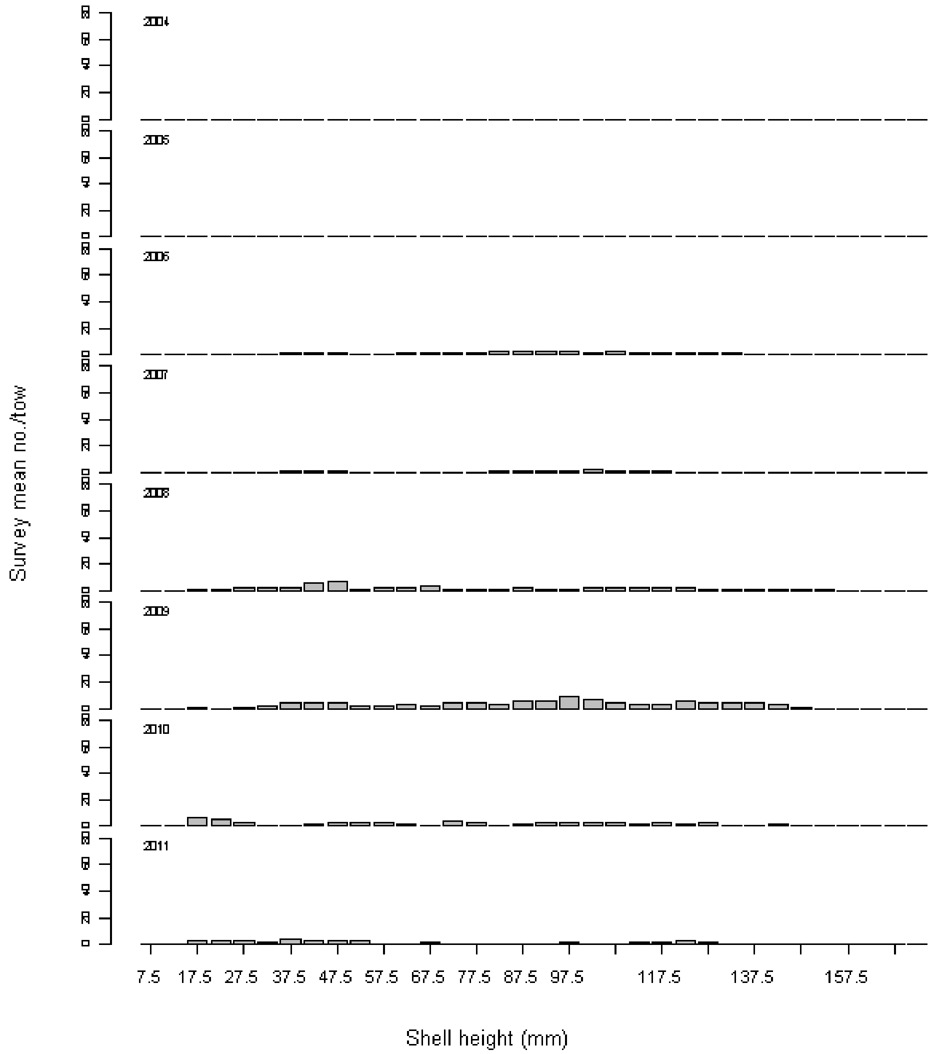

Figure 108. Comparison of shell height frequencies from the 2004 to 2008 surveys of SPA 6C. No survey was conducted in 2004 or in 2005.

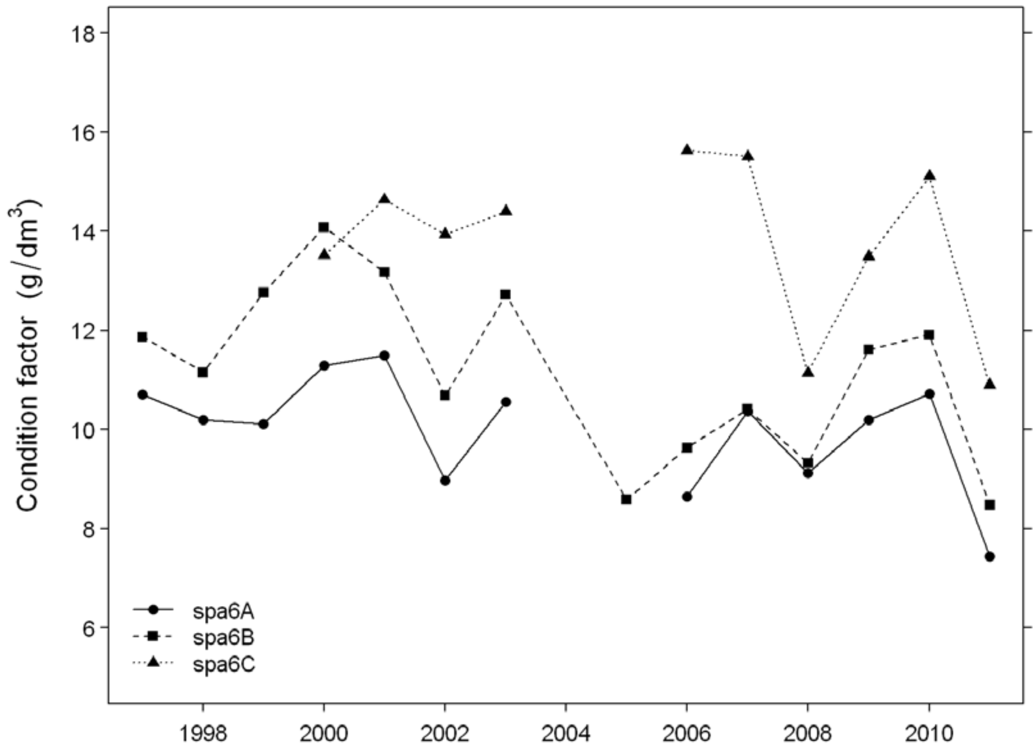

Figure 109. Annual trend in condition factor (CF) for scallops from the annual surveys of Scallop Production Area 6.

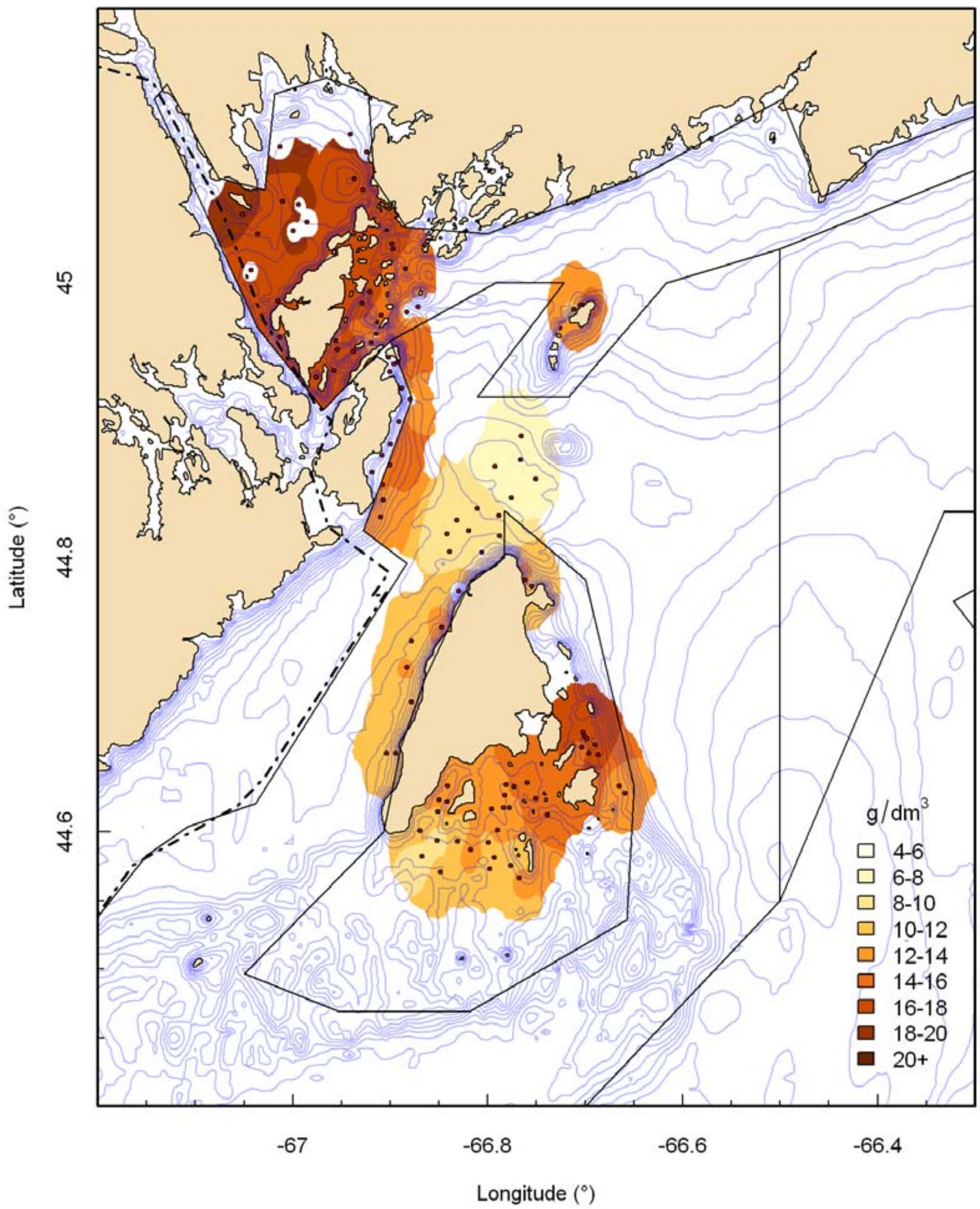

Figure 110. Spatial distribution of condition factor (g/dm^3) from the 2010 survey data for Scallop Production Area (SPA) 6.

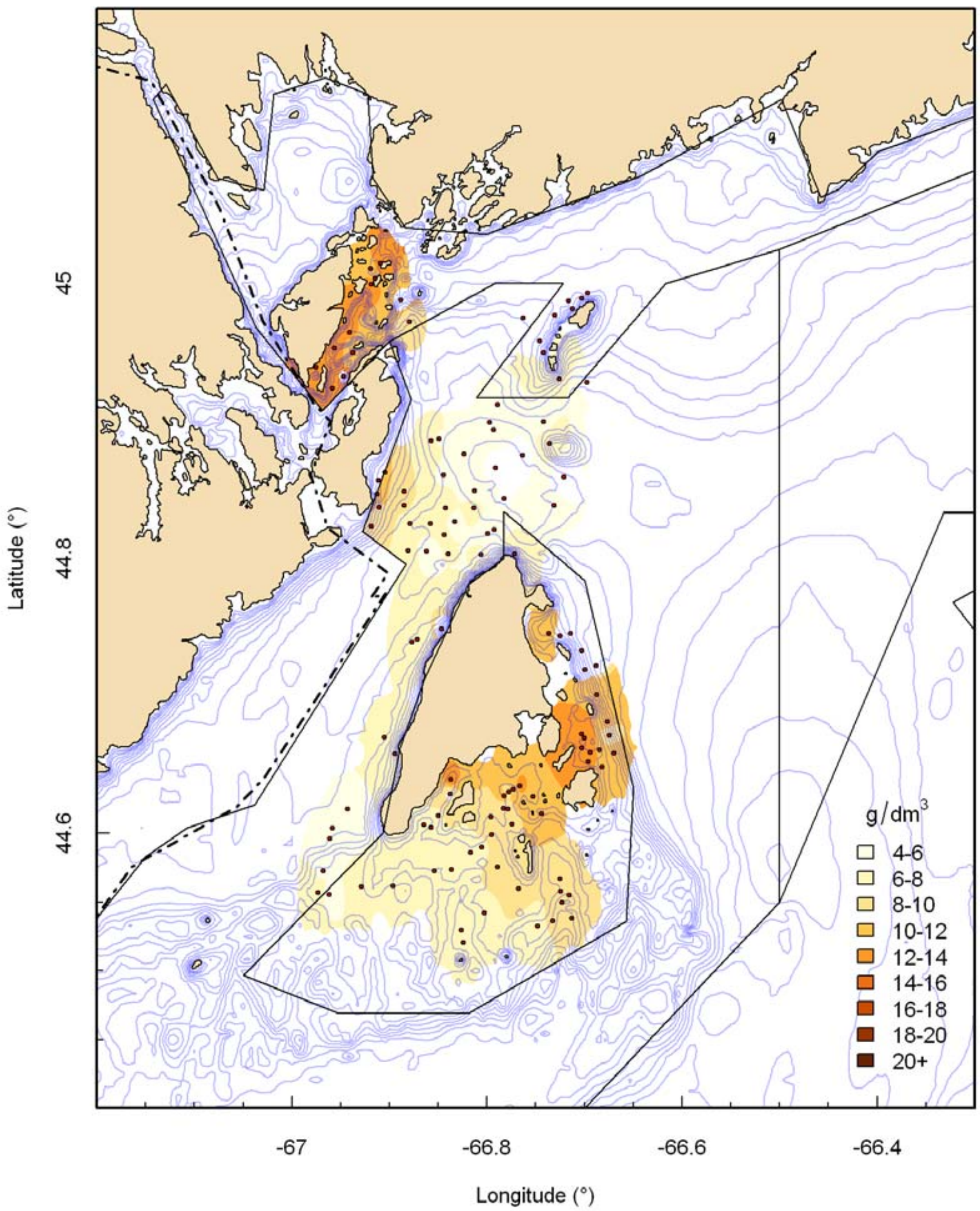

Figure 111. Spatial distribution of condition factor (g/dm^3) from the 2011 survey data for Scallop Production Area (SPA) 6.