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Scallop Production Areas in the Bay of Fundy: Stock Status for 2013 and Forecast for 2014

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Foreword

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

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ABSTRACT

This research 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 2012/2013 with advice for 2013/2014. The Bay of Fundy is fished by three separate scallop fishing fleets: Full Bay, Mid Bay, and Upper Bay. The Full Bay fleet fishing season is from 1 October to 30 September, while the Mid and Upper Bay fleet season is from 1 January to 31 December.

In this assessment, the temporal patterns in condition and stock composition are used to calculate overall growth parameters for use in population models. Changes were made to the models in the 2013 assessment to include survey variance. Potential reference points were also developed and are presented in this document.

The Full Bay fleet caught 206 t against a Total Allowable Catch (TAC) of 200 t in SPA 1A in 2012/2013. Condition in this area increased, and survey biomass increased. Population biomass estimated by the model was 1,607 t (meats) in 2013, up from the estimate of 1,231 t for 2012, which was approximately equal to the median (1997 to 2011) biomass of 1,206 t. A catch of 300 t for 2013/2014 should correspond to the reference exploitation rate and is projected to result in no change in biomass for 2014.

The Full Bay fleet caught 202.8 t against a TAC of 190.315 t in SPA 1B in 2012/2013. The Mid Bay fleet caught 162.7 t against a TAC of 133.95 t, and Upper Bay fleet caught 57.4 t against a TAC of 50.735 t. Catch rates increased for all fleets, doubling in some areas. Population biomass estimated by the model was 2,635 t (meats) in 2013, a substantial increase from the estimate of 1,757 t for 2012 and well above the median biomass of 1,798 t. A catch of 500 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 9.4% increase in biomass.

The Full Bay fleet caught 261 t against a TAC of 260 t in 2012/2013. Catch rates in St. Mary’s Bay increased from 2011/2012, and did not change in Brier/Lurcher. Population biomass estimated by the model was 1,606 t (meats) in 2013, an increase from the estimate of 1,195 t for 2012 and well above the long-term median biomass of 1,008 t. A catch of 300 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 7.2% increase in biomass.

The Full Bay fleet caught a total of 119.4 t against a TAC of 110 t in SPA 4 in 2012/2013. Catch rates in this area increased in 2013 and are above the long-term median. Recruitment in this area is low, essentially unchanged from 2012. Population biomass estimated by the model was 1,041 t (meats) in 2013, an increase of 33% from the estimate of 782 t in 2012, despite below average recruitment in 2012. A catch of 160 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 13.7% decrease in biomass.

In SPA 5, landings were 5.7 t against a TAC of 10 t. Catch rates increased and are just above the long-term median. The annual survey was discontinued in this area as of 2009 and prospects of future recruitment events are unknown.

A total of 125.6 t was caught in SPA 6 against at TAC of 140 t. Full Bay fleet caught 8.1 t of their 21 t TAC, and Mid Bay fleet caught 117.5 t of their 119 t TAC. These values are from Quota Monitoring and do not match values obtained by Fisheries and Oceans Canada (DFO) Science Branch scallop staff through a close examination and validation of available logbooks. Based on those values, Full Bay catch is 7.4 t and the Mid Bay catch is 115.8 t. The evidence suggests that the stock in SPA 6 is in equilibrium for the current level of exploitation. If a change in TAC is being contemplated for the 2014 season then further discussions with the Full and Mid Bay fleets on TAC options will need to take place before the season opens.

Zones de production de pétoncles dans la baie de Fundy : État du stock en 2013 et prévisions pour 2014

RÉSUMÉ

Le présent document de recherche examine la situation des stocks de pétoncles dans les zones de production de pétoncles (ZPP) 1, 2, 3, 4, 5 et 6 (baie de Fundy et ses environs) pour 2012-2013, et apporte des conseils pour 2013-2014. Trois flottilles de pêche du pétoncle indépendantes pêchent dans la baie de Fundy, soit la flottille de la totalité de la baie, la flottille du milieu de la baie et la flottille de la partie supérieure de la baie. La saison de pêche de la flottille de la totalité de la baie s'étend du 1er octobre au 30 septembre, tandis que la saison de pêche des flottilles du milieu et de la partie supérieure de la baie s'étend du 1er janvier au 31 décembre.

Dans cette évaluation, les tendances temporelles de la condition et de la composition des stocks sont utilisées pour calculer les paramètres de croissance globale qui seront utilisés dans les modèles de population. Des modifications ont été apportées aux modèles pour l'évaluation de 2013 afin d'inclure les écarts de relevé. Les points de référence éventuels ont également été élaborés et sont présentés dans le présent document.

La flottille de la totalité de la baie a pêché 206 t, pour un total autorisé des captures (TAC) de 200 t dans la ZPP 1A en 2012-2013. La condition des stocks dans cette zone s'est améliorée, et la biomasse dans les relevés a augmenté. La biomasse de la population estimée par le modèle était de 1 607 t (chairs) en 2013, soit un chiffre supérieur de 1 231 t à l'estimation pour 2012, qui était à peu près égale à la biomasse médiane de 1 206 t (de 1997 à 2011). Une prise totale de 300 t en 2013-2014 devrait correspondre au taux d'exploitation de référence et n'aboutir à aucun changement de la biomasse en 2014.

La flottille de la totalité de la baie a capturé 202,8 t, pour un TAC de 190,315 t dans la ZPP 1B en 2012-2013. La flottille du milieu de la baie a capturé 162,7 t, pour un TAC de 133,95 t, et la flottille de la partie supérieure de la baie a capturé 57,4 t, pour un TAC de 50,735 t. Les taux de prises ont augmenté pour les trois flottilles, allant jusqu'à doubler dans certains endroits. L'estimation de la biomasse de la population par le modèle était de 2 635 t (chairs) en 2013, soit une augmentation substantielle par rapport à l'estimation de 1 757 t pour 2012 et un chiffre bien supérieur à la biomasse médiane de 1 798 t. Une prise totale de 500 t en 2012-2013 devrait correspondre au taux d'exploitation de référence (0,15) et aboutir à une augmentation de la biomasse de 9,4 %.

La flottille de la totalité de la baie a capturé 261 t, pour un TAC de 260 t en 2012-2013. Les taux de prise dans la baie St. Mary's ont augmenté par rapport à ceux de 2011-2012, mais ils n'ont pas changé dans le secteur de l'île Brier et du haut-fond Lurcher. L'estimation de la biomasse de la population par le modèle était de 1 606 t (chairs) en 2013, soit une augmentation par rapport à l'estimation de 1 195 t pour 2012 et un chiffre bien supérieur à la biomasse médiane à long terme de 1 008 t. Une prise totale de 300 t en 2012-2013 devrait correspondre au taux d'exploitation de référence (0,15) et aboutir à une augmentation de la biomasse de 7,2 %.

Le total des prises de la flottille de la totalité de la baie a été de 119,4 t, pour un TAC de 110 t dans la ZPP 4 en 2012-2013. Les taux de prise dans cette zone ont augmenté en 2013 et sont supérieurs à la médiane à long terme. Le recrutement dans cette zone est faible, et n'a pratiquement pas changé par rapport à 2012. La biomasse de la population estimée par le modèle était de 1 041 t (chairs) en 2013, soit une augmentation de 33 % par rapport à l'estimation de 782 t en 2012, même si le recrutement était inférieur à la moyenne cette année-là. Une prise totale de 160 t en 2012-2013 devrait correspondre au taux d'exploitation de référence (0,15) et aboutir à une baisse de 13,7 % de la biomasse.

Dans la ZPP 5, les débarquements étaient de 5,7 t, pour un TAC de 10 t. Les taux de capture ont augmenté et sont supérieurs à la médiane à long terme. Le relevé annuel n'est plus effectué dans cette zone depuis 2009 et les perspectives relatives aux périodes de recrutement futures sont inconnues.

Un total de 125,6 t a été capturé dans la ZPP 6, par rapport à un TAC de 140 t. La flottille de la totalité de la baie a capturé 8,1 t du TAC de 21 t et la flottille du milieu de la baie a capturé 117,5 t du TAC de 119 t. Ces valeurs ont été obtenues à partir de la surveillance des quotas et ne correspondent pas aux valeurs obtenues par le personnel de la Direction des sciences de Pêches et Océans Canada (MPO) responsable du pétoncle par l'examen approfondi et la validation des journaux de bord disponibles. D'après ces valeurs, les prises de la flottille de la totalité de la baie atteignent 7,4 t et celles de la flottille du milieu de la baie, 115,8 t. Les éléments à disposition laissent entendre que le stock dans la ZPP 6 se trouve en équilibre pour le niveau actuel d'exploitation. Si un changement au TAC est envisagé pour la saison 2014, il faudra tenir des discussions avec les responsables des flottilles de la totalité et du milieu de la baie sur les options en matière de TAC avant le début de la saison de pêche.

INTRODUCTION

The Bay of Fundy is fished by three separate scallop fishing fleets: Full Bay, Mid Bay, and Upper Bay. Full Bay scallop license holders are able to fish scallops anywhere in the Bay of Fundy, and the fleet has traditionally been based in Digby. Mid Bay license holders can only fish for scallops on the northern side of the Mid Bay line (Figure 1), and the fleet consists mainly of New Brunswick-based vessels with multiple licenses for different species. Upper Bay license holders fish east of the Upper Bay line, and are often Nova Scotia- and New Brunswick-based multi-species vessels. 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 (SPAs), fleet access, 2012/2013 Total Allowable Catch (TAC), landings, and years for which data is available for both the survey (strata shown in Figure 2) and commercial catch-per-unit-effort (CPUE) are given in the table below. No TAC has been set for SPA 2 and fishing can take place subject to special license conditions. The Decision column indicates whether advice is provided in terms of a formal model or on the basis of trends in the survey indices.

Bay of Fundy scallops 2012/2013. Survey strata shown in Figure 2. N/a: not applicable.

SPA	Fleets	TAC (meats,t)	Landings (meats, t)	CPUE	Survey (strata)	Decision
1A	Full Bay	200	206.0	1976-2013	1981-2013 (8 to 16), 1984-2013 (2 to 8),1997-2002, 2004-2013 (MBS)	Model, Reference Points
1B	Full Bay	190.315	202.8	1982-2013	1997-2013 (Cape S., MBN),2002-2003, 2005-2013 (UB)	Model, Reference Points
	Mid Bay	133.95	162.8	1992-2013		
	Upper Bay	50.735	57.4	1997-2013		
2	Marginal Area	n/a	n/a	n/a	n/a	n/a
3	Full Bay	260	261	1996-2013	1996-2013	Model, Reference Points
4	Full Bay	110	109.3	1976-2013	1981-2013	Model, Reference Points
5	Full Bay	10	5.7	1976-2013	1997-2008	Trends
6	Full Bay	21	8.1	1976-2013	1997-2003, 2005-2013	Trends, Reference Points
	Mid Bay	119	116.3	1993-2013		
	All	1095	1129.4			

The last formal assessment of the stock status and scientific advice on catch levels for the Bay of Fundy and Approaches was reported in Nasmith et al. (2013). For the 2012 survey, new survey gear consisting of nine-gang steel Miracle gear, with flat tire chafers and two inch teeth was used in SPAs 1A, 1B, 3, and 4. A comparison study between the Miracle gear and the four-gang Digby gear previously used for the survey was conducted at that time. The results showed that the two gears were comparable in catch for both commercial and recruit size scallops and that no conversion factor was needed for the new survey series (Smith et al. 2012a). In 2013, the new gear was used for the first time in SPA 6. Industry members questioned the use of toothed gear in SPA 3 and the 2013 survey was conducted with flat-bar gear in this area. A series of comparative tows with toothed gear was also included in the survey and those results are presented in the section on SPA 3 in this report.

Scallop removals accounted for in the assessment include landings from the inshore scallop fleets and Food, Social and Ceremonial (FSC) catch when applicable. Landed recreational and FSC catch by dip netting, diving, tongs, and hand are not recorded and, therefore, not available.

REFERENCE POINTS

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. In 2012 and 2013, DFO Science continued consultations with industry about the implementation of the Precautionary Approach and the development of reference points as specified in DFO policy[1]. In addition, the Full Bay scallop fishery was certified by the Marine Stewardship Council in 2013 and is required to implement the Precautionary Approach along with reference points as a condition of this certification[2].

For those areas with an assessment model (SPA 1A, 1B, 3, and 4), the fishing industry has agreed to set the Lower Reference Points (LRPs) to the lowest biomass in the time series from which a sustained recovery occurred. Determining how to set the Upper Stock Reference (USR) point has been more problematic and, after meetings of an industry/DFO working group this summer (2013), it was decided that these would be based on the equilibrium biomass and exploitation rate associated with maximum catch. These were obtained by projecting the assessment model forward by 50 years from the current year for a range of constant exploitation rates. Mortality rates were sampled from annual estimates in the current model and growth was simulated by predicting an average shell height and randomly generating condition factor based on past estimates. Median recruitment was assumed due to the lack of evidence for stock/recruitment relationships. This is admittedly a strong assumption for the recruitment dynamics as it implies strong density dependence and does not take into account potential changes in recruitment at very low or very high stock sizes. Industry agreed to this method, acknowledging that using median recruitment is a conservative approach. Research on recruitment dynamics for scallops is needed before this approach can be improved upon.

Once an appropriate exploitation rate was determined from the projections, a range of candidate biomass levels for the USR were evaluated in terms of a Harvest Control Rule (HCR) similar to that specified in the DFO policy with the following elements (see also Figure 3):

- If stock status is above USR (healthy), fish at reference exploitation level as long as <50% chance of entering the cautious zone. If not, then decrease exploitation until <50%.
- If stock is below USR but above LRP (cautious), fish at an exploitation determined by the formula (Biomass-LRP)/(USR-LRP)×reference exploitation level, if greater than minimum TAC. A minimum TAC was set for which the fishery could be open, so that if the exploitation results in a TAC less than the minimum, the TAC will be set at the minimum unless that results in a >50% chance that the stock will drop below the LRP in which case the fishery will close.
- If stock is below LRP, the fishery is closed.

Performance of the HRC for specific USRs were evaluated over a 50 year time frame in the context of median biomass, exploitation, catch, and percent of time the fishery was closed due to the biomass falling below the LRP. The median biomass and catch provided from this evaluation are not intended to predict actual biomass and catch because the 50 year projection

[1] For more information on the DFO policy, please visit website: http://www.dfo-mpo.gc.ca/fm-gp/peches-fisheries/fish-ren-peche/sff-cpd/precaution-eng.htm (accessed 25 April 2014).
[2] For more information on the FBSA Canada Full Bay sea Scallop status, please visit the MSC website: http://www.msc.org/track-a-fishery/fisheries-in-the-program/certified/north-west-atlantic/fbsa_canada_full_bay_sea_scallop (accessed 25 April 2014).

was made using median recruitment. Instead, the results for the various USRs should be evaluated in two ways. First, the USR results are to be compared to the biomass and catch expected for the case where no USR was used (removal reference point only). Potential choices for USR should provide higher median catches than that for the no-USR case. Secondly, choices of a USR to be used can be evaluated with respect to expected median catch and percentage of time that the harvest control predicts that the fishery could be closed. The standard harvest scenario tables used to provide TAC advice now include probabilities associated with exceeding the LRP and USR, with the latter chosen from the evaluation described above for illustration purposes.

POPULATION MODEL

This assessment models the population dynamics for all SPAs (excluding 5 and 6) using a simplified version of the assessment model (Quinn and Deriso 1999) with modifications presented in Smith et al. (2012b),

$$B_{t+1} = \left(e^{-m_t} g_t \left(B_t - C_t\right) + e^{-m_t} g_{Rt} R_t\right)\tau_t \quad (1)$$

where B_t, g_t, and m_t are the population biomass, growth rate 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 and g_{Rt} is the growth rate of the portion of the population recruiting to the fishery in year $t+1$. C_t is the commercial catch in year t. The τ_t represents random process 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 modifications implemented in Smith et al. (2012b), and used here, were intended to better estimate and predict biomass by including annual and spatial variability in condition factor for the relationship between meat weight and shell height. Condition factor was calculated as the ratio of meat weight over the cube of the shell height, assuming an isometric length weight relationship (Hubley et al. 2011),

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

Spatial patterns of growth and condition were examined and, in the case of condition, incorporated into estimates of survey biomass. In order to calculate weight, average shell heights of commercial or recruit size scallops from the survey were converted to meat weights using the annual condition factors.

The annual varying growth rates for the model are the ratios between the observed average meat weight of commercial or recruit scallops and the observed average meat weight of the same scallops the following year. The growth rates (g_t and g_{Rt}) for the model are then calculated as

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

where $\overline{w}_t$ is the average weight of scallops adjusted for condition in year t and $\overline{w}_{t-1}$ is the average weight of those same scallops adjusted for condition in year t-1 (Smith et al. 2012b). Natural mortality (m) was estimated within the model using ratio of clappers (dead scallops with hinged shells) to live scallops and the estimated dissolution time (*S*) (Smith and Lundy 2002). Other details of the model including the formulation of the prior distributions can be found in Smith et al. (2008, 2012b). The current approach to estimating the catchability of the survey was detailed in DFO (2004, pages 11–14).

In previous assessments, single variance terms were estimated for the commercial size and recruit size survey observation models. However, annual variances are routinely estimated for both survey indices and design changes have been made in recent years to reduce those variances. Smith and Hubley (2013) present methods for incorporating these annual variances into the assessment models and all models in this assessment include sample variances from the survey time series in the observation models. The main difference between models with and without the annual survey variances included is that, in the latter case, the more recent model estimates have increased precision reflecting changes in the survey designs.

Model forecasts of biomass require estimates of expected biomass growth (and condition) and natural mortality for future years. These estimates are based on current conditions and, therefore, may not reflect actual changes over the next two years.

SPA 1A: SOUTHWEST BAY OF FUNDY

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 206 t against a TAC of 200 t during the 2012/2013 fishery in SPA 1B. For the 2013/2014 fishing season, an interim quota of 150 t was set for 1 October 2013. As of 28 October 2013, 4.18 t landings were reported. Annual trends for landings and quotas are presented in Figure 4. TAC has decreased 100 t in this area since 2010/2011.

Full Bay fleet TAC and landings in SPA 1A.

Commercial Data	Avg. 02–07[1]	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014
TAC (t)	510	216	265	300	300	200	200	150[3]
Landing (t)	399.6	226	267	297	278.1	206.4	206.0[2]	4.2[2]

1. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.
2. Landings based on quota report 28 October 2013.
3. Interim TAC.

In the 2012/2013, SPA 1A fishery, there were 53 vessels, and 99% of the fishing log records were usable (Table 1). Commercial catch rates in 2012/2013 increased from the 2011/2012 fishing season to 20.5 kg/h, above the long-term median (1995/1996 to 2010/2012) of 15.3 kg/h. Effort decreased to below the long-term median (Figure 5). The highest catch rates were along the border with SPA 4 and in Middle Bay South near the Mid Bay line and the Outer strata of Upper Bay. Most fishing in 2012/2013 was conducted in the 2 to 8 and 8 to 16 mile areas (Figure 6).

SURVEY

The 2013 survey in SPA 1A was conducted in July and August and consisted of 130 tows in three subareas: 2 to 8 miles (11 tows; strata 6, 7 in Figure 2), 8 to 16 miles (73 tows; strata 12-20 in Figure 2), and Middle Bay South (46 tows).

Condition factor (g/dm^3) increased in this area over the last two years. The increase was most dramatic in the Middle Bay South subarea, which has increased from 11 to 15 g/dm^3 since 2011 (Figure 7). The condition in 2 to 8 mile subarea did not change in 2013, after increasing between 2011 and 2012. Condition in Middle Bay South and the 2 to 8 mile areas is evenly distributed (Figure 8), while the 8 to 16 mile area has a gradient of condition, starting out higher close to the Middle Bay South and decreasing further down the Bay.

The abundance of commercial scallop (≥ 80 mm) in the survey has been relatively stable in all subareas of SPA 1A since the last large year class recruited. In 2013, there was no substantial change in commercial abundance in any of the areas (figures 9-11). Improvements in condition in Middle Bay South and 8 to 16 mile have resulted in increases in the biomass of commercial scallops in the survey. There was little change in recruit (65-79 mm) scallops in the survey for biomass or abundance (figures 9-11). Combined population abundance for SPA 1A has changed little each year in the past five years, but there was an increase in 2013 (Figure 12). The distribution of commercial scallop has not changed since 2012, with higher abundances and biomass found in the 8 to 16 mile area, below Digby Gut (Figure 13), while distribution is patchier in the 2 to 8 mile area, and Middle Bay South. Recruits were present in Middle Bay South near the Mid Bay Line and the margin with Outer Bay. Recruits were more widely distributed in the 8 to 16 mile area, with the greater biomass found along the Mid Bay line (Figure 14). Spatial variability in condition and the average shell height of the commercial scallops from the survey was used to calculate what the meat count would be for a given location assuming all scallops > 80 mm were kept; therefore, meat count is affected by condition but also by shell height frequencies in a subarea. Meat counts have changed along with condition in SPA 1A. Meat count is generally better in Middle Bay South, and there is greater meat counts in the 8 to 16 mile area below Digby Gut, where condition is also poor (Figure 15).

Pre-recruits (<65 mm) were present in all subareas of SPA 1A, with the greatest abundance in the 8 to 16 mile zone, near the Mid Bay line and below Digby Gut (Figure 16). Pre-recruits in this area had a mode of 40 mm (figures 17-19). Scallops of this size are about 1 year old. Since this is the size limit for the lined fishing gear used in the survey (mesh size of lined gear is 38 mm), estimates for scallop under 40 mm should be considered qualitative. Pre-recruit scallops of this size are often seen in this area in very low numbers. The abundance of pre-recruits currently observed in the 8 to 16 mile area (Figure 18) is the highest in the survey since 2000.

The abundance of commercial and recruit clappers in the survey has been very low in all subareas of SPA 1A for the past decade (Figure 20).

REFERENCE POINTS

The equilibrium analysis derived from model simulations for the next 50 years shows that exploitation rates near 0.15 resulted in the highest median catches, while fishing at lower exploitation rates resulted in a higher median biomass (Figure 21). These results, however, are based on strong assumptions about recruitment and are meant to illustrate how a HCR can make relative improvements to long-term median catch levels. Table 2 shows median catch and biomass levels over the 50 year projections when a HCR is used with a LRP of 480 t and various USRs. Generally, using a HCR will increase the median catch and biomass. A USR of 1000 t specifically produced the highest median catch (205 t) with a median biomass of 1087 t, compared to a median catch of 163 t and a median biomass of 817 t when fished at similar exploitation rates but without a HCR (Table 2). Once LRP and USR values are selected, the probabilities of biomass dropping below these levels for various catch scenarios become important factors to consider in setting the TAC (Table 3).

POPULATION MODEL

The stock assessment model was fit to the survey and catch data from 1997 to 2013. Stratified survey indices from both the 8 to 16 and 2 to 8 mile areas 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 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. In general, the addition of another year of data changed very little over the results. The model fit the survey mean estimates quite closely for both commercial size and recruit size scallops, and including sample variances from the survey time series in the observation models reduced the amount of uncertainty in the estimates compared to those presented in Nasmith et al. (2013) (Figure 22). The comparison of posterior distributions with the priors indicated that the informative priors for the S term and survey catchability q_I were influential (Figure 23).

STOCK STATUS AND FORECAST

Exploitation and survival estimates (i.e., e^{-m}) are presented in Figure 24. Natural mortality has been quite low since 2008, while exploitation had increased from 2007, levelled off in 2010, and then declined to 0.11 in 2013. Biomass posterior medians along with 95% credible intervals indicate an increase in the biomass of commercial and recruit size scallops in the last four years (Figure 25). Population biomass estimated by the model was 1,607 t (meats) in 2013, up from the estimate of 1,231 t for 2012, which was approximately equal to the median biomass of 1,206 t. Estimates of recruit biomass increased from 79 t in 2012 to 152 t in 2013, which is well above the long-term median level of 65 t. Biomass is projected to increase by 10% under the interim TAC of 150 t, which would correspond to an exploitation rate of 0.08. Other catch scenarios for 2013/2014, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2014/2015) are presented in Table 3.

A catch of 300 t for 2013/2014 should correspond to the reference exploitation rate and is projected to result in no change in biomass for 2014. The probability that biomass would decline at this level of catch is 0.50. If this catch was realized in the 2013/2014 season, then a catch of 288 t next year (2014/2015) 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 (Figure 26). Another consequence of the reduced uncertainty in the model, now that survey variances are being incorporated, was that it produced much more precise predictions of biomass for the following year. Whereas in Nasmith et al. (2013), all of the model estimates fall within the 50% credible interval of the prediction from the previous year these credible intervals were much wider and not as meaningful as the are now. In Figure 26, it was seen that the estimates usually fall near to or within the 50% credible interval, but the 2012 prediction for 2013 biomass is somewhat lower than the 2013 estimate. However, this was largely due to an unexpected increase in condition and when that is factored into the analysis the predictions and estimates are closer (Figure 26, lower panel).

SPA 1B: NORTHWEST/UPPER BAY OF FUNDY

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 202.77 t against a TAC of 190.315 t in 2012/2013. An interim quota of 125 t was set for 1 October 2013 for the Full Bay 2012/2013 season and as of 28 October, 17.67 t had been landed.

Full Bay fleet TAC and landings in SPA 1B.

Commercial Data	Avg. 02–07[1]	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014
TAC (t)	185	206.3	195.4	205.5	203	152.3	190.3	125[3]
Landing (t)	154	210	192.7	151.9	84.2	159.9	202.8[2]	17.7[2]

1. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.
2. Landings based on quota report as of 28 October 2013.
3. Interim TAC.

The Mid Bay fleet caught 162.73 t against a TAC of 133.95 t, and Upper Bay caught 57.45 t against a TAC of 50.735 t. Landings for all three fleets can be seen in Figure 27.

Mid Bay (MB) and Upper Bay (UB) TAC and landings in SPA 1B.

Commercial Data	Avg. 02–07	2008	2009	2010	2011	2012	2013
MB TAC (t)[1]	165	148.3	137.5	144.7	142.9	107.2	133.95
MB Landing (t)	143.3	120	142.5	138.6	123.3	103.1	162.7[2]
UB TAC (t)	n/a[1]	85.5	52.1	54.8	54.1	40.6	50.7
UB Landing (t)	64.7	87.4	54.4	54.4	54.7	39.97	57.4[2]

1. TAC in 1B for 2002/2003 to 2006-2007 was from MB and UB combined.
2. Landings based on quota report as of 28 October 2013.

In the 2012/2013 SPA 1B fishery, there were 129 vessels and 97% of the fishing log records were usable (Table 1). Catch rates increased for all fleets fishing in SPA 1B (Figure 28). In 28B and 28D, catch rates almost doubled for Full Bay. Mid Bay had increases of over 50% in both areas fished, and Upper Bay had an increase of 62% in 28D and 42% in 28C. The fleets in 1B tend to cover the same areas from year to year, so patterns, in terms of location, observed in 2013 were similar to what was seen in 2012 (Figure 29). These increases in catch rate are from increases in abundance, biomass, and condition.

SURVEY

The 2013 survey in SPA 1B took place in July and August and consisted of 146 tows in seven subareas (Figure 2). The survey excluded 28D Inner and the southern portion of Outer 28D as past work has shown these areas to be marginal scallop habitat (Smith et al. 2009).

Condition factor increased in all subareas of SPA 1B since 2011 (Figure 30). Most subareas are at, or near, a high in the time series. In 2013, the greatest increases were observed in Middle Bay North, and the smallest gains in Cape Spencer. Condition was distributed evenly throughout most of SPA 1B (Figure 8). The best condition, in Middle Bay North, was found along the Mid Bay line. There was similarly good condition in the Outer strata, also near the Mid Bay line and the margin with Middle Bay South. Meat counts improved over 2012 for many of the subareas (Figure 15, 2012 not shown). In Upper Bay, meat counts were greater in the northern half of the subarea in 2012, but that changed in 2013 resulting in lower (better) meat counts than 2012, with the southern half of the subarea having lowest meat counts for this subarea. Scots Bay and Spencer's Island have meat counts greater than 45 scallops/ 500 g.

The abundance of commercial scallop in Cape Spencer increased in 2013 after a few years of declines, and this has likely resulted from the increase in recruits observed in 2012 (Figure 31). There were more young commercial scallops in the survey in 2013 (90-95 mm), and older commercial scallop have a mode of 120-125 mm (Figure 32). There have been positive signs of recruitment in this area for the past two years, with the number of recruits in the survey increasing over the past two years (Figure 31). Biomass of commercial scallops has also increased in this area after remaining fairly stable from 2009-2012. Distribution of commercial scallop abundance and biomass in Cape Spencer is more evenly distributed than in some other areas (Figure 13). Recruits were found all over this area (Figure 14). The abundance of pre-recruit scallops in this area is the highest it has been in recent years (Figure 32), and they were found all over Cape Spencer (Figure 16).

The abundance of commercial scallop in Middle Bay North increased slightly in 2013 after a few years of decline (Figure 33). Biomass of commercial scallop also increased slightly in 2013, but overall biomass in this area has not changed much over the last five to six years. Abundance and biomass of commercial scallop in this area is generally patchy; there are areas of better biomass near the border with Cape Spencer and along the border with Upper Bay (Figure 13). In 2012, there was an increase in pre-recruit scallops in Middle Bay North. In 2013, the number of recruit scallops in the survey increased (figures 33, 34), and they were found in greatest numbers along the border with Upper Bay but were also wide spread throughout the subarea (Figure 14). Pre-recruits were observed in this subarea again in 2013 (Figure 34), although at lower abundances than in some other parts of the Bay. There was a high abundance of pre-recruits in the middle of the subarea (Figure 16), which is an area that generally does not have high recruit or commercial densities (figures 13, 14).

Upper Bay (28C) also had an increase in the number and biomass of commercial scallops in the survey (Figure 35). This abundance is concentrated mostly in the bed near the Upper Bay Line (Figure 13). In 2012, there was an increase in pre-recruits in this subarea (Figure 36), and in 2013, there was an increase in recruit scallop numbers from 0.8 to 3.3 per tow in the survey (Figure 35). These recruits are also mostly located in the bed that lies on the Upper Bay Line (Figure 14). Pre-recruits were observed again in 2013, at a larger range of sizes, but in numbers comparable to some previous years (e.g., 2008; Figure 36).

Commercial scallop abundance increased in Advocate Harbour, as did biomass of commercial scallop (Figure 37). The commercial population in this area is relatively young, with a mode of 90-100 mm. In 2012, pre-recruit scallops were observed in this subarea. In 2013, they reached recruit size, and the numbers of recruit scallops in the survey almost doubled from 24.3 per tow to 42.5 per tow, which is the highest recruit abundance observed in this area since 2009 (figures 37, 38). Historically, Advocate has good recruitment; cohorts seen as pre-recruits are often seen recruiting into the fishery. Pre-recruits are present in this subarea in most years, and in 2013 there were present in lower numbers than 2012 (Figure 38).

Outer Bay did not follow the trend observed in other parts of SPA 1B, commercial numbers in this area declined by about 40% from 17 to 9.9 per tow. This is the second lowest in the 12 year time series, the lowest being 4.1 per tow in 2010 (Figure 39). Commercial scallops less than 120 mm are present only in very low numbers (Figure 40). Commercial scallops in the area surveyed are patchy and tend to be more abundant near Isle Haute and closer to Advocate Harbour (Figure 13). Recruitment in this subarea is usually very low. In 2012, no recruits were observed. In 2013, they were observed at 0.02 per tow, which is greater than the time series median for this subarea of 0.006 per tow (Figure 39). There were some pre-recruits in Outer

Bay in 2013, the abundance of which were low compared to other areas, but high for this subarea (Figure 40).

The commercial abundance from the survey in Spencer's Island was 0.3 scallops per tow (Figure 41). Abundance has been declining in this subarea for the past two years and is at a low in the nine-year time series. However, the survey only had five tows in this subarea, so it is likely that commercial size scallop are present, but not in high abundances. The abundance of recruits increased from a time series low of 5.9 per tow in 2012 to 11.1 per tow in 2013 (figures 41, 42). There were very few pre-recruits observed in this subarea (figures 42, 16).

Scots Bay has had increasing abundances and biomass of both commercial and recruit scallops over the last two years (Figure 43). However, survey coverage in this subarea is sparse (3 tows in 2013). Commercial scallops in Scots Bay are young, with a mode of 95-100 mm (Figure 44). While there were some pre-recruits in the survey, low coverage in this area means that the survey does not track recruitment as well as in some other subareas.

Overall, biomass in SPA 1B is always greater in Cape Spencer and Middle Bay North (28B), with all other areas containing lower total biomass. The commercial biomass increased in 28B, and recruit biomass also increased mainly in the Cape Spencer subarea (Figure 45).

Clapper abundance in the survey is variable throughout the subareas. In 2013, the number of commercial clappers increased in a number of subareas (Figure 46), most notably in Scots Bay. Scots Bay also had the largest increase, and the largest abundance, of recruit clappers.

REFERENCE POINTS

The equilibrium analysis derived from model simulations for the next 50 years shows that exploitation rates near 0.15 resulted in the highest median catches, while fishing at lower exploitation rates resulted in a higher median biomass (Figure 47). These results, however, are based on strong assumptions about recruitment and are meant to illustrate how an HCR can make relative improvements to long-term median catch levels. Table 4 shows median catch and biomass levels over the 50 year projections, when a HCR is used with a LRP of 880 t and various USRs. Generally, using a HCR will increase the median catch and biomass. A USR of 1800 t specifically produced the highest median catch (356 t) with a median biomass of 1937 t, compared to a median catch of 271 t and a median biomass of 1355 t when fished at similar exploitation rates but without a HCR (Table 4). Once LRP and USR values are selected, the probabilities of biomass dropping below these levels for various catch scenarios become important factors to consider in setting the TAC (Table 5).

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 2013. Middle Bay North was divided into two strata by a line from (Lat. 45.237°, Lon. -65.197°) to (Lat. 45.459°, Lon. -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°, Lon. -65.032°) to (Lat. 45.292°, Lon. -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 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 recruits, and including sample variances from the survey time series in the observation models reduced the amount of uncertainty in the estimates compared to those presented in Nasmith et al. (2013) (Figure 48). The posterior distributions show well defined posteriors for these parameters and that the prior for the survey catchability q_I was fairly influential (Figure 49).

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 (Figure 50). The estimated exploitation rate for 2013 was 0.14. Population biomass estimated by the model was 2,635 t (meats) in 2013, a substantial increase from the estimate of 1,757 t for 2012 and well above the median biomass of 1,798 t. Estimates of recruit biomass decreased slightly from 580 t in 2012 to 449 t in 2013, but it remains well above the long-term median level of 134 t (Figure 51). Biomass is projected to increase to 3266 t under the interim TAC of 125 t, which would correspond to an exploitation rate of 0.04. The probability that biomass would decline at this level of catch is 0.18. Other catch scenarios for 2012/2013, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2014/2015), are presented in Table 5. A catch of 500 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 9.4% increase in biomass. If this catch was realized in the current season, then a catch of 555 t next year would be expected to have a 50% chance of resulting in an exploitation rate greater than 0.15 for 2013/2014 (Table 5).

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 (Figure 52). Biomass predictions are more precise than in Nasmith et al. (2013) as a result of survey variances being incorporated in the model. Still, most 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

The Full Bay fleet caught a total of 260.98 t against a TAC of 260 t in 2012/2013. An interim quota for the 2013/2014 season of 130 t was set for 1 October 2013 for the Brier/Lurcher area. As of 21 October, 135.56 t had been landed and the area was closed pending the stock assessment. Trends in landings and TAC can be seen in Figure 53. In 2012, extra TAC (75 t) was allotted to 3B, an area of Lurcher not generally fished. Only 5.1 t of that TAC was caught.

Full Bay fleet TAC and landings in SPA 3.

Commercial Data	Avg. 2002-2007	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014
TAC (t)	240	70	60	50	50	300	260	130[1]
Landing (t)	177	80.2	63	56	72.96	264.8	261	135.6[2]

1. Interim TAC.
2. Landings based on quota report as of 28 October 2013.

In the 2012/2013 SPA 3 fishery, there were 63 vessels, and 97% of the fishing log records were usable (Table 1). Commercial catch rates in 2013 for St. Mary's Bay increased 26% from 2012, while June catch rates for the Brier/Lurcher area did not change (Figure 54). Mean daily catch rates for the four fishing periods from 1 October 2011 to June 2013 are presented in Figure 55. Catch rates in June 2013 were up from June of the previous year, but down from the start of the fishery in October (Figure 55).

Fishing in the Brier/Lurcher area continued to be concentrated in the inshore part of the area as identified previously using Vessel Monitoring System (VMS) data, which was used to re-stratify the survey for the 2011 assessment (Smith et al. 2012b; Figure 56). Some fishing did take place in the Outside area but at the margin of the Inside area.

COMPARATIVE SURVEY

In the 2012 survey of SPA 1, 3, and 4, the same gear configuration was used for all areas, that is Miracle drags (2 ft × 1 ft) each with 5×2-inch teeth and 3 1/4 inch rings in a nine-gang configuration (Smith et al. 2012a). Industry representatives at the 2012 DFO Maritimes Region science advisory process meeting criticized the use of toothed gear in SPA 3 and recommended changing the gear for the 2013 survey. A few members of the industry had fished at some of the science survey locations and thought their catch far exceeded what was observed at the same tow in the survey, with the difference being attributed to the teeth on the survey gear and the flat bar (i.e., no teeth) on their gear. The 2013 survey of SPA 3 was carried out with the flat bar gear, but it included comparative tows between gear with and without teeth to assess the magnitude of the problem and to determine what, if any, correction may be needed to the 2012 data.

Methods

The Miracle gear for the 2013 SPA 3 survey was configured with nine drags, each having one side with 5×2-inch teeth and the other with flat bar (no teeth). The comparison was assigned 15 tows that were randomly selected between the Briar survey area, the Lurcher survey area, and St. Mary's Bay to ensure areas with different bottom types and different scallop abundances were sampled. While it would have been ideal to randomize which configuration was fished first at each location, the logistics of setting up the side of the gear to be towed resulted in the side fished second at one location being fished first at the next location. In a few cases, the gear rotated in the water and fished the toothed side first thus determining the towing order.

At each station, 8 minute tows, at a speed of 2.5-3.5 knots, were conducted. For each tow, the tow track was recorded using OLEX navigational software, along with a distance coefficient, start and end location, bearing, tide cycle, depth, and amount of wire out. The catch was dumped on the table with the dividers installed to ensure the catch per drag was separate. For each catch, the volume of scallop catch was recorded in bushels for the lined (2) and all unlined drags (7), and then the shell height frequency in the lined drags and unlined drags were determined. The gear was rotated to the opposite side and the tow was repeated on the same tow track, on the same tide cycle with same height frequency information for the lined and unlined gear.

The statistical analysis of the data followed the methods used in Smith et al. (2012a). The numbers of scallops caught by each gear (y_{ij}) were characterized by a generalized linear model using a gamma distribution for the numbers caught and a log link for the linear predictor. That is,

$$E[y_{ij}] = \exp(\alpha + \gamma_j),$$

where α is the overall mean catch and γ_j is a four-level factor defined as:

1. Catches from Toothed gear|Toothed towed first
2. Catches from Flat bar gear|Toothed towed first
3. Catches from Toothed gear|Flat bar towed first
4. Catches from Flat bar gear|Flat bar towed first

The contrasts of interest here were between levels 1 and 2, and levels 3 and 4. These contrasts were tested using a-posterior multiple comparison tests available in the R package multcomp (Hothorn et al. 2008).

Results

All 15 tows were successfully completed (Figure 57). A comparison of the mean number per tow from the two gears for scallops above and below commercial size (80 mm shell height) indicates that there was little difference between catches (Figure 58). For scallops less than commercial size, 14 of the tows had similar numbers per tow except for tows 74/75 where the gear with teeth caught far more scallops in the 20 to 30 mm range than the gear with just the flat bar on the drags. The mean shell height frequencies for the two gear types with these tows removed were almost identical over most of the shell height bins (Figure 59). Within the size classes used for the stock assessment, mean number per tow was always higher for teeth gear, but the standard errors for the means were quite high for both gears suggesting that these differences may not be significant given the observed variability (Table 6).

The differences between the catches from the tow gears depended upon tow order, with the flat bar gear having higher numbers per tow for all except the recruit size class when it was towed second at a site (Table 7, see also Figure 60). The teeth gear had higher numbers per tow for all size classes when it was towed second. However, results from statistical tests of the differences between the mean catches based on tow order did not find any significant differences between the two gears with or without tows 74 and 75 included (only latter results presented in Table 8).

The scallop survey gear uses liners in two of the drags and no liner in the remaining seven drags. The liners are used to capture the smaller scallops that could fit through the rings in the drags. Standard survey protocol for all inshore areas is to use the catches from the lined gear to estimate the numbers of scallops less than 80 mm in shell height while the unlined gear is used to estimate the numbers of scallops greater than or equal to 80 mm. While both lined and unlined gear will capture scallops over all sizes, the experience with the Digby gear has been that the lined gear will not capture as many scallops ≥80 mm as the unlined gear. The shell height frequencies for lined and unlined gear for the flat bar version of the gear used in this study showed differences for the commercial size scallops consistent with what would be expected for the Digby gear that also lacked teeth (Figure 61, Table 9). However, the Miracle gear with teeth showed very little difference between lined and unlined gear (Table 9).

Discussion

The tows used to calculate survey estimates in 2013 for SPA 3 were all conducted with the flat bar configuration of the survey gear. The flat bar gear caught more rocks, shells, and other material from the bottom and catches usually took much longer to pick through than those from the gear with teeth. The first impression of the scientific crew during the survey was that the flat bar gear was catching more scallops than the gear with teeth, but the results presented here indicate that this was not true overall. Catches were similar enough within the variation observed that survey indices calculated using the tows from either configuration would not result in different estimates of stock status. Miracle gear with teeth have been used for the 2012 and 2013 surveys in the Bay of Fundy and, based on these results, there does not seem to be any reason to not use the same gear configuration for future surveys in SPA 3.

SURVEY

The 2013 survey in SPA 3 took place in June and consisted of 135 tows in St. Mary's Bay (23 tows) and Brier Island/Lurcher Shoals (BILU, 112 tows). As in the most recent assessments, the Brier/Lurcher area was separated based on stratification from VMS data into "Inside" and "Outside" areas. The Inside area represents the frequently fished areas. The Outside area represents an area that has not been routinely fished in recent years. The Inside area had 64 tows and the Outside area had 61. As in previous assessments, survey results are presented for St. Mary's Bay and Brier/Lurcher, as well as the Inside and Outside areas of Brier/Lurcher.

Condition increased over all of SPA 3 (Figure 62). The best condition was observed in St. Mary's Bay, which increased in 2013 after two years of decline. Condition in St. Mary's Bay is currently above the long-term (1996-2012) mean of 14.7 g/dm^3. Condition in Brier/Lurcher is better in the Inside area, closer to shore (Figure 63). Condition in the Inside area is above the long-term mean of 9.1 g/dm^3, while condition in the Outside area is at the long-term mean for that subarea (8.3 g/dm^3), after being below the mean since 2005 (Figure 62). The abundance of commercial scallops increased in the Brier/Lurcher area, but the increase was only in the Inside VMS area and abundance actually decreased in the Outside VMS area (Figure 64). There was no change in St. Mary's Bay abundance. Biomass of commercial scallops has increased in St. Mary's Bay and Inside Brier/Lurcher since 2010 (Figure 65). Weight per tow decreased in the Outside area in 2013. In areas with good condition, high abundance is indicative of high biomass, and that is observed in the distribution of commercial scallop and biomass in St. Mary's Bay and the Inside VMS area of Brier Lurcher (Figure 66). The lowest densities and biomass are seen in the Outside area. The meat count pattern in 2013 is similar to 2012, with St. Mary's Bay having generally lower counts, and there is a large area of high counts at the Western edge of Brier/Lurcher (Figure 67).

The abundance of recruits in the survey decreased in SPA 3. Number and biomass per tow of recruits in St. Mary's Bay decreased by 27 and 21%, respectively, but in both cases current values are above time series medians for this subarea. In the Outside area, there was a 60% decrease in recruits per tow, and it is at the lowest since 2006. The Inside area changed the least from 2012, with only minor decreases in numbers and abundance of 6 and 3%, respectively. While recruits are present in all subareas, they are more widespread in St. Mary's Bay and the Inside area (Figure 68).

Pre-recruits were not observed in St. Mary's Bay to the extent they were in other areas (Figure 69), although scallops of this size are commonly found in St. Mary's Bay (Figure 70). Pre-recruits were seen in very large abundances in both the Inside and Outside VMS area of Brier/Lurcher (figures 69, 71, 72). High abundances have been observed in these areas in the past. The Outside area does not have a good history of recruitment of these cohorts; it tends to have less suitable habitat for scallop. Recently, in 2007, there was a high abundance of pre-recruits (mode 25-30 mm) in the Outside area that did not survive to recruit size in appreciable numbers (Figure 72). Generally, if pre-recruits of these sizes survive in significant numbers, it is in the Inside area, which has more suitable habitat.

Clappers in St. Mary's Bay and the Inside area did not change from 2012, and in the Outside area clappers decreased (Figure 73).

REFERENCE POINTS

The equilibrium analysis derived from model simulations for the next 50 years shows that exploitation rates near 0.15 resulted in the highest median catches, while fishing at lower exploitation rates resulted in a higher median biomass (Figure 74). These results, however, are based on strong assumptions about recruitment and are meant to illustrate how an HCR can make relative improvements to long-term median catch levels. Table 10 shows median catch and biomass levels over the 50 year projections when a HCR is used with a LRP of 600 t and various USRs. Generally, using a HCR will increase the median catch and biomass. A USR of 1000 t specifically produced the highest median catch (206 t) with a median biomass of 1,092 t, compared to a median catch of 142 t and a median biomass of 708 t when fished at similar exploitation rates but without a HCR (Table 10). Once LRP and USR values are selected, the probabilities of biomass dropping below these levels for various catch scenarios become important factors to consider in setting the TAC (Table 11).

POPULATION MODEL

The stock assessment 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 2012 survey occurred after the fishery in June, the catch in October 2012 was included in predicting the biomass for next June to correspond to the 2013 survey. Survey indices from both St. Mary's Bay and BILU-Inside were used, combined with the missing years in the former series and filled in using simple interpolation. 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 (Figure 75). Generally, including sample variances from the survey time series in the observation models reduced the amount of uncertainty in the estimates compared to those presented in Nasmith et al. (2013). The posterior distributions show well defined posteriors for the estimated parameters (Figure 76).

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 (Figure 77). The estimated exploitation rate for 2013 was 0.14. Population biomass estimated by the model was 1,606 t (meats) in 2013, an increase from the estimate of 1,195 t for 2012 and well above the long-term median biomass of 1,008 t. The estimate of recruit biomass for 2013 was 149 t, similar to what it was in 2012 (147 t) and well above the long-term median level of 47 t (Figure 78). Biomass is projected to increase to 1,932 t under the interim TAC of 130 t, which would correspond to an exploitation rate of 0.06. The probability that biomass would decline at this level of catch is 0.26. Other catch scenarios for 2013/2014, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2014/2015), are presented in Table 11. A catch of 300 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 7.2% increase in biomass. If this catch was realized in the current season, then a catch of 332 t next year would be expected to have a 50% chance of resulting in an exploitation rate greater than 0.15 for 2014/2015.

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 (Figure 79). Biomass predictions are more precise than in Nasmith et al. (2013) as a result of survey variances being incorporated in the model making it more likely that estimates will fall outside the 50% credible interval of the prediction from the previous year. Under predictions of biomass have occurred in the past 3 years where the estimated biomass was greater than the 75th percentile of the prediction (Figure 79). This was noted in Nasmith et al. (2013) and discussed as to the possible causes one of which was changing condition which when taken into account does reduce the differences somewhat (Figure 79, lower panel). However, the root of this discrepency lies in the survey results which found higher numbers of fully-recruited scallops in 2013 than one would expect given the numbers of fully-recruited and recuit size scallops seen in the 2012 survey.

SPA 4: DIGBY

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 109.36 t against a TAC of 110 t in 2012/2013. An interim quota for the 2013/2014 season of 80 t was set for 1 October 2013. As of 28 October, 16.5 t had been landed. Trends in landings and TAC can be seen in Figure 80.

Full Bay fleet TAC and landings in SPA 4.

Commercial Data	Avg. 02–07	2007/ 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014
TAC (t)	608	100	100	120	140	120	110	80[1]
Landing (t)	554	79	98	114	138.2	114.8	109.4	16.5[2]

[1] Interim TAC.
[2] Landings based on quota report as of 28 October 2013.

In the 2012/2013 SPA 4 fishery, there were 48 vessels, and 98% of the fishing log records were usable (Table 1). Commercial catch rates in SPA 4 increased from 15 to 20 kg/h in 2013, and catch rates are currently above the long-term median. Since 2006/2007, fishing effort has been below the long-term median, and in 2013 it decreased by about 800 hours (Figure 81). Catch rates improved in most parts of SPA 4 (Figure 82). More of the near shore 0-2 mile zone, both above and below the Digby Gut, was fished in 2012 than 2013, and catch rates were better than in 2012.

SURVEY

The 2013 SPA 4 survey took place in July and August and consisted of 91 tows. Condition in this area increased in 2013 and is well above the median and among the highs in the time series (Figure 83). Condition is best above Digby Gut, and tends to decrease moving further down the Bay (Figure 8). Numbers of commercial scallop have been relatively stable in this area since 2005 (Figure 84). The biomass of commercial scallops has varied a bit more since 2005 but generally does not change much from year to year; in 2013, biomass increased from 1.7 to 2.3 kg/tow. SPA 4 showed changes in meat count with the increases in condition. The lowest meat counts were seen directly off and around Digby Gut (Figure 15).

Commercial scallops in this area are fairly large, with most commercial scallop being >120 mm (Figure 85). Commercial scallops were found in all survey tows in SPA 4, and many of the areas of higher biomass were found close to the border with SPA 1A (Figure 13). In 2012, the recruits in SPA 4 were very low for the area. They did not change much in 2013 (from 1.5 to 1.8 per tow), are still at low levels, and are absent from a lot of the area (Figure 14). Pre-recruits were observed in SPA 4 (Figure 16) at the highest levels since 2007 (Figure 85). That year class did recruit into the fishery, so there is potential for this strong year class to recruit.

Clapper abundance has been at consistently low levels since 2007. In recent years, they have been increasing slightly (Figure 86).

REFERENCE POINTS

The equilibrium analysis derived from model simulations for the next 50 years shows that exploitation rates near 0.15 resulted in the highest median catches, while fishing at lower exploitation rates resulted in a higher median biomass (Figure 87). These results, however, are based on strong assumptions about recruitment and are meant to illustrate how a HCR can make relative improvements to long-term median catch levels. Table 12 shows median catch and biomass levels over the 50 year projections when a HCR is used with a LRP of 530 t and various USRs. Generally, using a HCR will increase the median catch and biomass. A USR of 750 t specifically produced the highest median catch (156 t) with a median biomass of 818 t, compared to a median catch of 113 t and a median biomass of 565 t when fished at similar exploitation rates but without a HCR (Table 12). Once LRP and USR values are selected, the probabilities of biomass dropping below these levels for various catch scenarios become important factors to consider in setting the TAC (Table 13).

POPULATION MODEL

For SPA 4, the stock assessment model was fit to the stratified survey index and catch data from 1983 to 2012. As noted in Smith et al. (2012), in 2000, scallops at a size that were smaller than what were considered recruits (<65 mm) grew to commercial size the following year because of abnormally favourable growth conditions that year (Smith and Lundy 2002a). To correct this problem, the recruit index was adjusted for 2000 so that scallops between 40–79 mm were considered recruits. As with the other models,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 comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 89). The posterior distribution of q suggests information in the data pointed to q as being somewhat lower in SPA 4 than other areas. The model fits the survey mean estimates more closely now that sample variances from the survey time series were included in the observation models, reducing the uncertainty of the estimates (Figure 88).

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 (Figure 88). Generally, including sample variances from the survey time series in the observation models reduced the amount of uncertainty in the estimates compared to those presented in Nasmith et al. (2013). The posterior distributions show well defined posteriors for the estimated parameters (Figure 89).

STOCK STATUS AND FORECAST

Estimates of survival (i.e., $\exp(-m)$) show the very high levels of natural mortality that occurred 1989-1991 as the result of a catastrophic mortality event. Natural mortality has increased slightly to median levels after being very low in the previous six years. Exploitation decreased in 2013 to 0.09 from 0.16 in 2011 (Figure 90). Population biomass estimated by the model was 1,041 t (meats) in 2013, an increase of 33% from the estimate of 782 t in 2012, despite below average recruitment in 2012 (Figure 91). This was partly due to an increased condition factor in 2013 (Figure 83). Estimated recruitment in 2013 is 17 t, still below the long-term median of 38 t. Recruitment has been below the median since 2008. Biomass is projected to decrease by 6% to 989 t under the interim TAC of 80 t, which would correspond to an exploitation rate of 0.07. The probability that biomass would decline at this level of catch is 0.58. Other catch scenarios for 2013/2014, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 the following year (2014/2015), are presented in Table 13. A catch of 160 t for 2012/2013 should correspond to the reference exploitation rate (0.15) and is projected to result in a 13.7% decrease in biomass. If this catch was realized in the current season, then a catch of 139 t next year would be expected to have a 50% chance of resulting in an exploitation rate greater than 0.15 for 2014/2015.

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 (Figure 92). Biomass predictions are more precise than in Nasmith et al. (2013) as a result of survey variances being incorporated in the model making it more likely that estimates will fall outside the 50% credible interval of the prediction from the previous year. Still, six out of eight predictions evaluated had the estimates fall within the 50% credible interval. One that did not was the 2012 prediction of the 2013 biomass, which failed to predict the increase given the low recruitment in 2012, although improved condition was a factor in this discrepency (Figure 92, lower panel).

SPA 5: ANNAPOLIS BASIN

COMMERCIAL FISHERY

The fishery in the Annapolis Basin runs from 1 January to 31 March. In 2013, the Full Bay fleet caught a total of 5.68 t against a TAC of 10 t (Figure 93).

Full Bay fleet TAC and landings in SPA 5.

Commercial Data	Avg. 02–07	2007 2008	2008/ 2009	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013
TAC (t)	13	10	10	10	10	10	10
Landing (t)	9.6	7	6	8	9.7	5.7	5.7

In the 2013 fishery, there were 16 vessels and 96% of the log records were usable (Table 1). Catch rates in 2012/2013 increased to 19.7 kg/h, just above the long-term median of 18 kg/h. Effort in this area decreased by about 400 hours and is just below the long-term median of 375 hours (Figure 94).

SURVEY

The annual survey in this area was discontinued as of 2009 and the sampling effort was redirected to other areas in the Bay of Fundy.

STOCK STATUS AND FORECAST

TAC in this area has been set at 10 t since 1997/1998, except for a few years where it was increased to take advantage of good recruitment. Since 2006/2007, the average annual catch has been 6.5 t and the average catch rate has been 16.1 kg/h. The commercial catch rate is now just above the long-term median. The prospects of future recruitment events are unknown without an annual survey.

SPA 6: GRAND MANAN AND SOUTHWEST NEW BRUNSWICK

COMMERCIAL FISHERY

According to departmental quota monitoring reports, a total of 125.6 t was caught against a TAC of 140 t in SPA 6. Full Bay fleet caught 8.1 t of their 21 t TAC. Mid Bay fleet caught 117.5 t of their allocation of 119 t. These represent the highest landings in this area since 2001 (Figure 95). Landings in 2012 were the lowest in the series mainly due to very low condition of the scallops at the time of the fishery. For both of the fleets, a large proportion (e.g., 42-57% in 2013) of the catch usually comes out of SPA 6C (see table below).

Mid Bay and Full Bay SPA 6 TAC, and landings by subarea.

Fleet/Subarea	Avg02-07	2008	2009	2010	2011	2012	2013
Mid Bay TAC (t)	145	119	119	119	119	119	119
6A	20.8	15.8	25.5	32.3	23.9	11.4	39.2
6B	17.0	10.8	23.1	23.2	26.5	13.6	20.1
6C	31.3	27.6	34.8	46.7	46.5	25.3	51.8
6D	13.2	6.3	5.4	0.3	7.0	4.4	6.5
Mid Bay Total	85.9	60.6	88.8	102.5	103.9	54.7	117.5
Full Bay TAC (t)	26	21	21	21	21	21	21
6A	3.9	1.7	0.3	0.07	0	0.37	2.6
6B	1.4	1.9	0.8	0	0	0.18	0.3
6C	2.3	2.7	0.2	0	0	0.33	4.6
6D	1.3	1.1	0.05	0	0	0	0.63
Full Bay Total	8.6	7.4	1.3	0.07	0	0.88	8.1

Each year, DFO Science Scallop Unit staff validates the commercial logbook database for all scallop fisheries with respect to information on catch, effort, and location by comparing the data entries with the actual logbooks filled out by the fishermen. Typical errors found in either the database or in the logbooks include missing locations, catches attributed to the wrong subarea (e.g., catches in the Grey Zone assigned to 6A), completely missing or partially missing catch or effort, or both kinds of records. Missing or questionable locations are checked with VMS data. Corrections are routinely passed onto DFO's Commercial Data Division so that they can correct the database. However, at present, Commercial Data Division staff is behind in making many of these changes, most of which have been identified as being for SPA 6.

Differences in landings (t) based on log records and information from Quota Monitoring for Mid Bay and Full Bay fleets for the subareas of SPA 6, and the Grey Zone (GZ).

Fleet	Subarea	Logs	Quota Monitoring
Mid Bay	6A*	8.40	39.17
	GZ	15.25	
	6B	21.55	20.07
	6C	71.53	51.76
	6D	14.38	6.48
Full Bay	6A*	1.64	2.56
	GZ	2.85	
	6B	0.70	0.29
	6C	4.37	4.60
	6D	0.64	0.63
	Total	123.20	125.55

*Logbook amounts do not include Grey Zone.

While the total catch recorded in the logbooks was close to the total in the Quota Monitoring report (see table above), there were a large number of records marked as having unknown subarea in the database that were not included in the Quota Monitoring report. In addition, many of the records that Science has identified as Grey Zone were marked as 6A in the database. So, it is likely that the close agreement of the totals was more coincidental than confirmatory. Assuming that all of the Science edits to the database will be accepted, the end of year report should look more like the logbook version given above. The total for the Full Bay catch is now 7.4 t and the Mid Bay landed 115.8 t. The major differences between the two sets of landings were the higher catches in 6C and 6B+D, and the much lower landings in 6A. Also, note that in 2013, close to 15 t of the catch in 6C came from Friar's Bay in Campobello Island, whereas only just under 2 t was reported from there in 2012.

In the 2013 fishery, there were 80 vessels and 92% of the log records were usable with respect to information provided or corrections made (Table 1). There were still 0.51 t of hails that need to be reconciled, so there are still some logs that have yet to be submitted. Catch rates for the Mid Bay fleet increased in all subareas of SPA 6 (Figure 96). The Full Bay fleet vessels fished in all subareas of SPA 6, but there was not enough data to include them in the catch rate figure (Figure 97). Note that the catch rate in the Friar's Bay fishery was 24.6 kg/h, much higher than that for the rest of 6C (15.4 kg/h). In 2012, the catch rate for Friar's Bay was only 6.0 kg/h.

Increases in catch rates were widespread over the area (Figure 98). More area was fished in Mace's Bay and up the New Brunswick shoreline in 2013. More area was fished south of Grand Manan and between Grand Manan and Campobello Island in 2013 as well. Less area was fished around the Wolves.

SURVEY

The 2013 survey in SPA 6 took place in August and consisted of 123 tows in three subareas: 6A (42 tows), 6B (50 tows), and 6C (31 tows). The survey gear in this area was changed in 2013 to the Miracle gear used in the other Bay of Fundy surveys. A partial replacement survey design is used in SPA 6 to address the patchiness of scallop distribution in this area. A total of 9, 11, and 7 stations from the 2012 survey were repeated in the 2013 survey in 6A, 6B, and 6C, respectively. In 2013, two experimental tows were added in Friar's Bay (Figure 99) due to reports of large catches there in the winter fishery. These experimental tows were not included in the calculation of survey indices (e.g., number per tow) because this is not an area that is routinely covered in the survey.

Condition in SPA 6 increased in 2013 for 6A and 6B, and decreased in 6C. However, 6C still has the best condition relative to other subareas of SPA 6 (Figure 100). An area of good condition is found all along the eastern side of Deer Island and extends towards the mainland and down to the North West shore of Campobello Island. There is another area of high condition in Duck Island Sound (Figure 101).

Commercial numbers and biomass increased in both SPA 6A and 6B in 2013, but showed no change in 6C (figures102-104). The greatest abundances and biomass were found in the areas where condition is greatest, between Deer and Campobello islands, and in Duck Island Sound (Figure 105). However, commercial scallops were distributed over most of the area surveyed. There was still an area of high meat counts (>45 scallops/500 g) north of Grand Manan and up towards and around the Wolves, similar to 2012 (Figure 106, 2012 not shown). There were lower meat counts in 6B, south of Grand Manan than in 2012, along the Grey Zone border. Some of the lowest meat counts were found in 6C.

Abundance of recruits increased in all subareas (figures 102-104). The most dramatic increases were in 6A (from 5 to 21 per tow) and 6C (from 1.3 to 9.1 per tow). Recruits were observed in most areas surveyed except Mace's Bay and near the Wolves (Figure 107). Pre-recruits were observed in all subareas of SPA 6. The highest abundance was seen in 6A (mode 25-30 mm; Figure 108); the abundances in the other areas was less relative to 6A (figures 109,110). Most of the pre-recruits in 6A were found south of the Wolves (Figure 111), and other concentrations were found in Duck Island Sound and between Deer and Campobello islands.

Catches of commercial size scallop were compared for repeated tows in each subarea. In 6A, repeated tows had a high correlation, both between commercial scallop in both years (Figure 112), and commercial and recruits in 2012 and commercial scallop in 2013 (Figure 113). The overall mean number per tow of commercial scallop increased significantly, and the increase from commercial and recruit in 2012 to commercial in 2013 was also significant (Table 14).

In SPA 6B and 6C, there were increases in commercial scallop from 2012 to 2013, but these were not significant (Table 14). There were also small increases from commercial and recruits in 2012 to commercial in 2013 in 6B, but again they were not significant. In 6C, there was a small, non-significant decrease from commercial and recruits in 2012 to commercial in 2013 (Table 14). In area 6C, repeated tows were highly correlated for both comparisons (Figure 112, 113). The correlation between repeated tows was better in SPA 6B than 6C (Figure 112, 113).

Clapper abundance in SPA 6 tends to vary. Clapper abundance is generally lowest in 6C, clappers in 6A peaked in 2009, and have declined since, and clappers in 6B have been low with little change since 2009 (Figure 114). The experimental tows in Friar's Bay were not included in this series but were looked at separately. Clappers observed on these tows were higher than has been observed in other areas of SPA 6, both for commercial and recruit sizes (Figure 114). If the experimental tows are included, they increase the average in that area, to 49 per tow for commercial clappers, and 27 per tow for recruits. This was only from two tows, but given the average over the surveyed area of 6C (0.8 clappers per tow for commercial, and 2.6 per tow for recruits), clappers in Friar's Bay would be expected to be lower. The size distribution of these clappers shows a range of sizes, with a mode for commercial scallops at 80-85 mm (Figure 115). There were also more recruit clappers than commercial size clappers.

Shell height frequencies from the two tows in Friar's Bay show the major mode in the 80 to 100 mm range for the commercial size scallops. There are also indications of above average numbers of pre-recruits at 25 to 40 mm similar to other areas in SPA 6, as well as in other parts of the Bay of Fundy. There were also large numbers of clappers caught in these two tows. The offset of the peaks for the clappers and live scallops was about 10 mm. Based on recent growth curves for scallops in SPA 6C, scallops with a shell height of 80 mm were expected to grow between 10 and 13 mm in a year between surveys (Figure 116).

It is difficult to determine when these scallops died assuming that they all died around the same time because the timing will depend upon when the annual ring on the shell is formed and whether the shell grows continuously or not over the year. A number of studies (e.g., Stevenson and Dickie 1954, Tan et al. 1988) suggest that annual rings are formed in early winter when growth ceases due to low temperatures. The latter study (Tan et al. 1988) was based on relating oxygen isotope ratios in the shell to temperature trends and was only based on two shells from Browns Bank. A more recent study using oxygen isotopes for 14 shells from Georges Bank to the southern Mid-Atlantic Bight demonstrated that the rings form at the temperature maximum for the year that is coincident with spawning (August in the northern part of the range, Chute et al. 2012). Chute et al. (2012) hypothesize that shell growth ceases around the temperature maximum due to the stress of spawning and then starts up again once spawning is over. They also show that shell growth does slow down in the winter months only for the older scallops (>100 mm) in their sample.

STOCK STATUS AND FORECAST

The TACs set in this area since 1997 have varied reflecting average catch trends in recent years and were not based on an assessment model or any other indicator of productivity. The current total TAC of 140 t has been in place since 2007. The average total catch for 1997 to 2006 was 123 t with the Mid Bay fleet averaging 106 t. However, average catch rates during those years was almost half of the 2013 rate (8.6 versus 16.0 kg/h).

Advice on current stock status and catch levels for the 2013/2014 season for each of SPAs 1A, 1B, 3, and 4 is provided using assessment models fit to catch and survey data. These models estimate the current exploitation and biomass levels for the fishery and for this assessment. These levels are compared to removal rate and biomass reference points in the context of HCRs associated with the precautionary approach.

The usefulness of these assessment models depends on the ability of the annual surveys to detect changes in the population. One check of this ability has been the strength of the relationship between the survey and the commercial catch rate series, which are also assumed to reflect changes in the population. There are strong relationships between these two time series in the other SPAs (e.g., Figure 117) such that a previous year's survey biomass estimate can predict the next year's catch rate reasonably well, especially in SPAs 1A and 4. However, the relationships between the surveys and commercial catch rates[3] in SPA 6 were not as strong as in the other areas with only 6B showing a significant linear relationship (Figure 118). Of all the areas, 6B has the best survey coverage while 6C is a larger and more complex area to survey especially around Campobello Island and Passamaquoddy Bay areas. Given that the current management system assigns one TAC for all of SPA 6, a model based on more than just one subarea is required.

However, stock status can also be evaluated from commercial catch and effort data assuming the following relationship holds between catch (C_t), effort (E_t), and population biomass (B_t) for each year t. The q_t term refers to the proportion of the biomass that each unit of effort removes from the population biomass (sometimes referred to as the catchability coefficient). In single gear fisheries, q is often assumed to be constant over time.

$$C_t = q\, E_t\, B_t$$

This relationship implies that over time, effort should track changes in exploitation rate (proportion of the catch taken from the population). That is,

$$\frac{C_t}{B_t} = q\, E_t\,,$$

and changes in CPUE effort should track changes in population biomass, i.e.,

$$\frac{C_t}{E_t} = q\, B_t$$

In the other SPAs, exploitation rates are estimated from the assessment models and show very strong linear relationships with fishing effort (Figure 119). Differences in slopes over the different areas reflect the fact that each area has different amounts of fishable areas and exploitation and effort would need to be standardized by fishable area to be comparable. It is reasonable to assume that a similar relationship holds for SPA 6 and, therefore, annual trends in effort could

[3] Only Mid Bay catch and effort used in this section as being representative of the fishery.

be used as a proxy for annual trends in exploitation (Figure 120). Overall, the effort series[4] have fluctuated around their respective means in all of the areas except 6C, with 6A and 6B being below their means in 2013. The lower effort in 6A reflected the fact that landings declined from 2012 to 2013 there despite the increase in catch rate in 2013. Since 2005, effort levels appear to have generally increased in 6C, but in the context of a longer time series, this pattern may just be indicative of a slower fluctuation around the mean. Catch rates for the Mid Bay fleet have shown little trend since 2003, with the possible exception of 2012 and 2013 (Figure 96), suggesting that population biomass has been stable over that time period.

Previous assessments of this area had noted the decline in condition first picked up in the 2011 survey and then the notable improvement observed in the 2012 survey (e.g., Nasmith et al. 2013). A comparison of scallop condition in the late summer SPA 6 survey with the catch rates in SPA 6 in the following winter suggests that much of the fluctuation in catch rate may be due to annual changes in condition, especially in SPA 6B and 6D (Figure 121). The increase in catch rate for 2013 appears to be greater than expected given the change in condition but, in other SPAs where there were fisheries in the fall of 2012, condition was observed to have continued to improve throughout the fall at more than the usual rate. Personal observations from fishermen were reported to DFO Science that the animals appeared to be in better condition than usual in the early winter months of 2013. It is possible that the summer survey estimate of condition in 2012 underestimated the condition for the winter of 2013. All of this would suggest that, at the current exploitation level (i.e., mean effort levels), population numbers are close to equilibrium levels with biomass fluctuations subject more to changes in condition than to overall increases or decreases in numbers. It is not known if this equilibrium corresponds to a maximum catch situation. Evidence suggests that the increases in condition associated with the 2013 catch rates were much higher than usual, and catch rates may be closer to average in 2014 based on trends observed in the 2013 surveys and the fall fisheries in the other SPAs.

A stable catch rate results in linear relationships between catch and effort as shown in Figure 122. The one outlier in the panel for 6C corresponds to the 2013 catch. This point may differ from the expected relationship because of the large catch and high catch rate in Friar's Bay in 2013. Fishing at the mean effort level would result in a mean catch of 82 t for all of SPA 6, which in turn is the mean catch over the time series from 2002 to 2013.

While commercial log data is available back to 1997, the location data cannot be verified with respect to subarea because VMS was not available before 2002. Comparing catch and effort for all subareas combined for the time series starting in 1997 indicated a linear relationship since 2001; however, increasing levels of effort for 1997–2000 did not result in higher catches (Figure 123). Again, this suggests that population numbers have been at, or close to, equilibrium at the levels of effort applied to this fishery since 2001. Increasing effort beyond this level would probably result in a decline in population numbers.

The commercial catch rate series starting in 1997 has been proposed as the stock status indicator for this area (Figure 124). The lowest catch rate in the series of 6.2 kg/hr (1997) is being proposed as the LRP for SPA 6. The development of HCR for this SPA will need to incorporate the impact of changes in condition on catch rate that may not reflect changes in abundance, such as was observed in 2012.

The question remains as to whether the increase in 2013 was mainly due to an increase in condition or a combination of condition and recruitment. The increase in catch rate in 2013 was not matched by the survey biomass or abundance estimates in 2012 in any of 6A, B or C.

[4] Logbooks used to estimate effort in 2013.

Survey estimates in 2013 do indicate an increase in numbers and biomass for 2014. The 2013 catch rate increases appeared to be beyond what would be expected from the condition estimates from the 2012 survey; however, condition was reported to have continued to improve over the subsequent fall and into the winter, possibly more than in other years. If a change in TAC is being contemplated for the 2014 season, then further discussions with the Full and Mid Bay fleets on TAC options will need to take place before the season opens.

ECOSYSTEM CONSIDERATIONS

There were no fisheries observer trips in the Bay of Fundy scallop fishery in 2012/2013. Refer to Sameoto and Glass (2012) for past analysis of discards from the inshore scallop fishery. As part of the requirements for Marine Stewardship Council certification on the Full Bay sea scallop fishery, the Full Bay fleet is developing a by-catch monitoring program. A pilot for this program is to take place in Scallop Fishing Area (SFA) 29 in 2014.

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TABLES

Table 1. Summary of commercial fishing log data available by fishing area in the Bay of Fundy. Number of fished licenses is broken out by fleet: Full Bay (Full), Mid Bay (Mid) and Upper Bay (Upper). A logbook record is considered usable if it is assigned to an area, has catch, number of tows, and average tow length properly recorded on the log sheet and entered into the database. Dashes indicate that a particular fleet does not fish in that area.

Area	No. Fished Licenses			No. vessels	No. records	No. usable records	% usable records
	Full	Mid	Upper				
1A	56	-	-	53	1027	1020	99
1B	78	92	13	129	2095	2041	97
3	100	-	-	63	998	971	97
4	78	-	-	48	665	653	98
5	16	-	-	16	52	50	96
6A	5	32	-	36	120	108	90
6B	2	24	-	25	213	196	92
6C	4	53	-	56	684	632	92
6D	2	19	-	20	110	100	91
6 (all areas)	9	74	-	80	1127	1036	92

Table 2. Scallop Production Area 1A evaluation of proposed upper stock reference points (USR) and the median biomass, exploitation, and catch at that level from the model. Also shown is the percent time the biomass would fall below the USR. Lower reference point (LRP) for this area is 480 t.

USR (t)	Biomass (t)	Exploitation	Catch (t)	% Closed
600	865	0.17	173	2.97
700	901	0.16	180	1.70
800	954	0.16	189	0.95
900	1021	0.16	199	0.55
1000	1087	0.16	205	0.37
1100	1161	0.16	195	0.25
1200	1233	0.15	176	0.19
no USR	817	0.17	163	0.06

Table 3. Harvest scenario table for SPA 1A to evaluate 2013/2014 catch levels in terms of resulting exploitation (e), expected changes in biomass (%) , probability of biomass decline, probability that after removal the stock will be above the USR, and above the LRP. These calculations assume a USR of 1000 t and a LRP of 480 t. Potential catches in 2014/2015 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2013/2014						$Pr(e_{2014/2015} \geq 0.15)$					
Catch (t)	e	*% Change*	*Pr Decline*	*Pr > USR*	*Pr > LRP*	0.1	0.2	0.3	0.4	0.5	0.6
150	0.08	9.94	0.33	0.97	0.99	201	237	264	289	316	344
175	0.09	7.76	0.36	0.97	0.99	199	233	260	285	311	339
200	0.10	6.45	0.39	0.97	1	196	229	255	281	306	334
225	0.12	4.77	0.41	0.96	1	193	226	252	276	302	329
250	0.13	2.94	0.44	0.96	0.99	191	223	249	272	297	325
275	0.14	1.11	0.48	0.95	1	187	218	244	268	293	321
287	0.15	0.37	0.49	0.94	>0.99	186	217	242	267	291	317
300	0.16	-0.47	0.51	0.94	0.99	184	215	241	264	288	314
325	0.17	-1.75	0.54	0.94	0.99	182	213	238	262	286	312
350	0.18	-3.63	0.57	0.93	>0.99	179	210	234	257	282	308
375	0.20	-4.87	0.60	0.92	>0.99	175	206	230	253	276	302

Table 4. Scallop Production Area 1B evaluation of proposed USR and the median biomass, exploitation, and catch at that level from the model. Also shown is the percent time the biomass would fall below the USR. LRP for this area is 880 t.

USR (t)	Biomass (t)	Exploitation	Catch (t)	% Closed
1000	1454	0.17	291	5.21
1200	1538	0.16	307	2.91
1400	1660	0.16	329	1.42
1600	1799	0.16	350	0.75
1800	1937	0.16	356	0.48
2000	2093	0.15	332	0.30
2200	2249	0.15	299	0.21
no USR	1355	0.17	271	0.00

Table 5. Harvest scenario table for SPA 1B to evaluate 2013/2014 catch levels in terms of resulting exploitation (e), expected changes in biomass (%), probability of biomass decline, probability that after removal the stock will be above the USR, and above the LRP. These calculations assume a USR of 1800 t and a LRP of 880 t. Potential catches in 2014/2015 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2013/2014						$Pr(e_{2014/2015} \geq 0.15)$					
Catch (t)	e	*% Change*	*Pr Decline*	*Pr > USR*	*Pr > LRP*	0.1	0.2	0.3	0.4	0.5	0.6
300	0.09	16.91	0.25	0.94	0.99	347	413	472	530	588	653
350	0.10	15.90	0.27	0.93	0.99	345	412	469	524	579	644
400	0.12	13.26	0.30	0.92	0.99	336	405	461	515	569	634
450	0.13	11.05	0.33	0.92	0.99	333	397	453	504	559	622
500	0.15	9.39	0.35	0.90	0.99	328	392	444	498	555	618
550	0.16	6.90	0.39	0.89	0.99	319	381	436	489	546	607
575	0.17	6.40	0.40	0.89	0.99	318	380	432	485	539	601
600	0.18	5.15	0.42	0.88	0.99	314	378	431	483	537	596
650	0.19	3.27	0.45	0.87	>0.99	305	372	425	474	529	591
675	0.20	1.79	0.47	0.86	>0.99	305	367	419	471	526	584

Table 6. Mean number (standard error) per tow for different size class from comparative tows conducted using the Miracle gear with teeth or flat bar. All catches corrected for standard length of tow of 800 m and gear width of 5.334 m.

	All tows		Tows 74/75 removed	
Size class	Teeth	Flat bar	Teeth	Flat bar
All sizes	785.59 (209.85)	627.38 (174.06)	650.77 (166.88)	617.94 (180.3)
Commercial size (≥80 mm)	155.98 (31.77)	137.75 (29.25)	163.36 (32.07)	142.14 (30.01)
Recruits (65-79 mm)	21.75 (4.91)	11.60 (4.27)	23.30 (4.84)	12.43 (4.35)
Pre-recruits (<65 mm)	607.86 (200.13)	478.03 (149.96)	464.11 (144.50)	463.37 (154.45)

Table 7. Mean number of scallops per tow by size class by gear for comparative tows where the Miracle gear with teeth or flat bar was towed first. Note tows 74 and 75 removed (see text).

		Mean number per tow	
First tow	Size class	Teeth	Flat bar
Teeth	Total	579.68	633.27
	Commercial	115.38	132.63
	Recruit	19.85	10.72
	Pre-recruit	444.45	463.09
Flat bar	Total	704.09	606.44
	Commercial	199.34	154.81
	Recruit	25.89	14.70
	Pre-recruit	478.86	463.75

Table 8. Results of fitting a generalized linear model (family=Gamma, link=log) to mean number by tow by size class to determine differences due to gear type by tow order. Contrasts tested refer to a-posteriori multiple comparison tests for null hypothesis of zero differences between catches. Tows 74 and 75 were removed from the analysis for these results.

Size class	**Contrasts tested**	**Estimate**	**Standard Error**	**Z-value**	**Pr(>|Z|)**
Total	1(Teeth-Flat)|Teeth first	-0.088	0.646	-0.137	0.99
	2(Flat-Teeth)|Flat first	-0.149	0.559	-0.267	0.96
	1-2=0	0.061	0.854	0.071	0.94
Commercial	1(Teeth-Flat)|Teeth first	-0.294	0.447	-0.658	0.76
	2(Flat-Teeth)|Flat first	-0.408	0.387	-1.053	0.50
	1-2=0	0.114	0.591	0.192	0.85
Recruits	1(Teeth-Flat)|Teeth first	0.013	0.582	0.022	1.00
	2(Flat-Teeth)|Flat first	-0.594	0.412	-1.441	0.28
	1-2=0	0.606	0.713	0.850	0.40
Pre-recruits	1(Teeth-Flat)|Teeth first	-0.043	0.755	-0.056	0.99
	2(Flat-Teeth)|Flat first	-0.034	0.654	-0.051	0.99
	1-2=0	0.009	0.998	-0.009	0.99

Table 9. Results of fitting a generalized linear model (family=Gamma, link=log) to mean number per drag by tow by size class to determine differences due to gear type for lined and unlined drags. Contrasts tested refer to a-posteriori multiple comparison tests for null hypothesis of zero differences between catches. Tows 74 and 75 were removed from the analysis for these results.

Size class	**Contrasts tested**	**Estimate**	**Standard Error**	**Z-value**	**Pr(>|Z|)**
Commercial	(Flat-Teeth)|lined	-0.899	0.286	-3.141	0.003
	(Flat-Teeth)|unlined	-0.189	0.281	-0.672	0.75
	(Unlined-Lined)|Flat	0.816	0.286	2.850	0.009
	(Unlined-Lined)|Teeth	0.105	0.281	0.375	0.91
Recruits	(Flat-Teeth)|lined	-0.391	0.378	-1.037	0.51
	(Flat-Teeth)|unlined	0.089	0.374	0.238	0.97
Pre-recruits	(Flat-Teeth)|lined	-0.053	0.558	-0.095	0.99
	(Flat-Teeth)|unlined	0.392	0.617	0.636	0.77

Table 10. Scallop Production Area 3 evaluation of proposed USR points and the median biomass, exploitation, and catch at that level from the model. Also shown is the percent time the biomass would fall below the USR. LRP for this area is 600 t.

USR (t)	Biomass (t)	Exploitation	Catch (t)	% Closed
800	962	0.16	191	9.07
900	1023	0.15	200	6.89
1000	1092	0.15	206	5.01
1100	1161	0.15	190	3.96
1200	1232	0.15	172	3.13
no USR	708	0.17	142	0.88

Table 11. Harvest scenario table for SPA 3 to evaluate 2013/2014 catch levels in terms of resulting exploitation (e), expected changes in biomass (%) , probability of biomass decline, probability that after removal the stock will be above the USR, and above the LRP. These calculations assume a USR of 1000 t and a LRP of 600 t. Potential catches in 2014/2015 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2013/2014						$Pr(e_{2014/2015} \geq 0.15)$					
Catch (t)	e	***% Change***	***Pr Decline***	***Pr > USR***	***Pr > LRP***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
200	0.10	14.26	0.31	0.95	0.99	200	247	284	320	356	395
225	0.11	12.42	0.32	0.95	0.99	197	242	279	312	348	387
250	0.12	10.85	0.35	0.95	0.99	196	240	276	310	344	384
275	0.13	8.84	0.38	0.94	0.99	192	235	270	304	337	377
300	0.15	7.22	0.39	0.93	0.99	190	232	265	298	332	372
325	0.16	4.96	0.43	0.93	0.99	185	229	262	295	330	369
350	0.17	3.37	0.45	0.92	0.99	182	223	256	289	321	358
375	0.18	2.07	0.47	0.90	0.99	178	219	254	285	320	357
400	0.20	-0.13	0.50	0.90	0.99	176	217	250	282	314	349

Table 12. Scallop Production Area 4 evaluation of proposed USR points and the median biomass, exploitation, and catch at that level from the model. Also shown is the percent time the biomass would fall below the USR. LRP for this area is 530 t.

USR (t)	Biomass (t)	Exploitation	Catch (t)	% Closed
600	736	0.15	147	23.19
625	748	0.15	149	21.73
650	763	0.15	152	20.39
675	772	0.15	152	19.96
700	784	0.15	153	18.80
725	801	0.15	155	17.80
750	818	0.14	156	16.57
775	834	0.14	155	15.60
800	844	0.14	142	14.82
825	861	0.14	135	14.40
850	875	0.14	124	13.63
no USR	565	.17	113	5.1

Table 13. Harvest scenario table for SPA 4 to evaluate 2013/2014 catch levels in terms of resulting exploitation (e), expected changes in biomass (%) , probability of biomass decline, probability that after removal the stock will be above the USR, and above the LRP. These calculations assume a USR of 750 t and a LRP of 530 t. Potential catches in 2014/2015 are evaluated in terms of the posterior probability of exceeding exploitation rate of 0.15.

2013/2014						$Pr(e_{2014/2015} \geq 0.15)$					
Catch (t)	e	***% Change***	***Pr Decline***	***Pr > USR***	***Pr > LRP***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
80	0.07	-6.06	0.58	0.78	0.95	80	100	117	134	151	171
100	0.09	-7.80	0.60	0.75	0.94	78	98	114	130	148	168
120	0.11	-9.94	0.63	0.73	0.94	76	95	112	128	144	164
140	0.13	-12.00	0.65	0.71	0.93	74	93	109	126	142	162
160	0.15	-13.73	0.68	0.69	0.92	73	91	107	123	139	156
180	0.17	-15.55	0.70	0.67	0.91	72	90	106	121	136	154
200	0.19	-17.86	0.73	0.65	0.90	70	88	103	118	133	150
220	0.21	-18.95	0.74	0.63	0.89	68	86	101	115	131	148

Table 14. Sampling with partial replacement estimates of the mean number per tow, difference between mean number per tow 2012 and 2013 and the standard error (SE) of the difference for SPA 6 Test statistic evaluated using a Student's t distribution.

	Mean no/tow				**Test-statistic**
Area	**2012**	**2013**	**Difference**	**SE (Difference)**	**(ρ value)**
			Commercial size in 2012		
6A	46.62	77.3	+ 30.68	8.52	3.60 (ρ<0.001)
6B	44.65	78.28	+ 33.63	18.15	1.85 (ρ=0.07)
6C	16.37	16.48	+ 0.11	10.29	0.01 (ρ=0.99)
			Commercial + recruits in 2012		
6A	53.65	79.85	+ 26.2	9.03	2.90 (ρ=0.005)
6B	53.8	73.88	+20.08	18.06	1.11 (ρ=0.27)
6C	18.39	16.67	- 1.72	10.66	-0.16 (ρ=0.87)

FIGURES

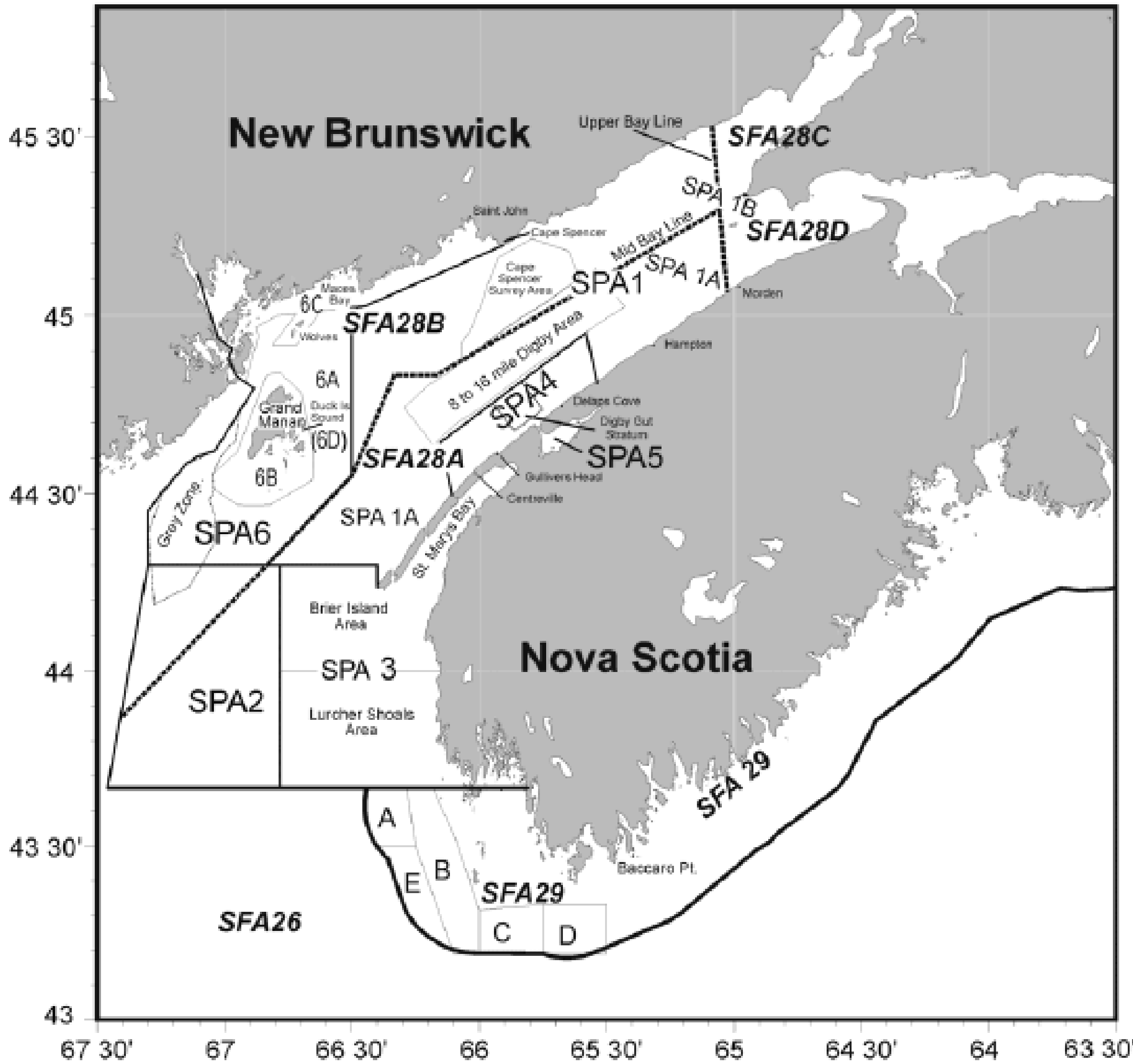

Figure 1. Map of Scallop Production Areas (SPA) and Scallop Fishing Areas (SFA) in the Bay of Fundy.

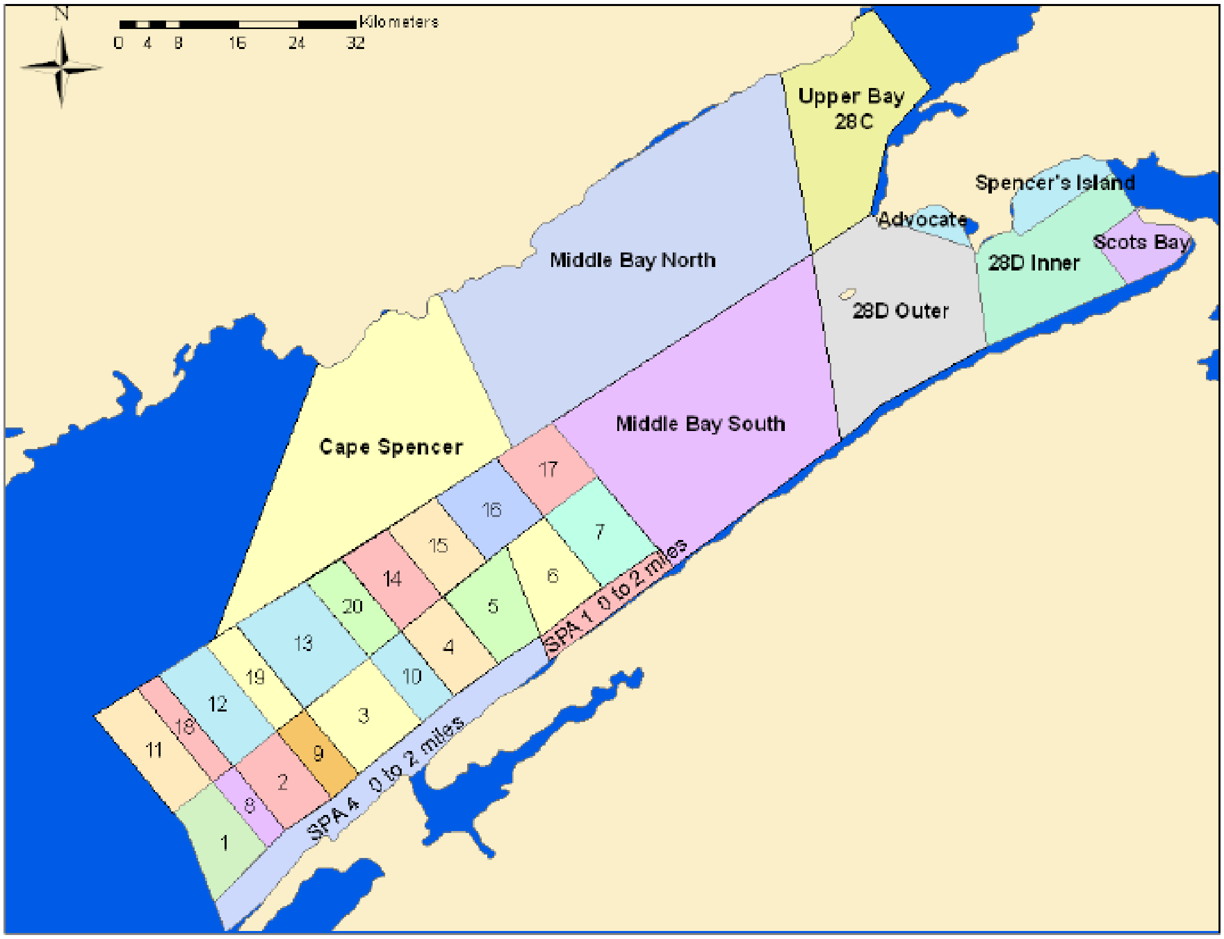

Figure 2. Map of the Bay of Fundy scallop survey strata.

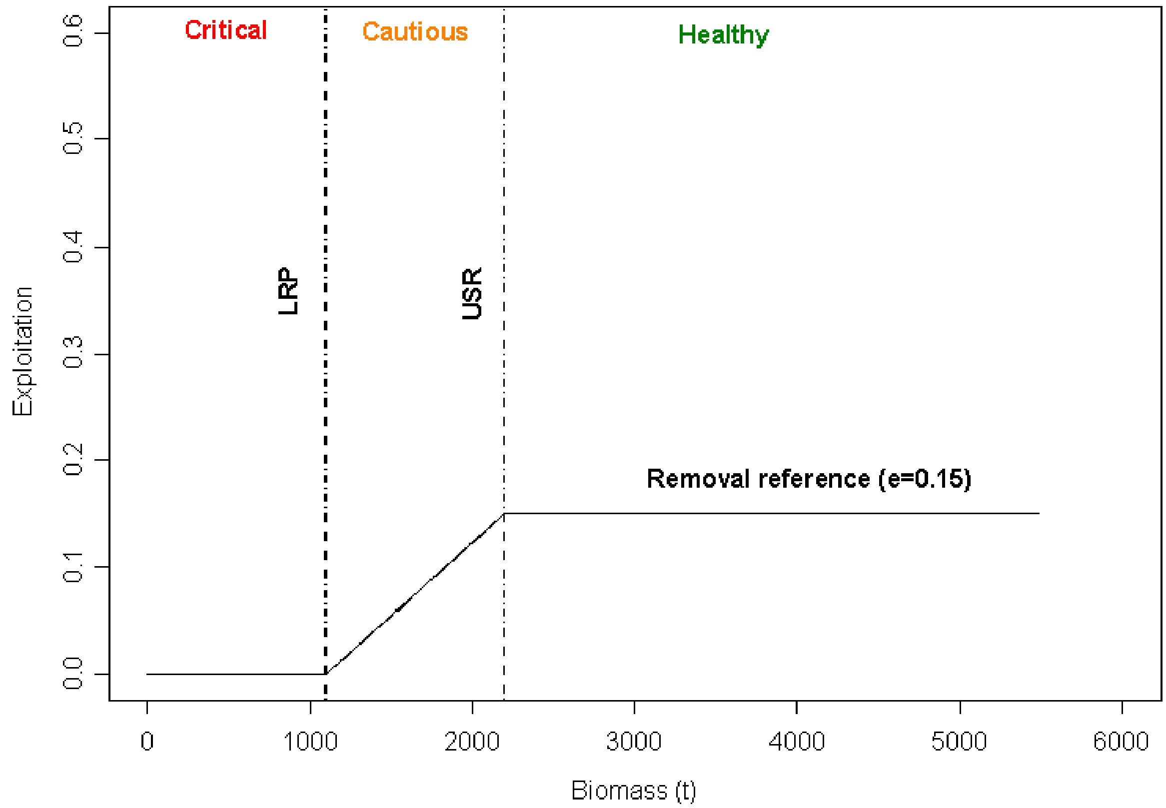

Figure 3. Idealized Harvest Control Rule (HCR) corresponding to the Fisheries and Oceans Canada precautionary approach to reference points. A fishery is in the Critical zone when biomass is below the Lower Reference Point (LRP), is in the Cautious zone when biomass is above the LRP and below the Upper Stock Reference (USR), and in the Healthy zone when biomass is above the USR.

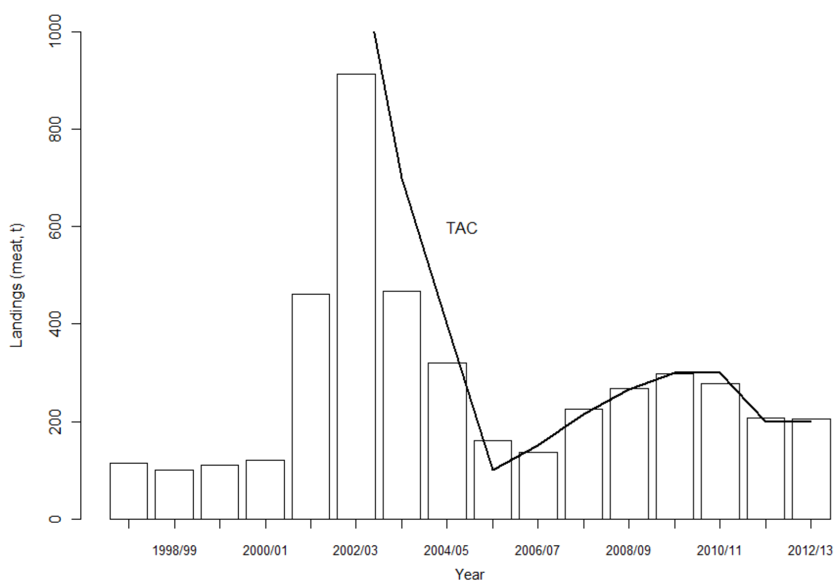

Figure 4. Scallop Production Area 1A landings (meats, tons) by the Full Bay fleet. Total Allowable Catch (TAC) is indicated by black line.

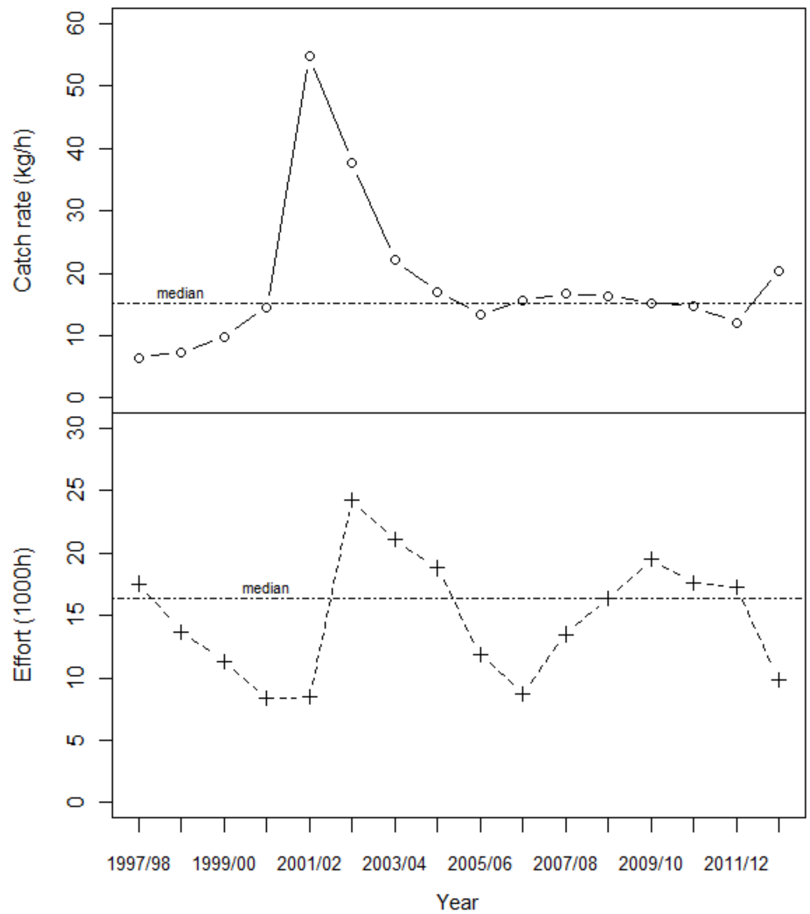

Figure 5. Scallop Production Area 1A trends in commercial catch rate (kg/h; upper panel) and effort (h; lower panel) by the Full Bay fleet. Median catch rate and effort from 1996/1996 to 2011/2012 indicated.

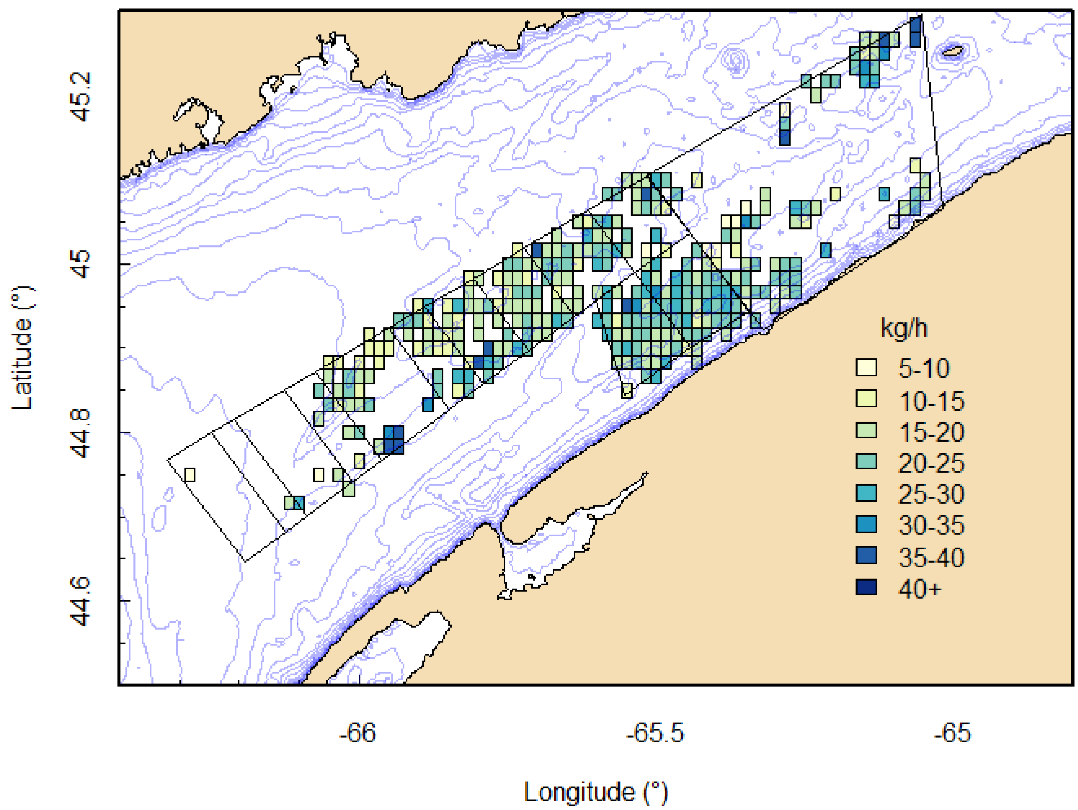

Figure 6. Mean commercial catch rates (kg/h) by 1 minute square from commercial fishing logs in Scallop Production Area 1A in the 2012/2013 fishing season by the Full Bay fleet. Lines indicate survey areas.

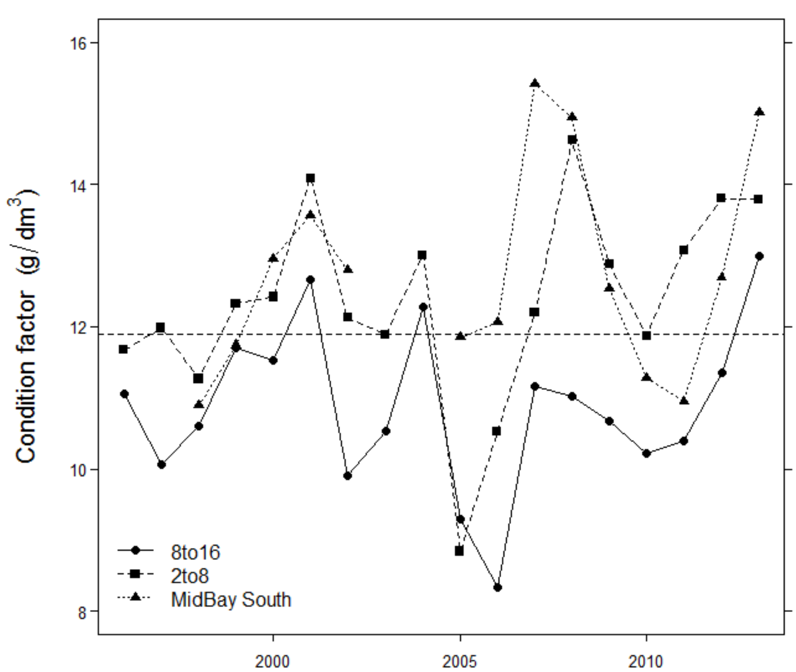

Figure 7. Scallop Production Area 1A trend in condition factor (g/dm^3) from the annual survey. Mean condition from 1996-2012 is indicated.

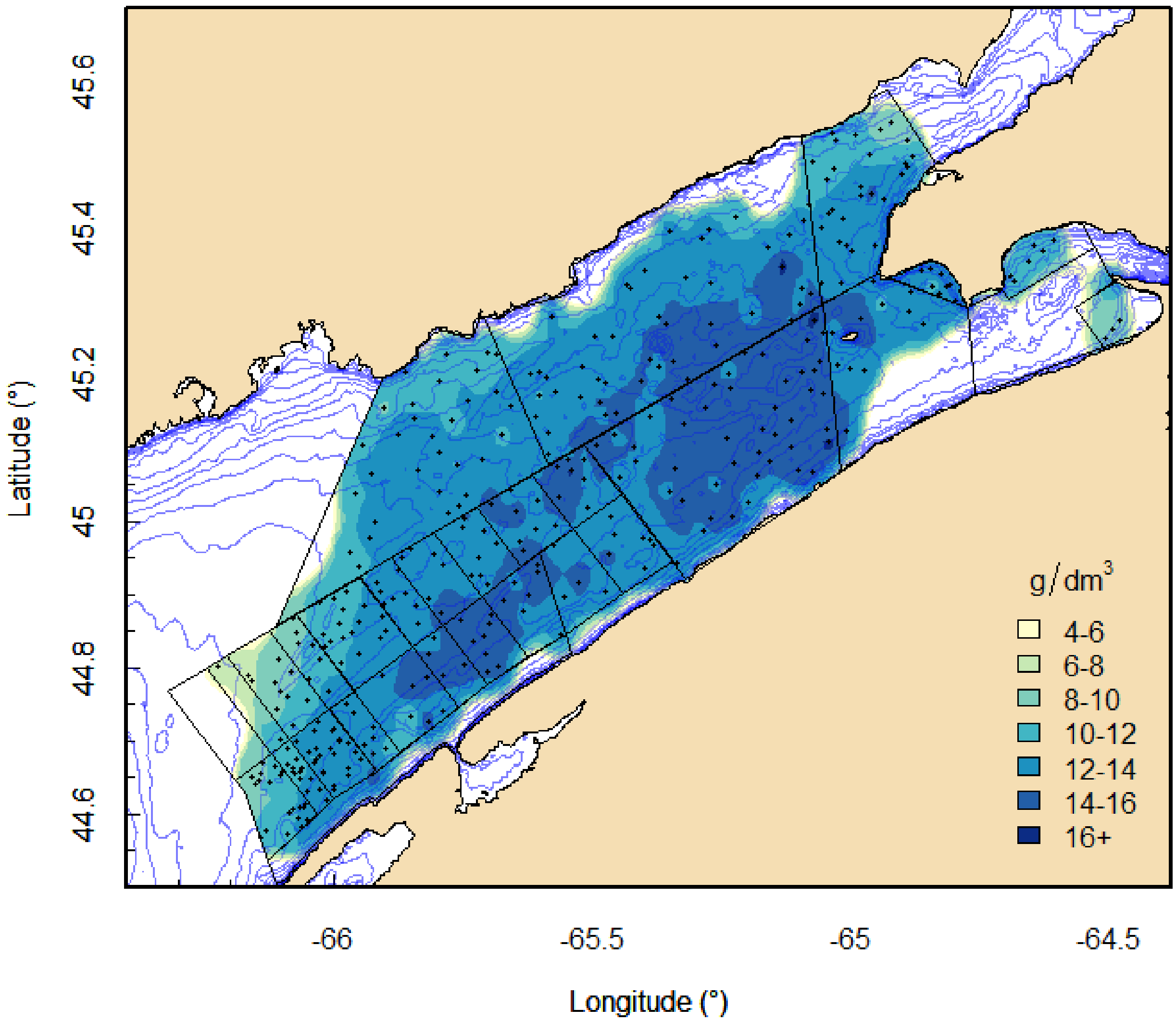

Figure 8. Spatial distribution of condition factor (g/dm^3) in Scallop Production Areas 1A, 1B, and 4, from the 2013 survey in the Bay of Fundy.

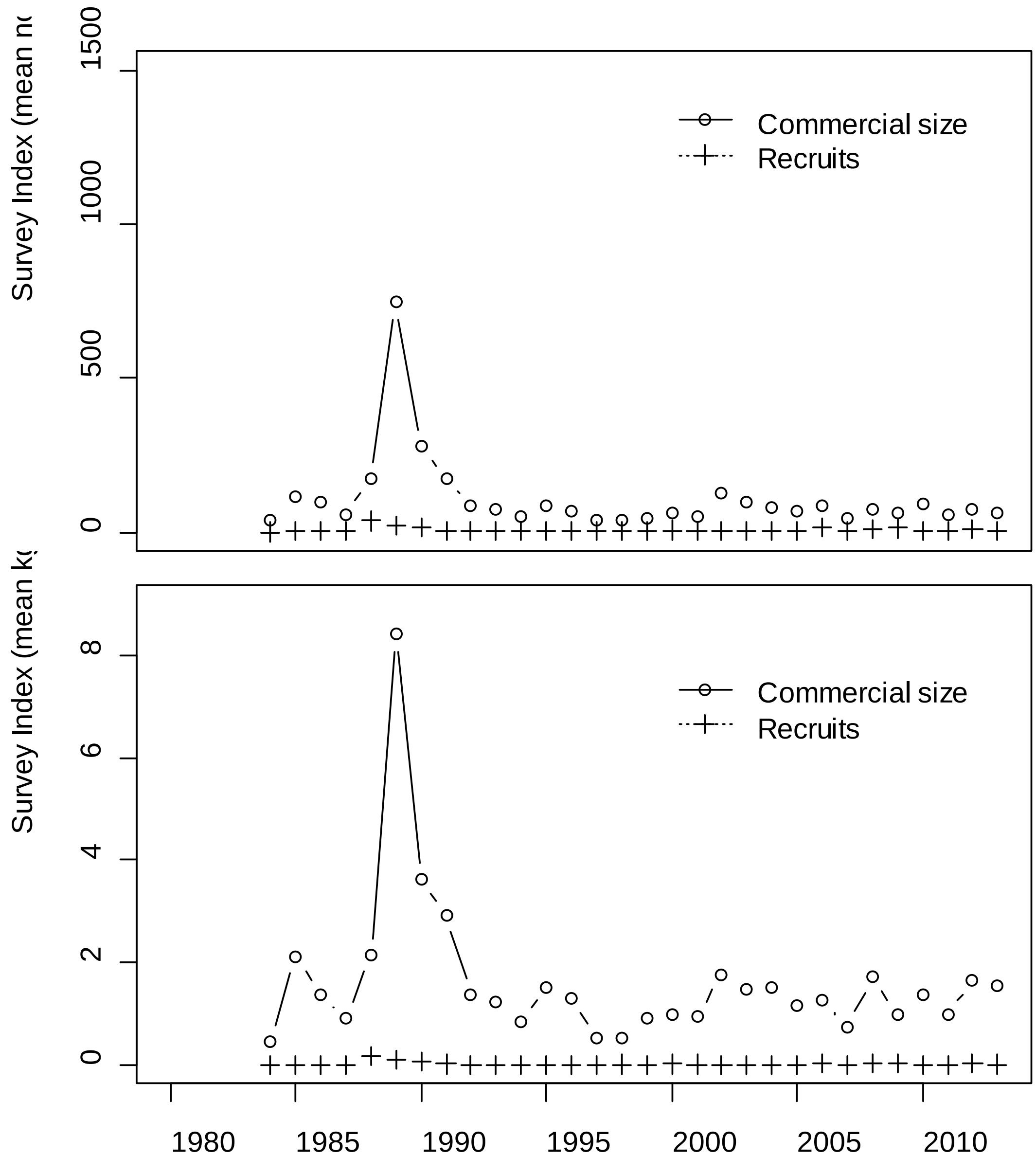

Figure 9. Scallop Production Area 1A, 2 to 8 mile zone trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops, from 1984-2013.

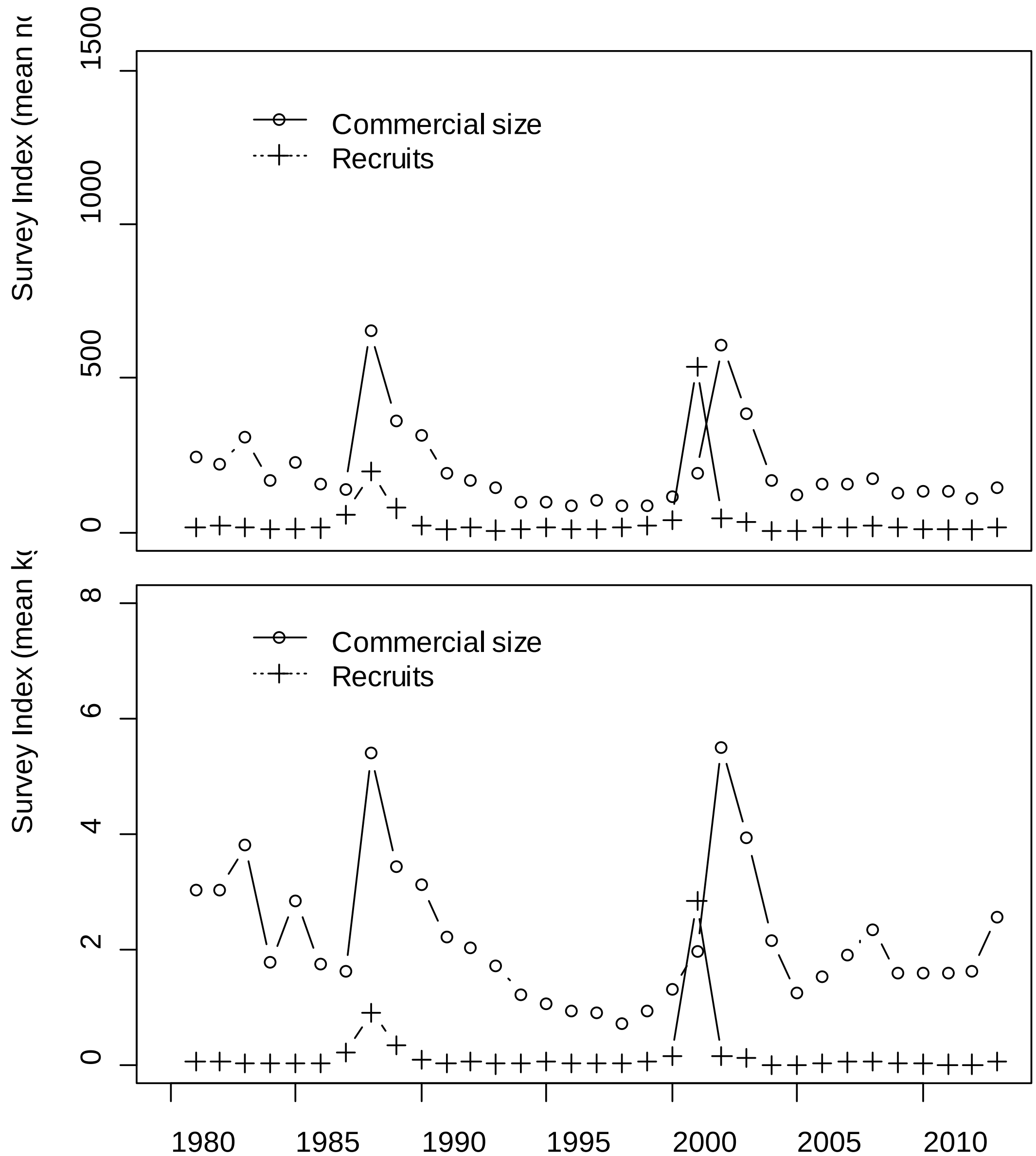

Figure 10. Scallop Production Area 1A, 8 to 16 mile zone trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1981-2013.

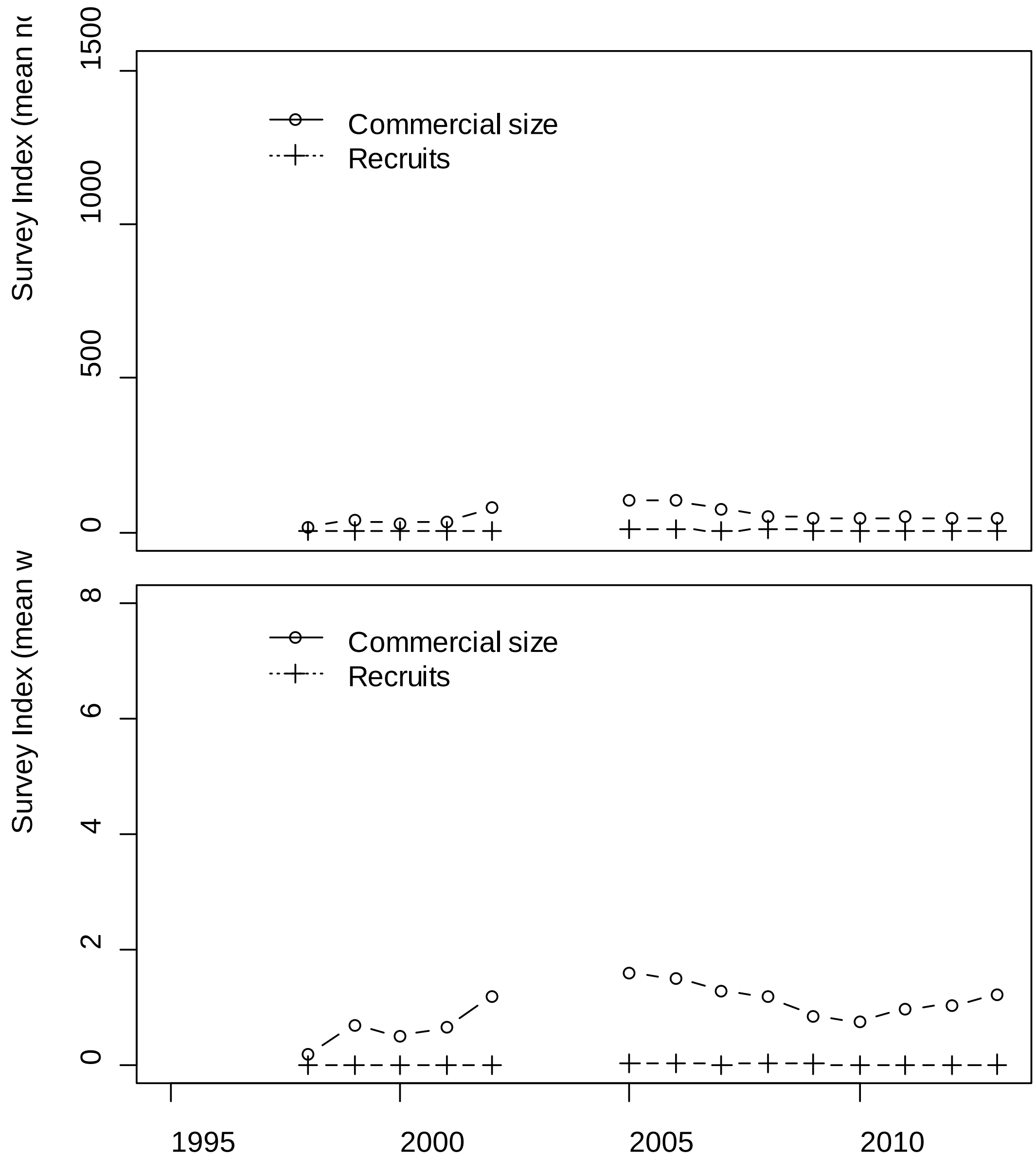

Figure 11. Middle Bay South zone of Scallop Production Area 1A trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops, from 1998-2013.

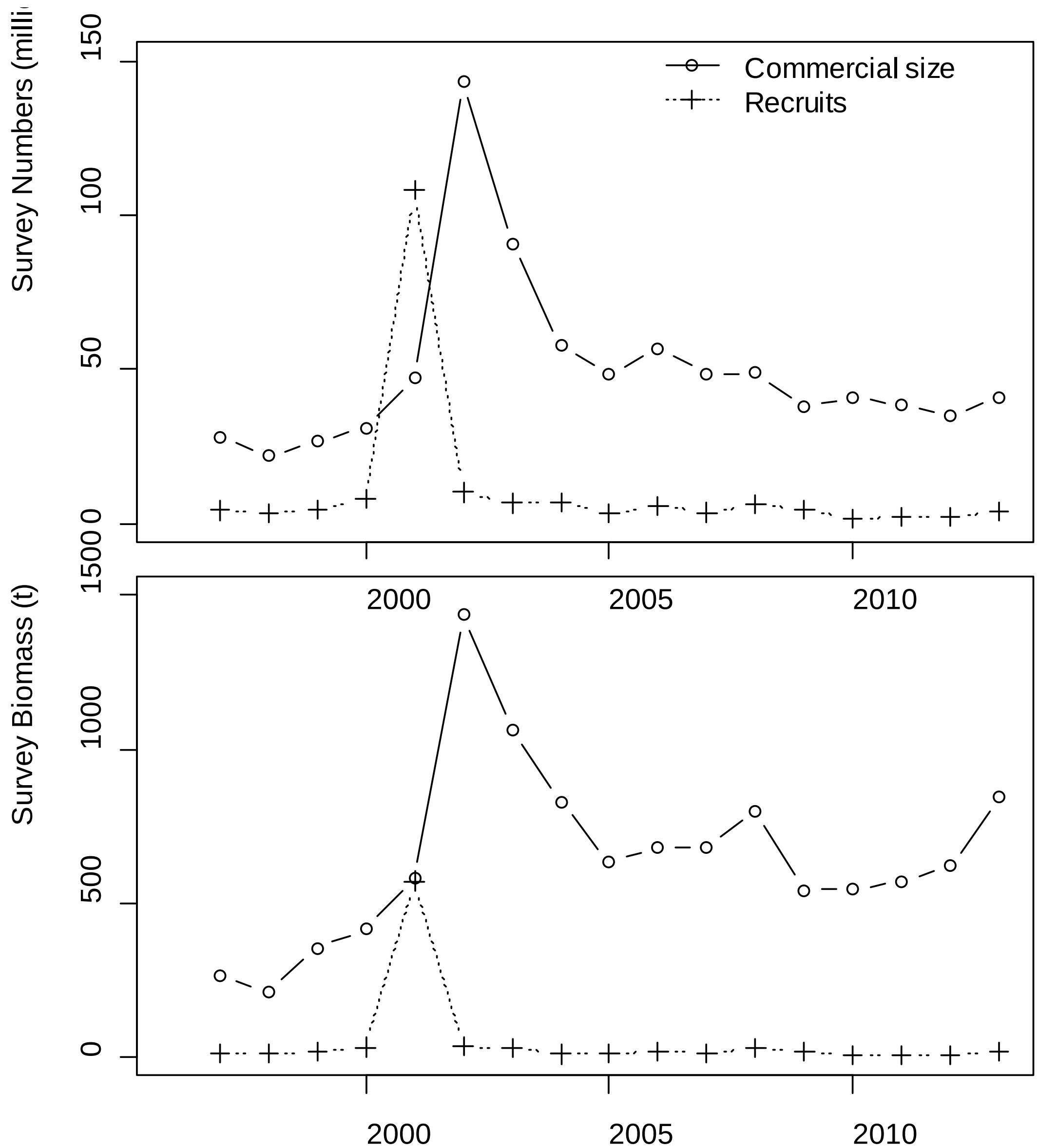

Figure 12. Scallop Production Area 1A trends in population abundance (upper panel; millions) and biomass (lower panel; meats, t) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1997-2013.

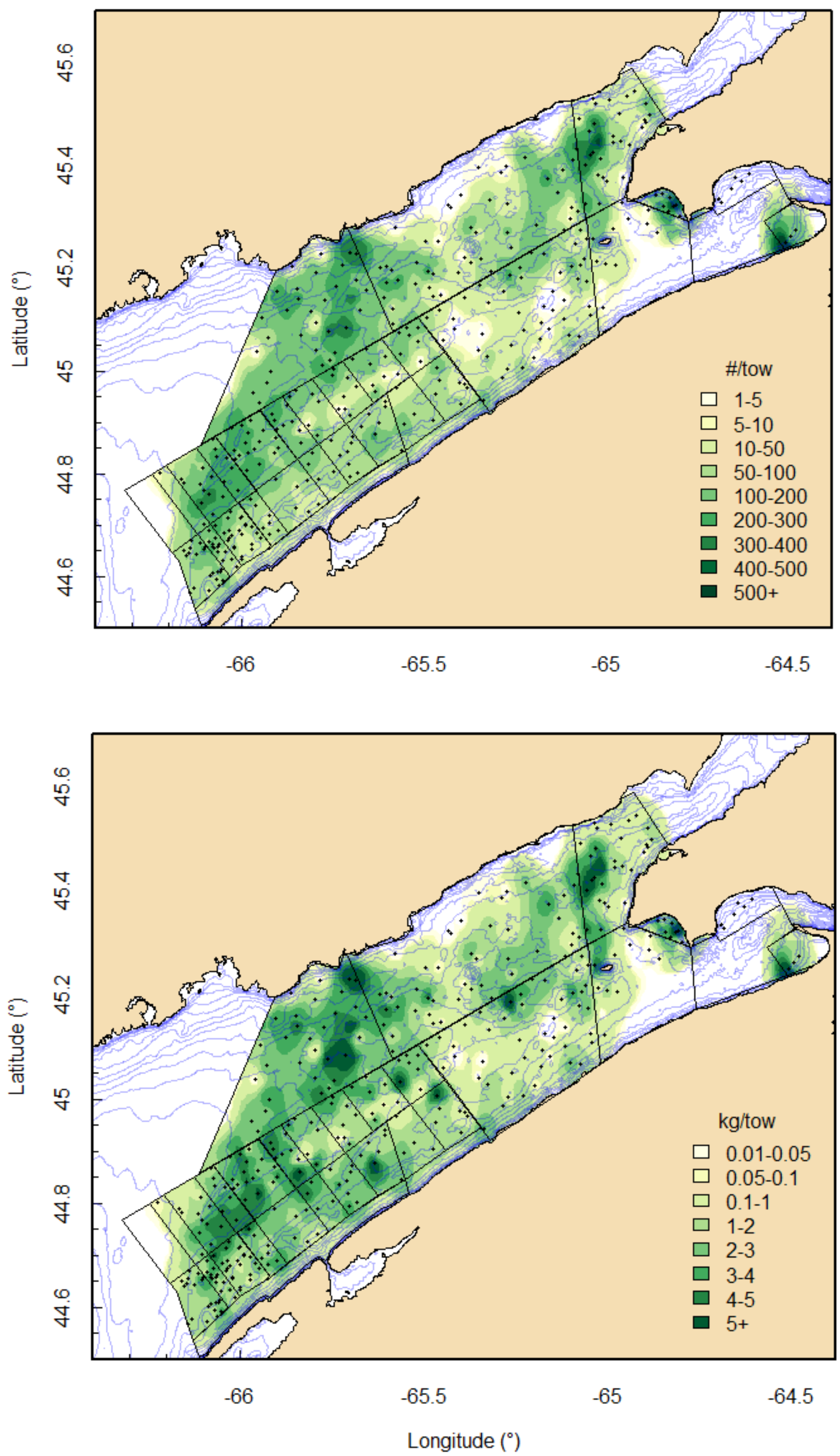

Figure 13. Spatial distribution of abundance (number/tow; upper panel) and biomass (kg/tow; lower panel) of commercial size (≥ 80 mm) scallop in Scallop Production Areas 1A, 1B, and 4, from the 2013 survey in the Bay of Fundy.

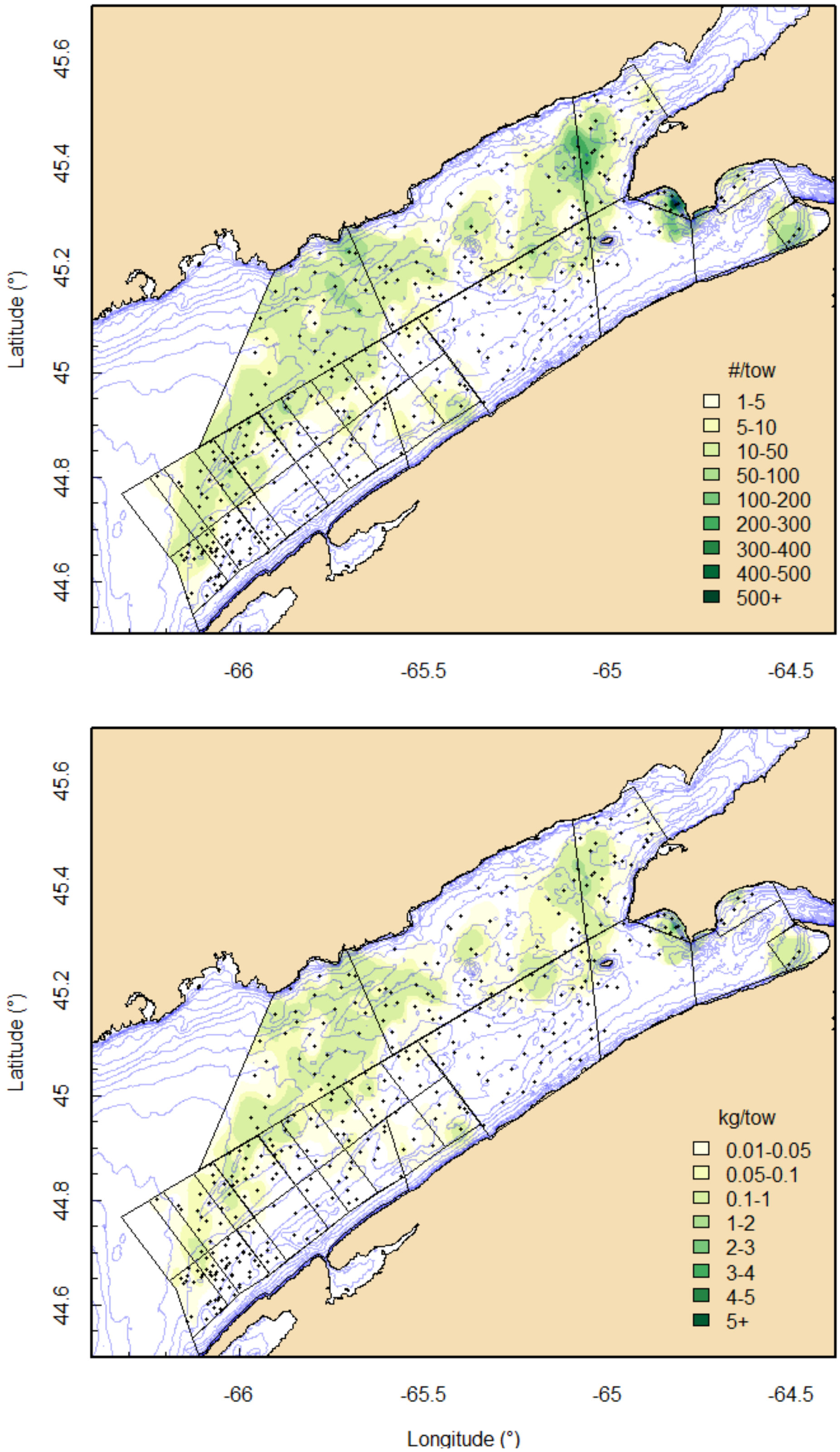

Figure 14. Spatial distribution of abundance (number/tow; upper panel) and biomass (kg/tow; lower panel) of recruit (65-79 mm) scallop in Scallop Production Areas 1A, 1B, and 4, from the 2013 survey in the Bay of Fundy.

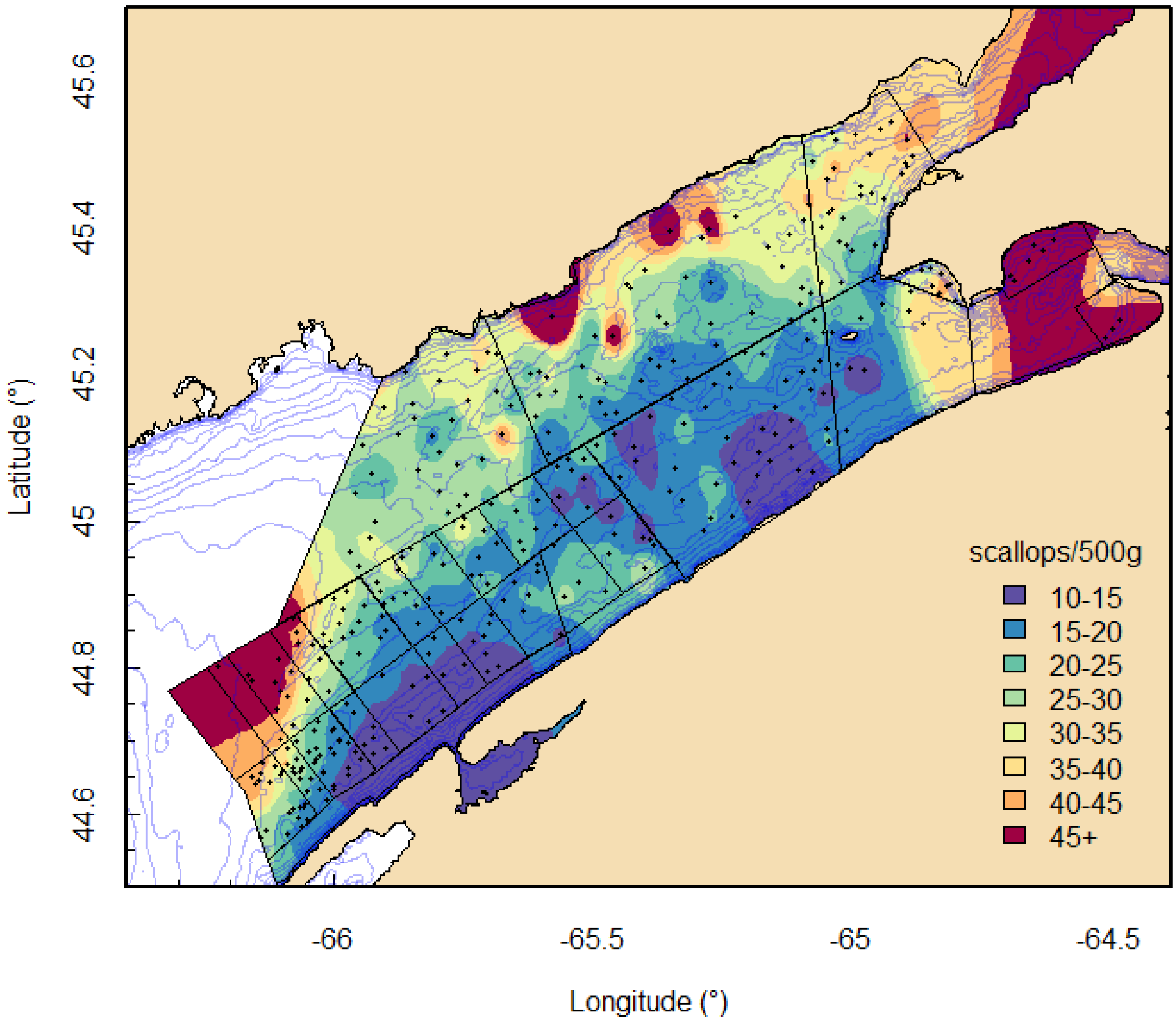

Figure 15. Spatial distribution of meat count (scallops/500 g) in Scallop Production Areas 1A, 1B, and 4, from the 2013 survey in the Bay of Fundy. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

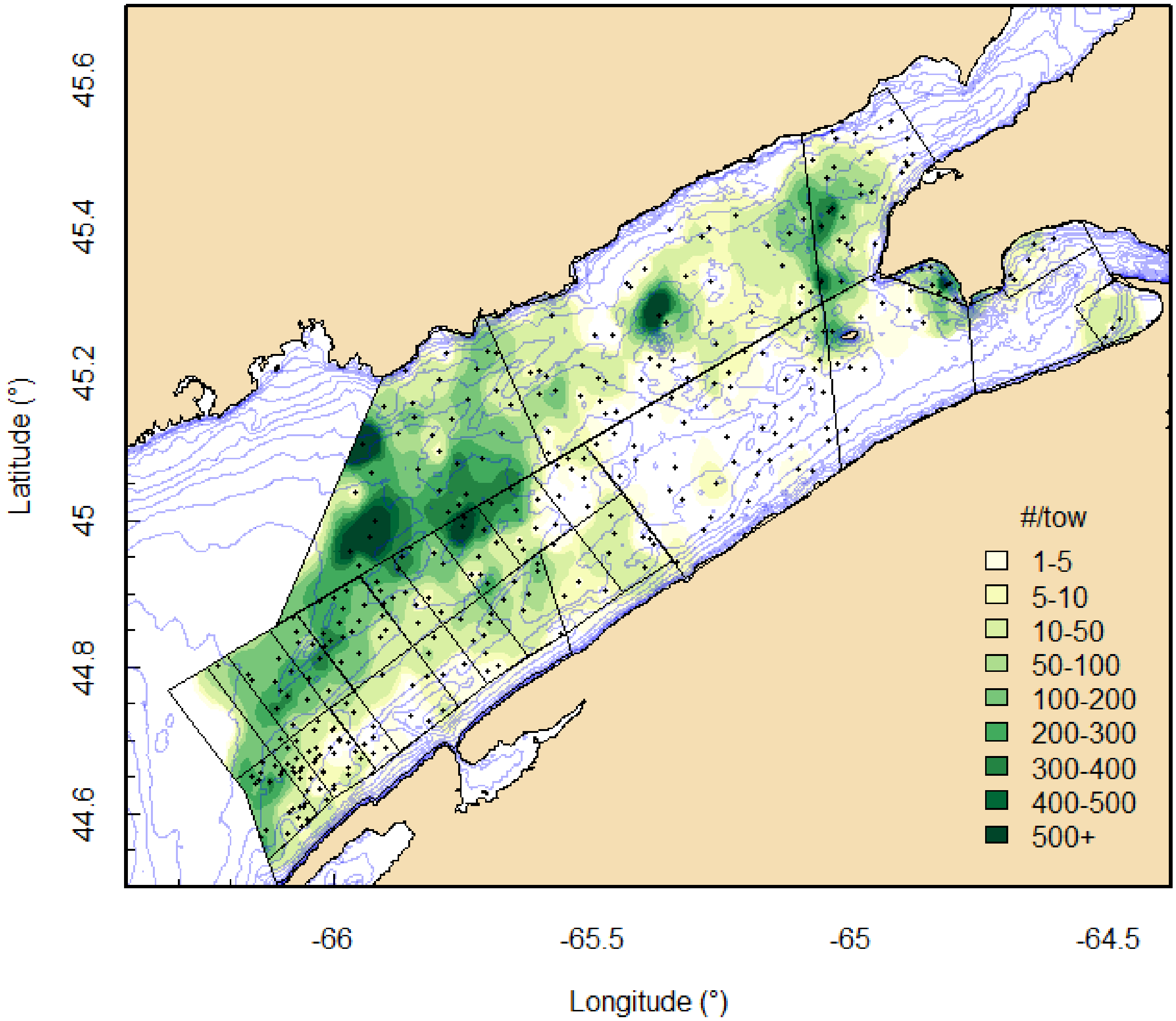

Figure 16. Spatial distribution of abundance (number/tow) of pre-recruit (<65 mm) scallop in Scallop Production Areas 1A, 1B, and 4, from the 2013 survey in the Bay of Fundy.

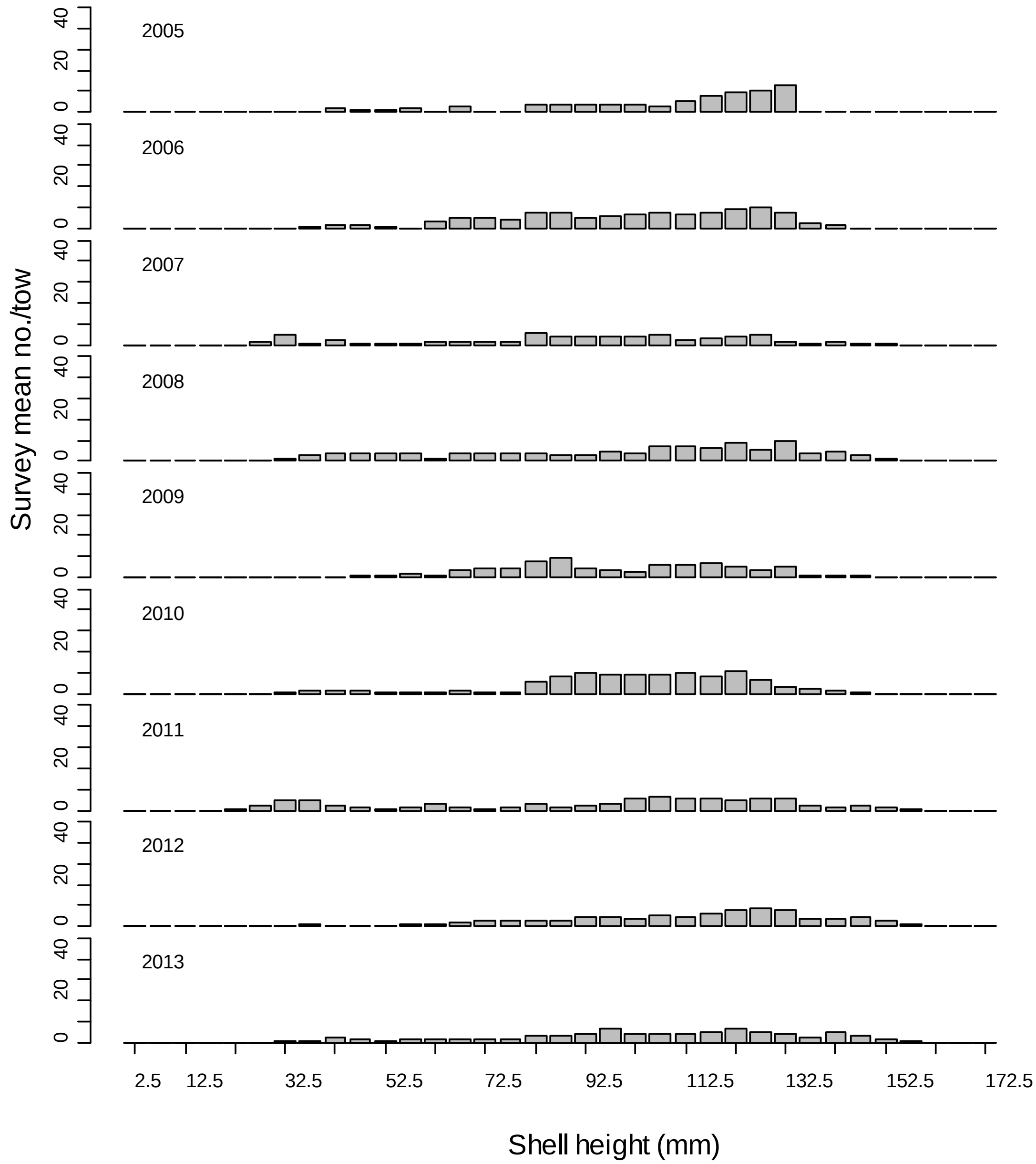

Figure 17. Scallop Production Area 1A, 2 to 8 mile zone survey shell height (mm) frequencies (mean number/ tow) from 2005-2013.

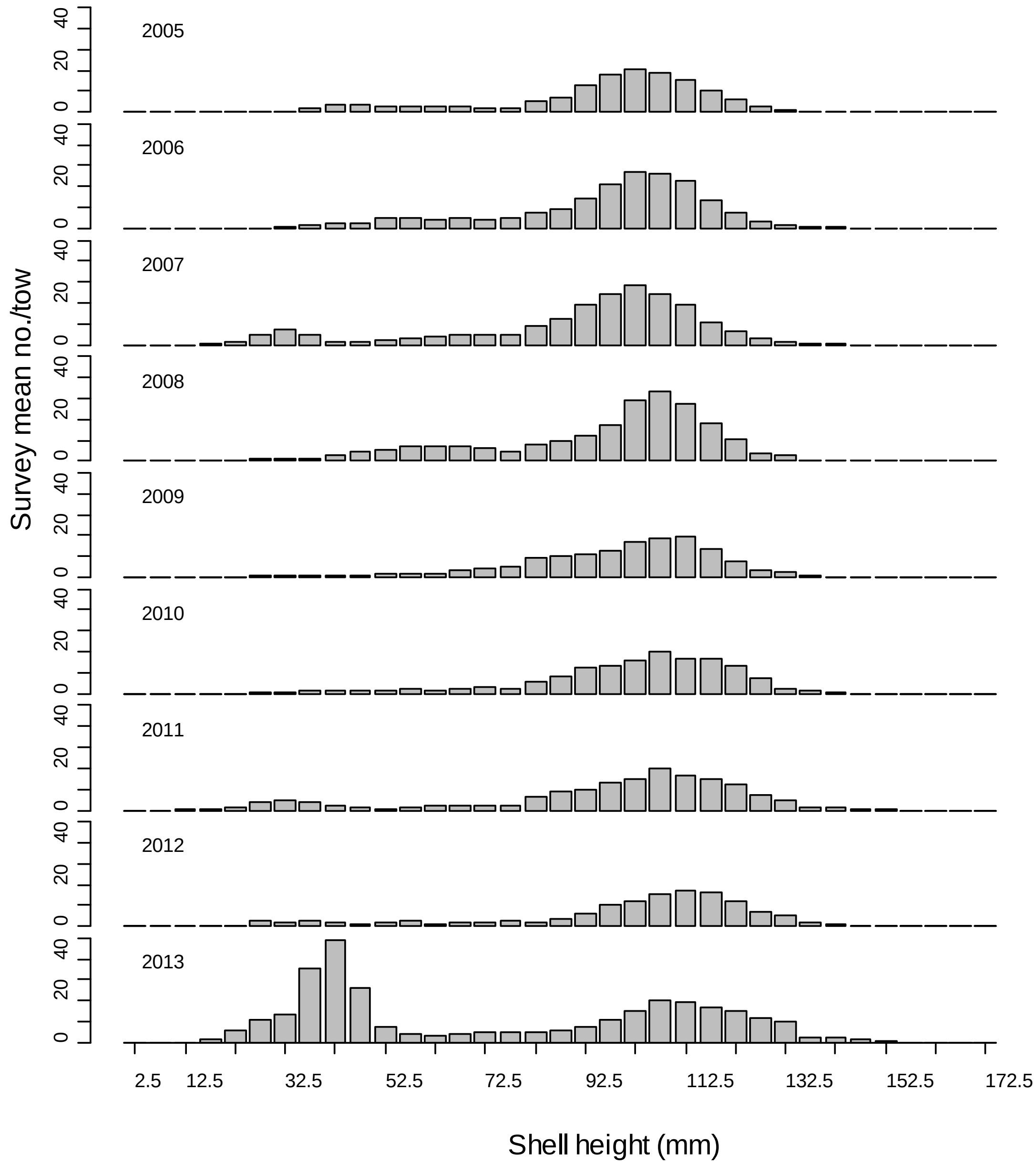

Figure 18. Scallop Production Area 1A, 8 to 16 mile zone of Scallop Production Area 1A survey shell height (mm) frequencies (mean number/ tow) from 2005-2013.

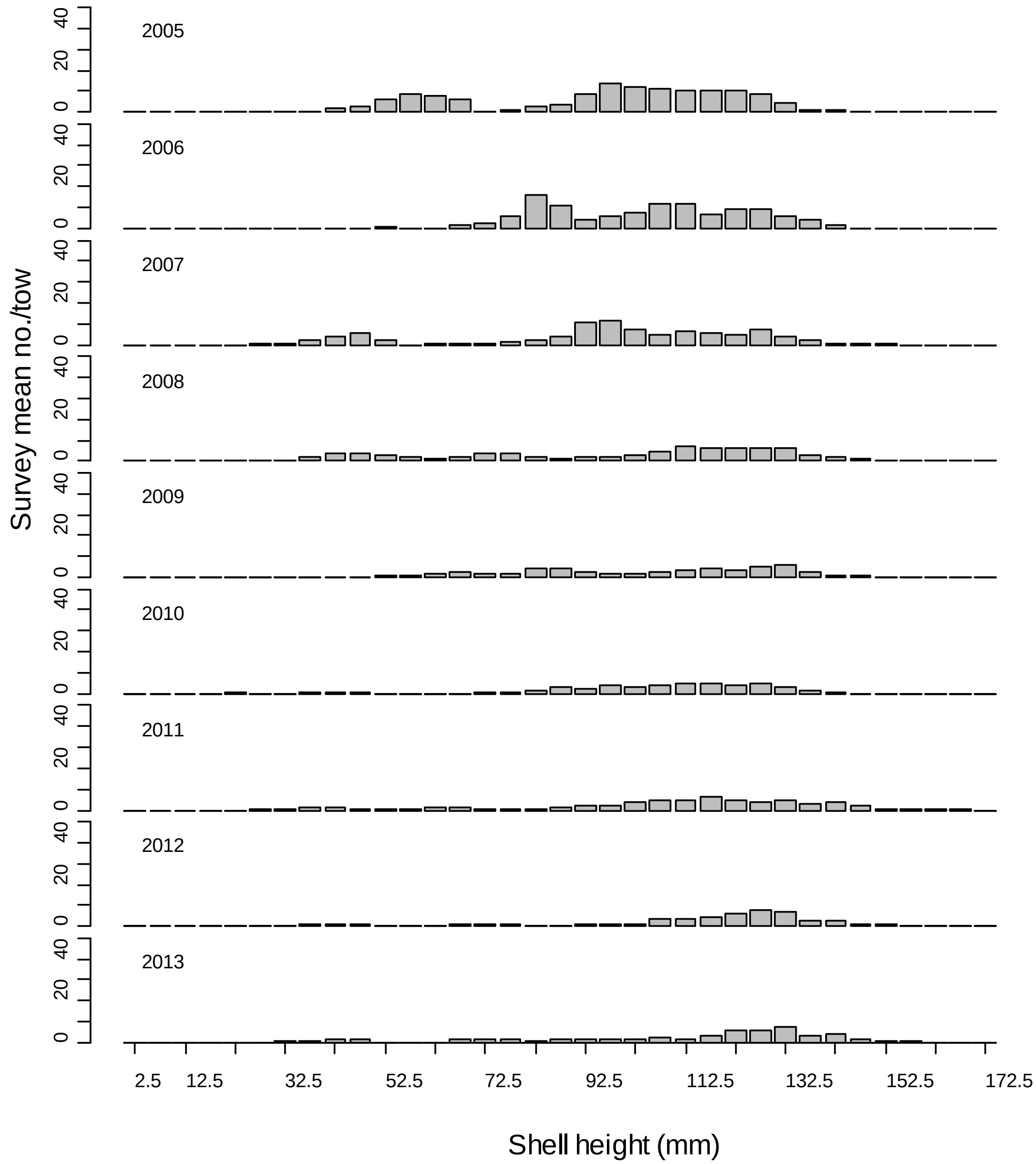

Figure 19. Middle Bay South zone of Scallop Production Area 1A survey shell height (mm) frequencies (mean number/ tow) from 2005-2013.

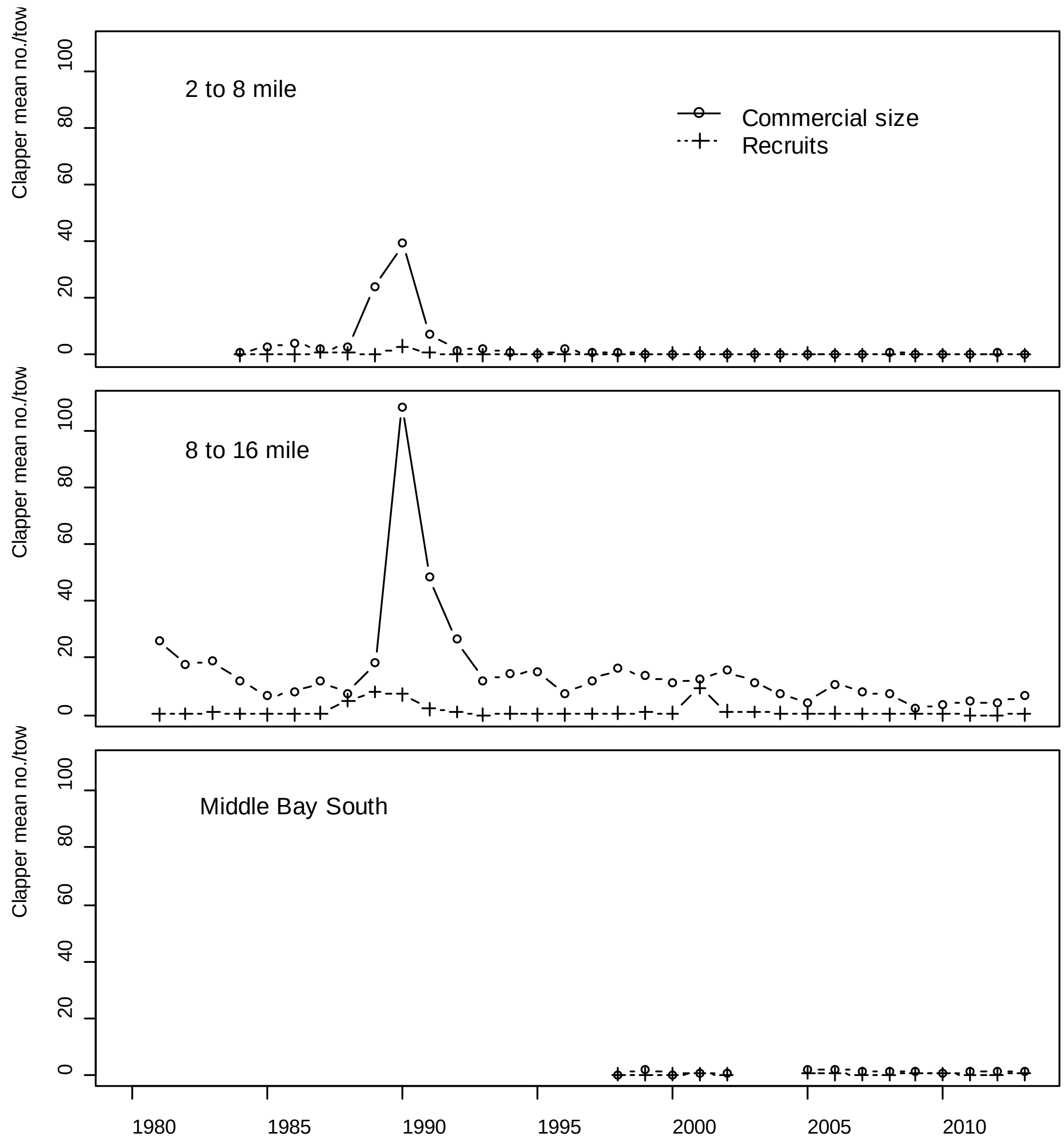

Figure 20. Scallop Production Area 1A subarea trends in survey abundance of clappers (no/tow of paired, dead shells) in 2 to 8 mile (upper panel) from 1984-2013, 8 to 16 mile (middle panel) from 1981-2013, and Middle Bay South (lower panel) from 1998-2013, for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops.

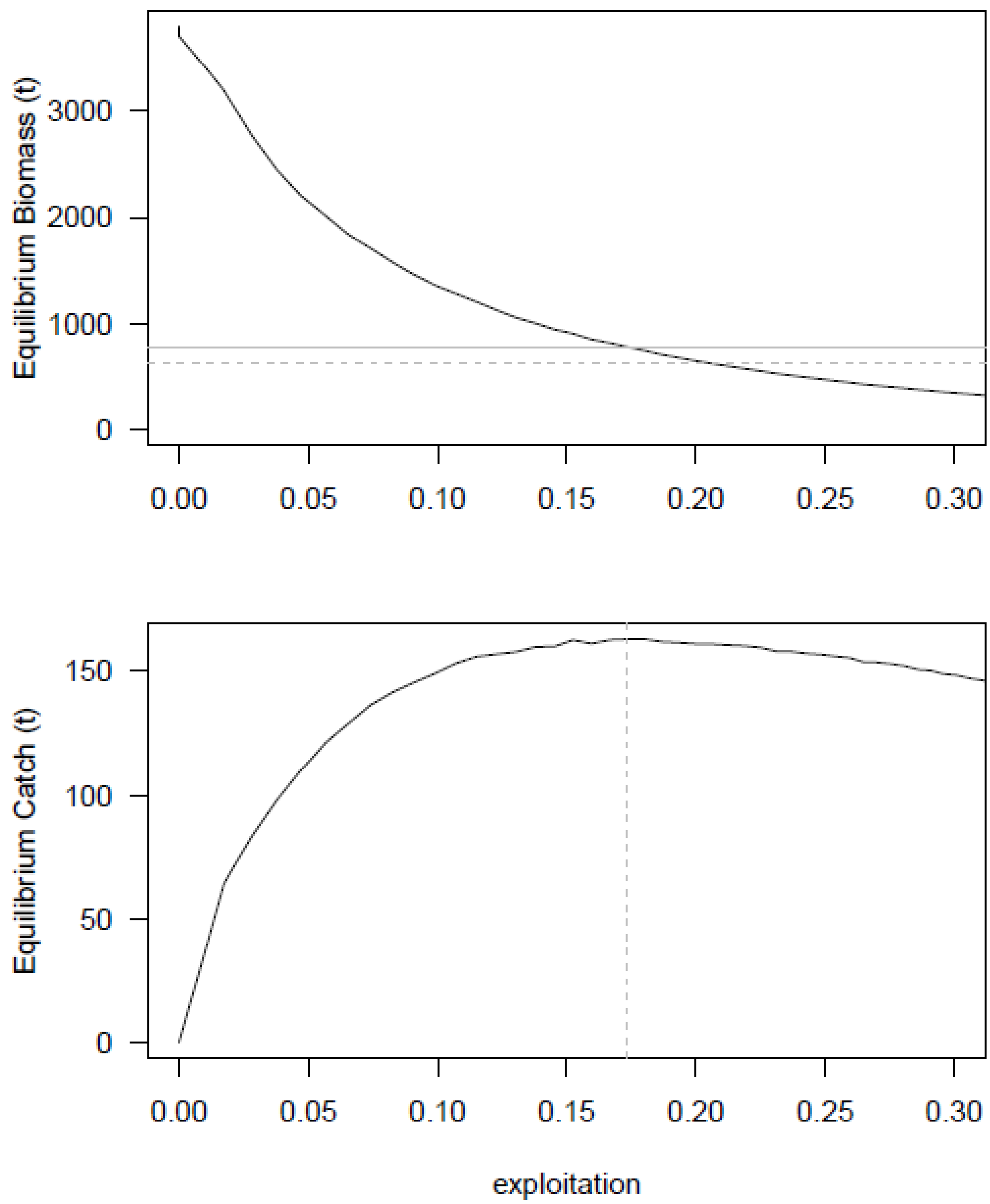

Figure 21. Equilibrium biomass (t; upper panel) and equilibrium catch (t; lower panel) used in determining the exploitation rate for maximum catch in Scallop Production Area 1A. These were obtained by projecting the model forward by 50 years from the current year for a range of constant exploitation rates. See Table 2 for an evaluation of the USR biomass levels.

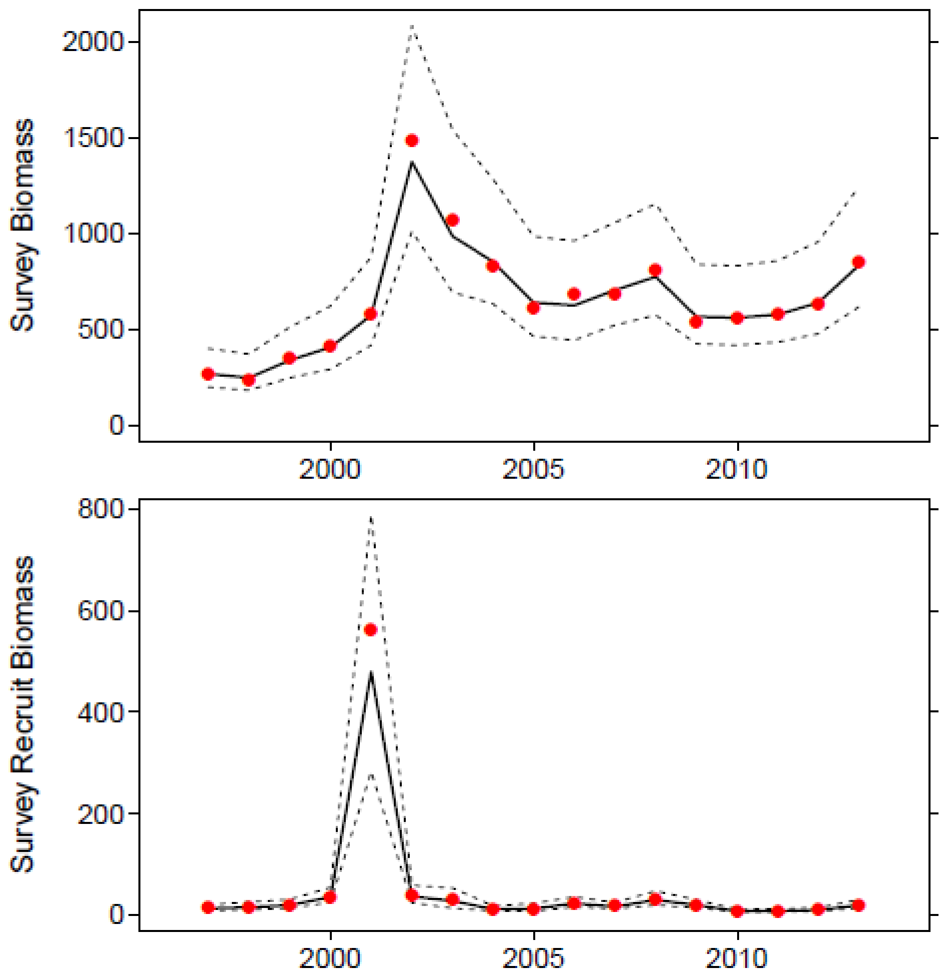

Figure 22. Scallop Production Area 1A, posterior median fit to the survey biomass series (from 1998 to 2013) for commercial (upper panel; t), and recruit (lower panel; t) size scallops from the Bayesian state-space assessment model used in this area.

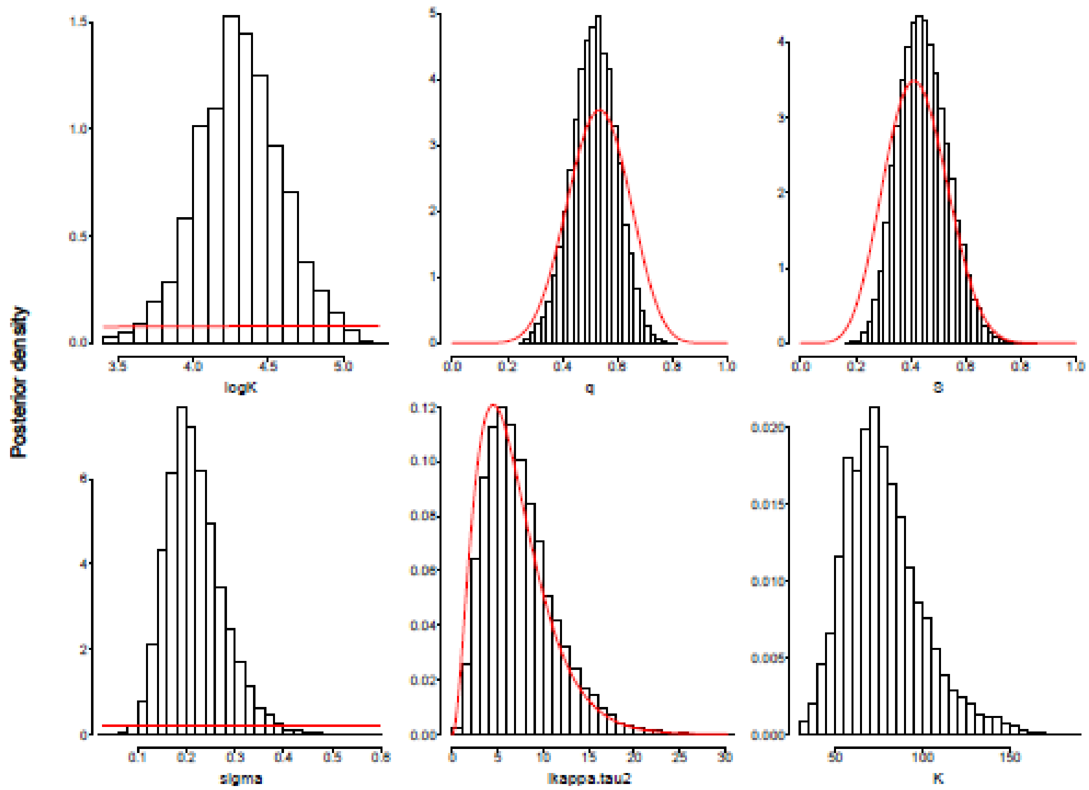

Figure 23. Scallop Production Area 1A, comparison of prior and posterior densities from the Bayesian state-space assessment model used in this area.

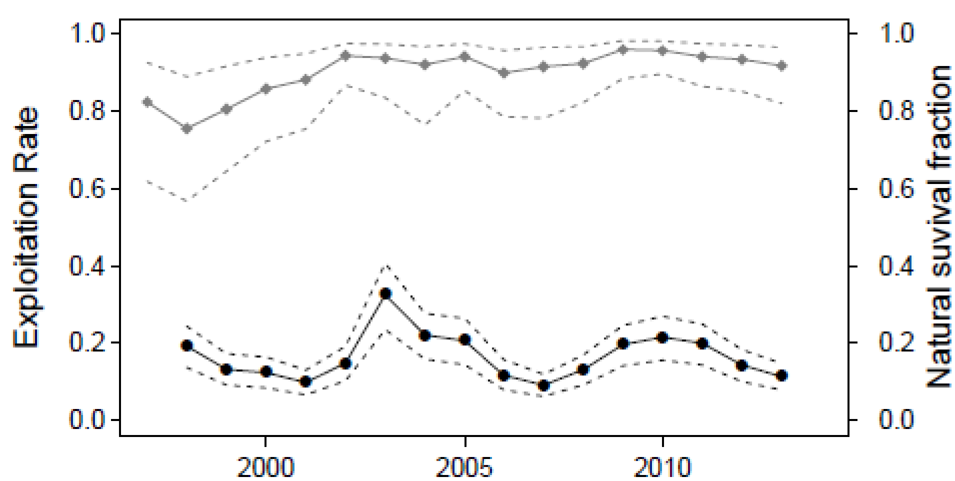

Figure 24. Scallop production Area 1A annual trends (from 1998-2013) in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey squares) from the Bayesian state-space assessment model used in this area.

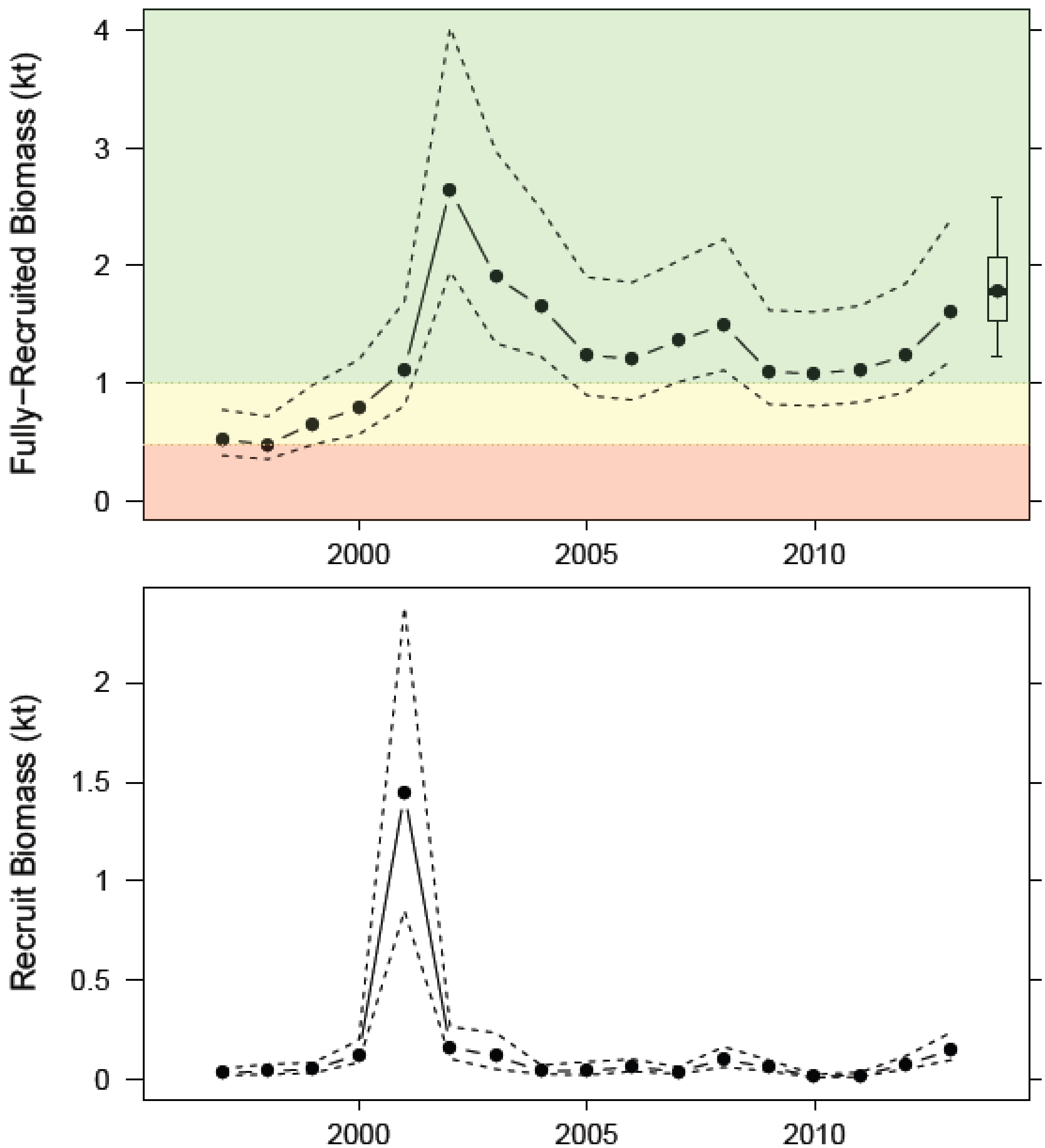

Figure 25. Scallop Production Area 1A biomass estimates for fully recruited scallops (upper panel; kt) and recruit scallops (lower panel, kt) from the assessment model fit to the survey and commercial data from 1997-2013). Dashed lines are the upper and lower 95% credible limits on the estimates. The predicted commercial size biomass for 2014, assuming the interim TAC (150 t), is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers). Green-shaded area represents the healthy zone (based on a USR of 1000 t), yellow area represents the cautious zone (based on LRP of 480 t) and red is the critical zone (<LRP).

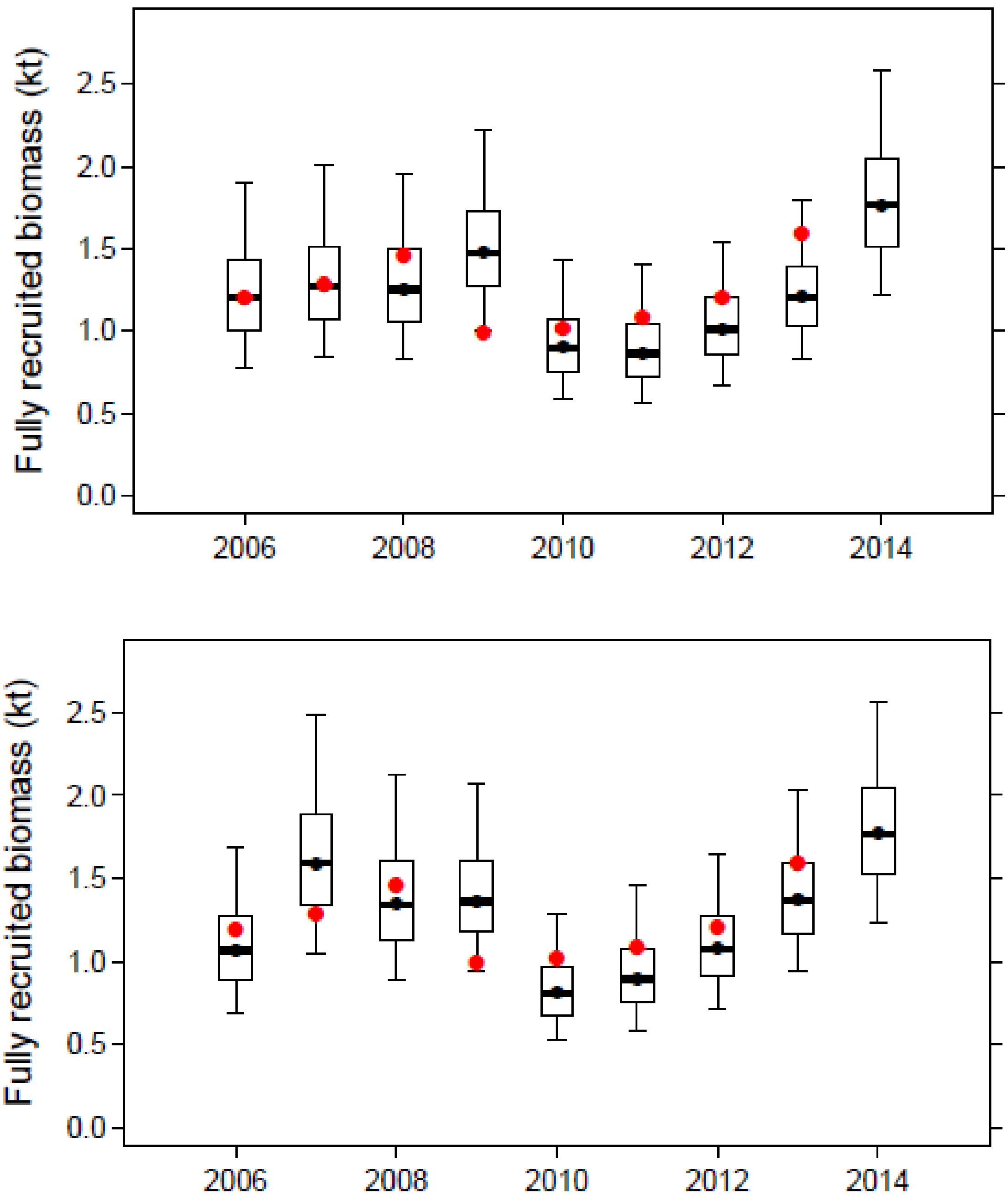

Figure 26. Scallop Production Area 1A evaluation of the model projection performance from 2006-2013, with unknown condition (upper), and assuming condition had been known (lower panel). Box and whisker plots summarise posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2006 predictions 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, from the Bayesian state-space assessment model used in this area.

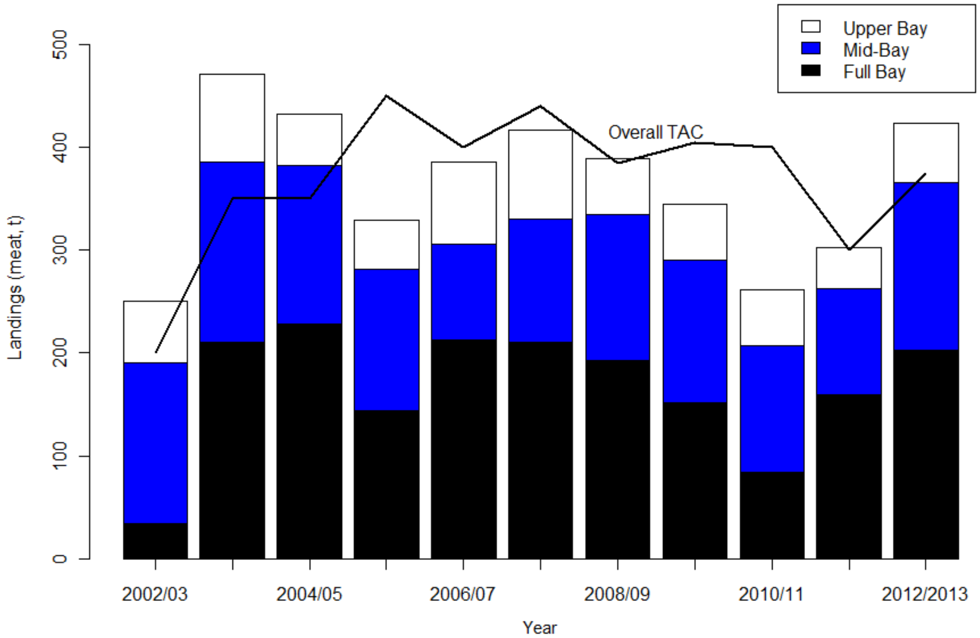

Figure 27. Scallop Production Area 1B landings (meats, tons) by the Full Bay fleet (black bars), Mid Bay fleet (blue bars), and Upper Bay fleet (white bars) from 2002-2013. Combined TAC for the three fleets is indicated by black line.

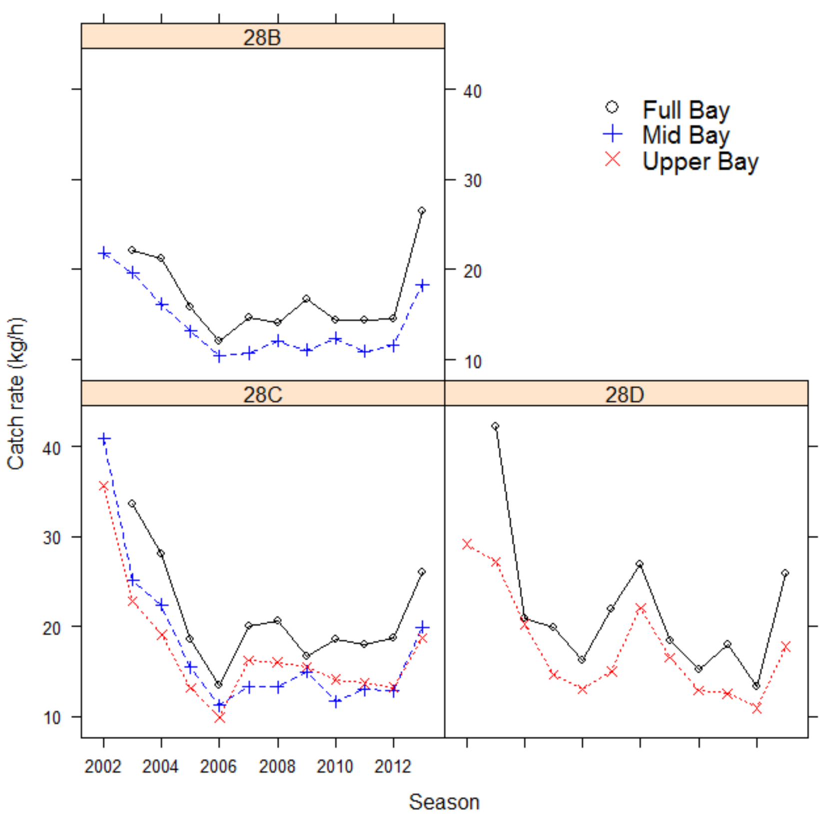

Figure 28. Scallop Production Area 1B trends in commercial catch rate (kg/h) for 28B (upper panel), 28C (lower left), and 28D (lower right) for each fleet: Full Bay (circles), Mid Bay (crosses) and Upper Bay (crosses) from 2002 to 2013.

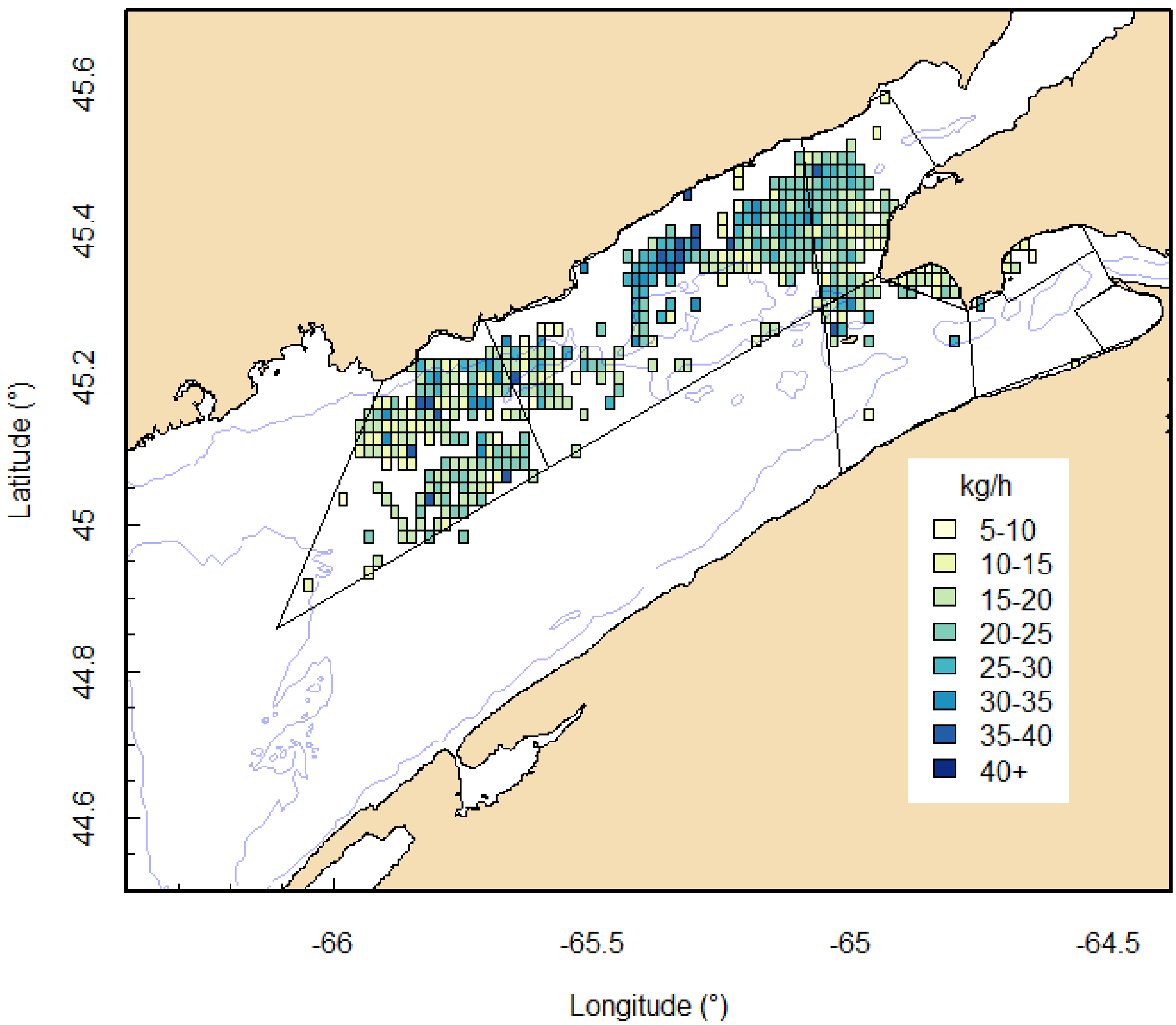

Figure 29. Mean commercial catch rates (kg/h) by 1 minute square from the commercial fishing logs in Scallop Production Area 1B in the 2012/2013 fishing season by the Full Bay, Mid Bay, and Upper Bay fleets combined. Lines indicate survey areas.

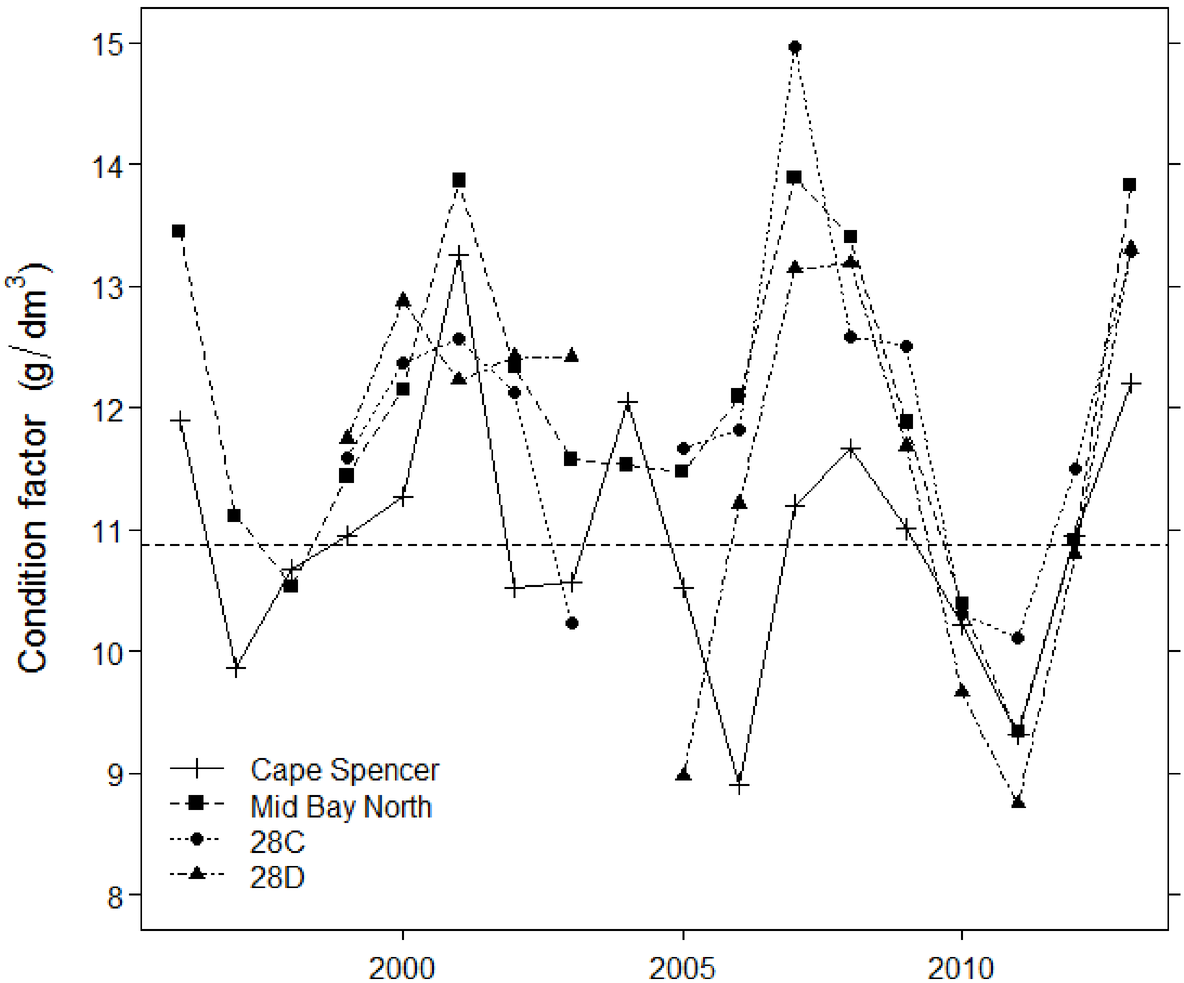

Figure 30. Scallop Production Area 1B trend in condition factor (g/dm[3]) from the annual survey by subarea: Cape Spencer (crosses), Middle Bay North (squares), 28C (circles), and 28D (triangles). From 1995-2013, mean condition from 1995-2012 is indicated.

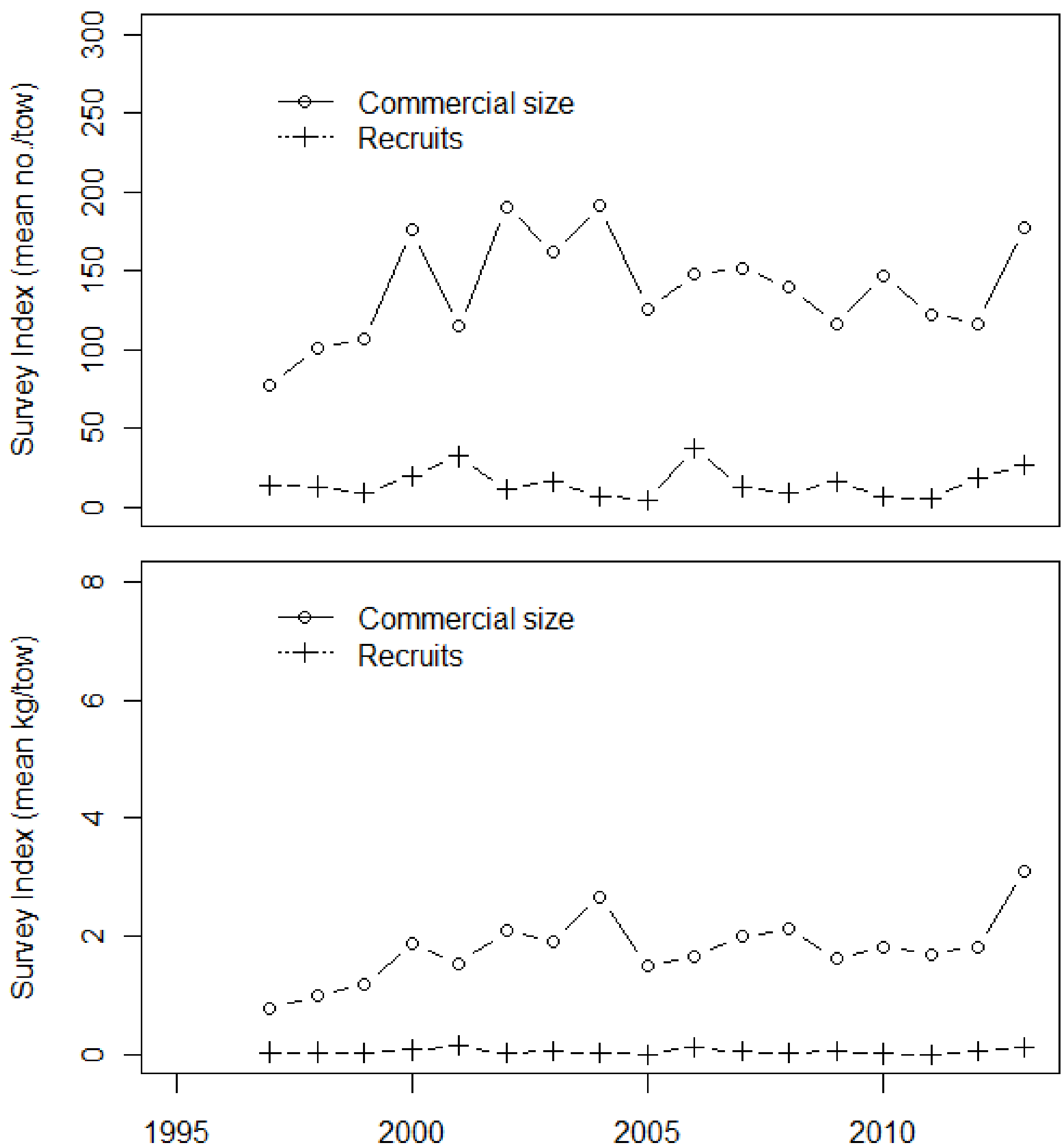

Figure 31. Cape Spencer zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1997-2013.

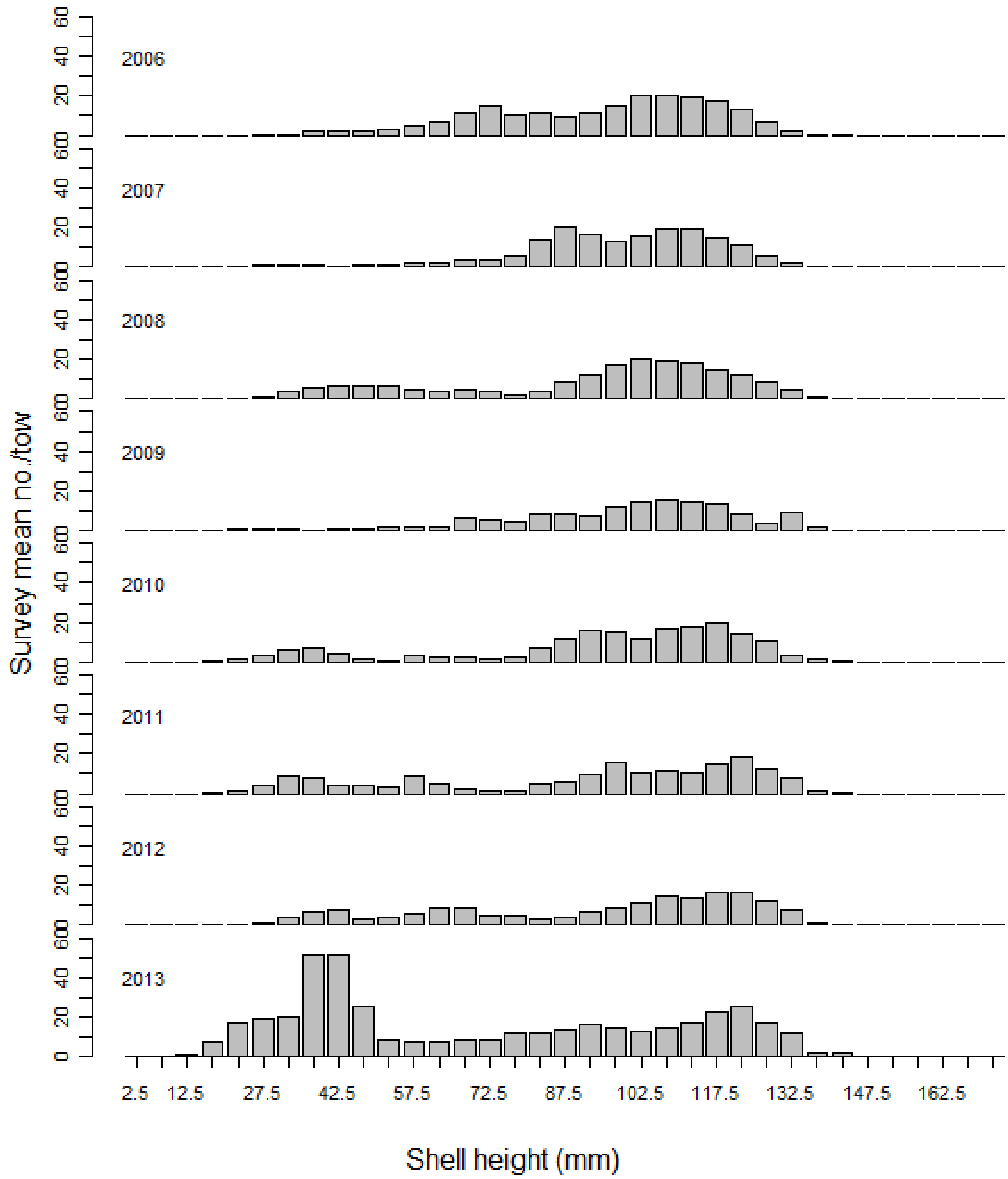

Figure 32. Cape Spencer zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

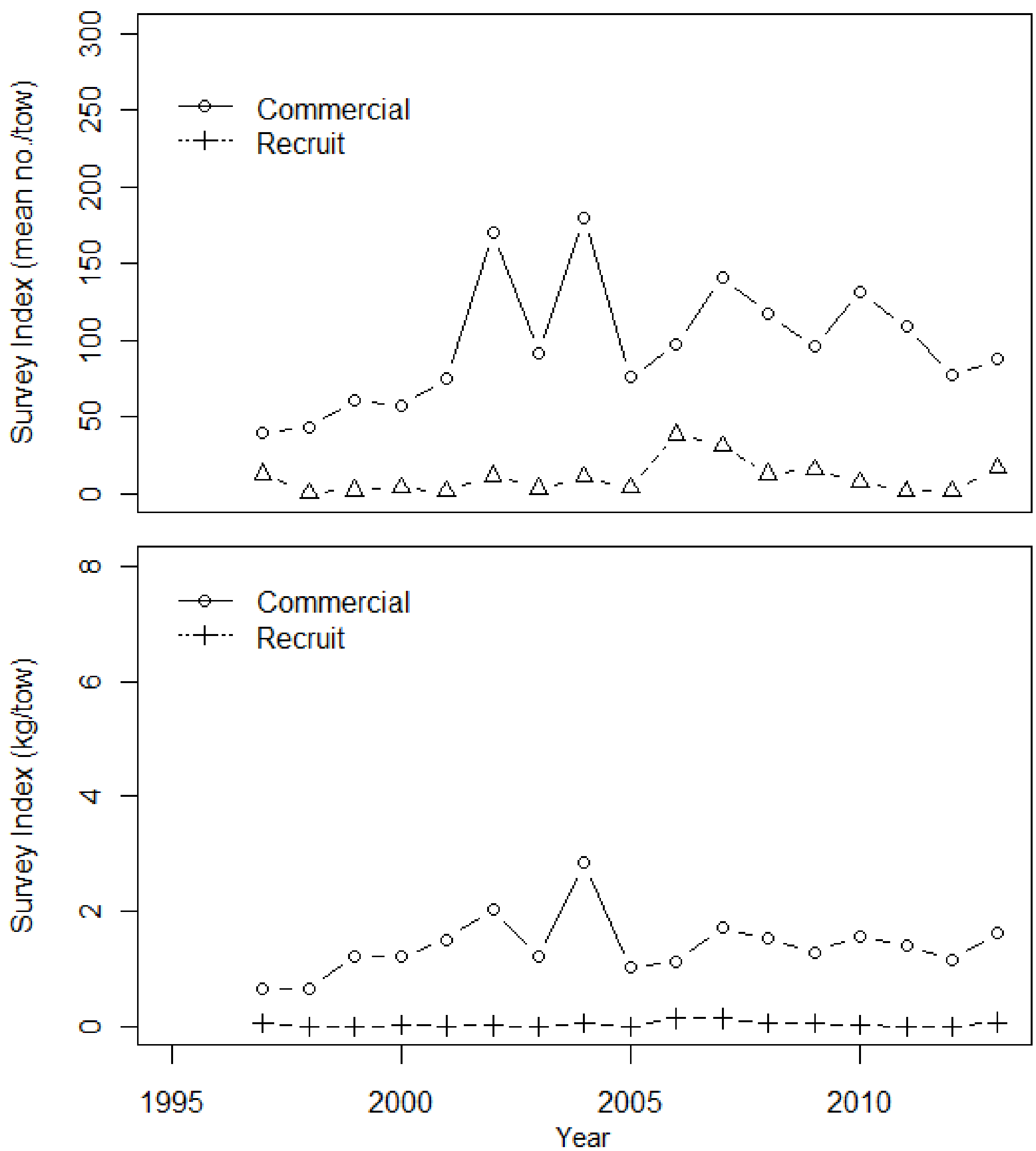

Figure 33. Middle Bay North zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1997-2013.

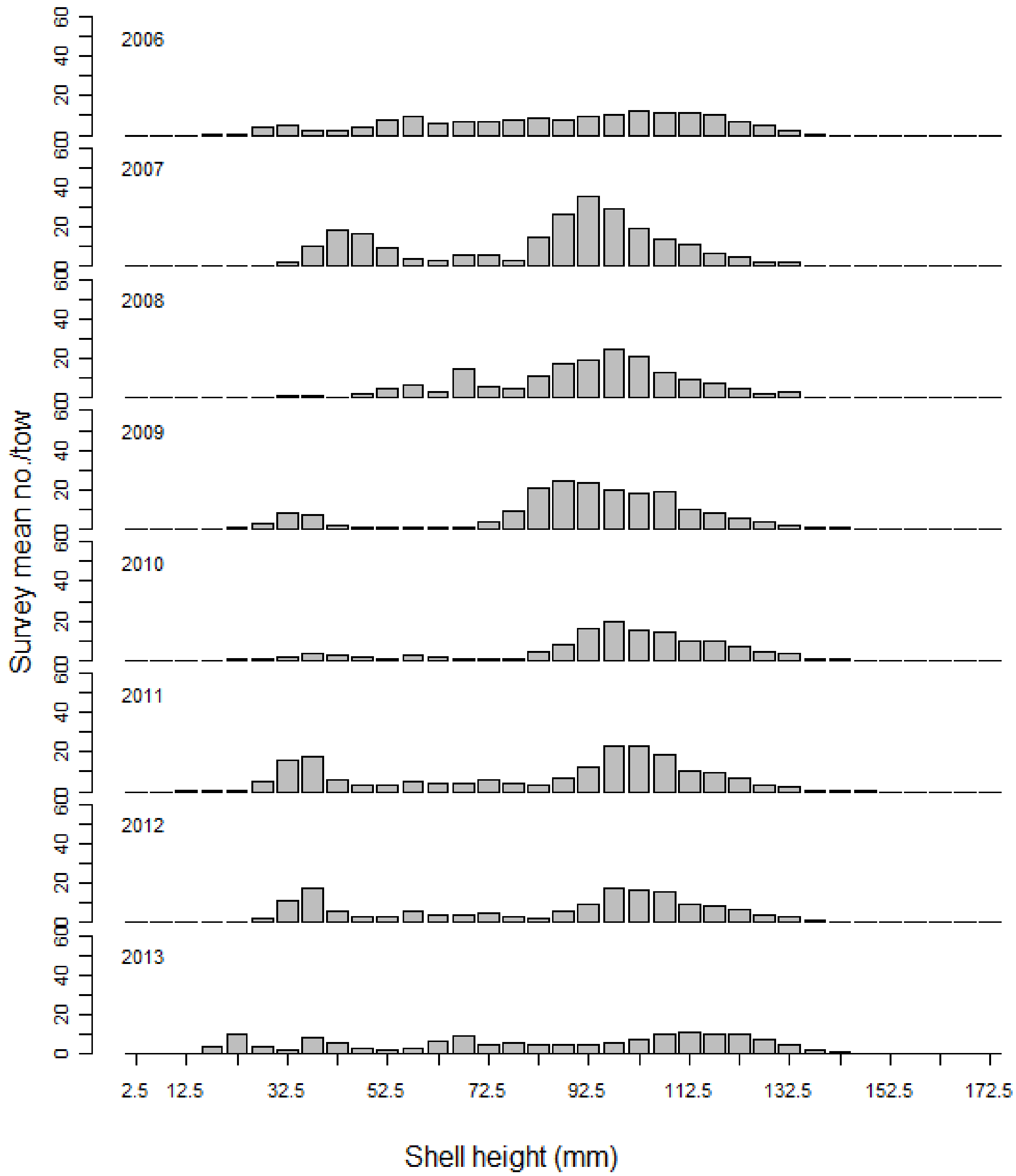

Figure 34. Middle Bay North zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

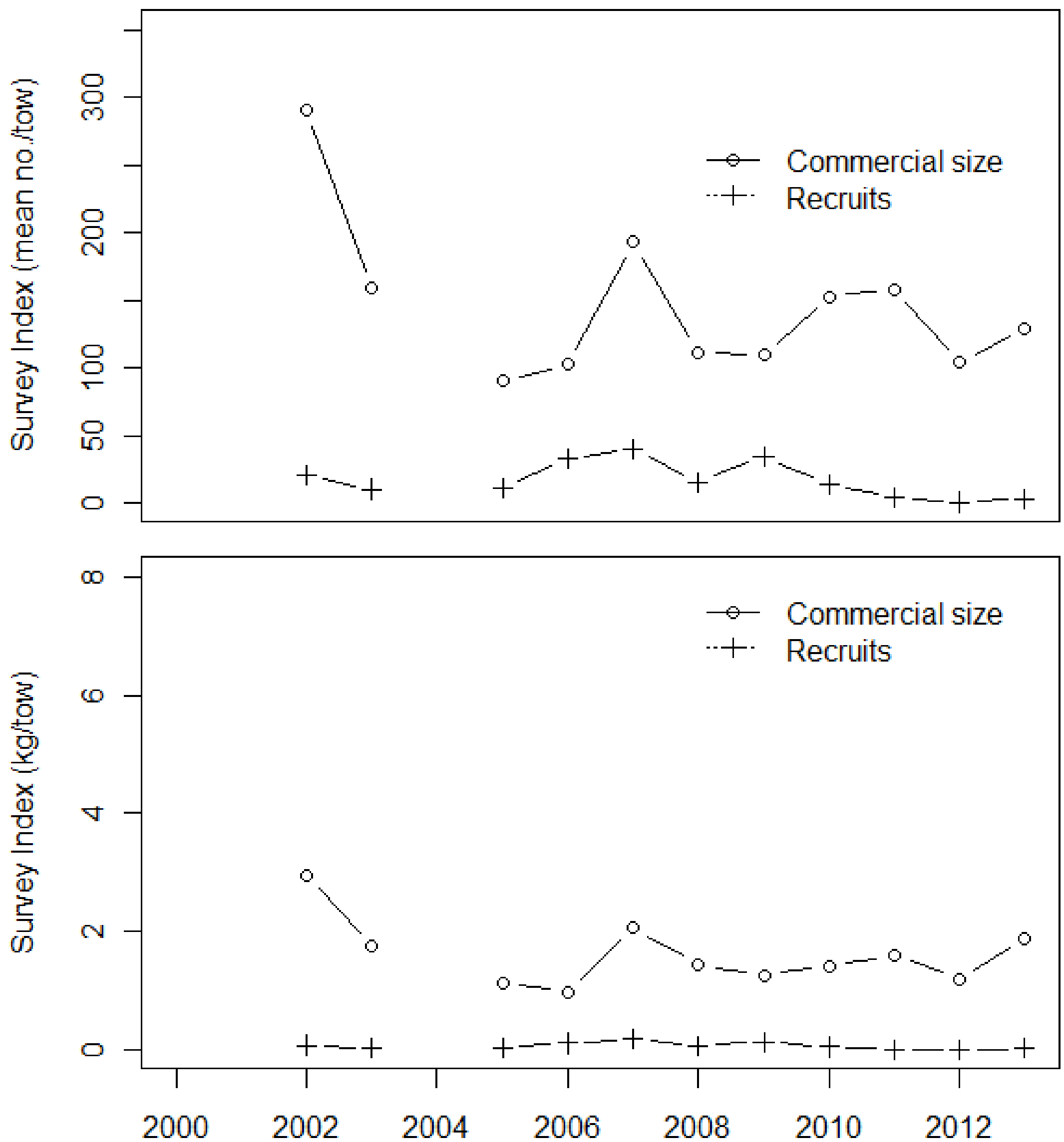

Figure 35. Upper Bay (28C) zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2002-2003 and 2005-2013.

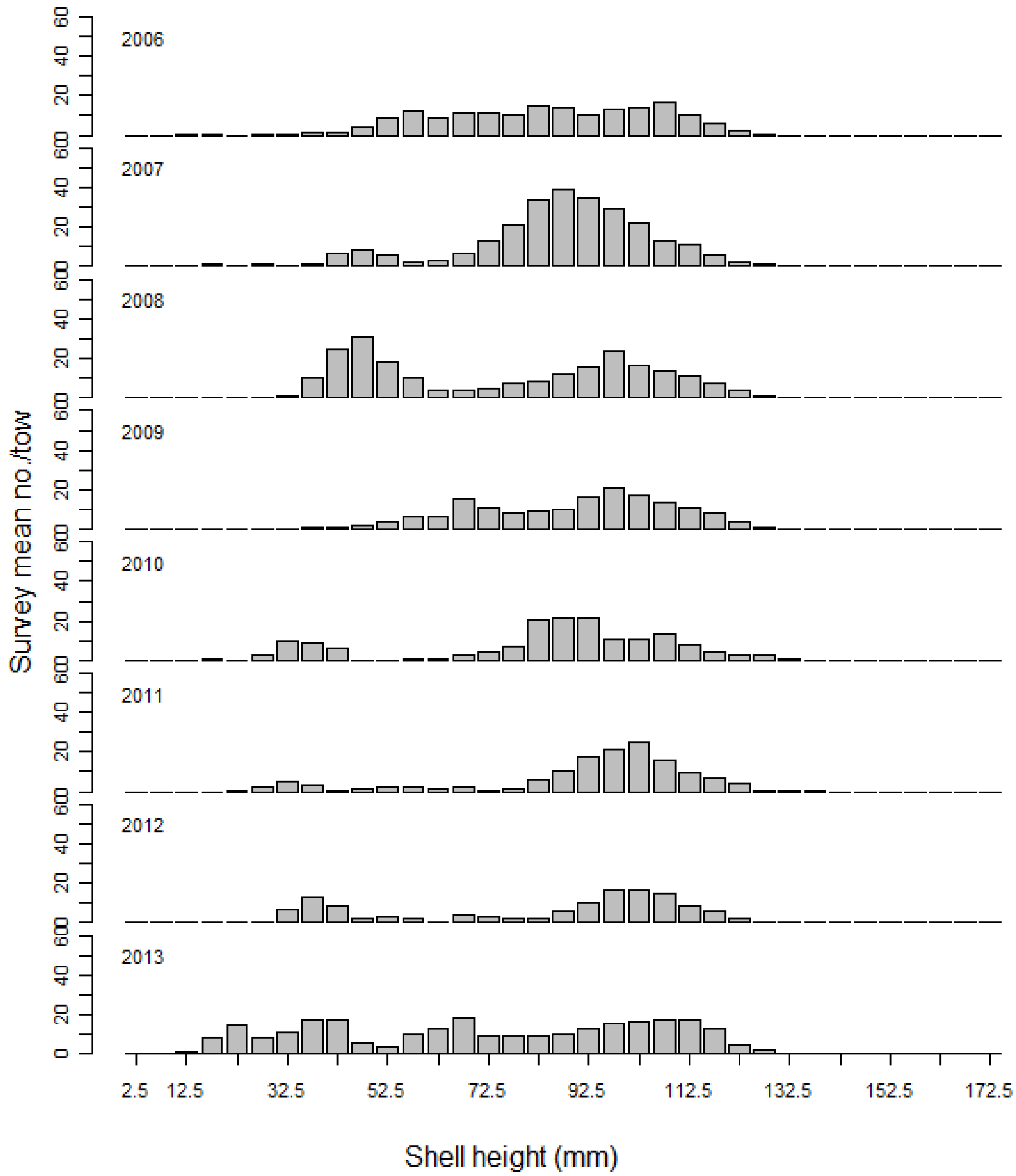

Figure 36. Upper Bay (28C) zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

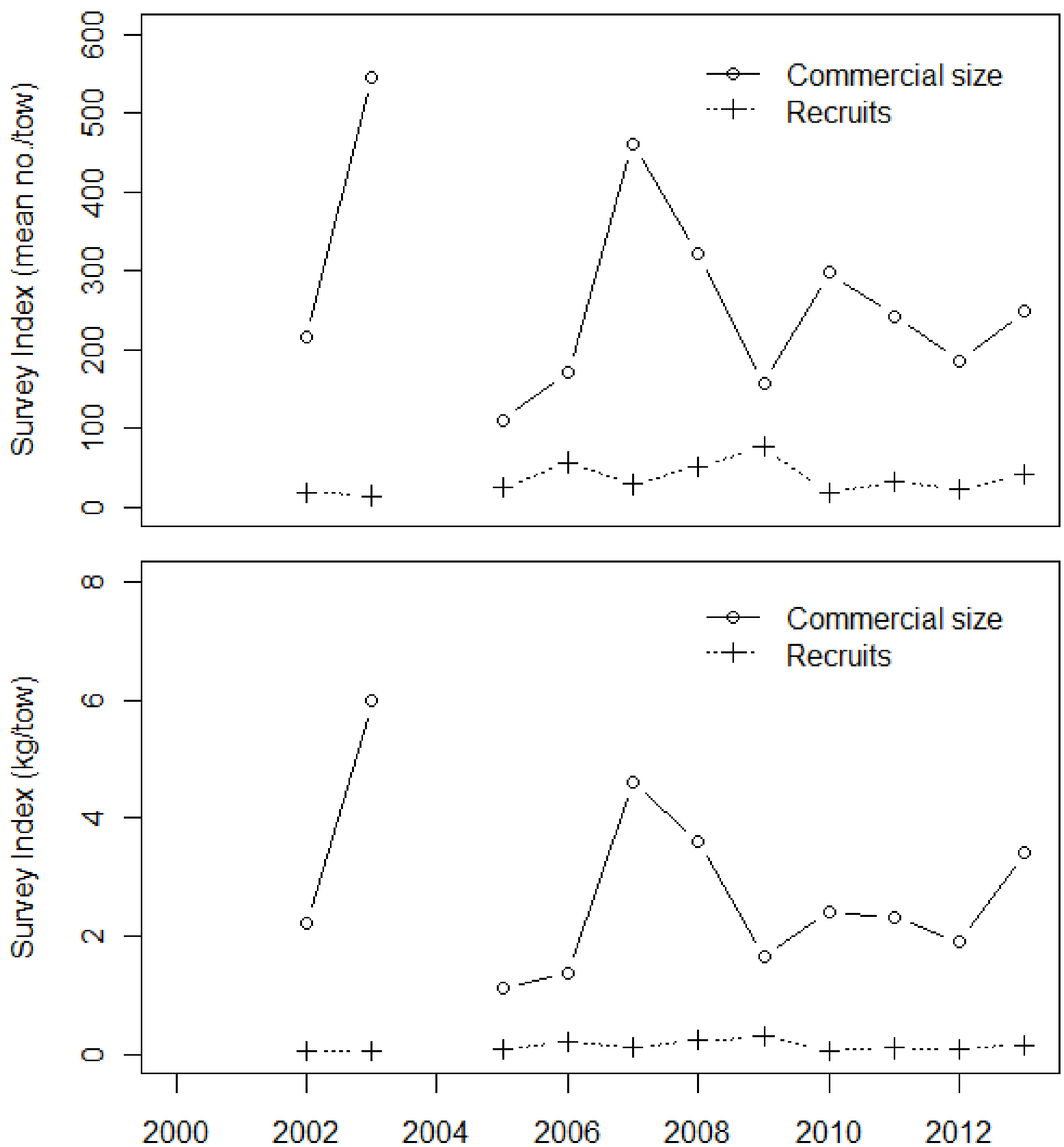

Figure 37. Advocate zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2002-2003 and 2005-2013.

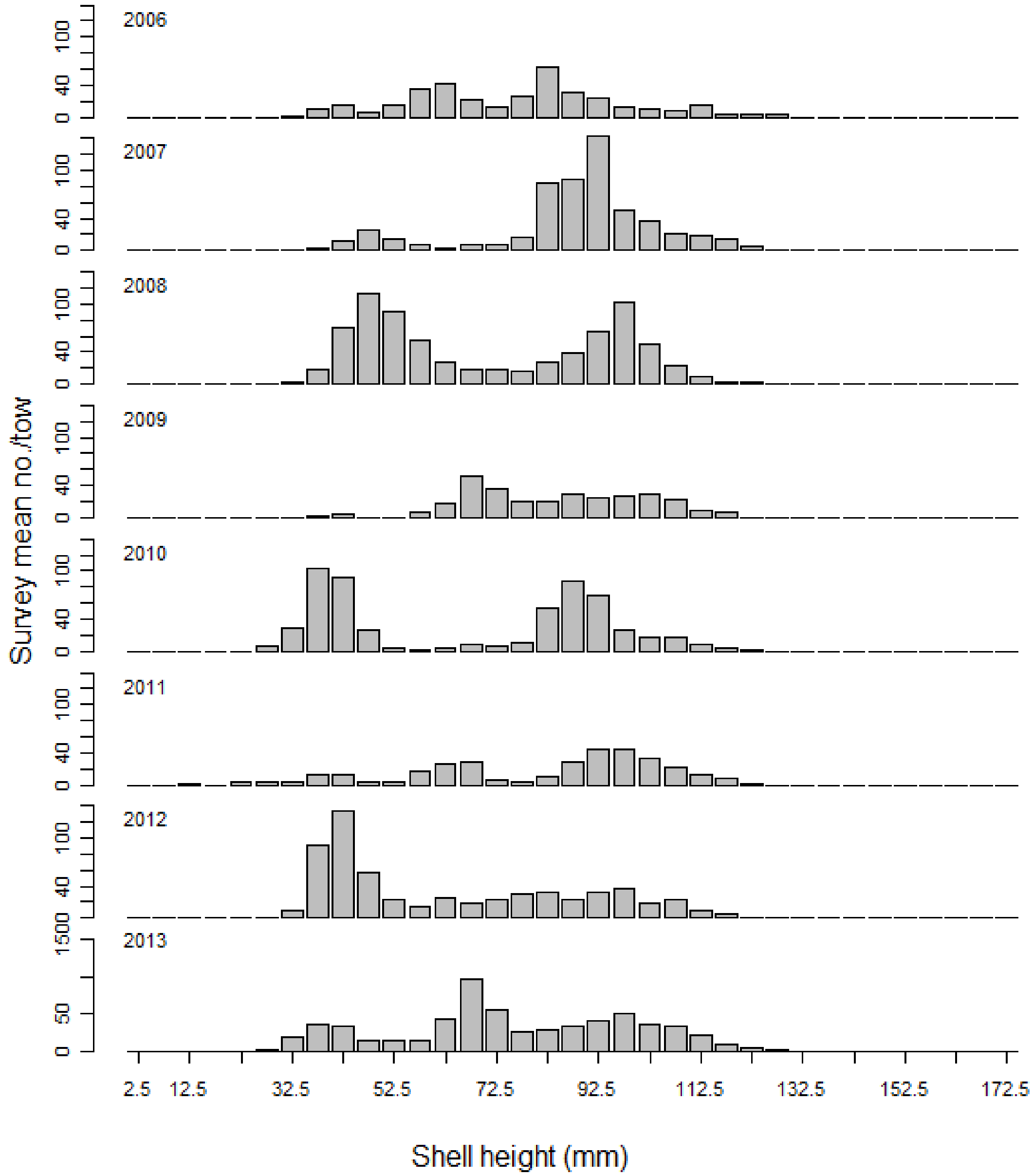

Figure 38. Advocate zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

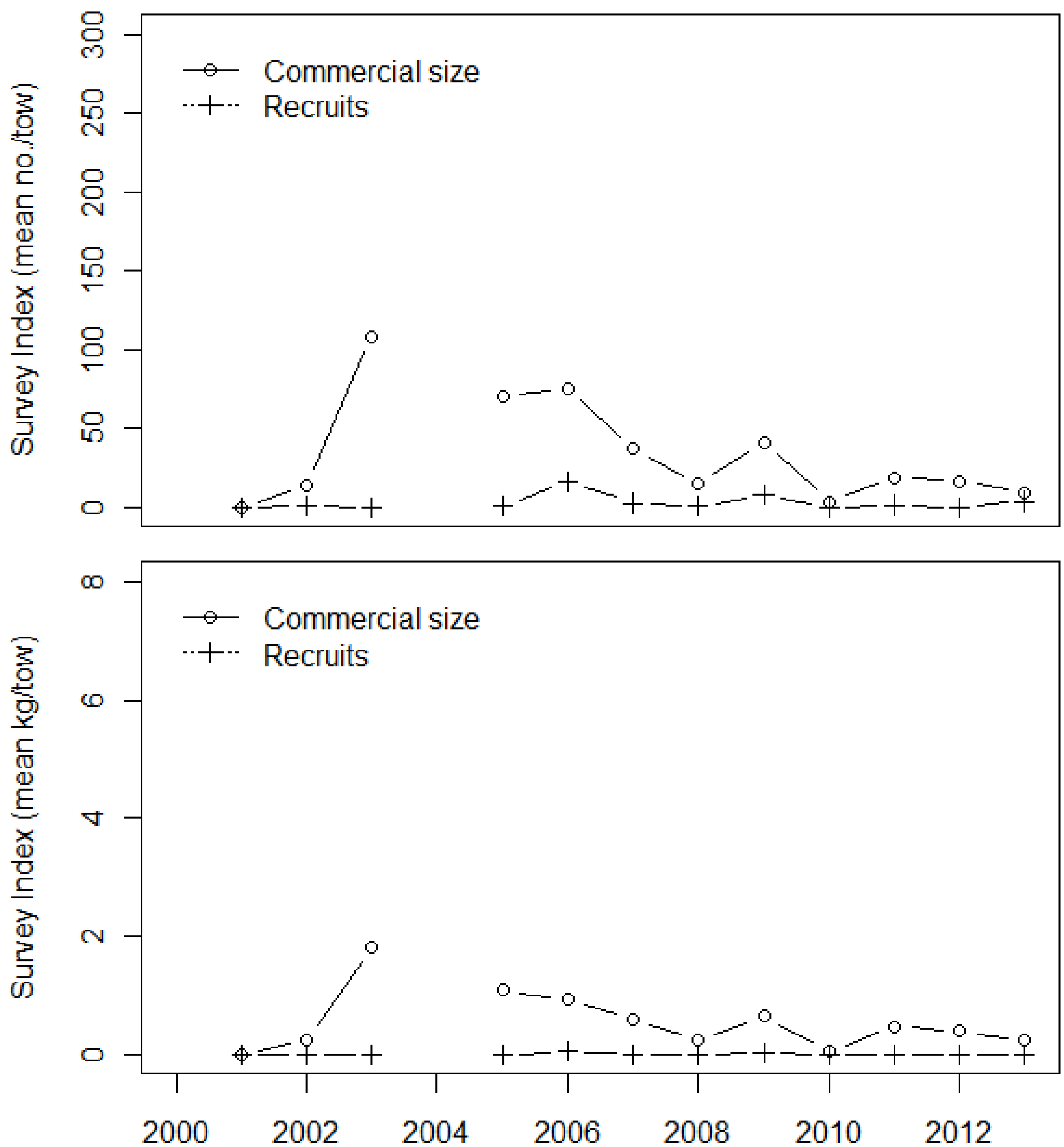

Figure 39. Outer (28D) zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2001-2003 and 2005-2013.

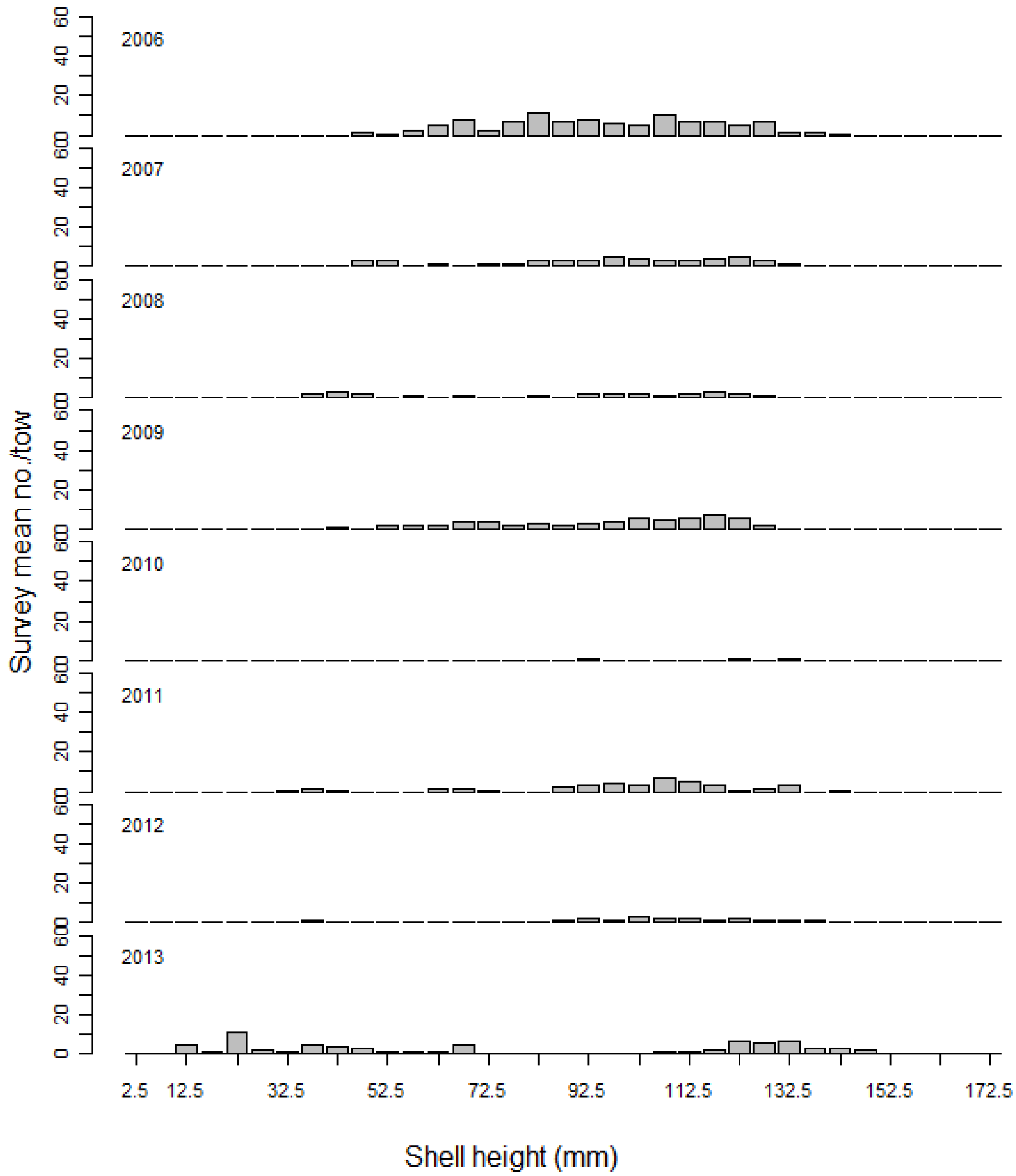

Figure 40. Outer (28D) zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

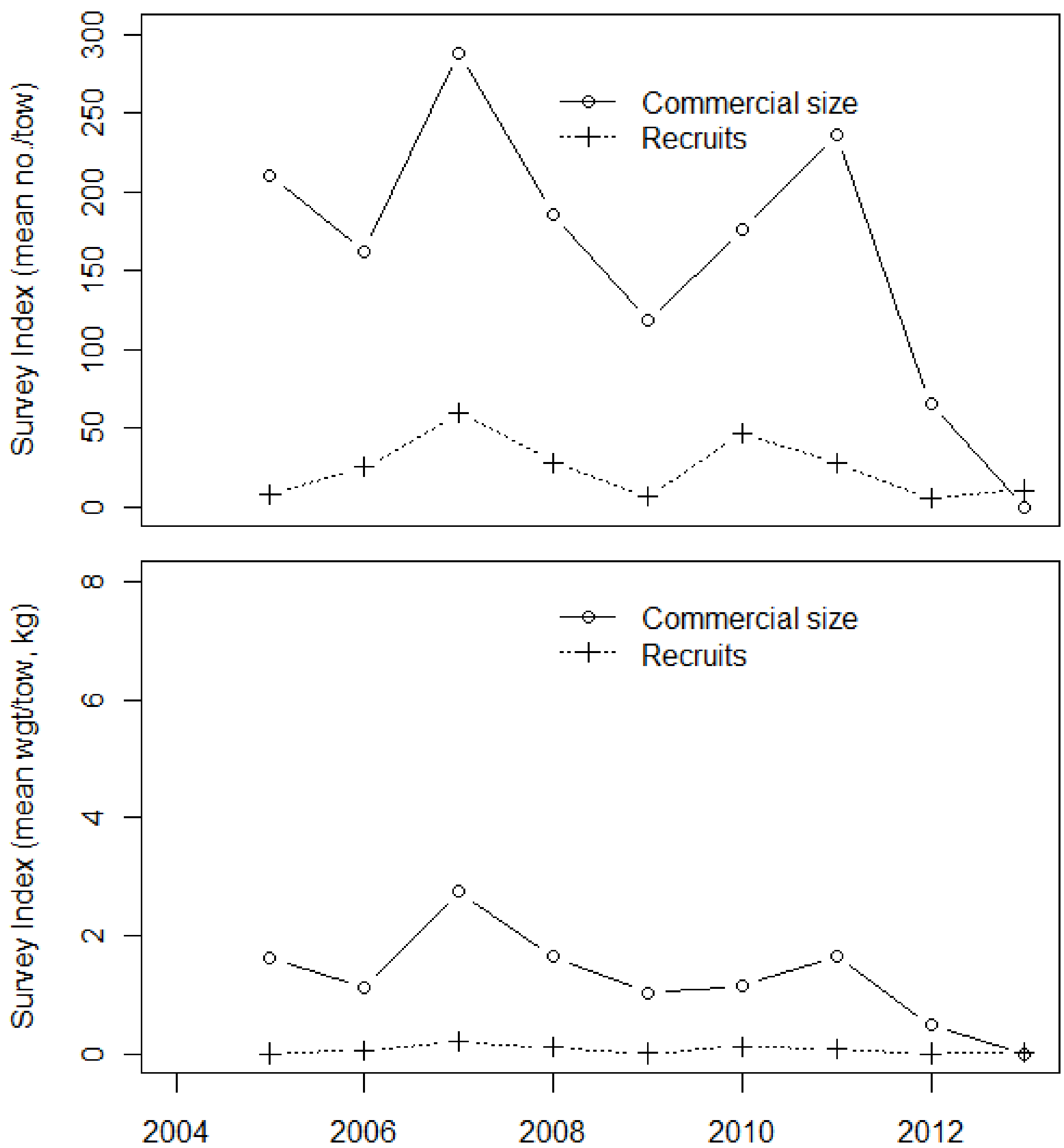

Figure 41. Spencer's Island zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2005-2013.

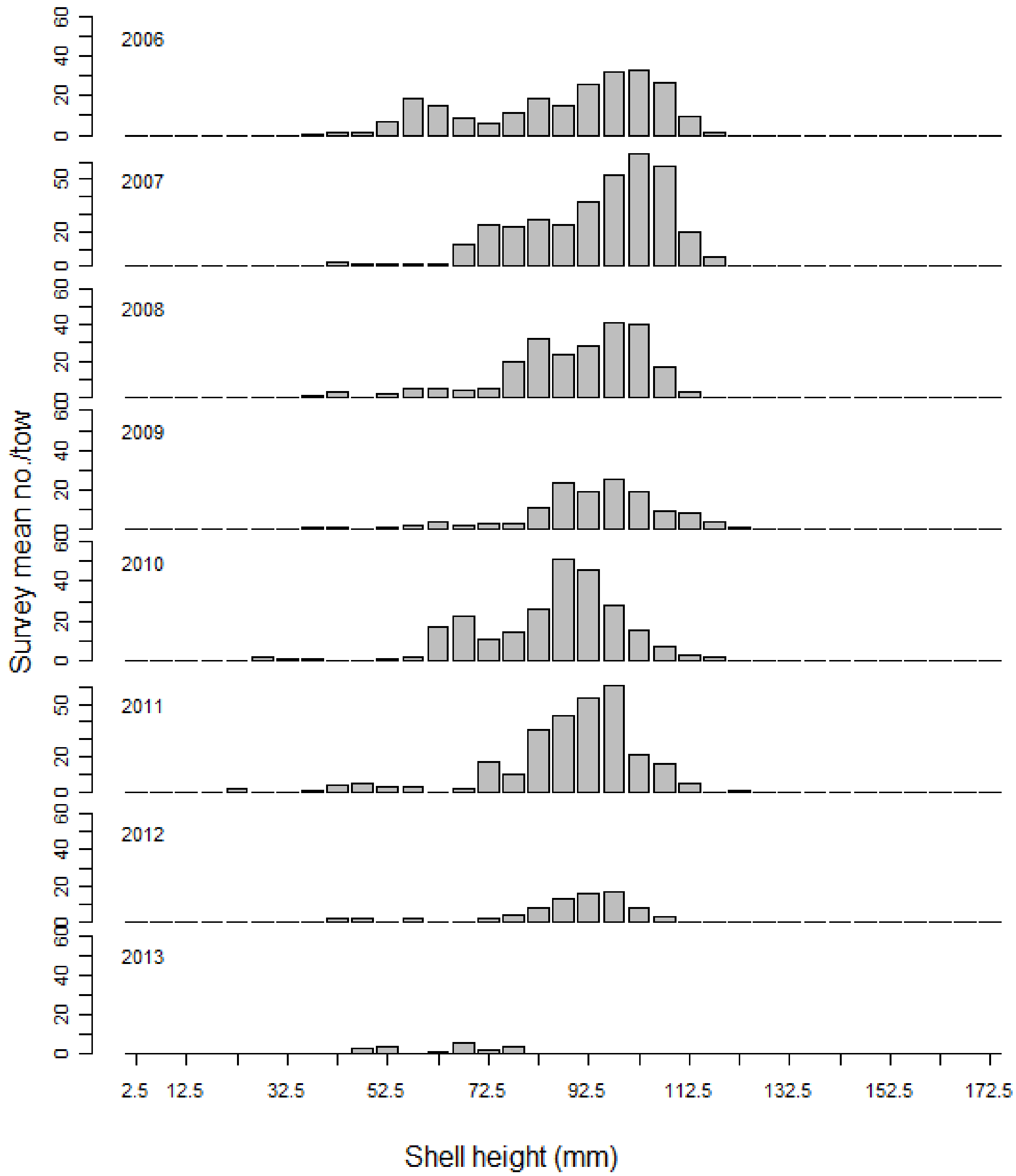

Figure 42. Spencer's Island zone of Scallop Production Area 1B survey shell height frequencies (mean number/ tow) from 2006-2013.

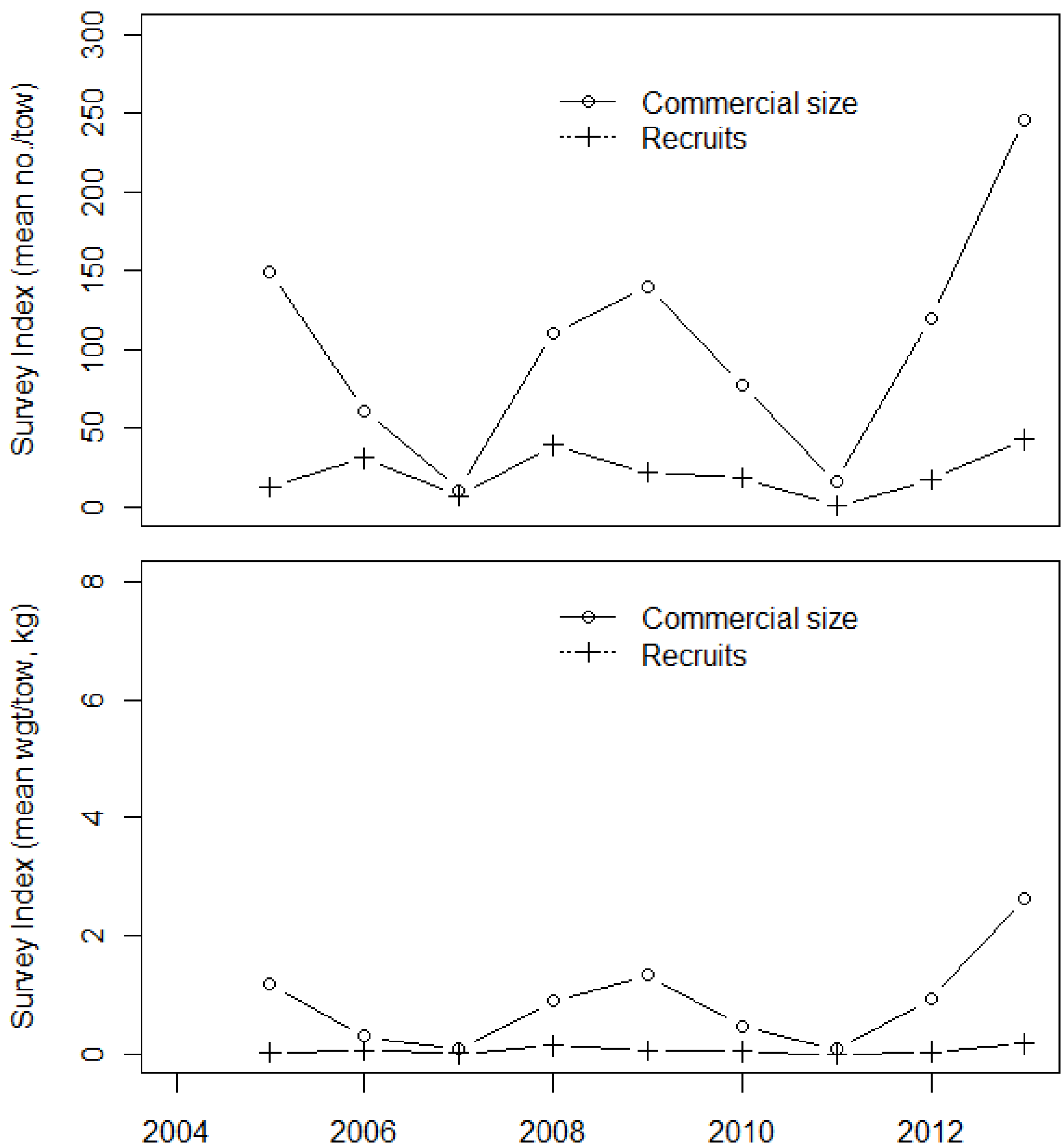

Figure 43. Scots Bay zone of Scallop Production Area 1B trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2005-2013.

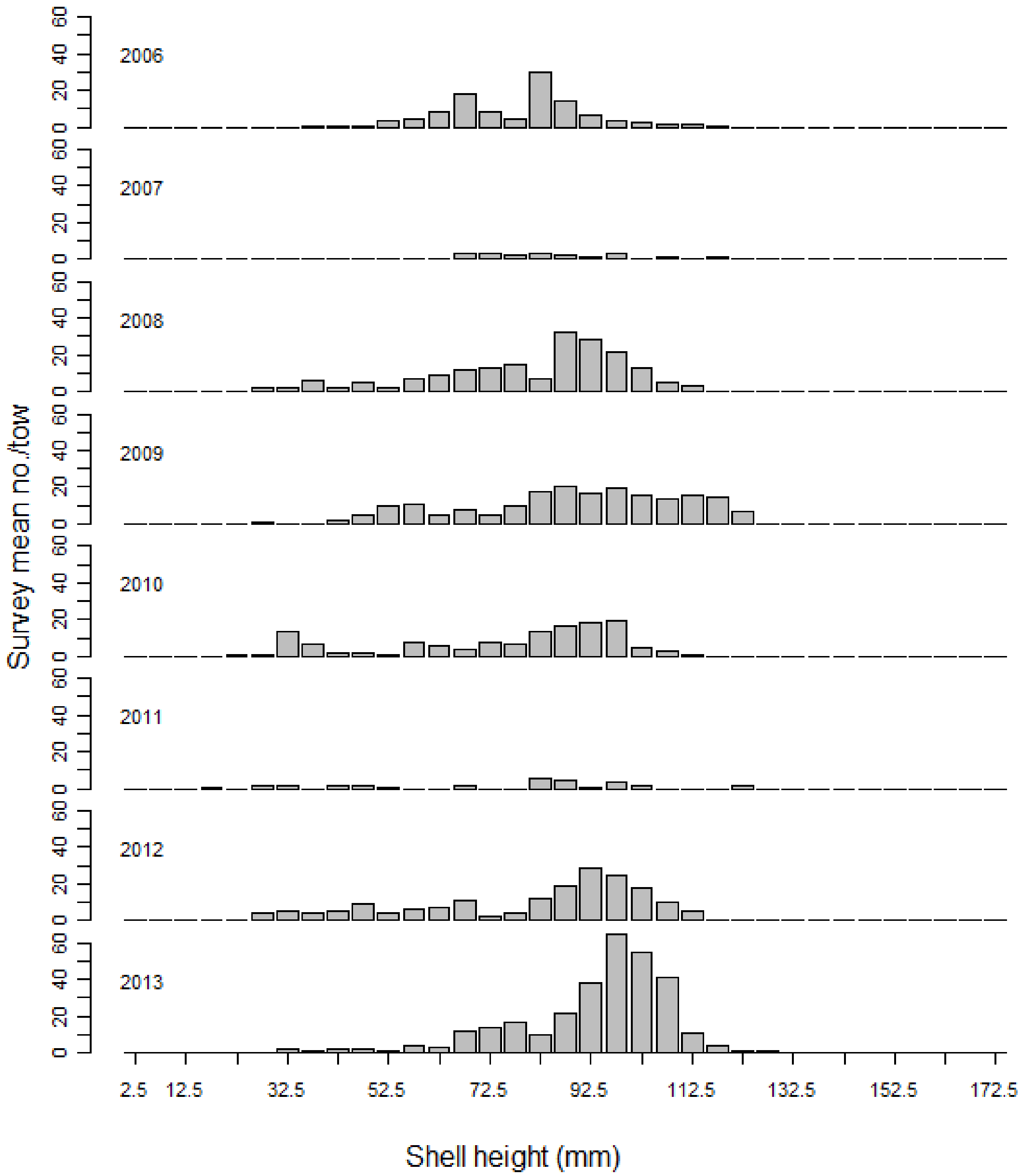

Figure 44. Scots Bay zone of Scallop Production Area 1B survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

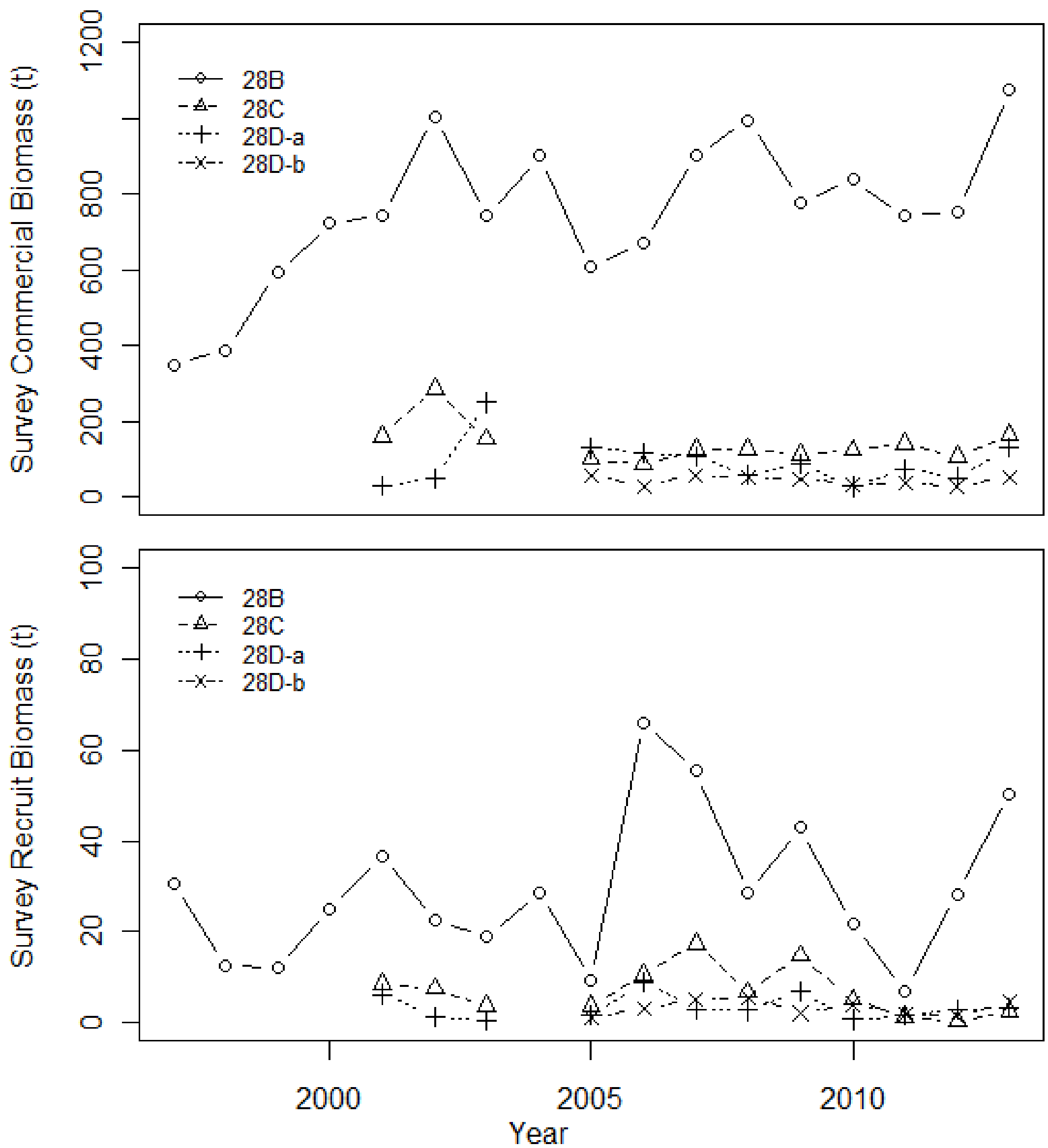

Figure 45. Scallop Production Area 1B trends in commercial population biomass (upper panel; meats, t) and recruit biomass (lower panel; meats, t) for subareas 28B (Cape Spencer and Middle Bay North; circles) from 1997-2013, 28C (triangles) from 2001-2003 and 2005-2013, 28D-a (Advocate and outer; crosses) from 2001-2003 and 2005-2013, and 28D-b (Spencer's Island and Scots Bay; crosses) from 2005-2013.

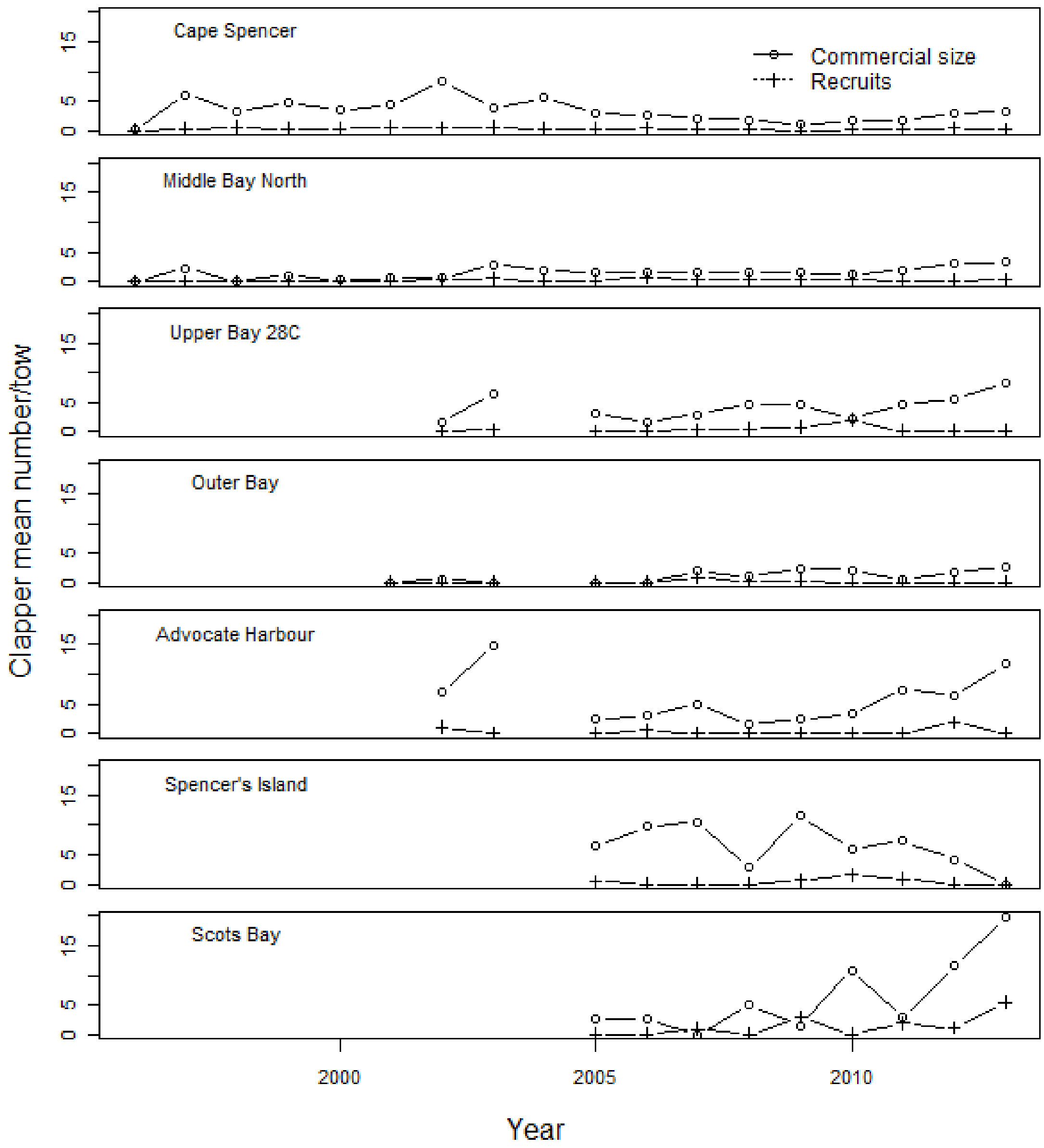

Figure 46. Scallop Production Area 1B trends in survey abundance of clappers (number/tow of paired, dead shells) in all subareas for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops for all subareas (from top to bottom): Cape Spencer (1997-2013), Middle Bay North (1997-2013), Upper Bay (2002-2003 and 2005-2013), Outer Bay (2002-2003 and 2005-2013) Advocate (2002-2003 and 2005-2013), Spencer's Island (2005-2013), and Scots Bay (2005-2013).

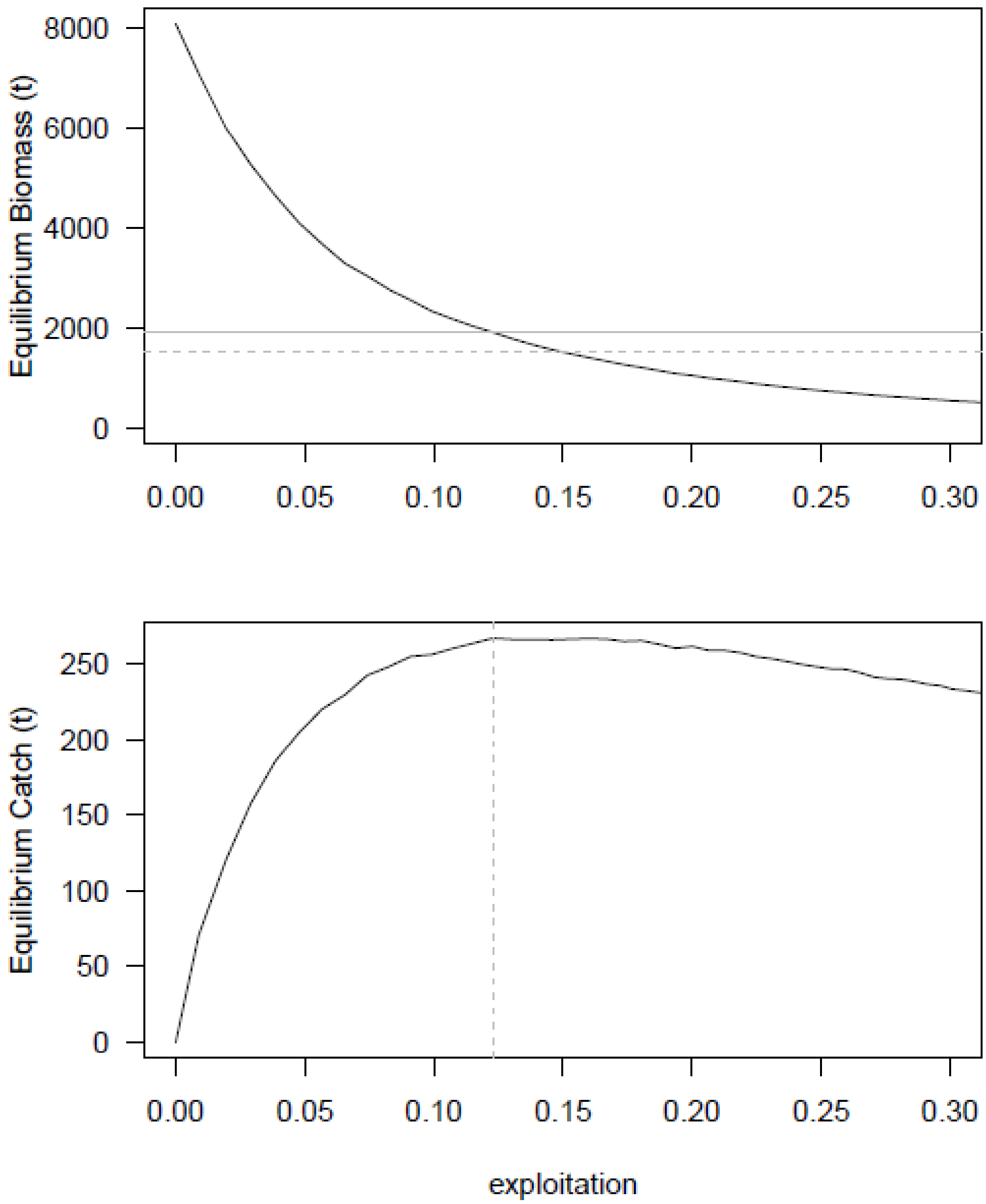

Figure 47. Equilibrium biomass (t; upper panel) and equilibrium catch (t; lower panel) used in determining the exploitation rate for maximum catch in Scallop Production Area 1B. These were obtained by projecting the model forward by 50 years from the current year for a range of constant exploitation rates. See Table 4 for an evaluation of the USR biomass levels.

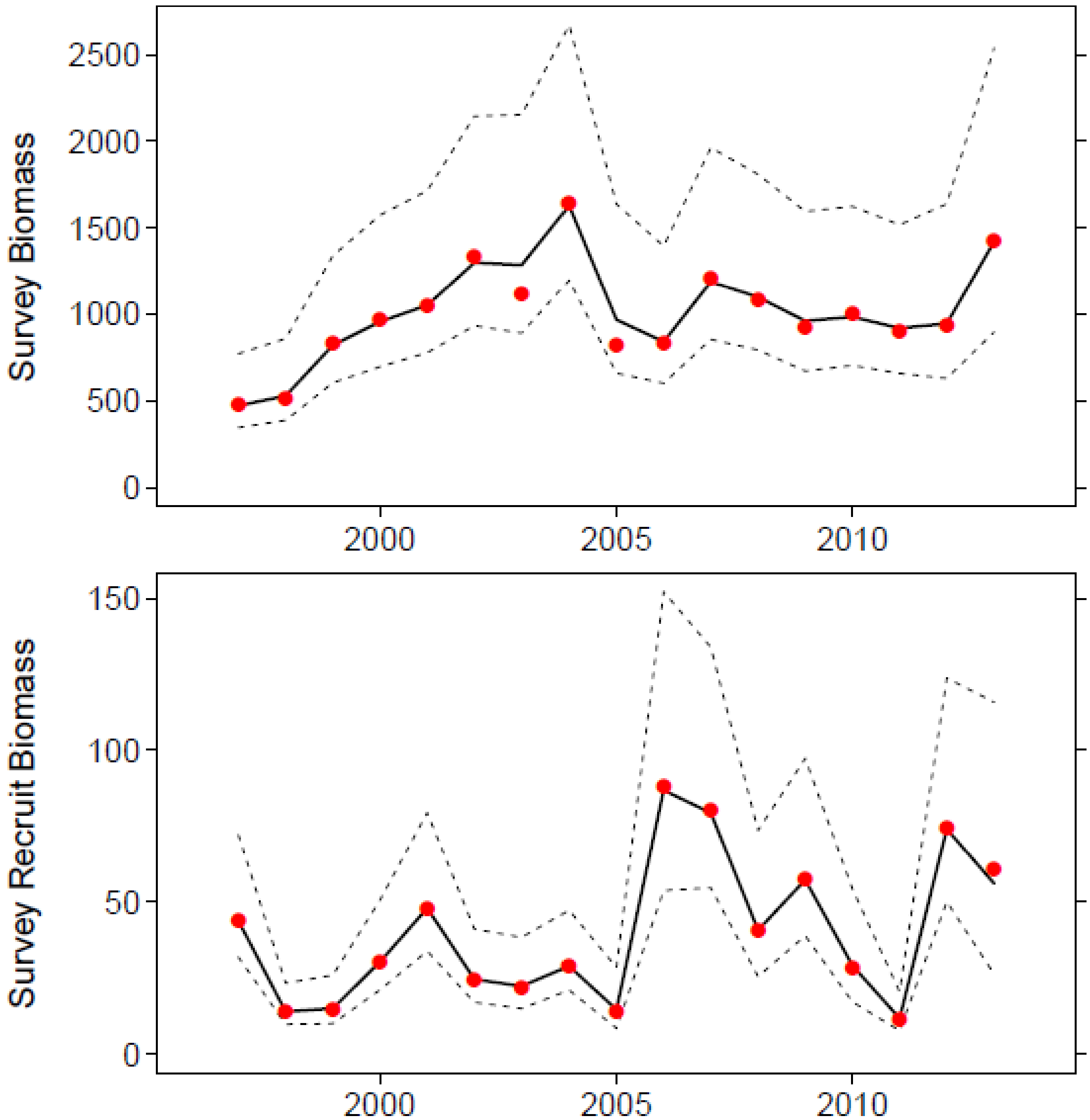

Figure 48. Scallop Production Area 1B, posterior median fit to the survey biomass series (1997-2013) for commercial (upper panel; t), and recruit (lower panel; t) size scallops from the Bayesian state-space assessment model used in this area.

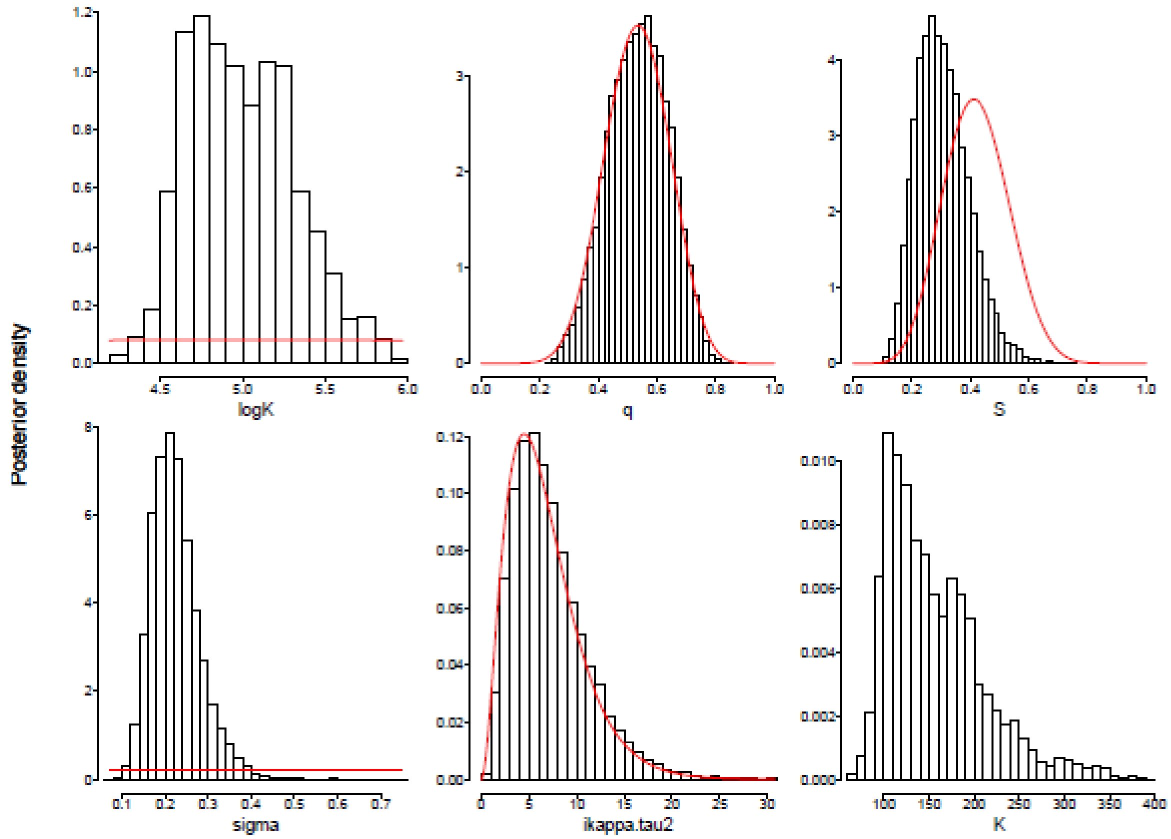

Figure 49 Scallop Production Area 1B, comparison of prior and posterior densities from the Bayesian state-space assessment model used in this area.

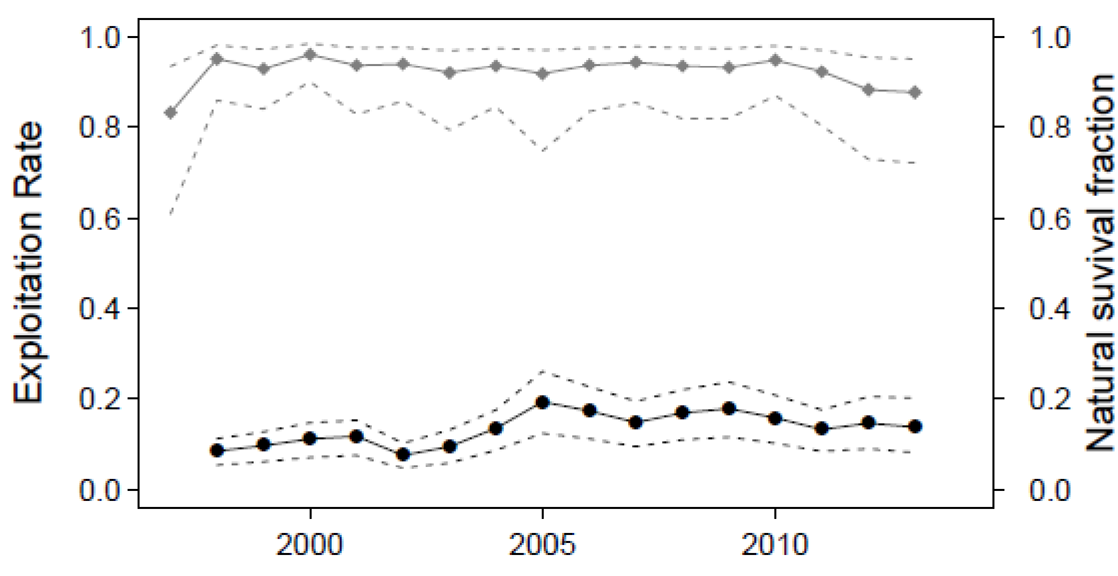

Figure 50. Scallop production Area 1B annual trends in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey squares) from 1998-2013 from the Bayesian state-space assessment model used in this area.

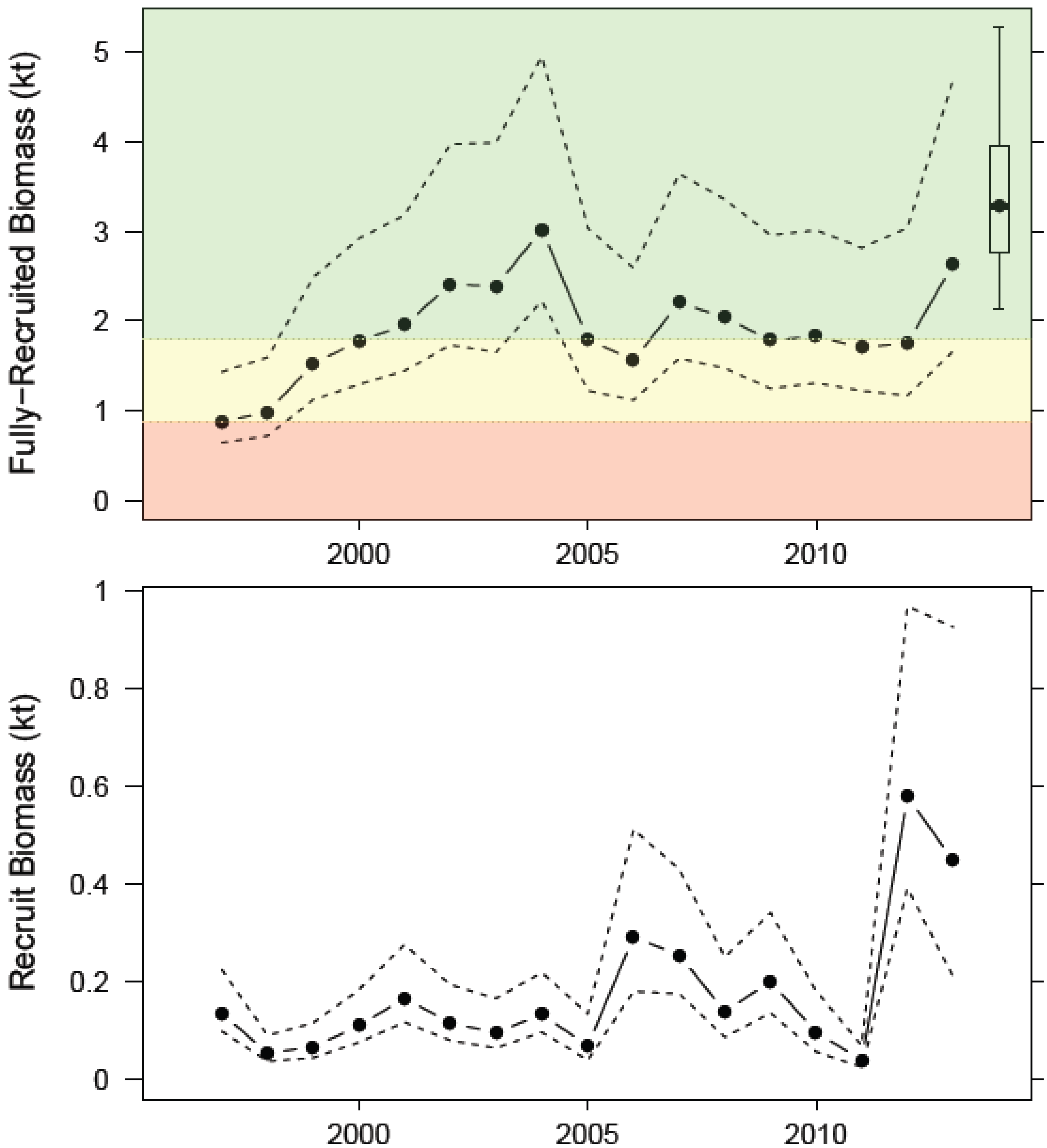

Figure 51. Scallop Production Area 1B biomass estimates for fully recruited scallops (upper panel; kt) and recruit scallops (lower panel, kt) from the assessment model fit to the survey and commercial data (1997-2013). Dashed lines are the upper and lower 95% credible limits on the estimates. The predicted commercial size biomass for 2014, assuming the interim TAC (125 t), is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers). Green-shaded area represents the healthy zone (based on a USR of 1800 t), yellow area represents the cautious zone (based on LRP of 880 t) and red is the critical zone (<LRP).

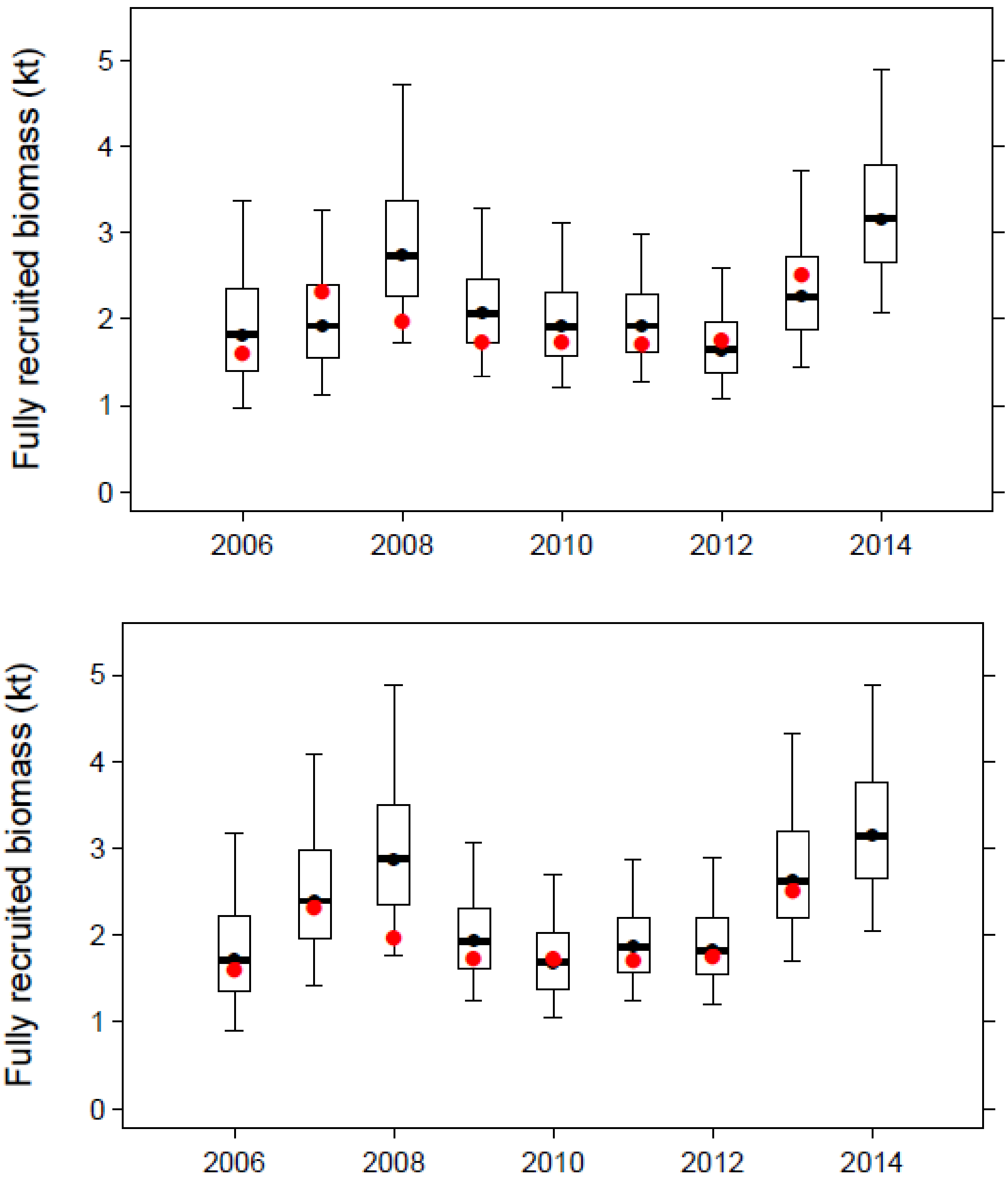

Figure 52. Scallop Production Area 1B evaluation of the model projection performance (upper), and model prediction performance had condition been known (lower), from 2006-2013. Box and whisker plots summarise posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2006 predictions 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, from the Bayesian state-space assessment model used in this area.

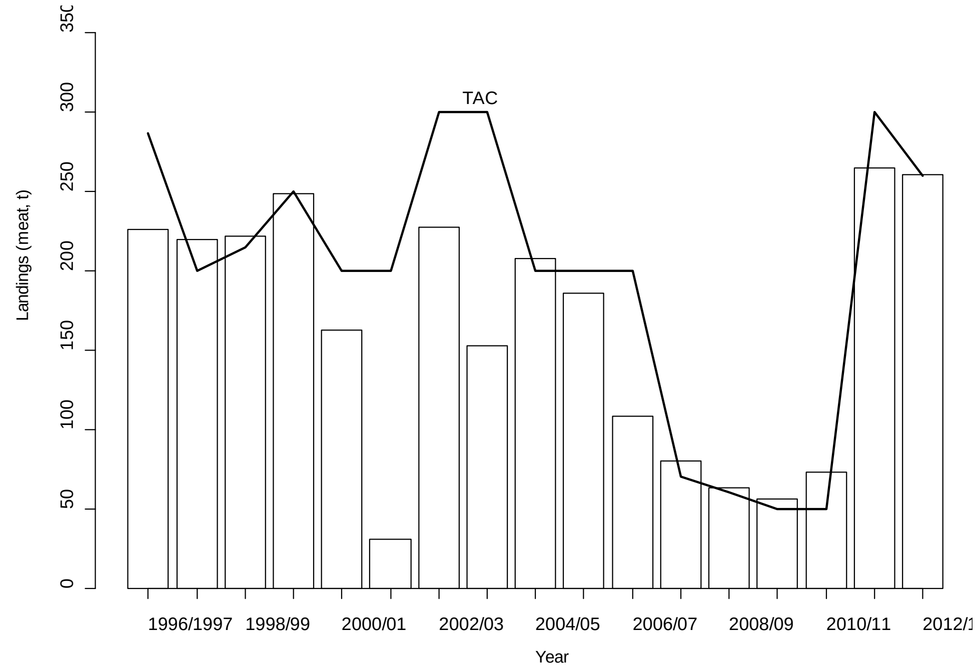

Figure 53. Scallop Production Area 3 landings (meats, tons) by the Full Bay fleet from 1996-2013. TAC is indicated by the black line. For the 2012/2013 fishing season, TAC was subdivided between 3A and 3B. Only 5.1 t of the 75 t quota for 3B was caught.

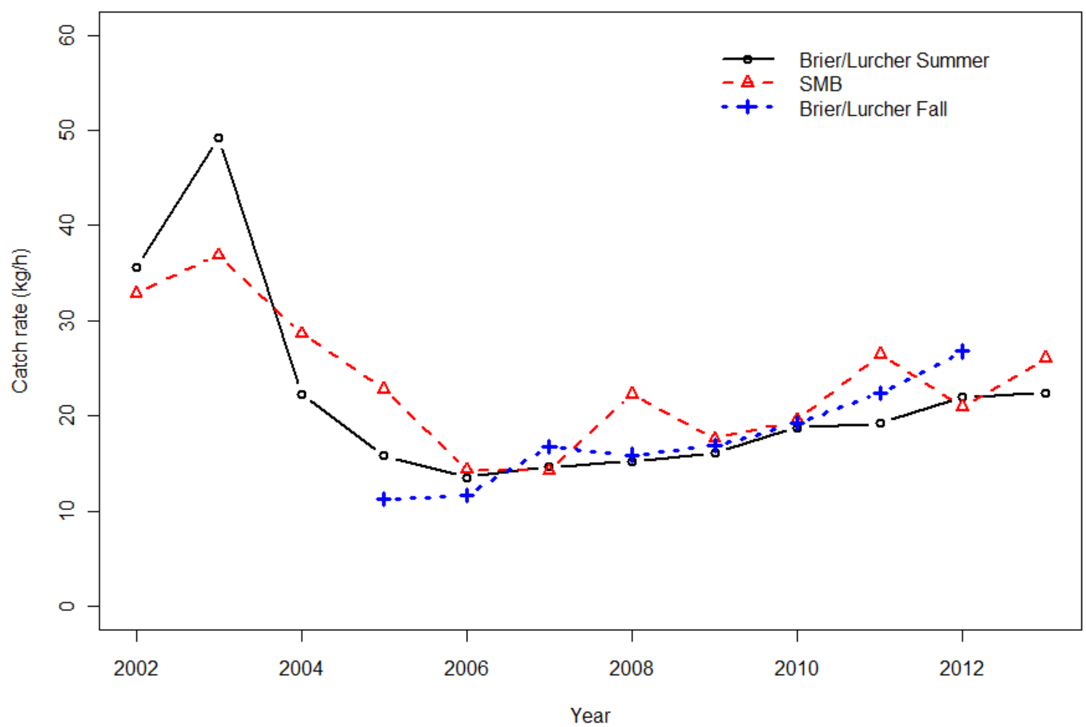

Figure 54. Scallop Production Area 3 trends in commercial catch rates (kg/h) by the Full Bay fleet. Catch rates separated as Brier/Lurcher summer fishery (circles) from 2002-2013, St. Mary's Bay (triangles) from 2002-2013, and Brier/Lurcher October fishery (crosses) from 2005-2013.

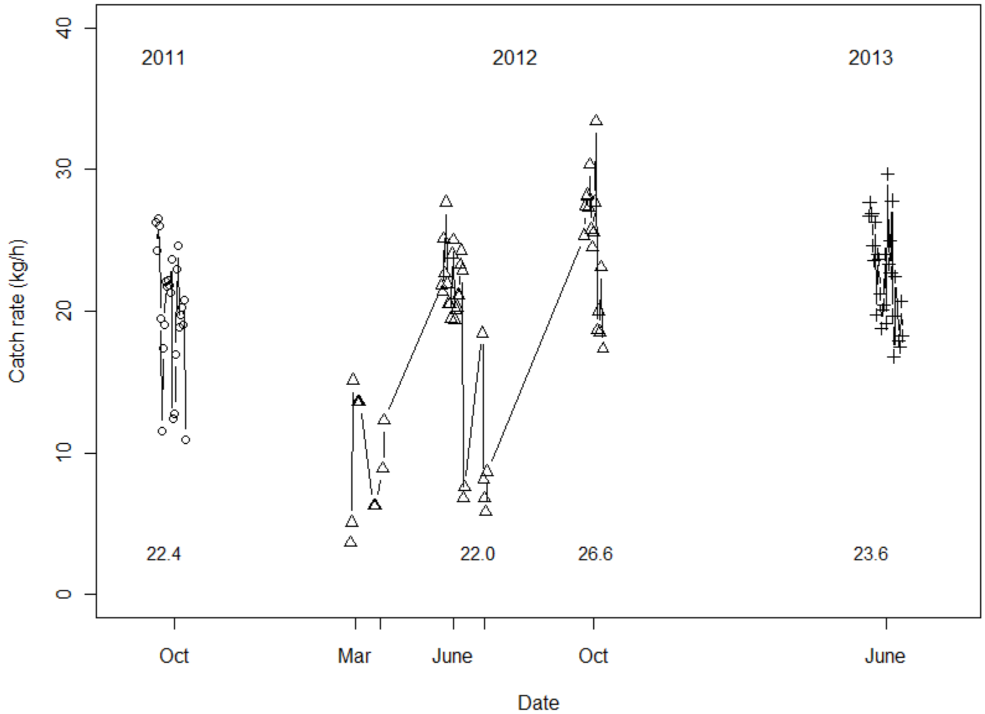

Figure 55. Scallop Production Area mean daily catch rates (kg/h) from October 2011 to June 2013 by the Full Bay fleet. Average catch rate for the time period given. For the 2012/2013 fishing season, TAC was subdivided between 3A and 3B, fishing in March/April 2012 correspond to fishing in subarea 3B only.

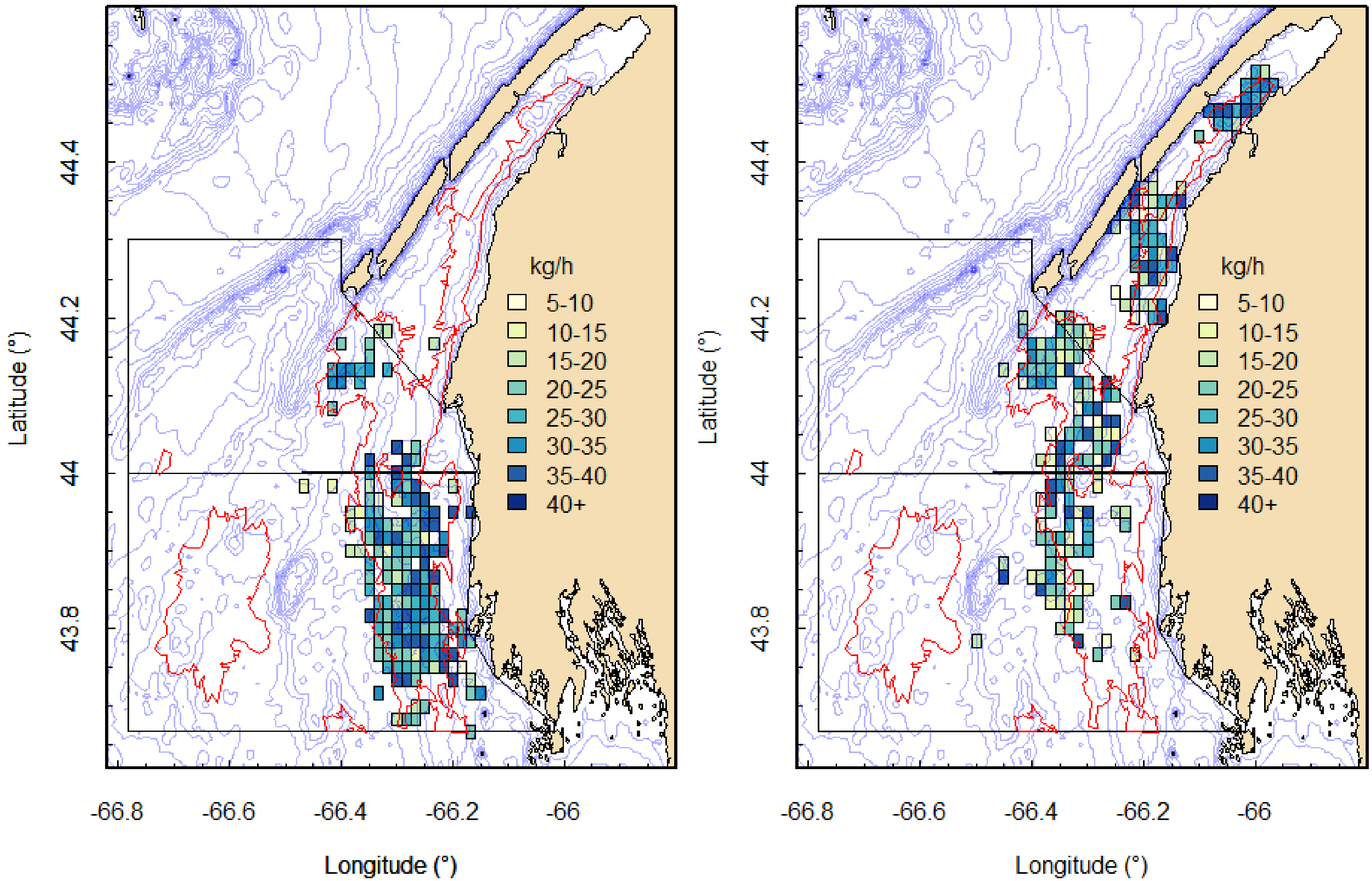

Figure 56. Scallop Production Area 3 mean catch rates (kg/h) by 1 minute square from commercial fishing logs for October 2012 (left) and June 2013 (right). Survey strata are shown in red.

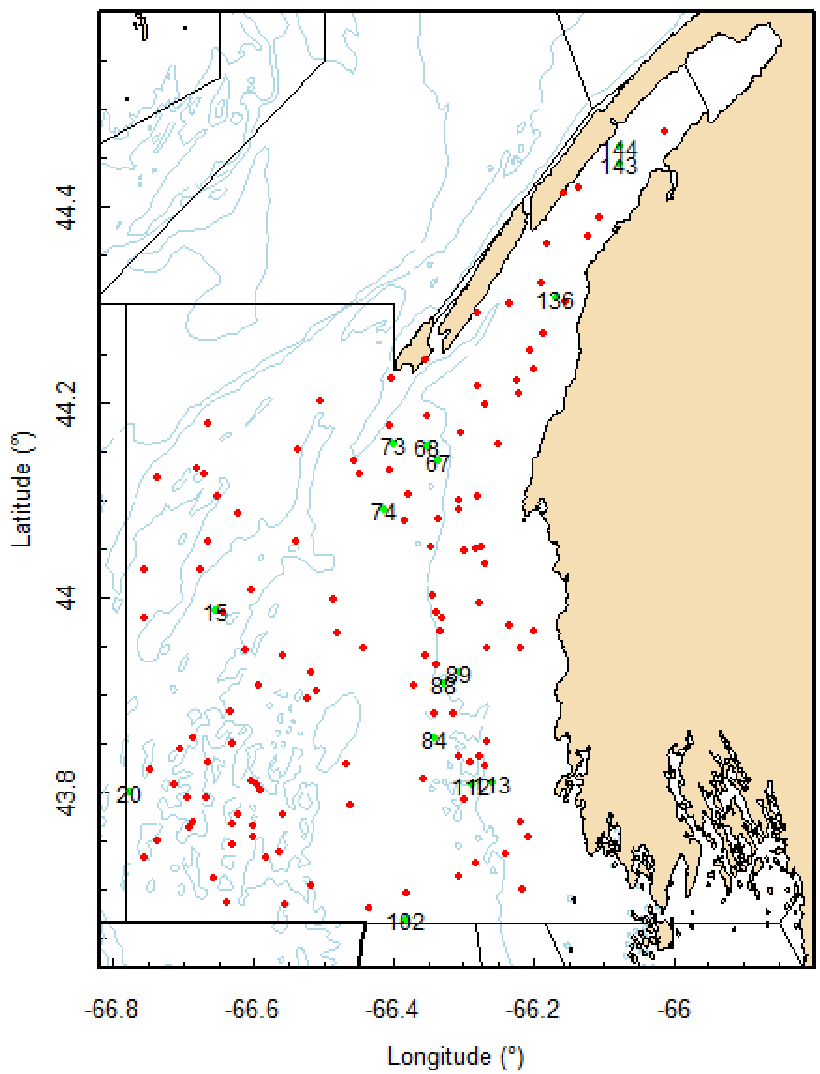

Figure 57. Locations of comparative tows between nine-gang Miracle gear with and without (flat bar) teeth during the 2013 Scallop Production Area 3 survey.

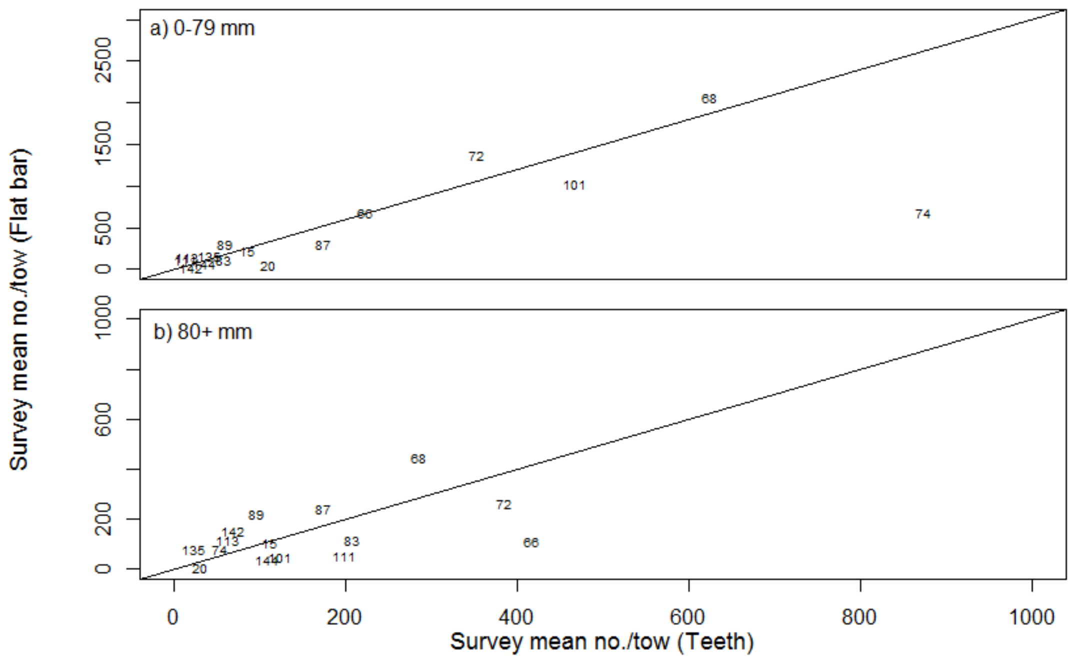

Figure 58. Mean number per tow by size range of scallops (0-79 mm: upper panel, >80 mm: lower panel) caught in each pair of comparative tows. Points labelled with tow number. The 1:1 line is shown.

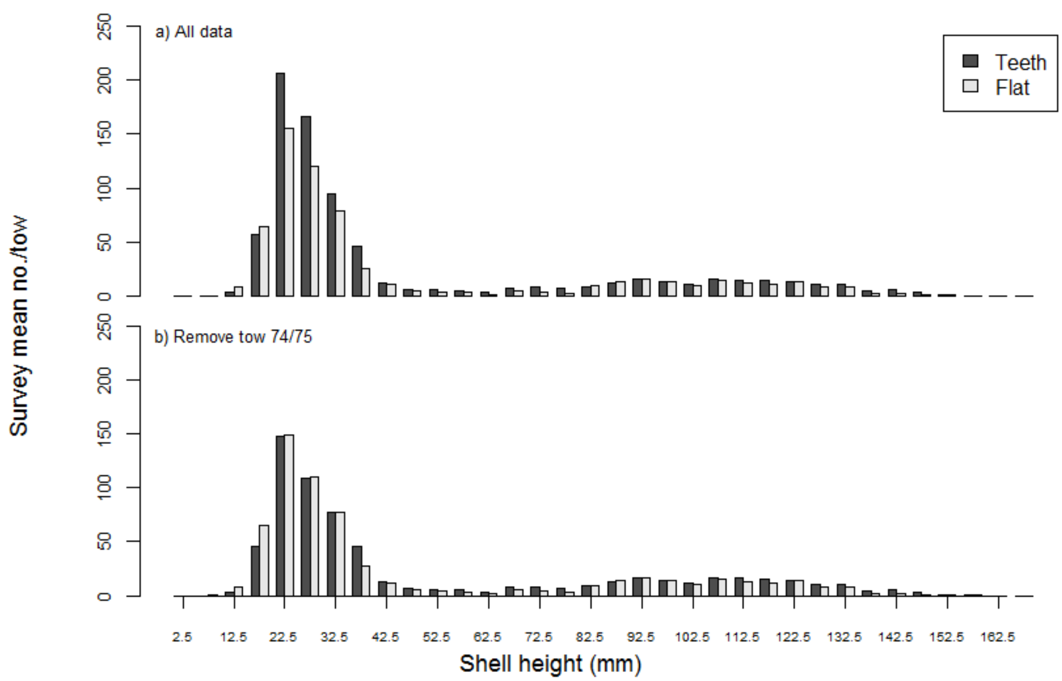

Figure 59. Comparison of shell height (mm) frequencies for mean number per tow for the two gear configurations. Top panel presents data for all tows, while bottom panel presents the data when tow 74/75 has been removed from the analysis.

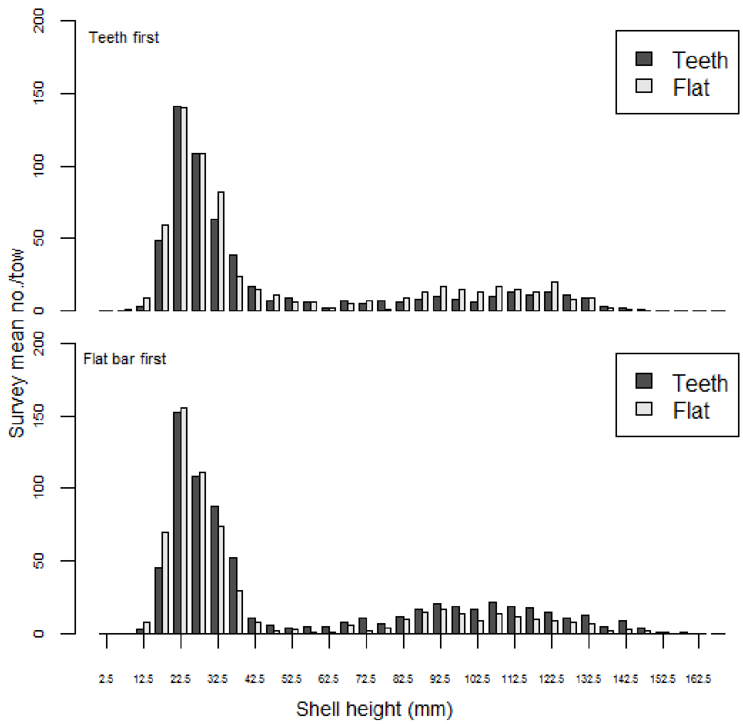

Figure 60. Comparison of shell height (mm) frequencies for the mean number per tow for the teeth (dark gray) and flat bar (light gray) configurations, conditional on which configuration was towed first in the pair: teeth (upper panel) or flat bar first (lower panel). Tow 74 and 75 were removed from this analysis.

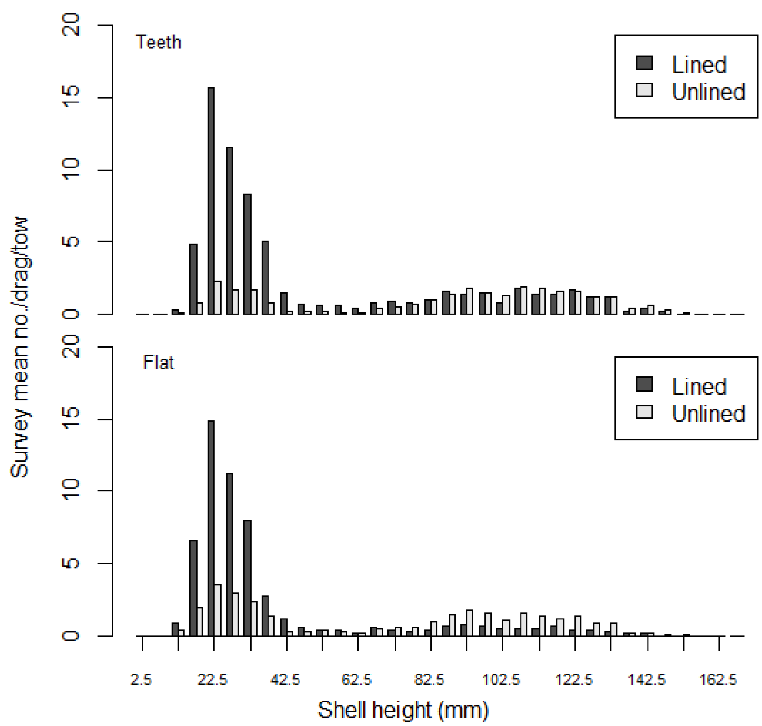

Figure 61. Comparison of shell height (mm) frequencies for the mean number per tow for the teeth (upper panel), and flat bar (lower panel) configurations for lined (dark gray) and unlined (light gray) drags. Tow 74 and 75 were removed from this analysis.

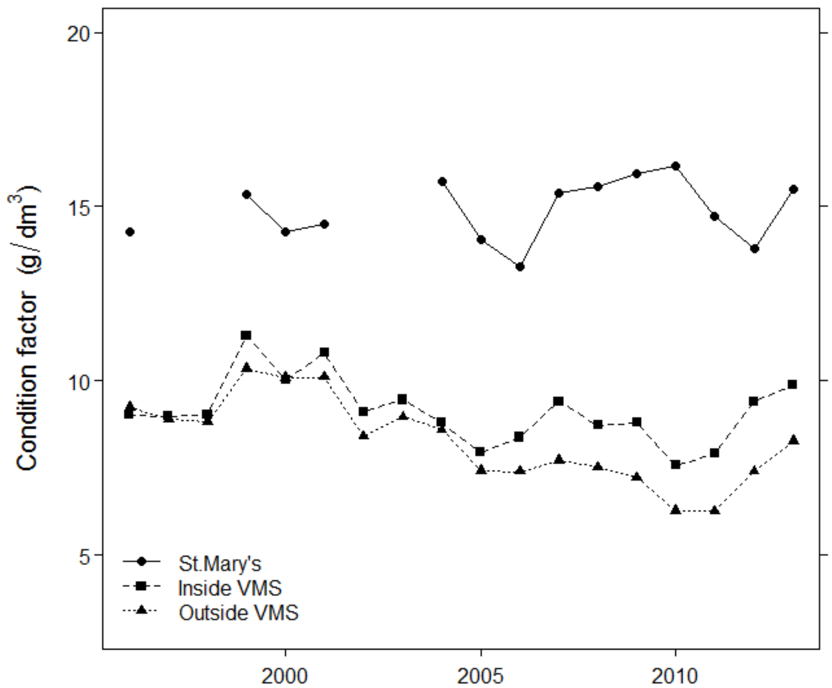

Figure 62. Scallop Production Area 3 trends in Condition Factor (g/dm^3) for each subarea, St. Mary's Bay (circles) from 1996,1999-2001, and 2004-2013, Brier/Lurcher Inside (squares) from 1996-2013, and Brier Lurcher Outside (triangles) from 1996-2013.

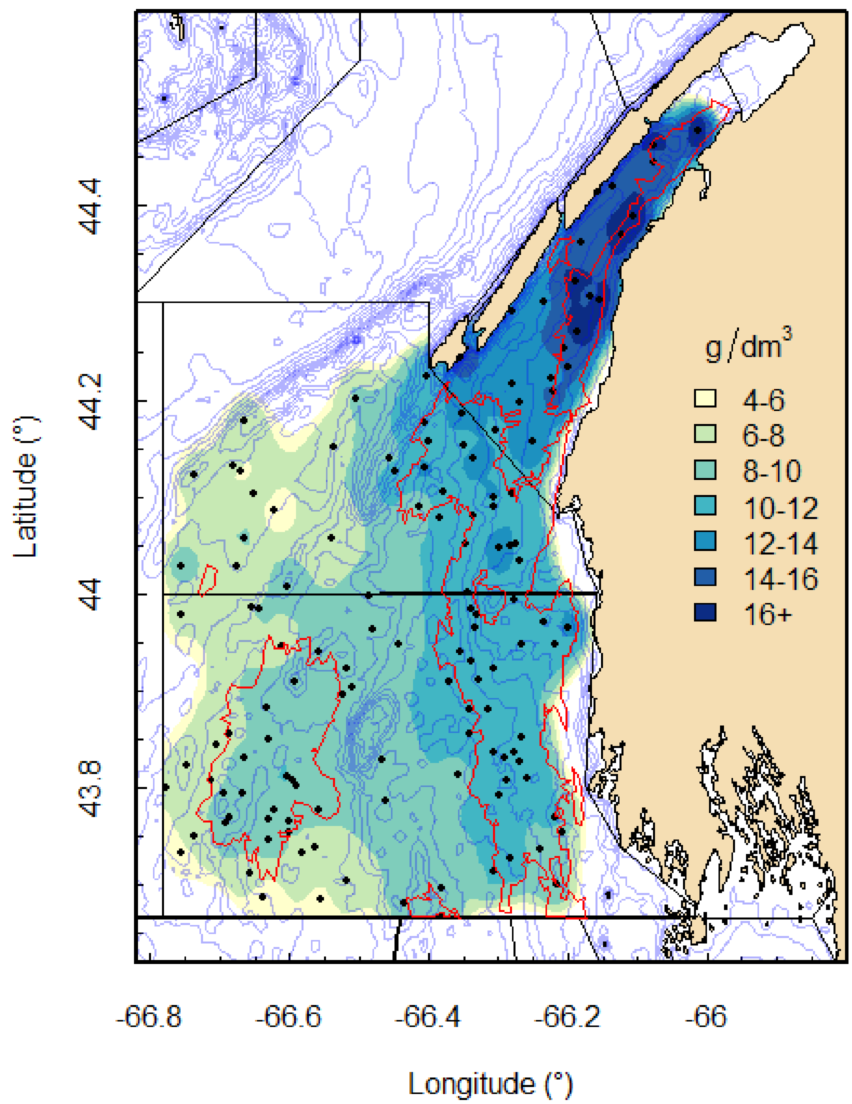

Figure 63. Spatial distribution of condition factor (g/dm³) in Scallop Production Area 3, from the 2013 survey. Survey strata are shown in red.

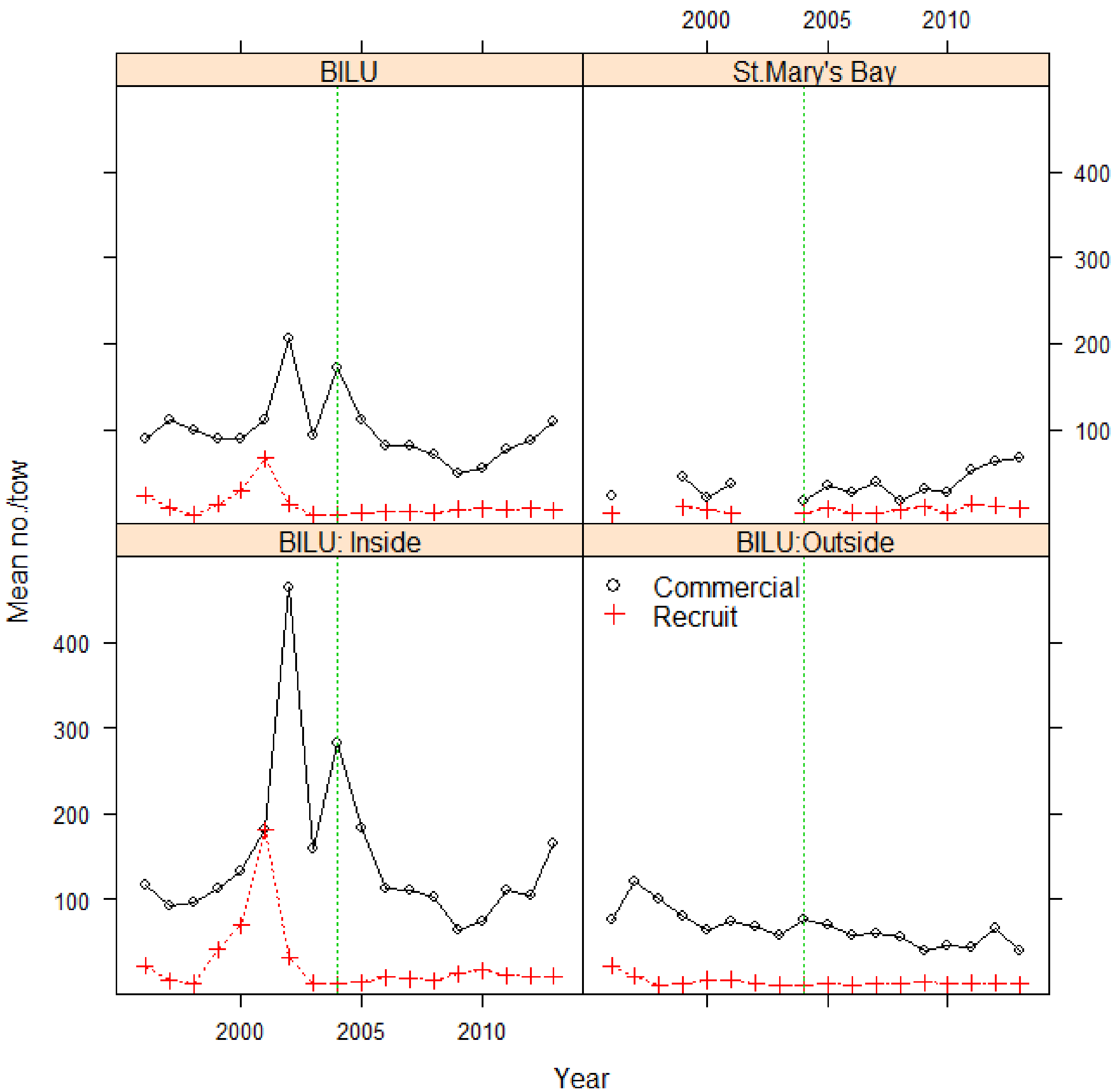

Figure 64. Scallop Production Area 3 trends in survey abundance (mean number/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops in Brier/Lurcher (upper left) from 1996-2013, St. Mary's Bay (upper right) from 1996,1999-2001 and 2004-2013, Brier/Lurcher Inside (lower left) from 1996-2013, and Brier/Lurcher Outside (lower right) from 1996-2013.

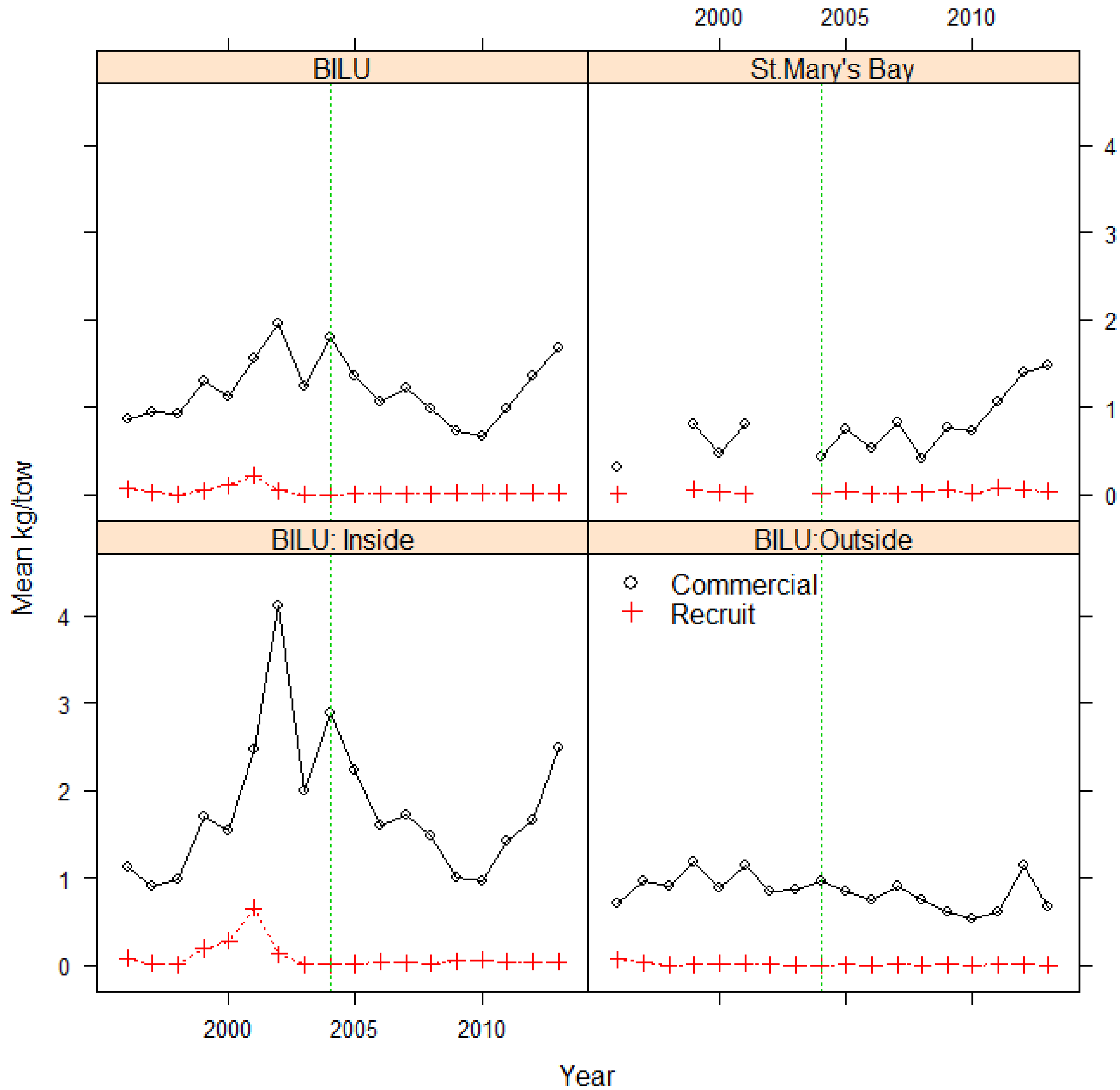

Figure 65. Scallop Production Area 3 trends in survey biomass (mean kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops in Brier/Lurcher (upper left) from 1996-2013, St. Mary's Bay (upper right) from 1996,1999-2001 and 2004-2013, Brier/Lurcher Inside (lower left) from 1996-2013, and Brier/Lurcher Outside (lower right) from 1996-2013.

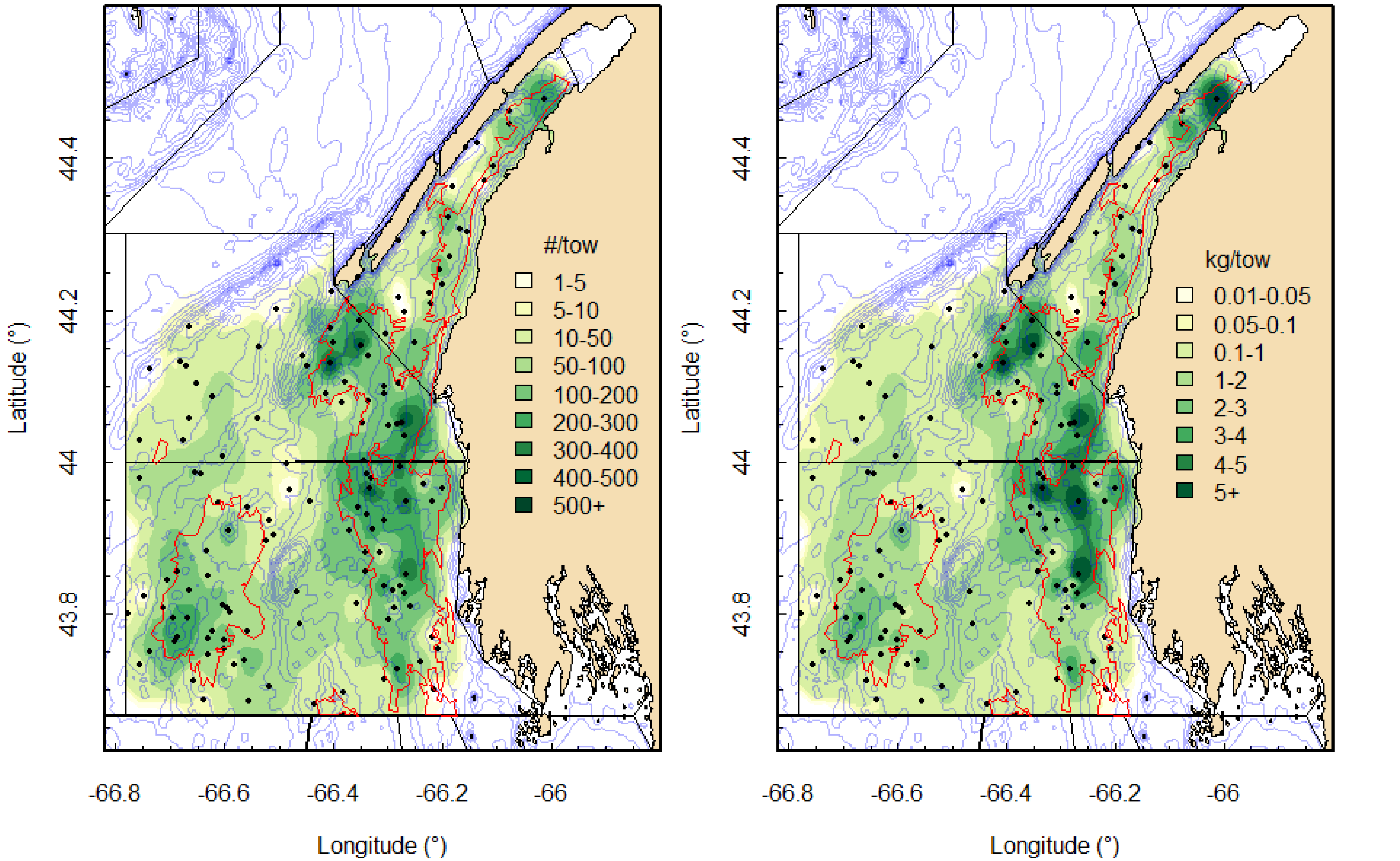

Figure 66. Spatial distribution of abundance (number/tow; left) and biomass (kg/tow; right) of commercial size (≥ 80 mm) scallop in Scallop Production Area 3 from the 2013 survey. Survey strata are shown in red.

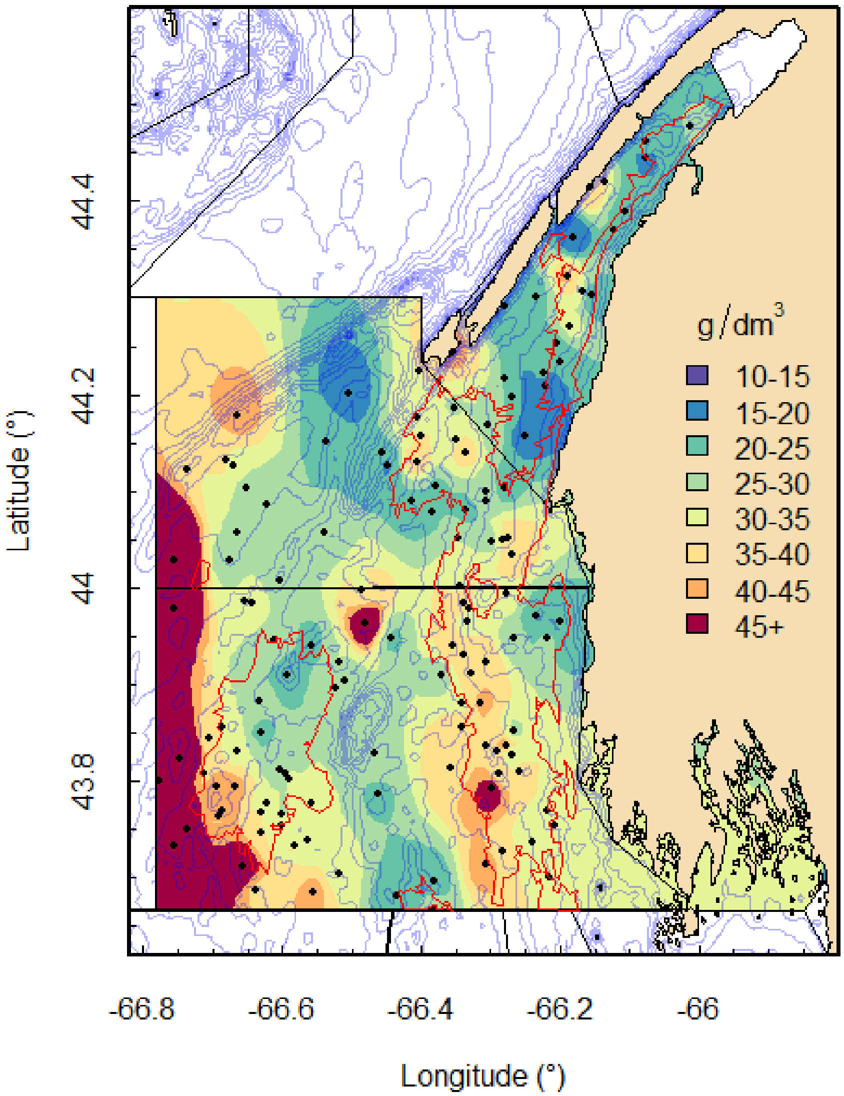

Figure 67. Spatial distribution of meat count (scallops/500 g) in Scallop Production Area 3 from the 2013 survey. Survey strata are shown in red. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

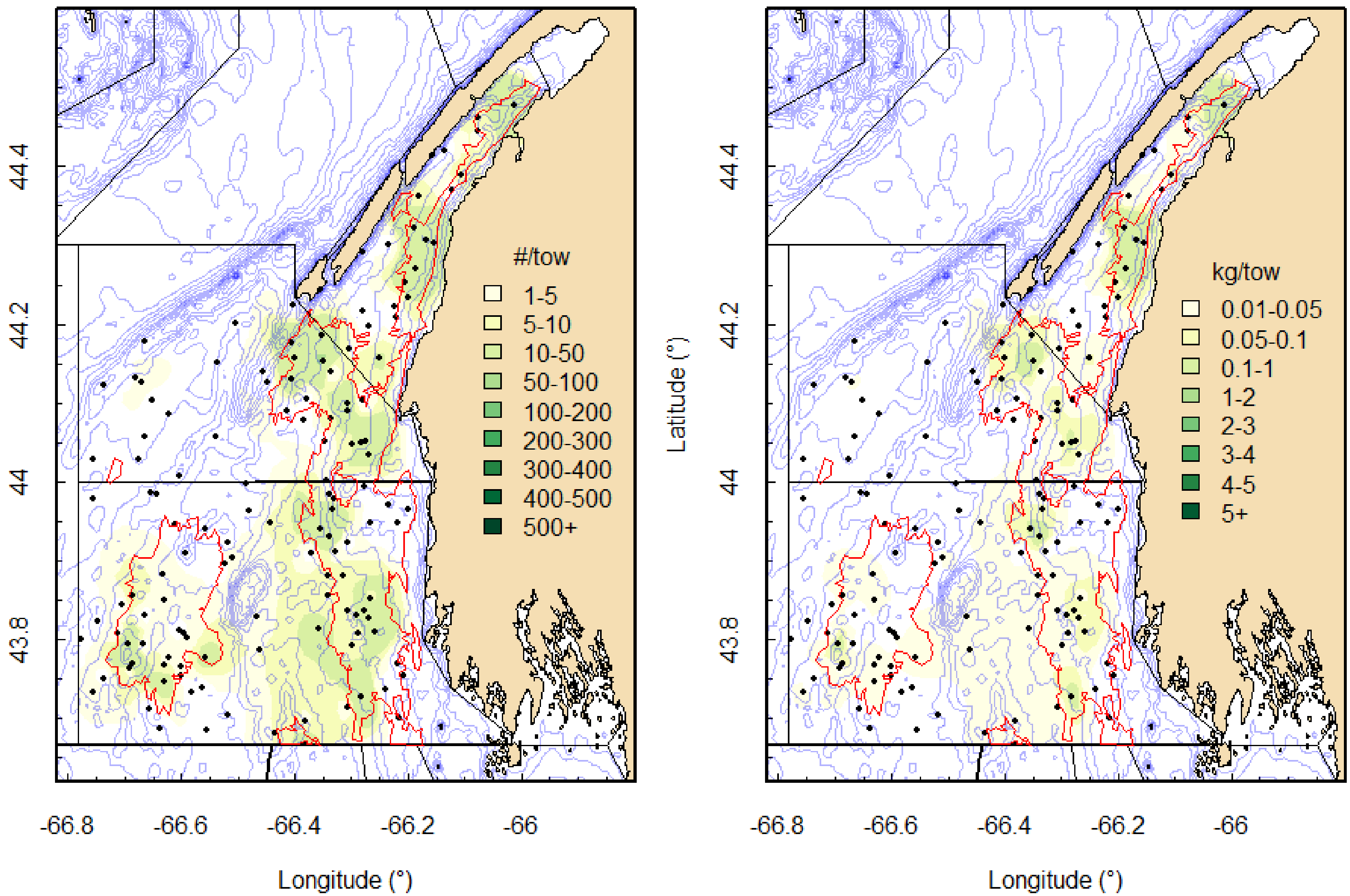

Figure 68. Spatial distribution of abundance (number/tow; left) and biomass (kg/tow; right) of recruit size (65-79 mm) scallop in Scallop Production Area 3 from the 2013 survey. Survey strata are shown in red.

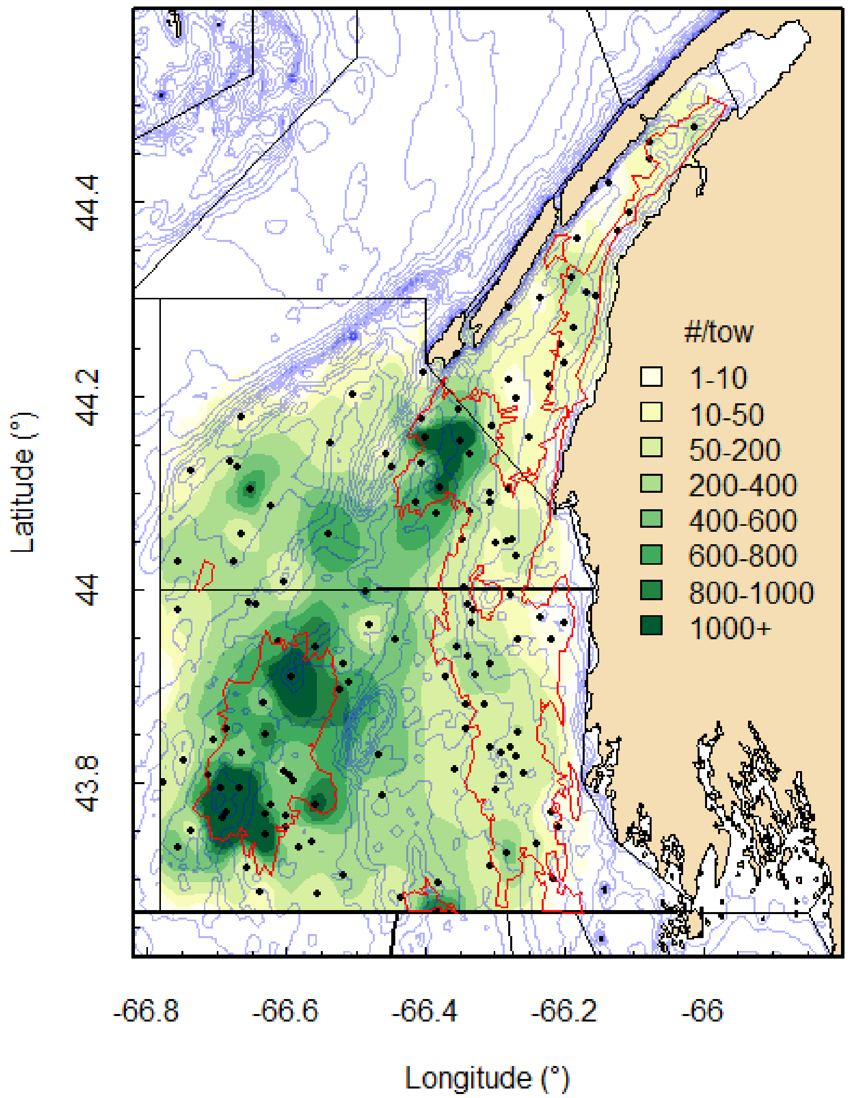

Figure 69. Spatial distribution (number/tow) of pre-recruit (0-64 mm) scallop in Scallop Production Area 3 from the 2013 survey. Survey strata are shown in red. Please note different scale relative to other abundance distribution figures.

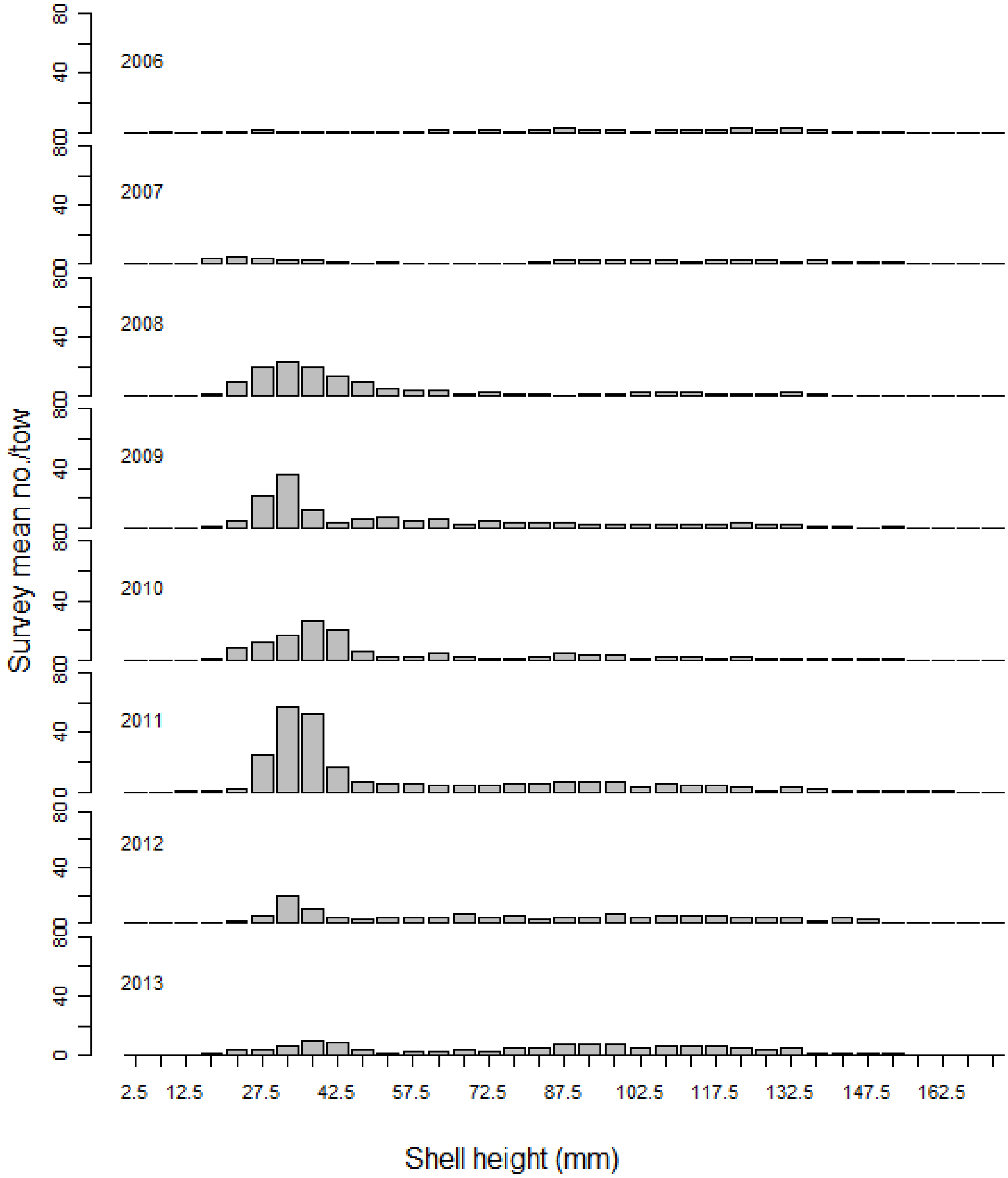

Figure 70. St. Mary's Bay zone of Scallop Production Area 3 survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

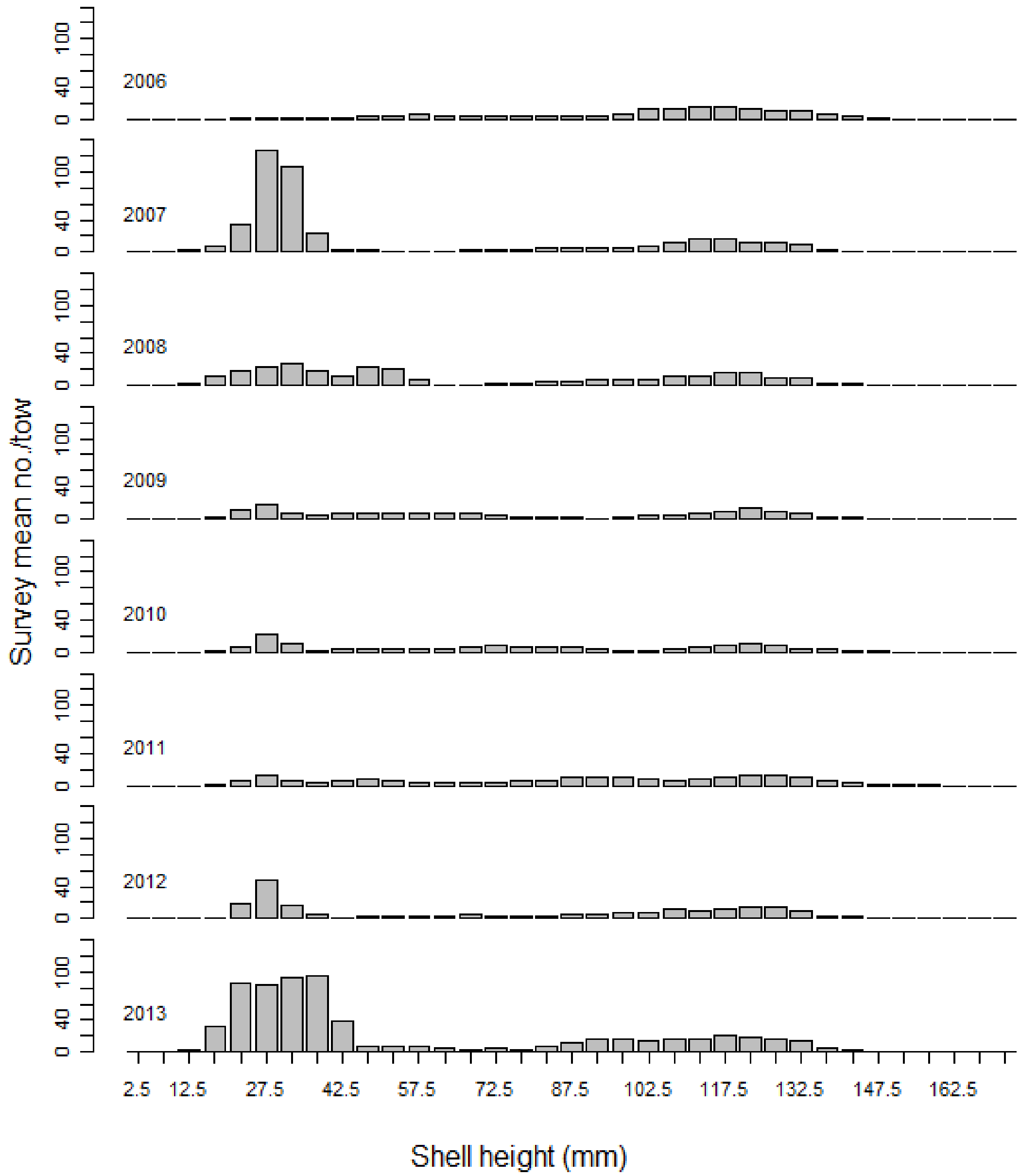

Figure 71. Inside VMS zone of Scallop Production Area 3 survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

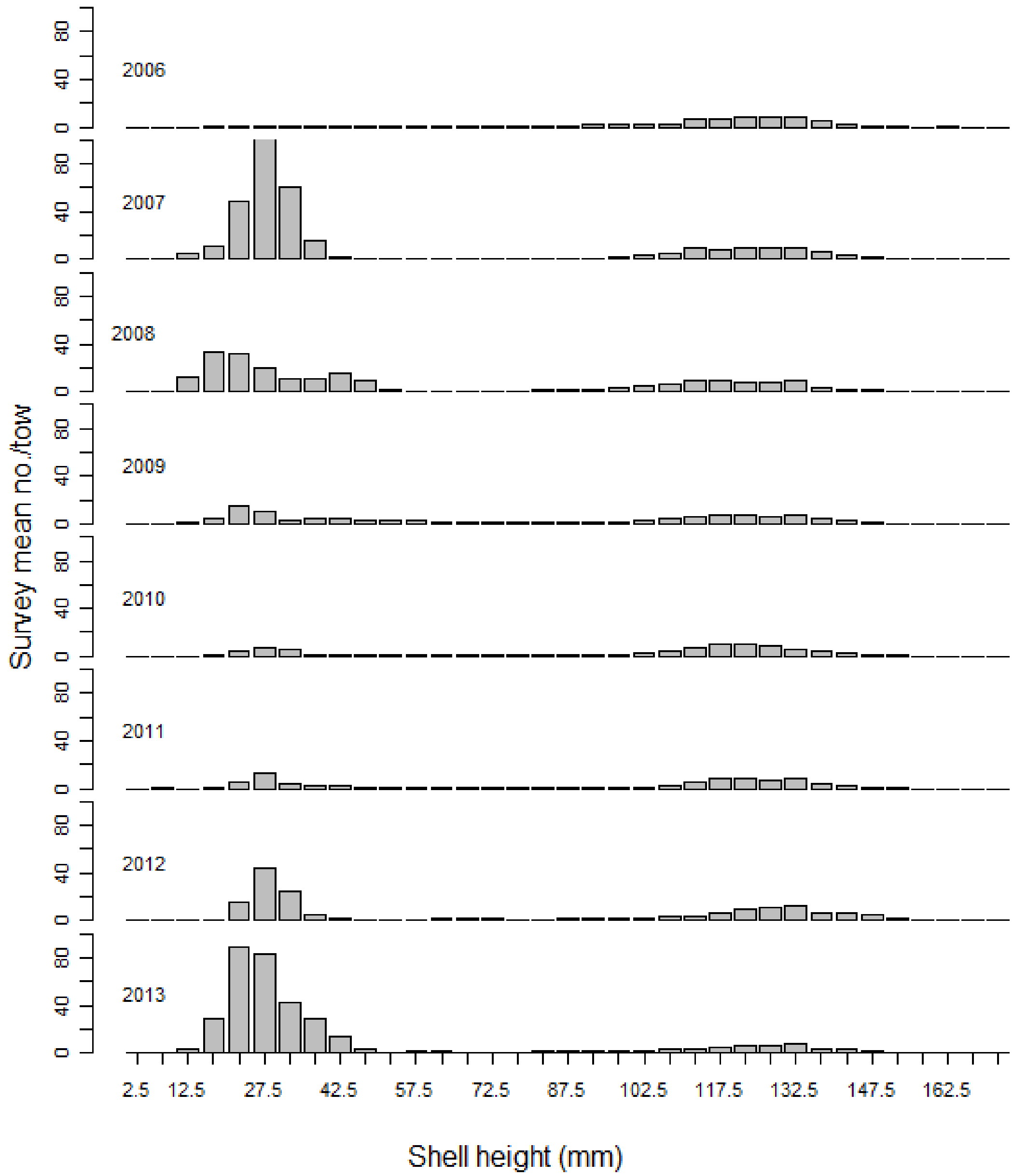

Figure 72. Outside VMS zone of Scallop Production Area 3 survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

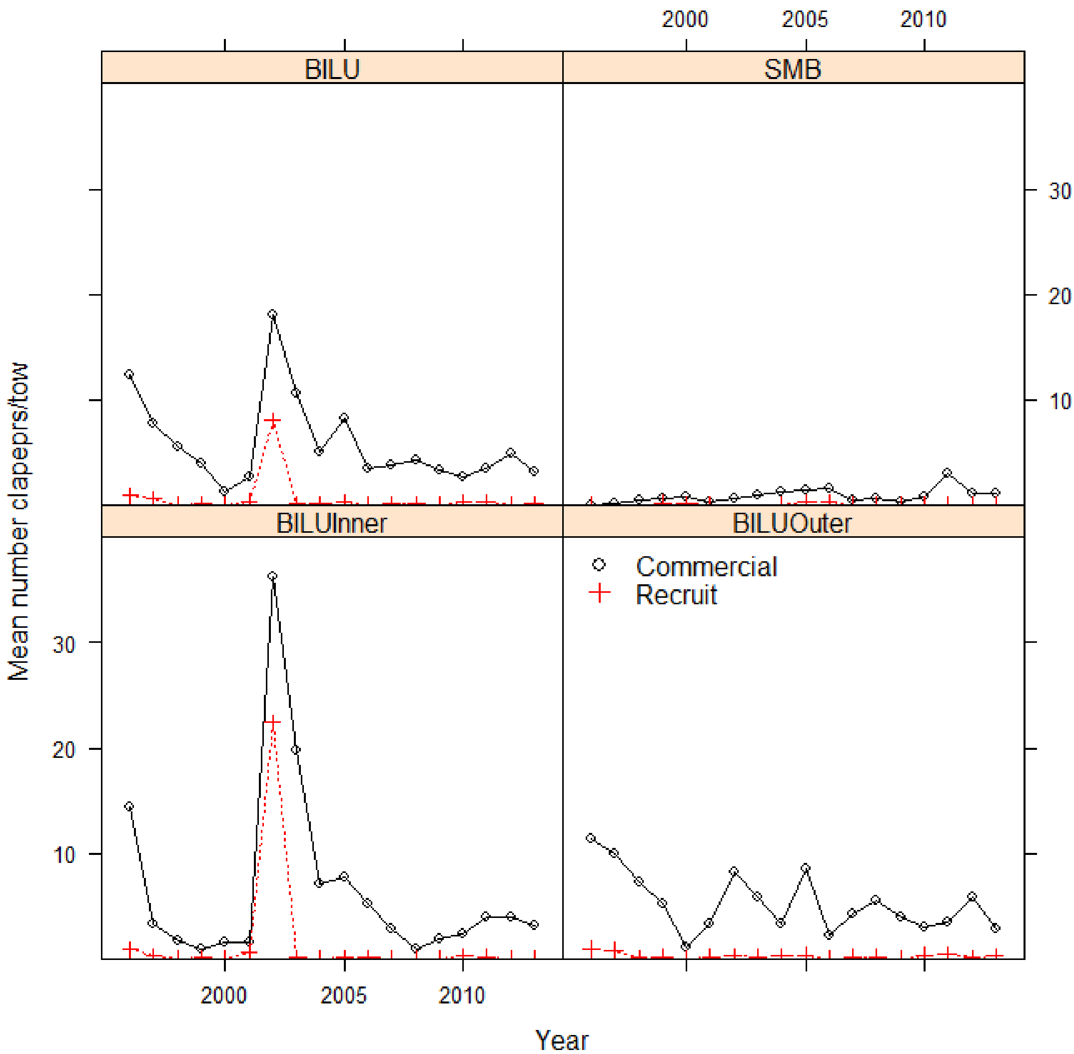

Figure 73. Scallop Production Area 3 trends in survey abundance of clappers (number/tow of paired, dead shells) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops in Brier/Lurcher (upper left) from 1996-2013, St. Mary's Bay (upper right) from 1996,1999-2001, and 2004-2013, Brier/Lurcher Inside (lower left) from 1996-2013, and Brier/Lurcher Outside (lower right) from 1996-2013.

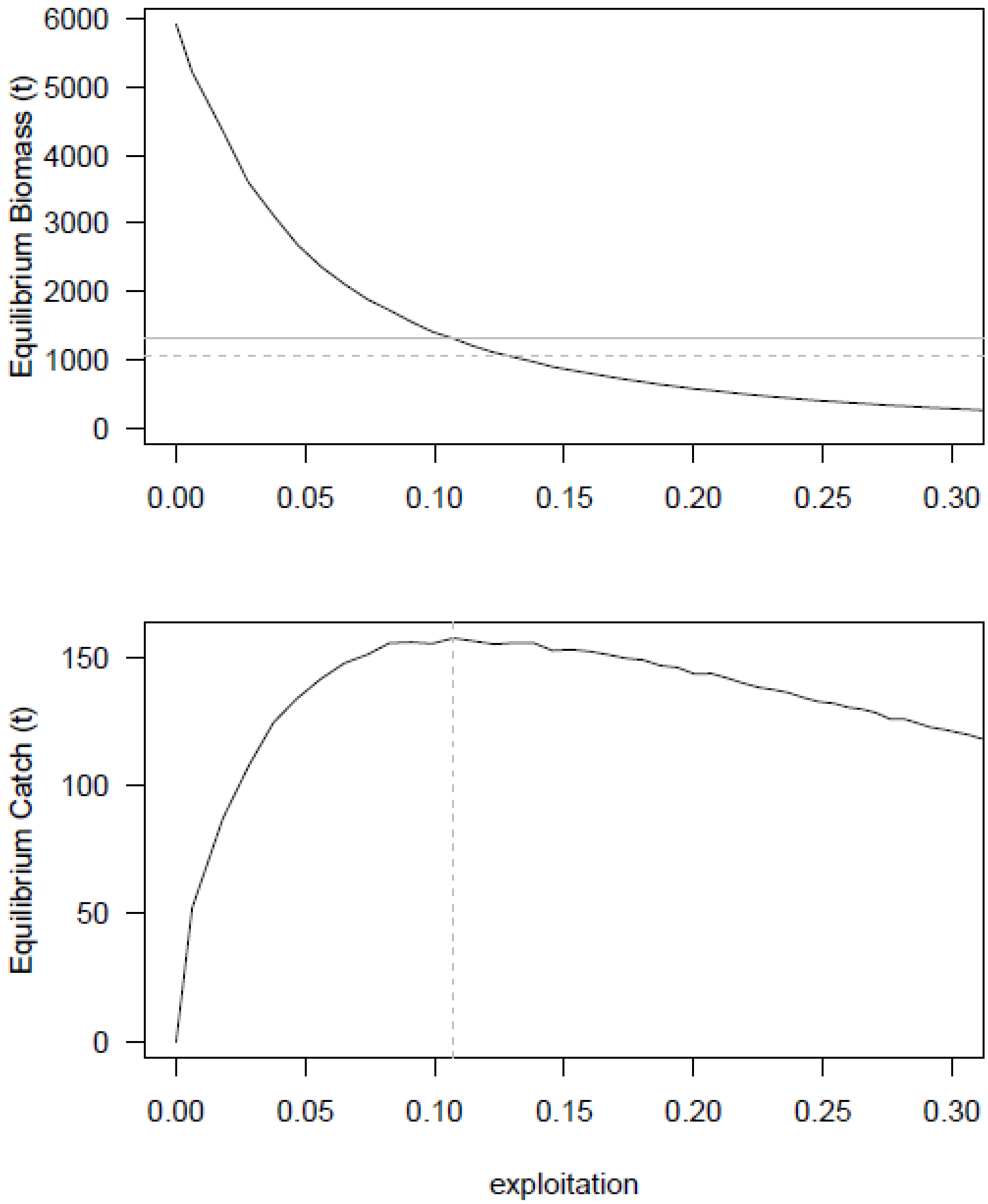

Figure 74. Equilibrium biomass (t; upper panel) and equilibrium catch (t; lower panel) used in determining the exploitation rate for maximum catch in Scallop Production Area 3. These were obtained by projecting the model forward by 50 years from the current year for a range of constant exploitation rates. See Table 10 for an evaluation of the USR biomass levels.

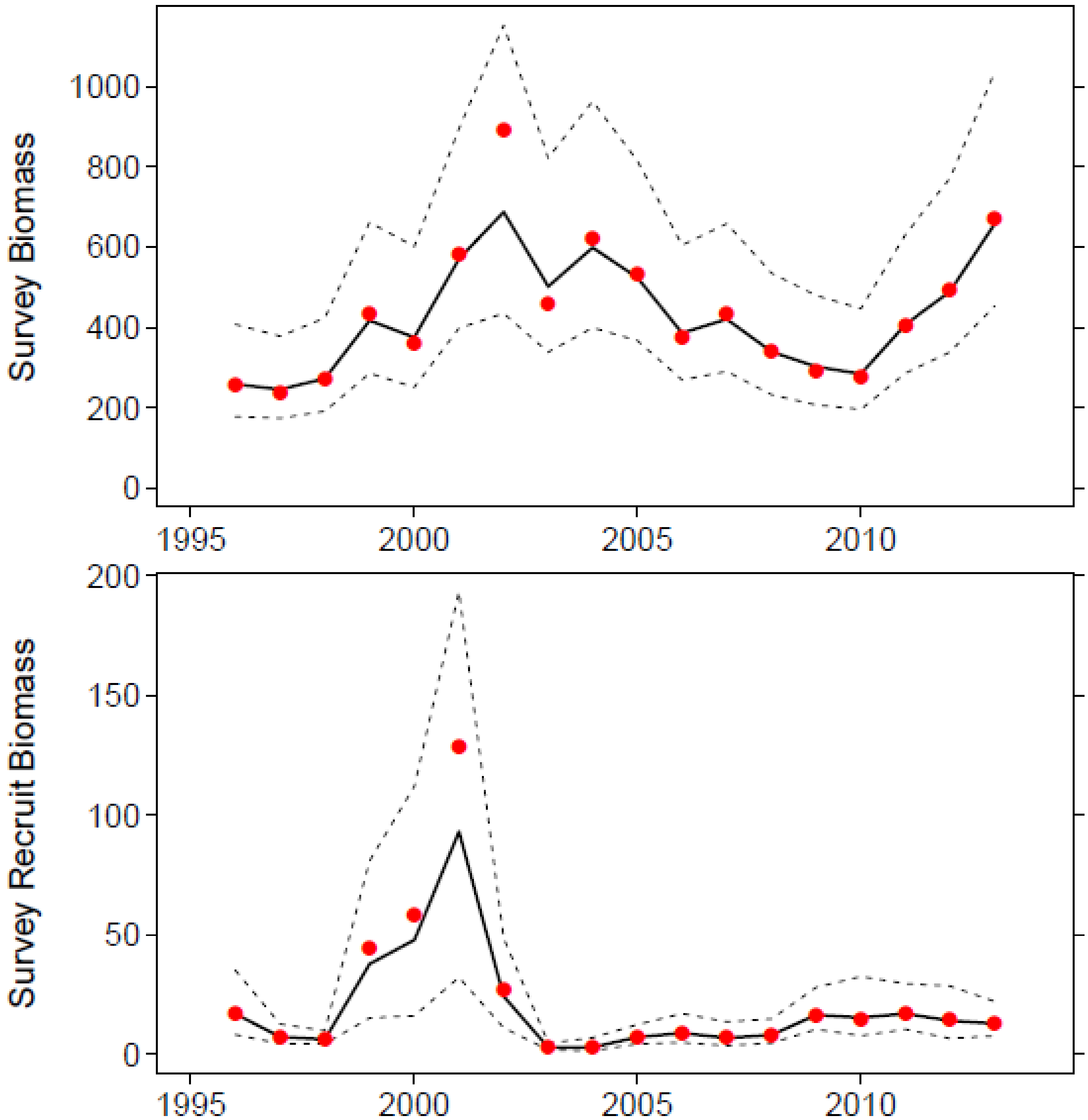

Figure 75. Scallop Production Area 3, posterior median fit to the survey biomass series (1996-2013) for commercial (upper panel; t), and recruit (lower panel; t) size scallops from the Bayesian state-space assessment model used in this area.

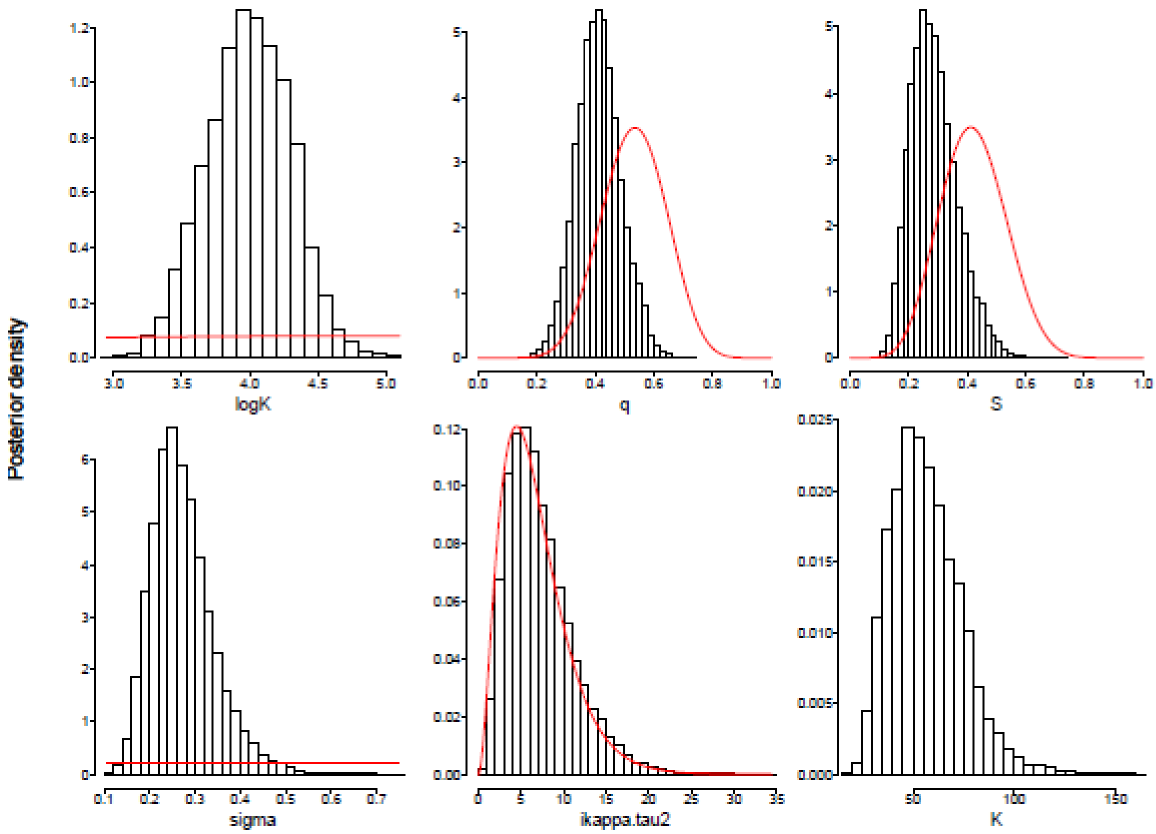

Figure 76. Scallop Production Area 3, comparison of prior and posterior densities from the Bayesian state-space assessment model used in this area.

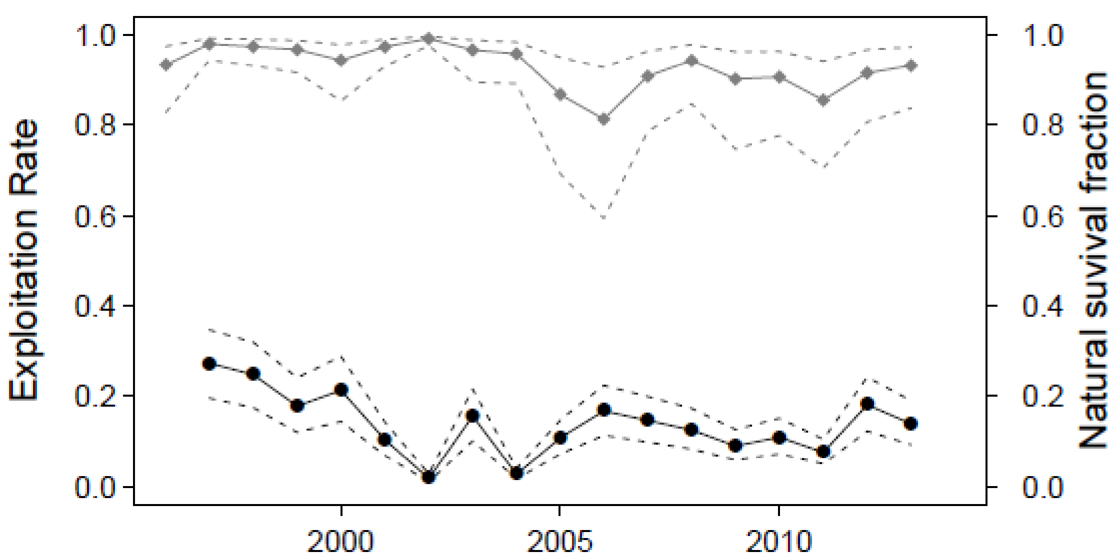

Figure 77. Scallop Production Area 3 annual trends in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey squares) from 1996-2013, from the Bayesian state-space assessment model used in this area.

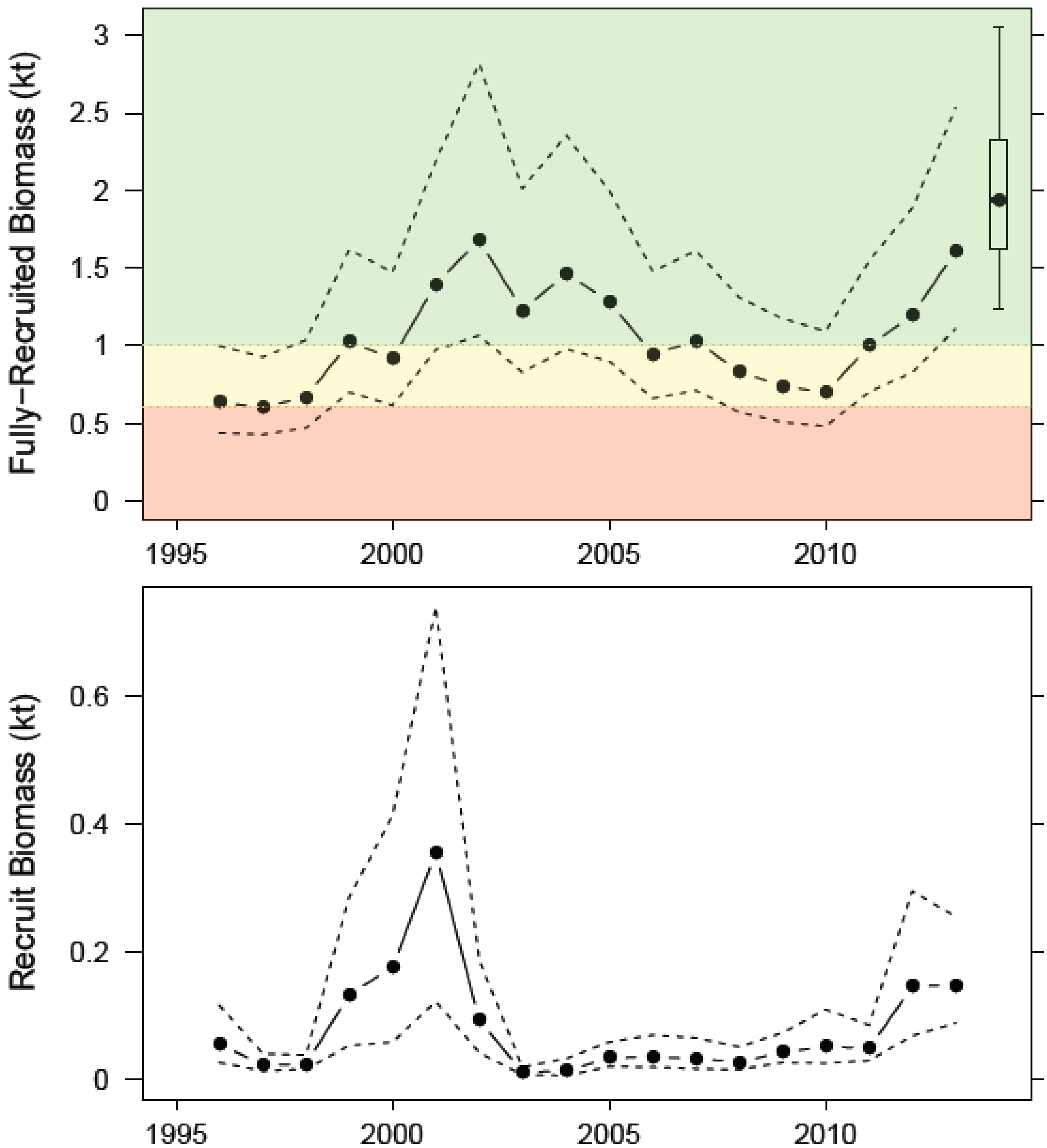

Figure 78. Scallop Production Area 3 biomass estimates for fully recruited scallops (upper panel; kt) and recruit scallops (lower panel, kt) from the assessment model fit to the survey and commercial data (1996-2013). Dashed lines are the upper and lower 95% credible limits on the estimates. The predicted commercial size biomass for 2014, assuming the interim TAC (130 t), is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers). Green-shaded area represents the healthy zone (based on a USR of 1000 t), yellow area represents the cautious zone (based on LRP of 600 t) and red is the critical zone (<LRP).

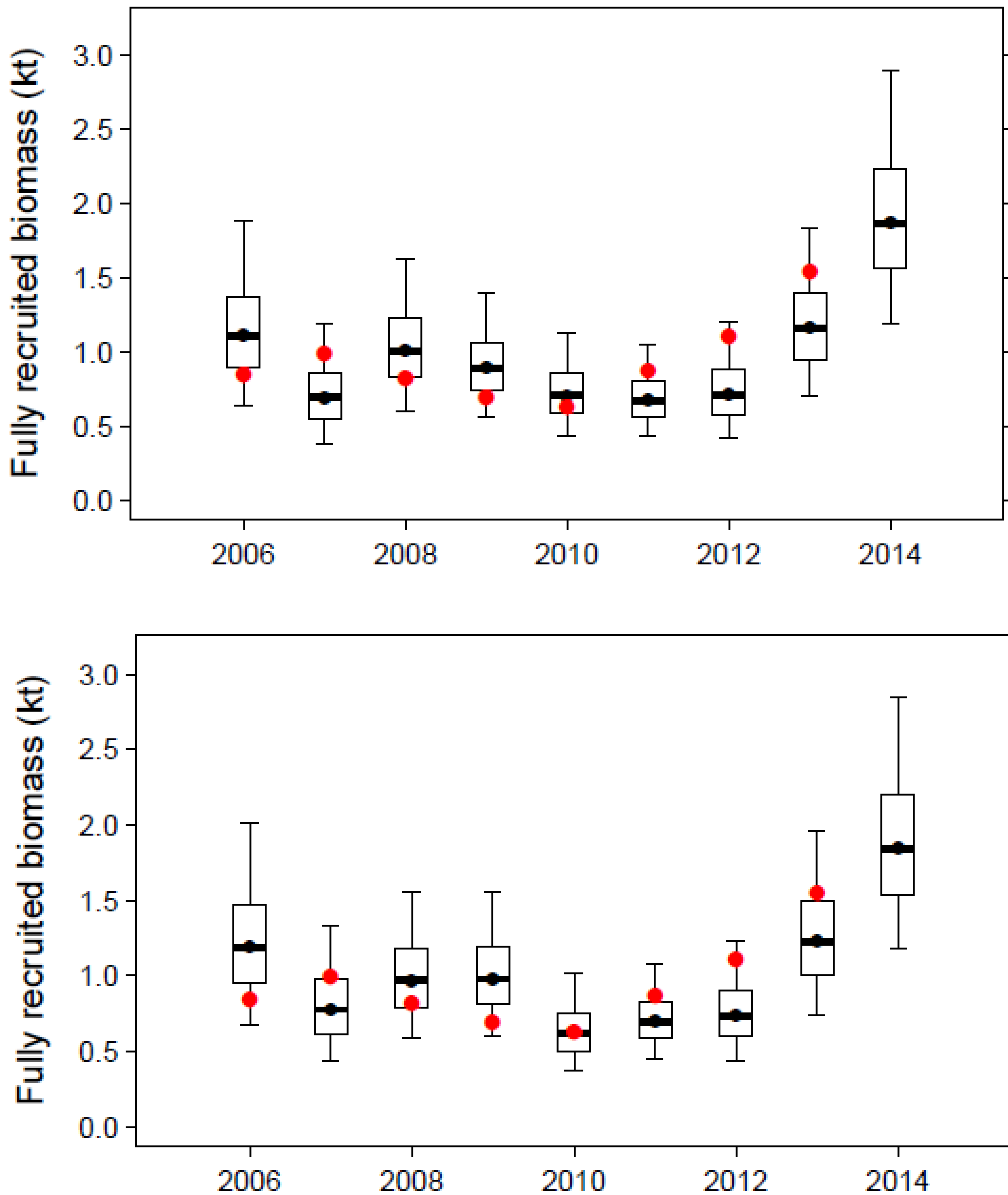

Figure 79. Scallop Production Area 3 evaluation of the model projection performance, with unknown condition (upper), and if condition were known (lower) from 2006-2013. Box and whisker plots summarise posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2006 predictions 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, from the Bayesian state-space assessment model used in this area.

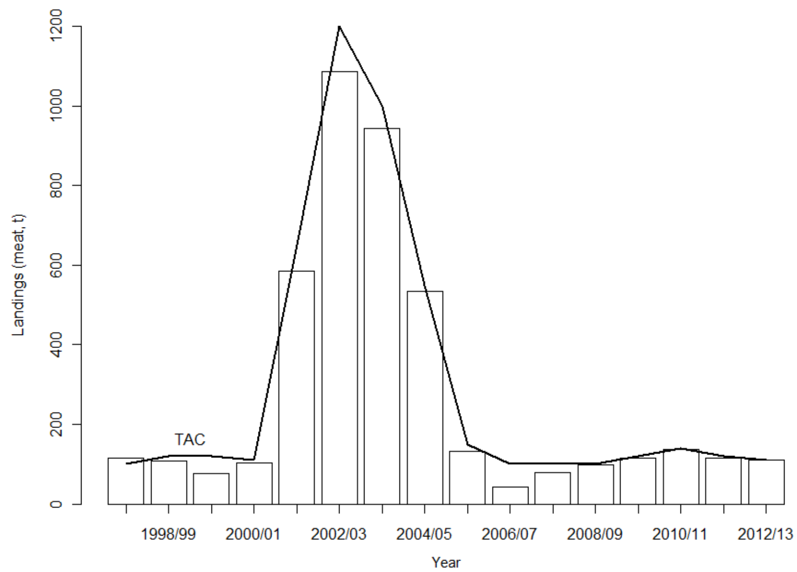

Figure 80. Scallop Production Area 4 landings (meats, tons) by the Full Bay fleet from 1997-2013. TAC is indicated by the black line.

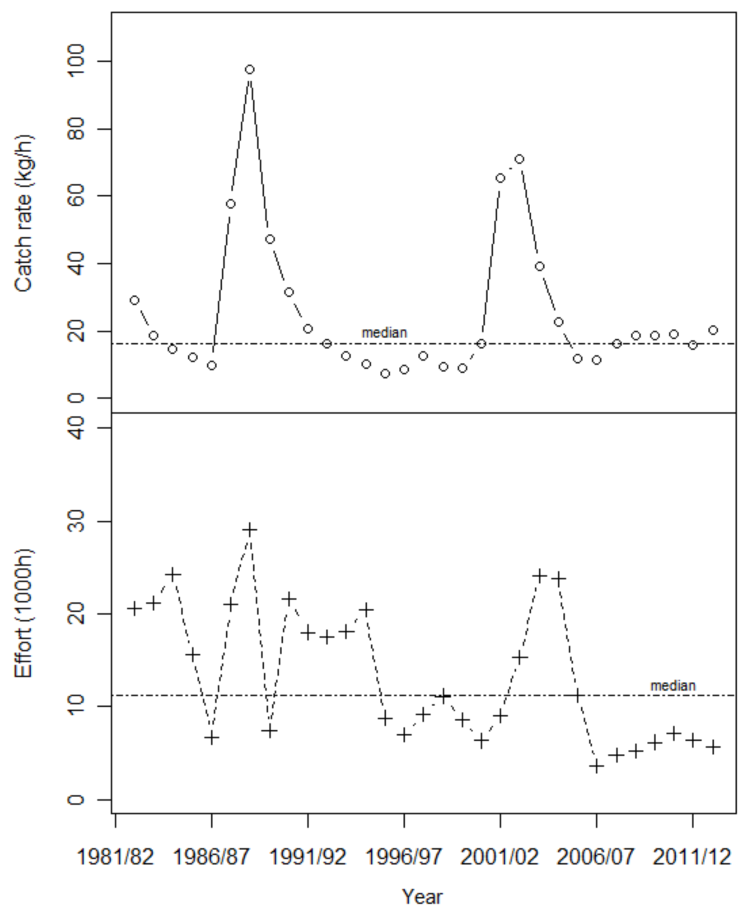

Figure 81. Scallop Production Area 4 trends in commercial catch rate (kg/h; upper panel) and effort (h; lower panel) by the Full Bay fleet from1981-2013. Median catch rate and effort from 1996/1996 to 2011/2012 indicated.

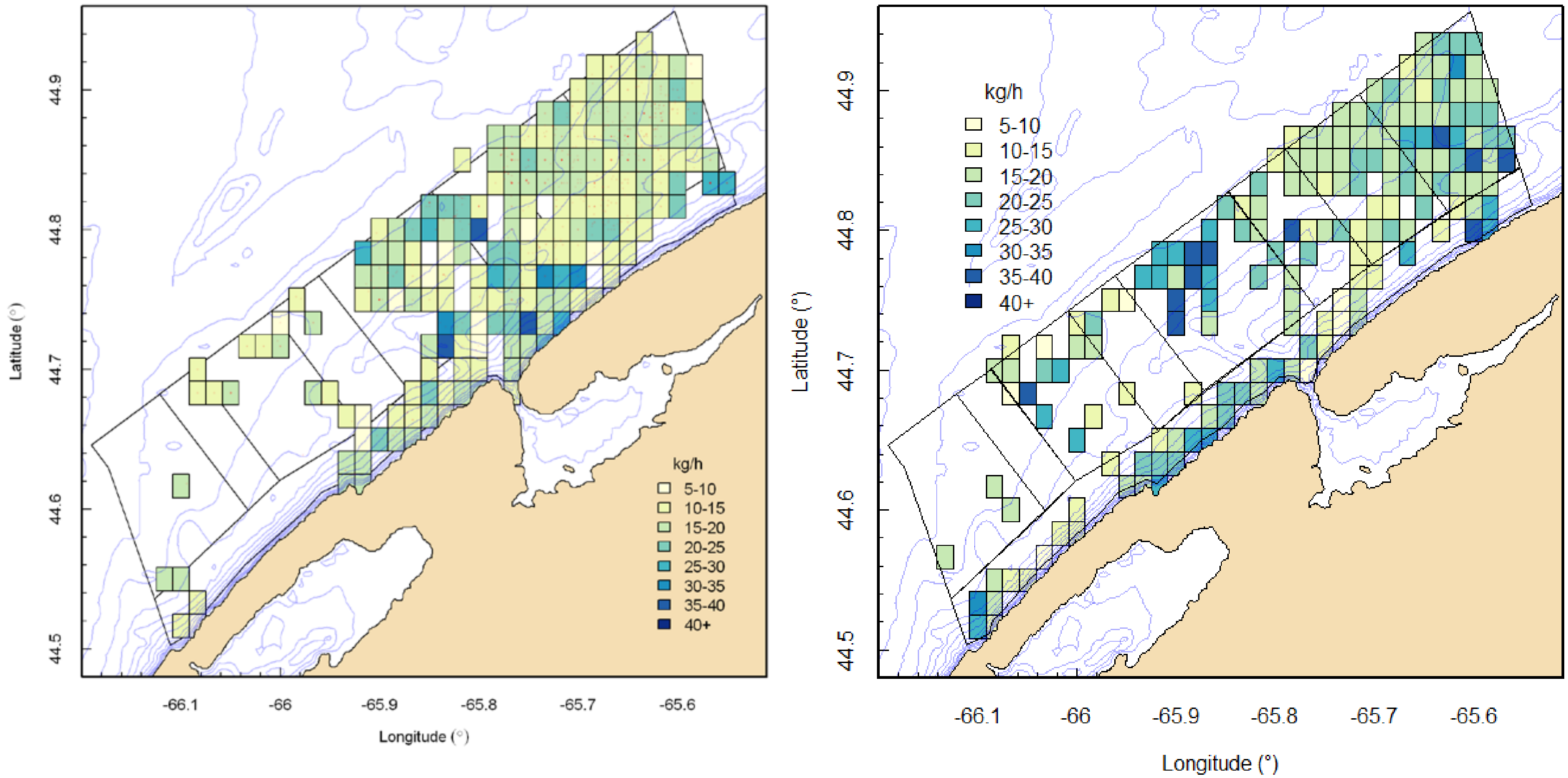

Figure 82. Scallop Production Area 4 mean catch rates (kg/h) by 1 minute square from commercial fishing logs for the2011/2012 (left) and 2012/2013 (right) fishing seasons. Survey strata are indicated.

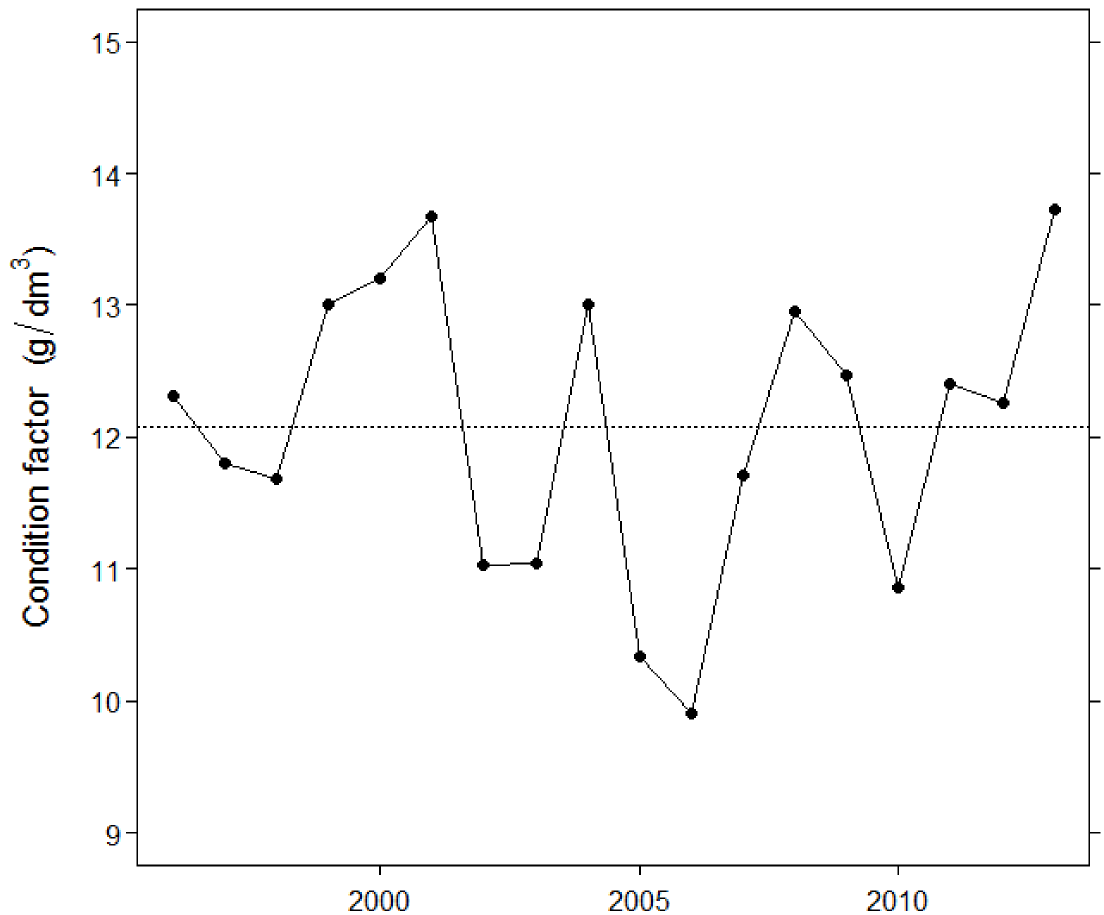

Figure 83. Scallop Production Area 4 trends in Condition Factor (g/dm^3) from 1996-2013.

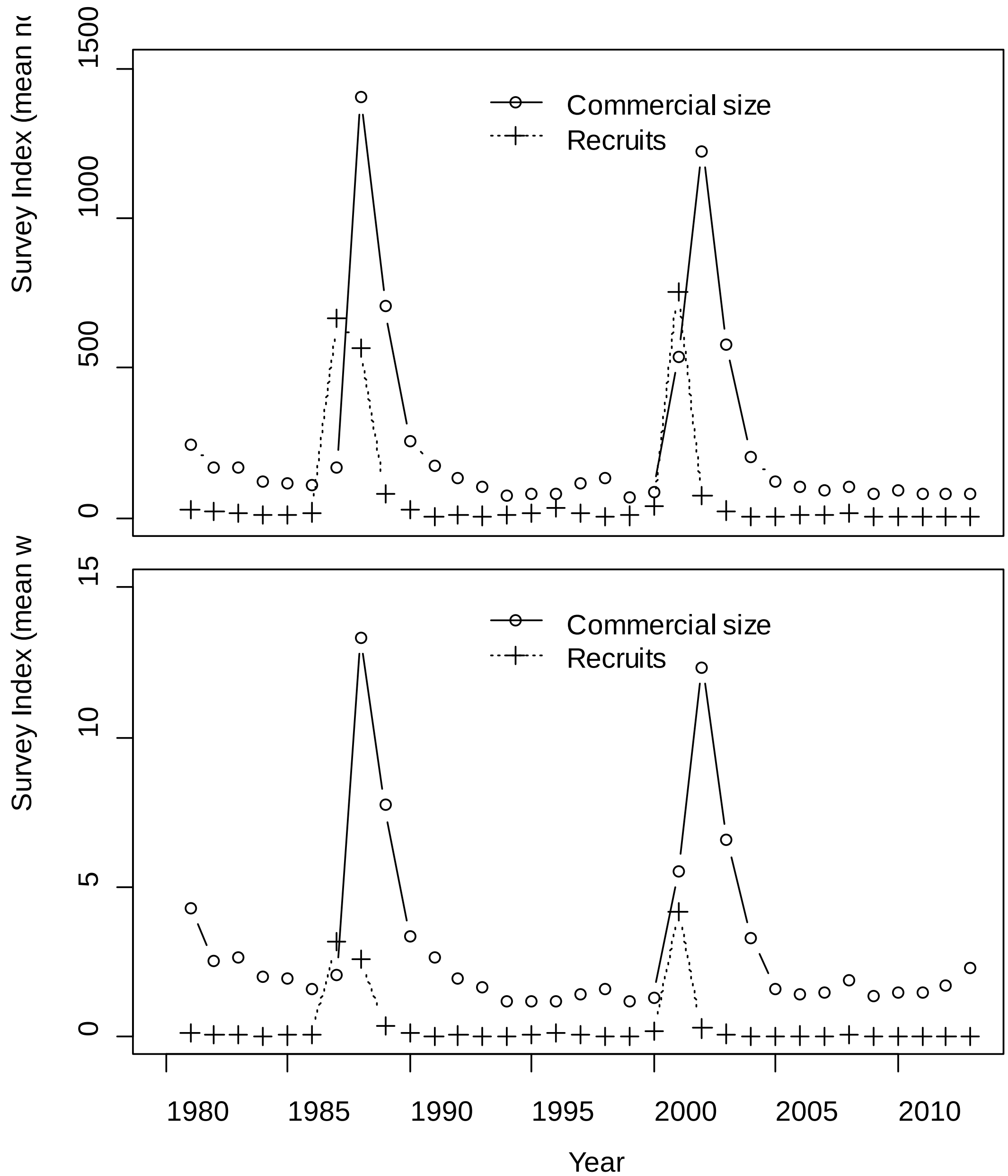

Figure 84. Scallop Production Area 4 trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1981-2013.

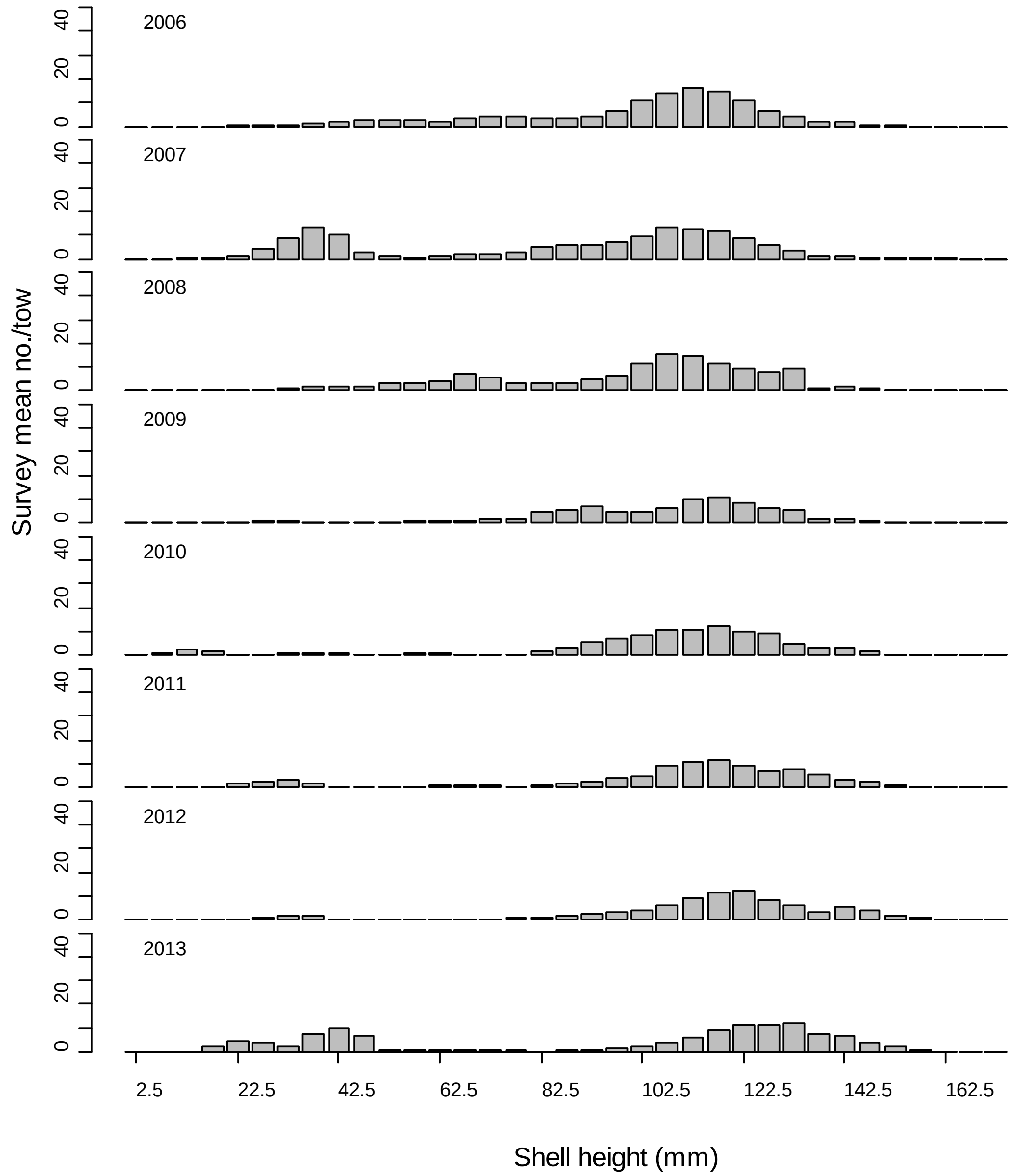

Figure 85. Scallop Production Area 4 survey shell height (mm) frequencies (mean number/ tow) from 2006-2013.

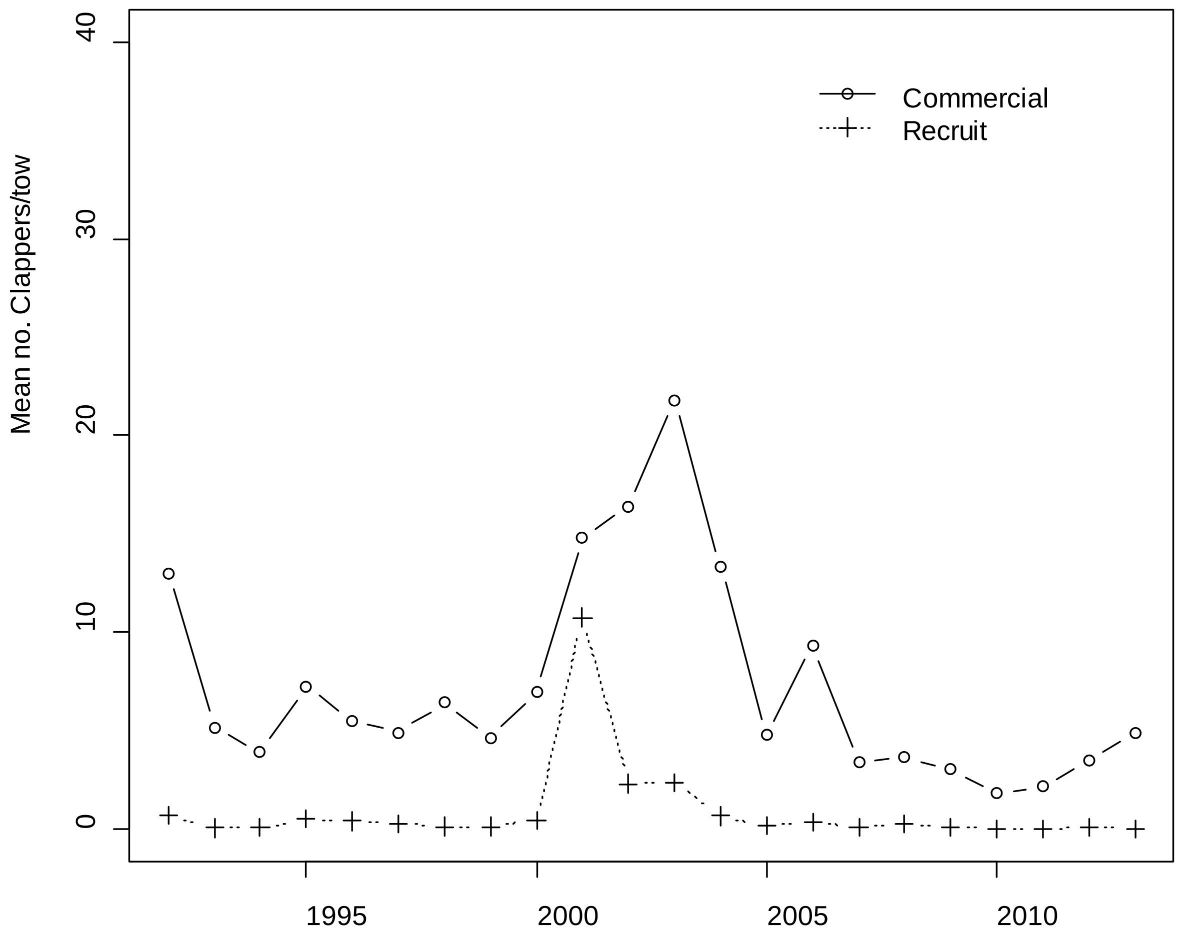

Figure 86. Scallop Production Area 4 trends in survey abundance of clappers (number/tow of paired, dead shells) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1992-2013.

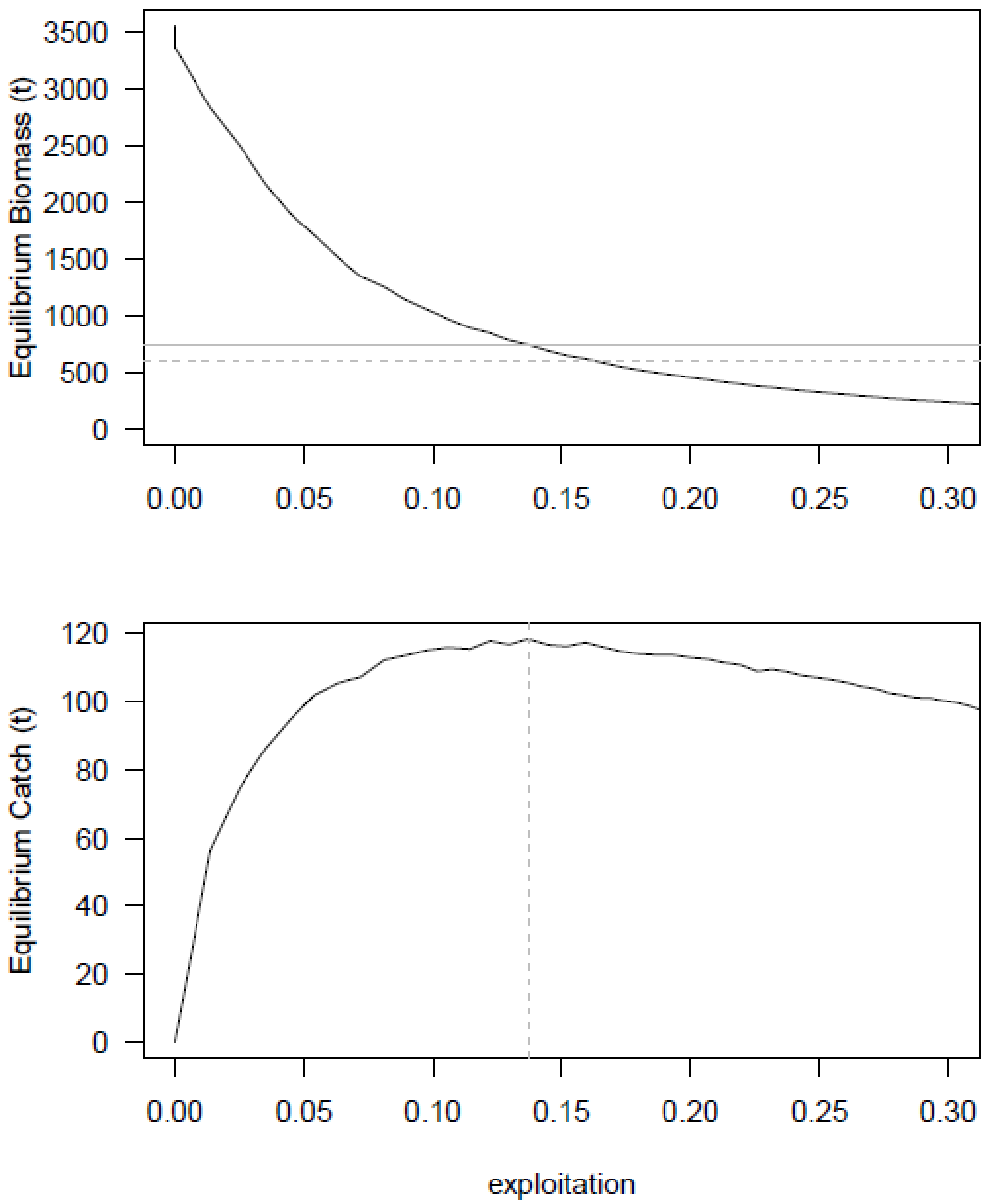

Figure 87. Equilibrium biomass (t; upper panel) and equilibrium catch (t; lower panel) used in determining the exploitation rate for maximum catch in Scallop Production Area 4. These were obtained by projecting the model forward by 50 years from the current year for a range of constant exploitation rates. See Table 12 for an evaluation of the USR biomass levels.

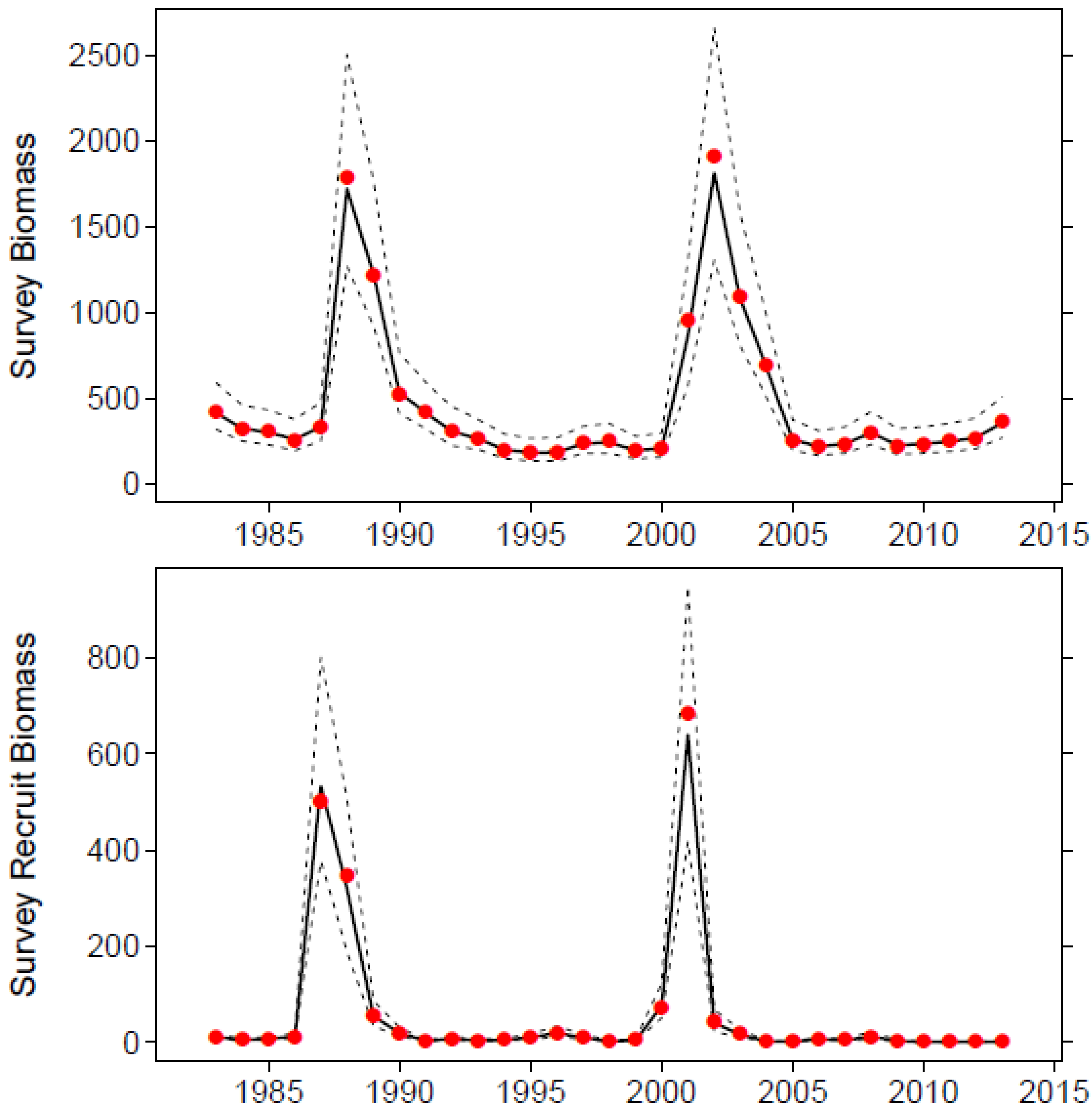

Figure 88. Scallop Production Area 4 posterior median fit to the survey biomass series (1983-2013) for commercial (upper panel; t), and recruit (lower panel; t) size scallops from the Bayesian state-space assessment model used in this area.

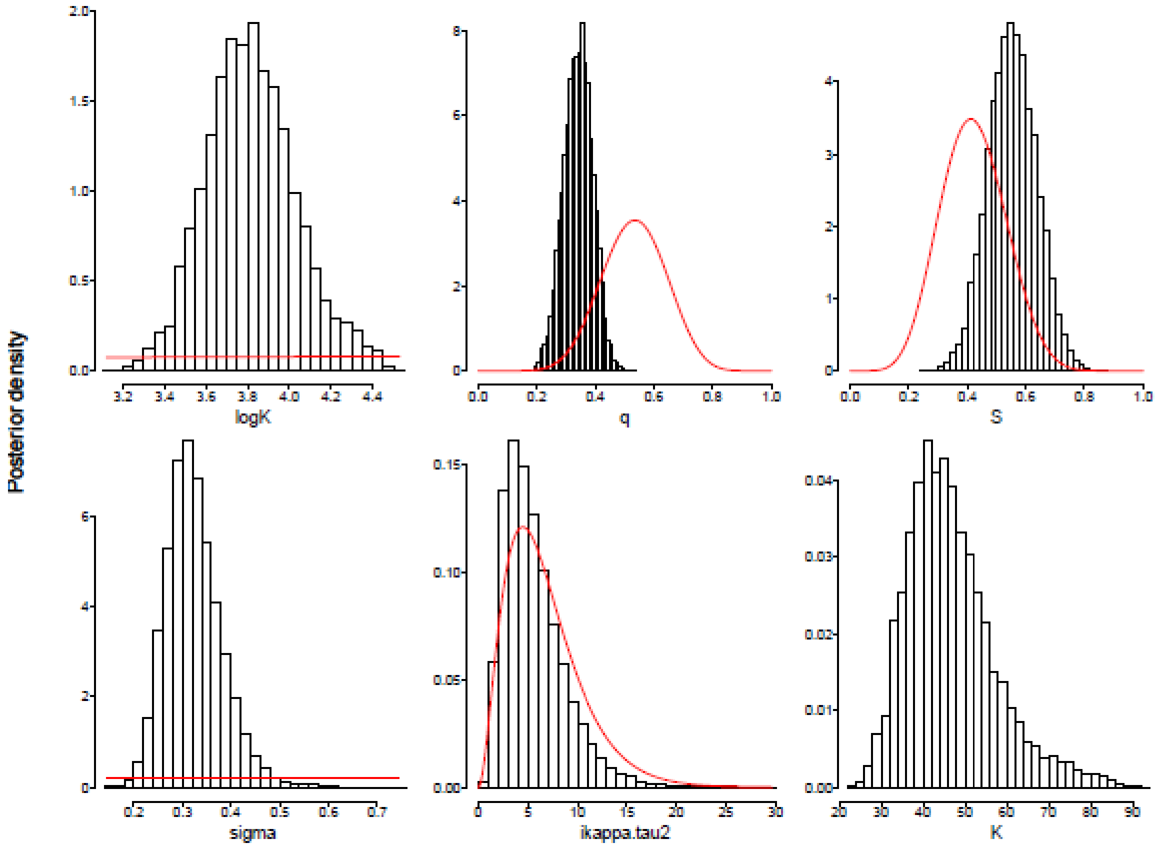

Figure 89. Scallop Production Area 4, comparison of prior and posterior densities from the Bayesian state-space assessment model used in this area.

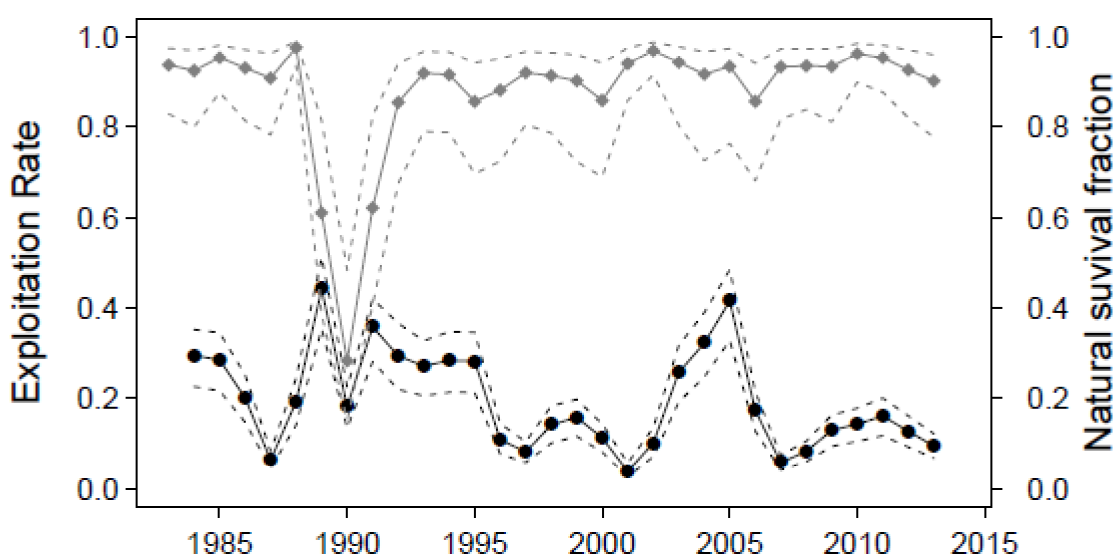

Figure 90. Scallop production Area 4 annual trends in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey squares) from 1984-2013, from the Bayesian state-space assessment model used in this area.

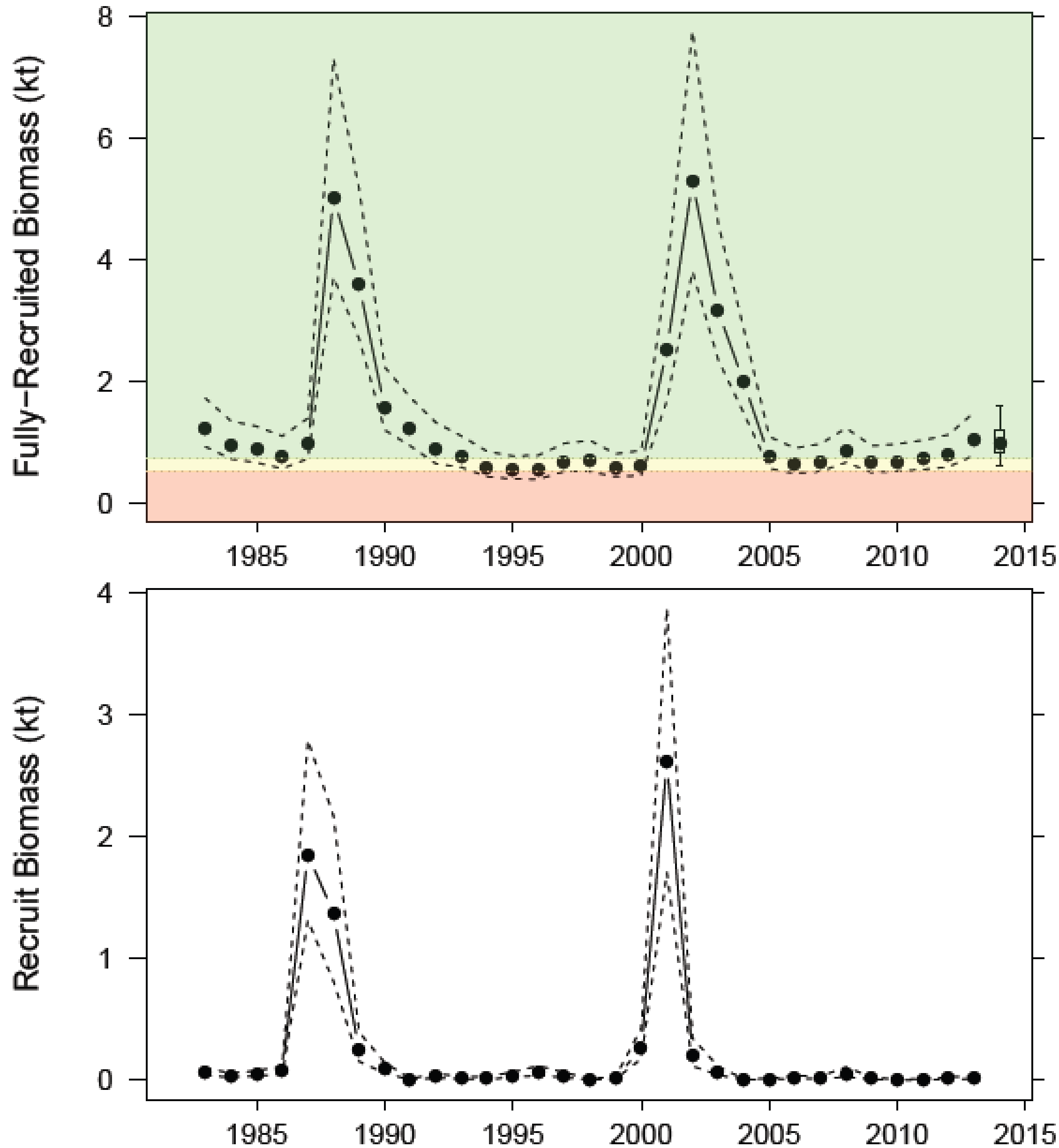

Figure 91. Scallop Production Area 4 biomass estimates for fully recruited scallops (upper panel; kt) and recruit scallops (lower panel, kt) from the assessment model fit to the survey and commercial data (1983-2013). Dashed lines are the upper and lower 95% credible limits on the estimates. The predicted commercial size biomass for 2014, assuming the interim TAC (80 t), is displayed as a box plot with median, 50% credible limits (box) and 80% credible limits (whiskers). Green-shaded area represents the healthy zone (based on a USR of 750 t), yellow area represents the cautious zone (based on LRP of 530 t) and red is the critical zone (<LRP).

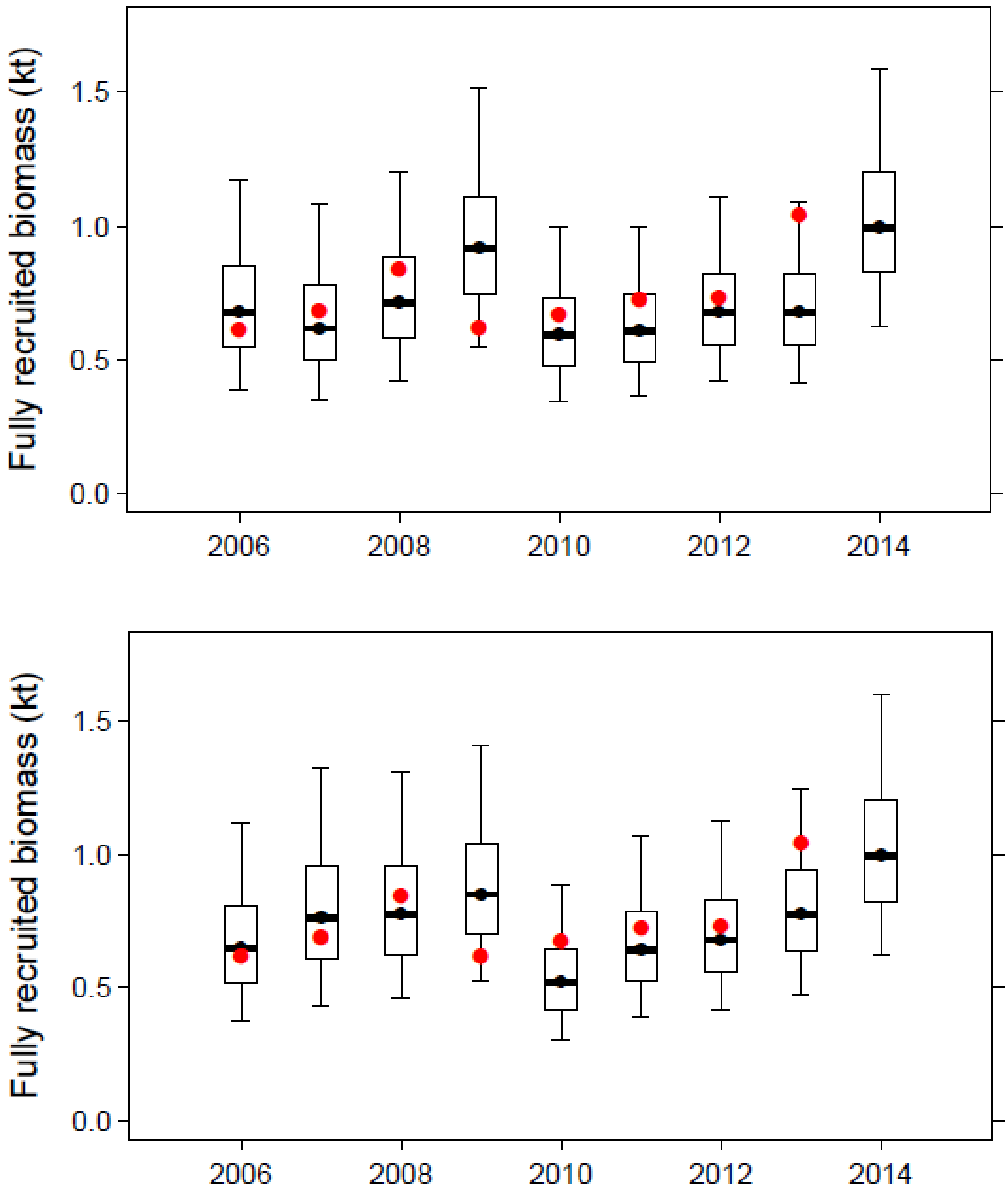

Figure 92. Scallop Production Area 4 evaluation of the model projection performance (upper) and projection performance if condition had been known (lower) from 2006-2013. Box and whisker plots summarise posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2006 predictions 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, from the Bayesian state-space assessment model used in this area.

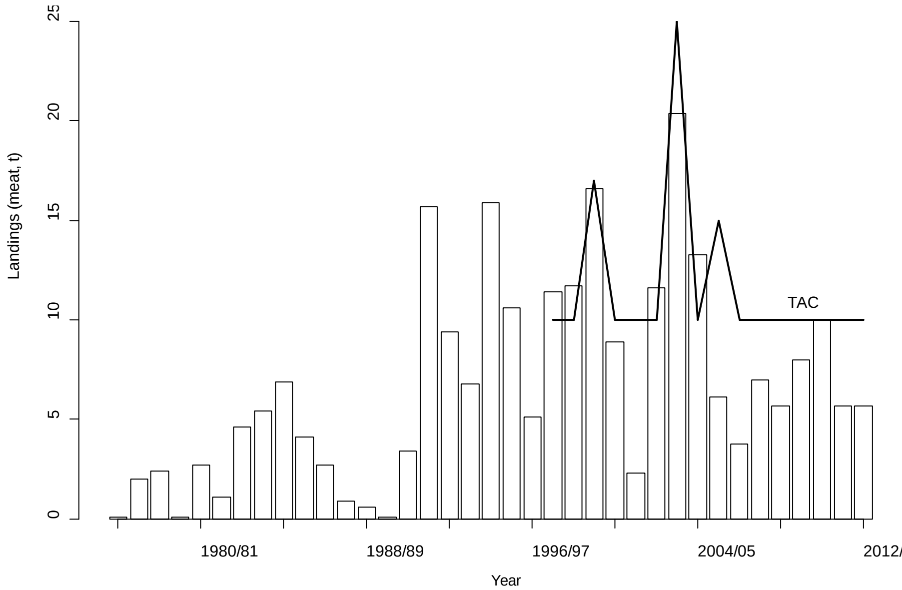

Figure 93. Scallop Production Area 5 landings (meats, tons) by the Full Bay fleet from 1976-2013. TAC is indicated by black line.

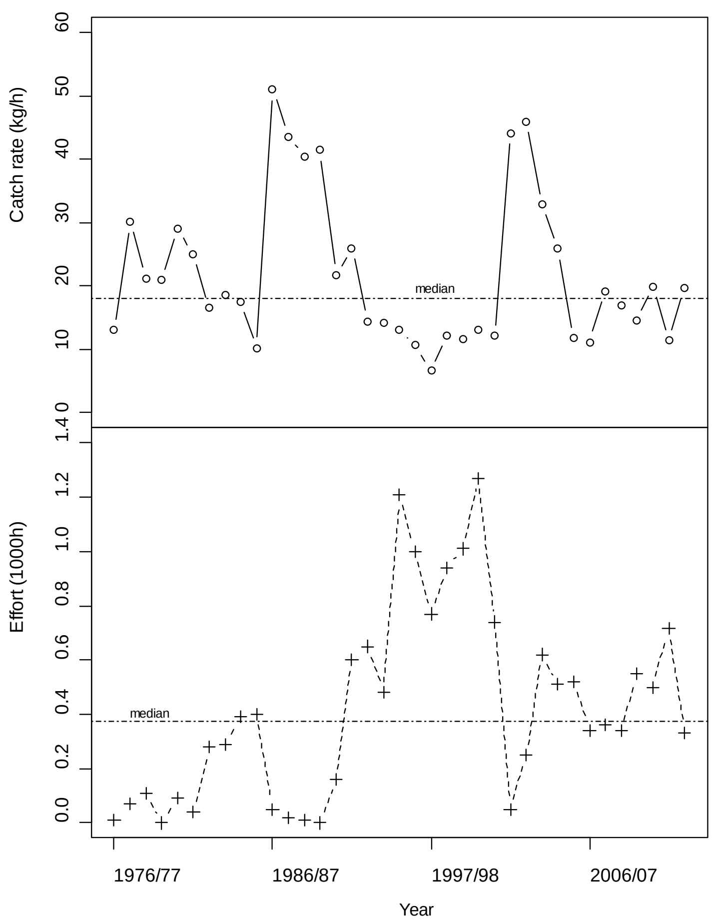

Figure 94. Scallop Production Area 5 trends in commercial catch rate (kg/h; upper panel) and effort (h; lower panel) by the Full Bay fleet from 1976-2013. Median catch rate and effort from 1976/1977-2011/2012 indicated.

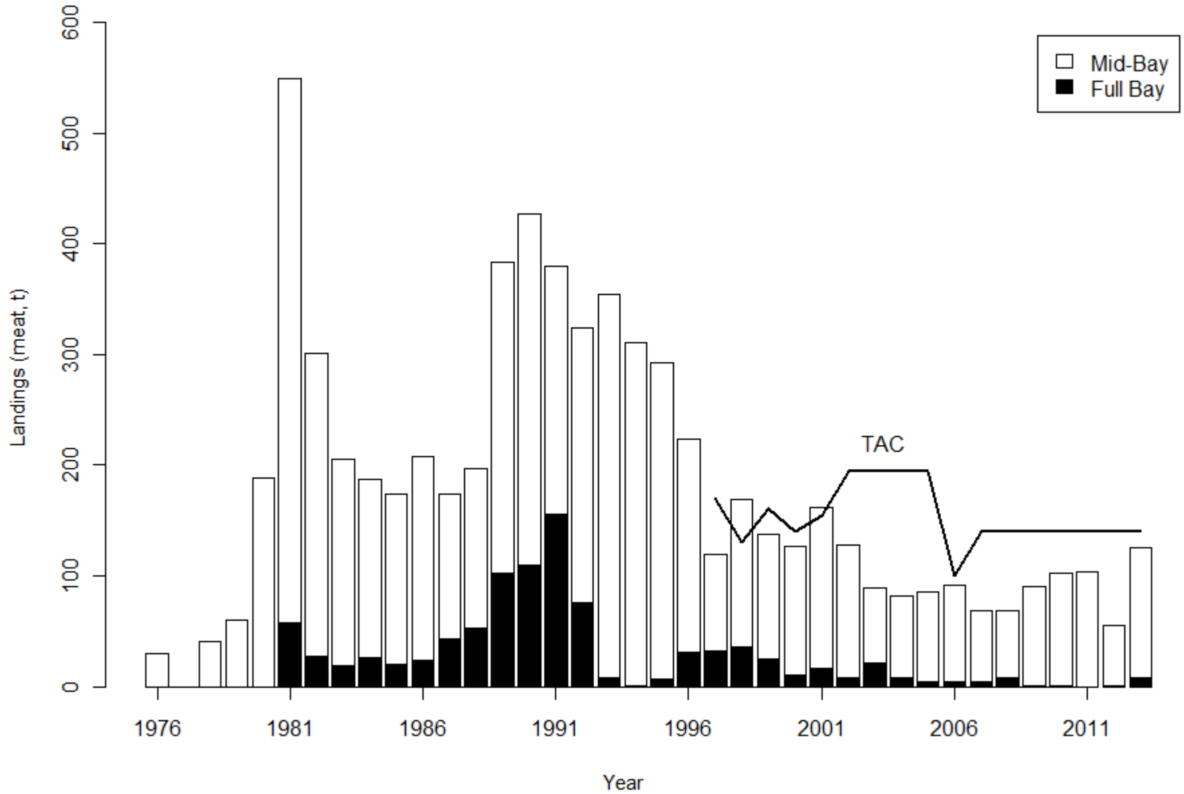

Figure 95. Scallop Production Area 6 landings (meats, tons) by the Full Bay fleet (black) from 1981-2013, and Mid Bay fleet (white) from 1976, 1978-2013. Combined TAC is indicated by black line.

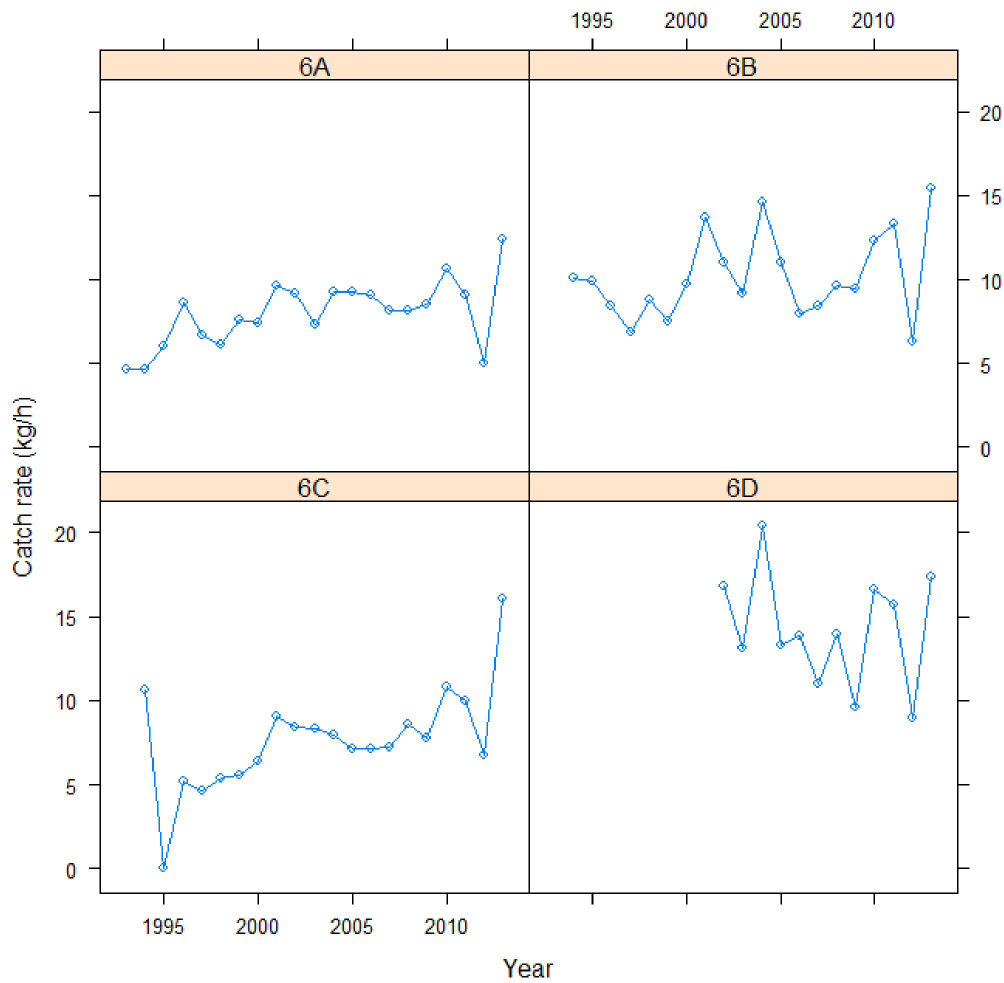

Figure 96. Scallop Production Area 6 trends in commercial catch rate (kg/h) for 6A (upper left), 6B (upper right), 6C (lower left), and 6D (lower right) for the Mid Bay fleet from 1994-2013 for 6A, B, and C, and 2001-2013 for 6D.

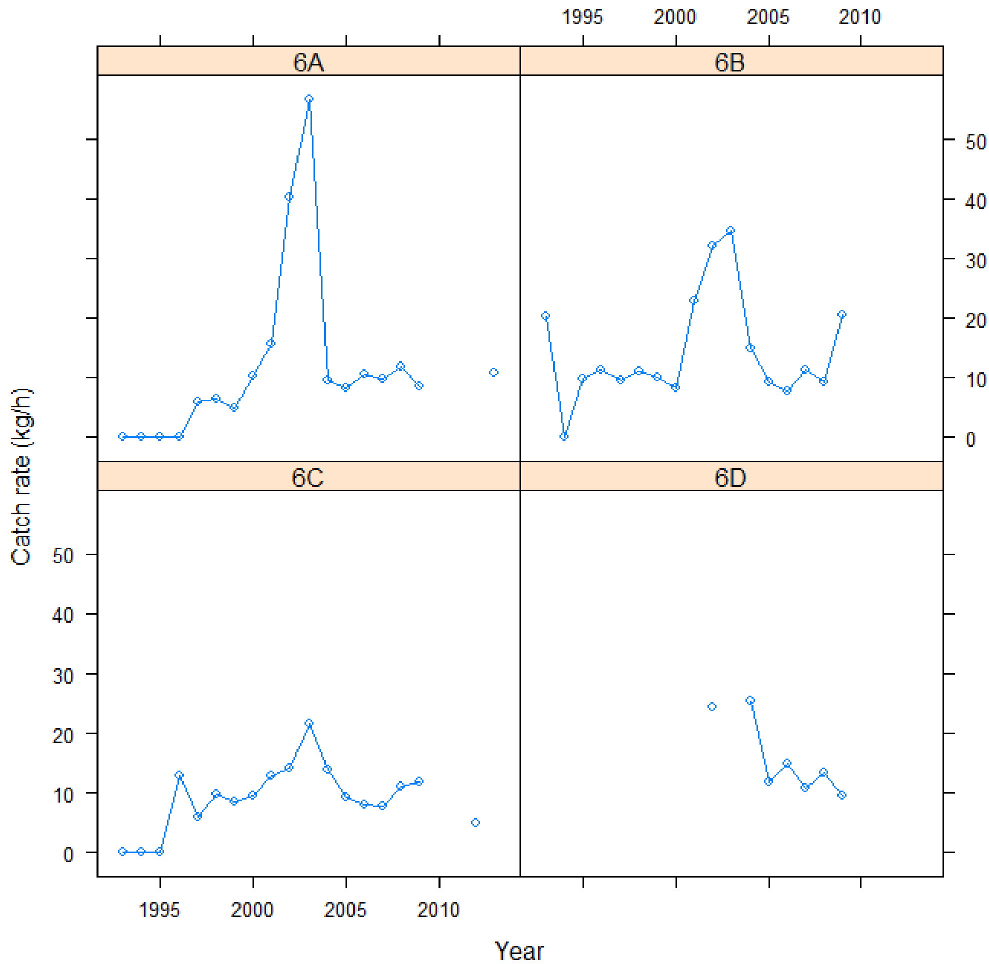

Figure 97. Scallop Production Area 6 trends in commercial catch rate (kg/h) for 6A (upper left), 6B (upper right), 6C (lower left), and 6D (lower right) for the Full Bay fleet from 1993-2009, 2011 for 6A and 6C, 1993-2009 for 6, and 2002, 2004-2009.

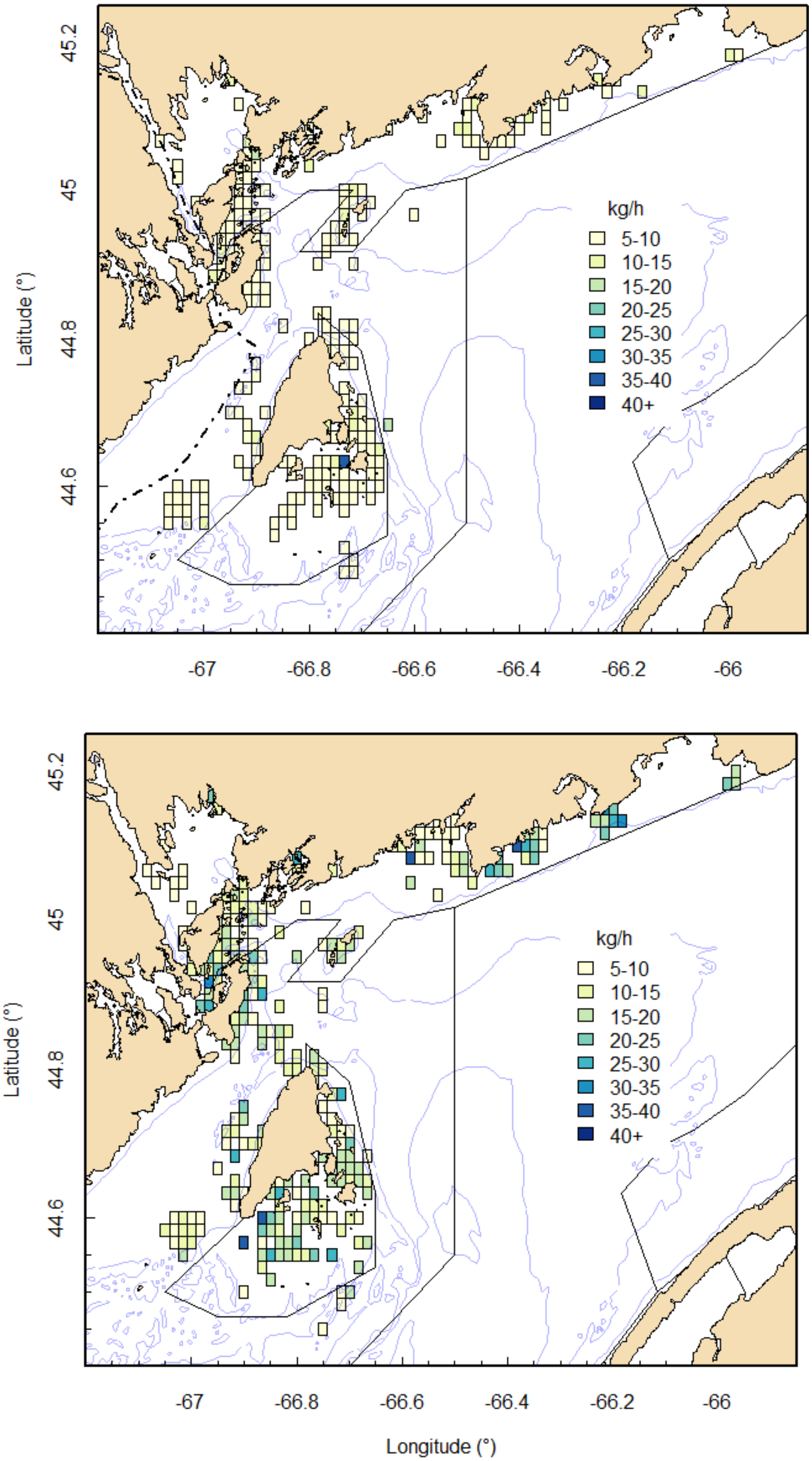

Figure 98. Scallop Production Area 6 mean catch rates (kg/h) by 1 minute square from commercial fishing logs for the 2011/2012 (upper) and 2012/2013 (lower) fishing seasons. Survey strata are indicated.

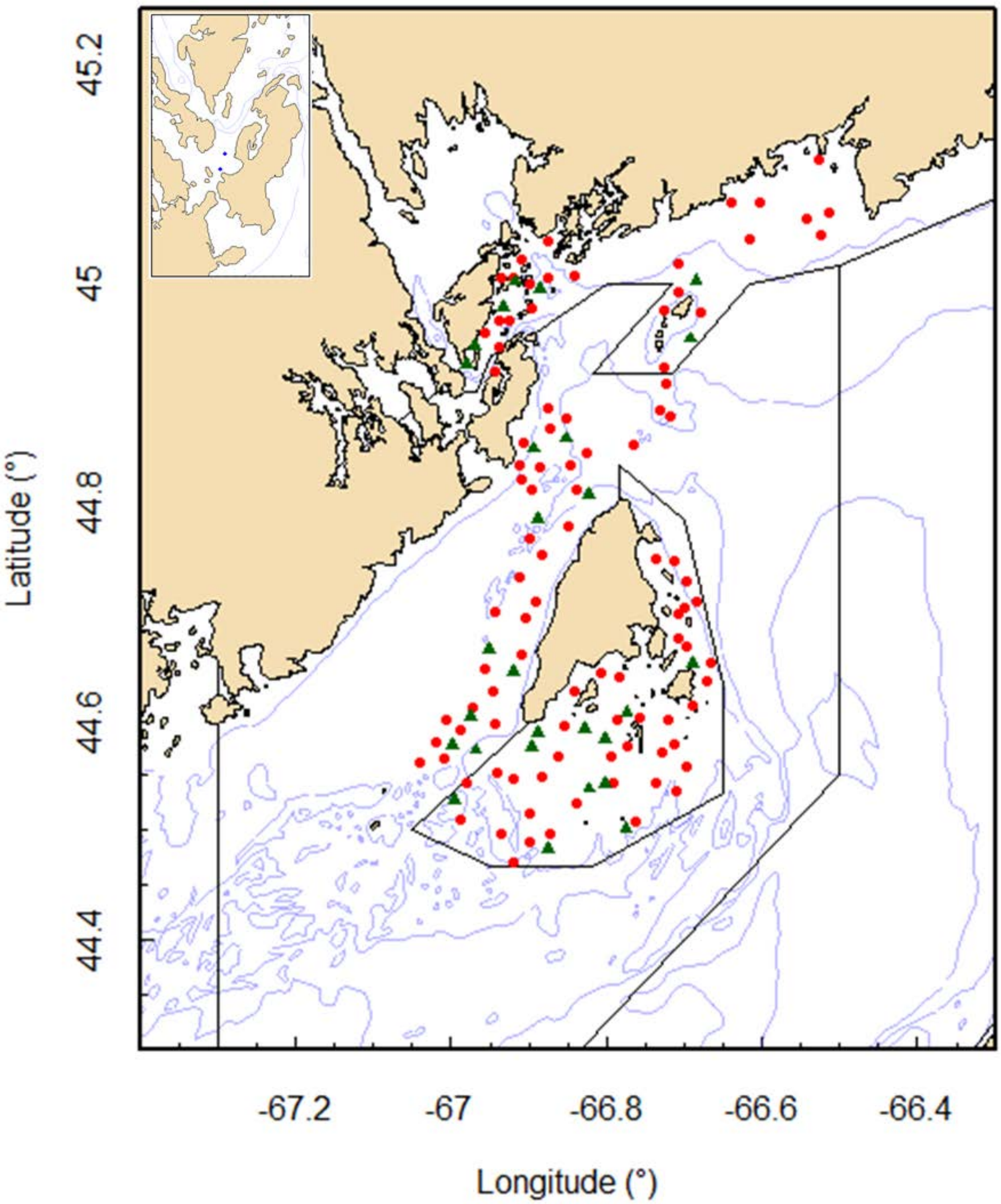

Figure 99. Scallop Production Area 6 survey tow locations. Regular survey tows are in red circles, repeated tows from 2012 are green triangles. Inset shows two experimental tows in Friar's Bay.

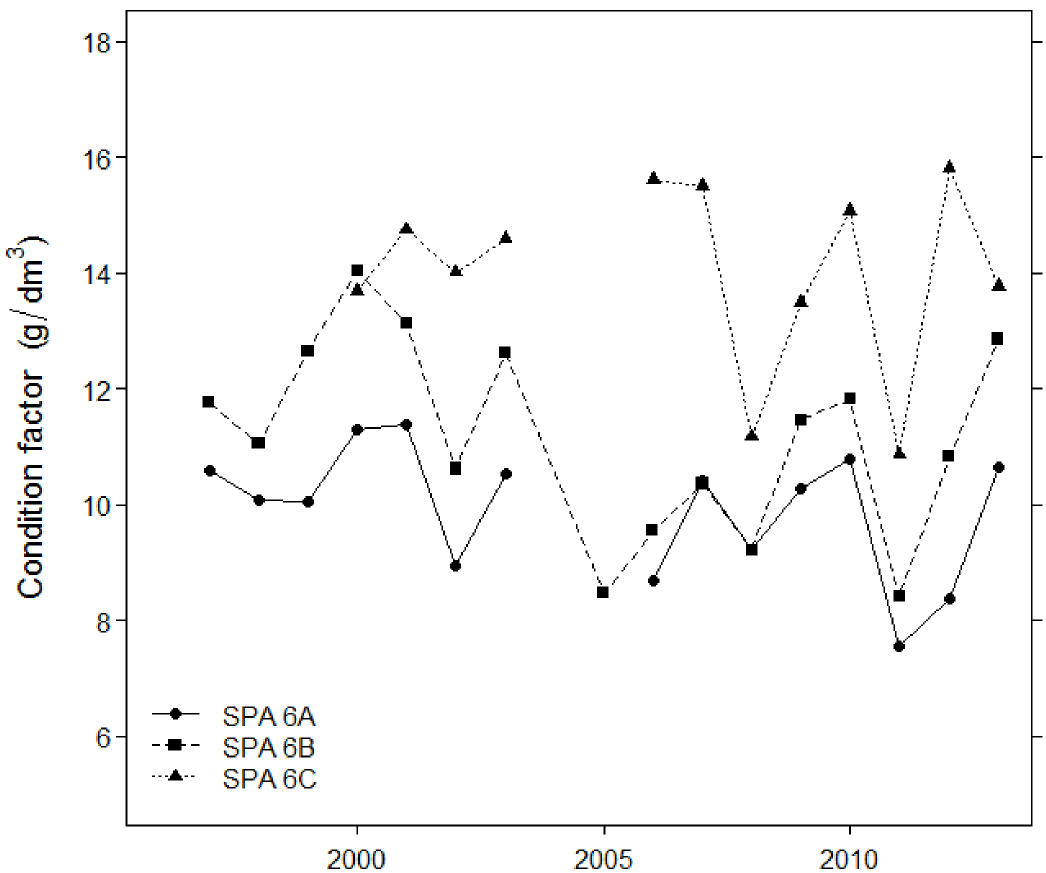

Figure 100. Scallop Production Area 6 trends in Condition Factor (g/dm^3) for 6A (circles) from 1997-2003, 2006-2013, 6B (squares) from 1997-2003,2005-2013, and 6C (triangles) from 2000-2003,2006-2013.

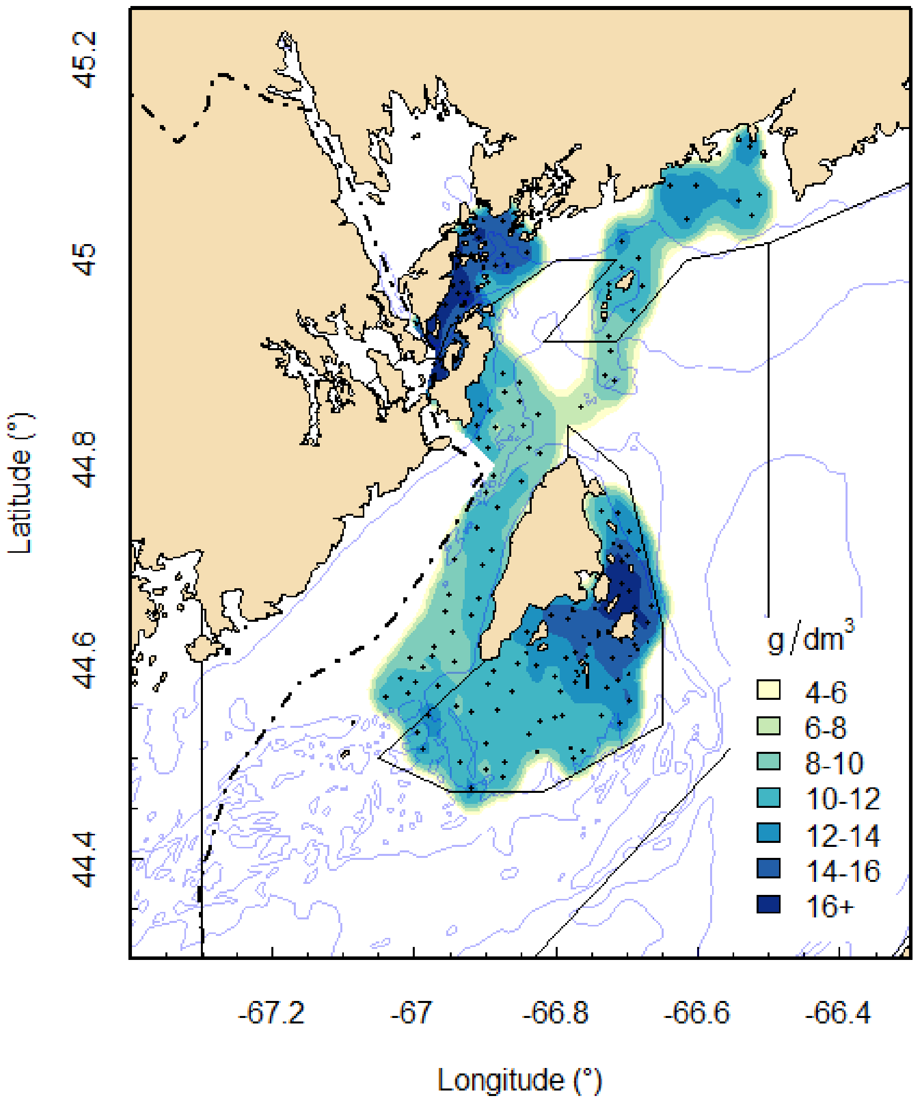

Figure 101. Spatial distribution of condition factor (g/dm^3) in Scallop Production Area 6, from the 2013 survey. Survey strata are shown.

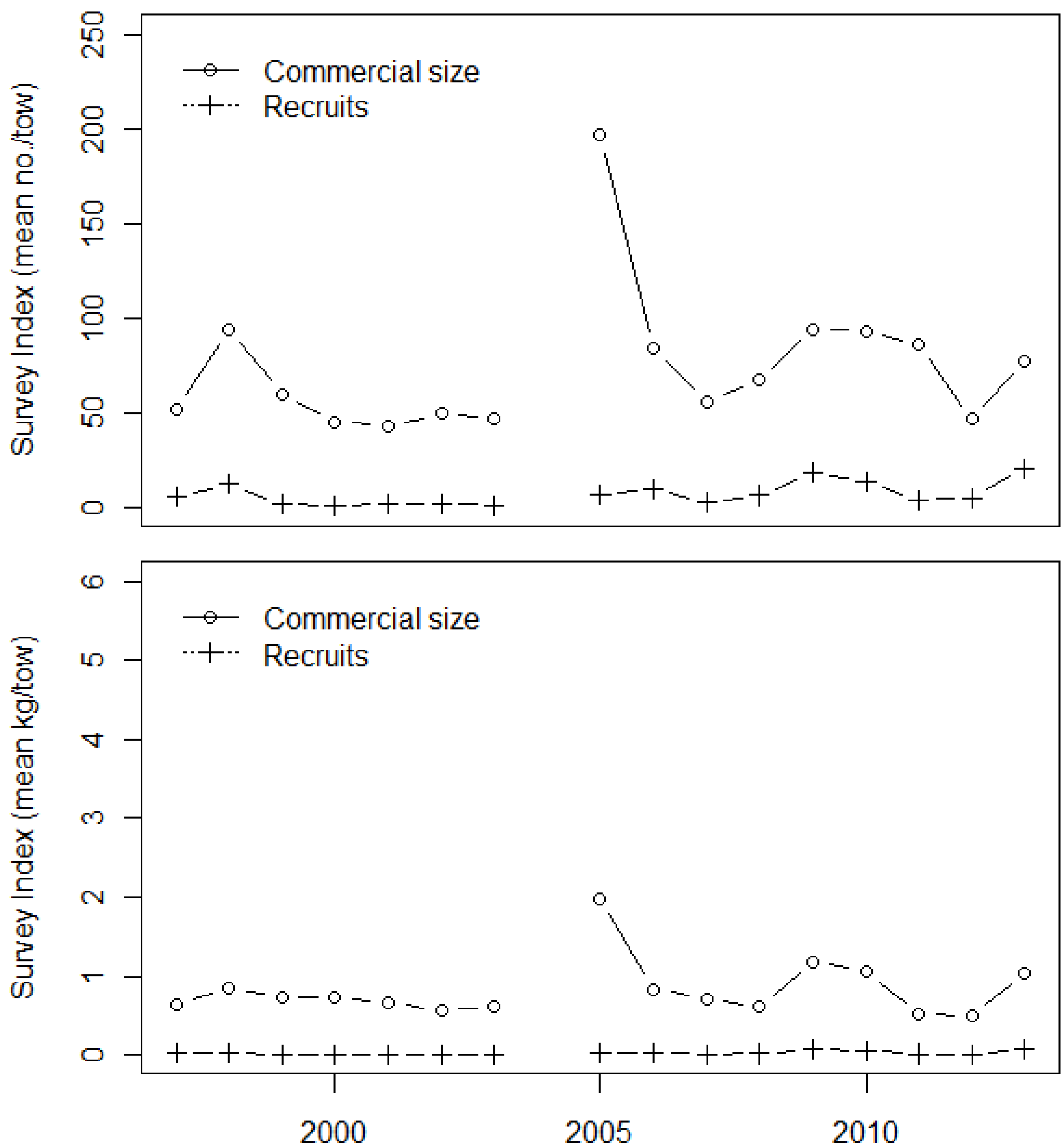

Figure 102. The 6A zone of Scallop Production Area 6 trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1997-2003, 2005-2013.

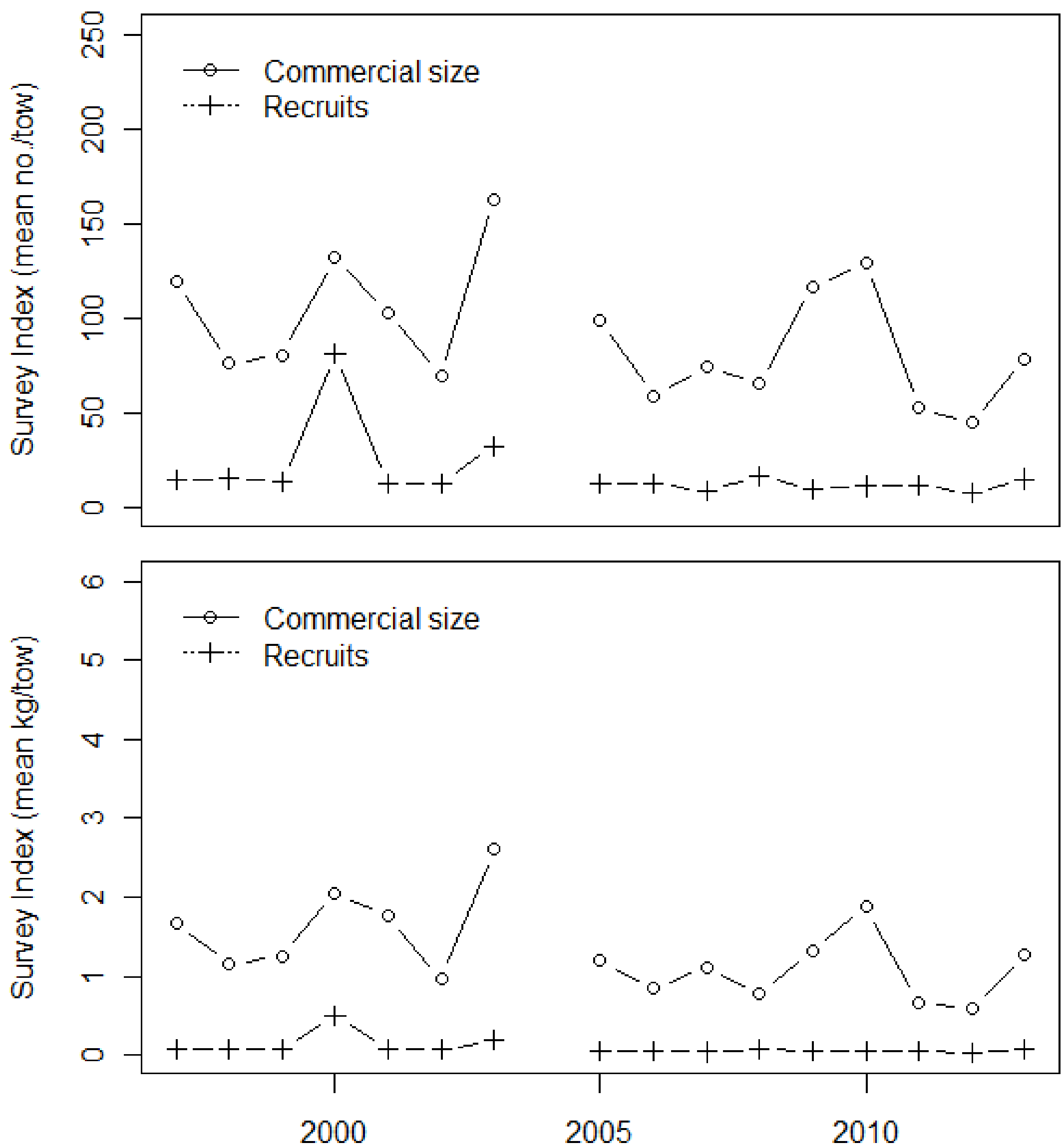

Figure 103. The 6B zone of Scallop Production Area 6 trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 1997-2003, 2005-2013.

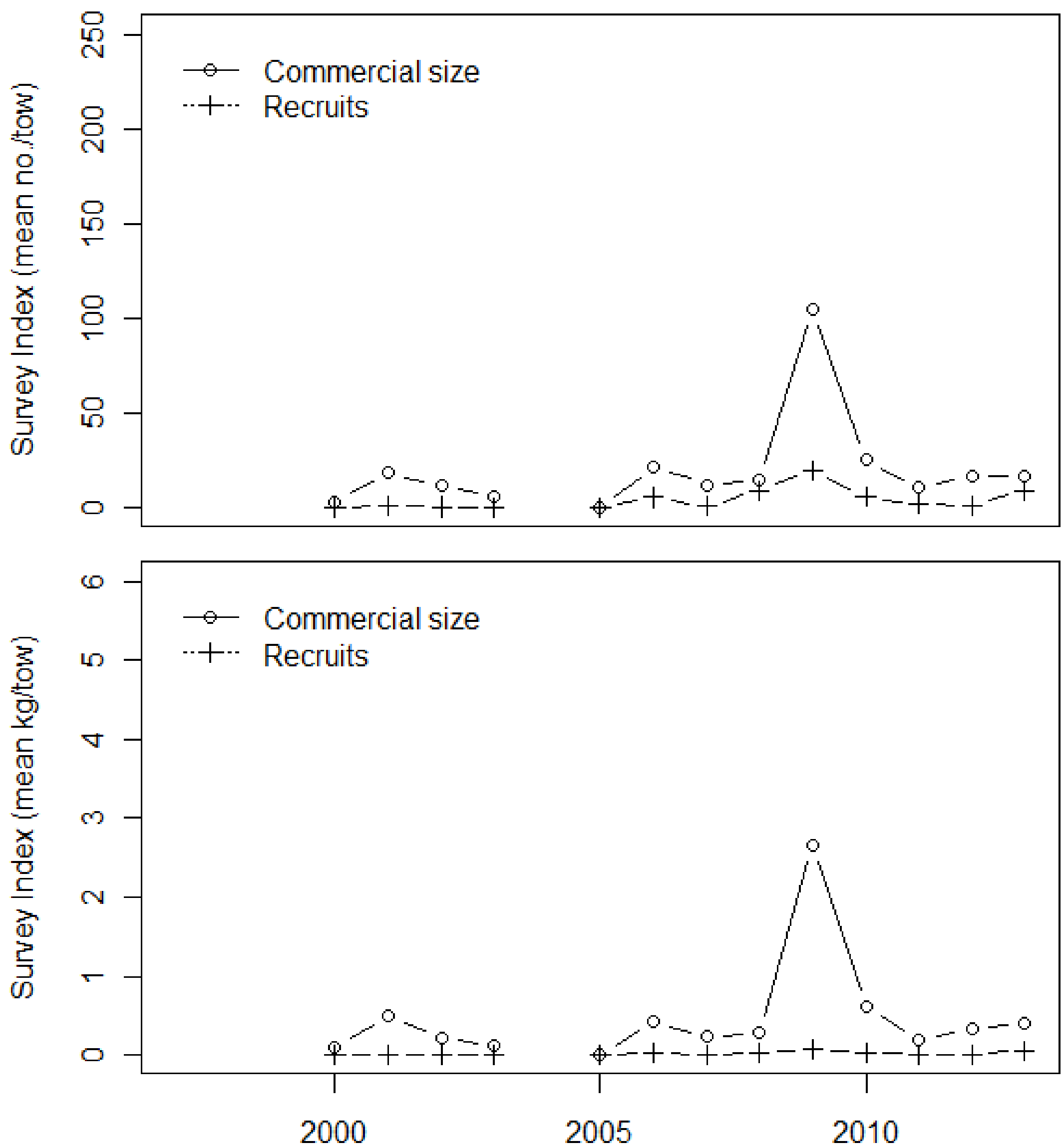

Figure 104. The 6C zone of Scallop Production Area 6 trends in survey abundance (upper panel; mean number/tow) and biomass (lower panel; kg/tow) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops from 2000-2003, 2005-2013.

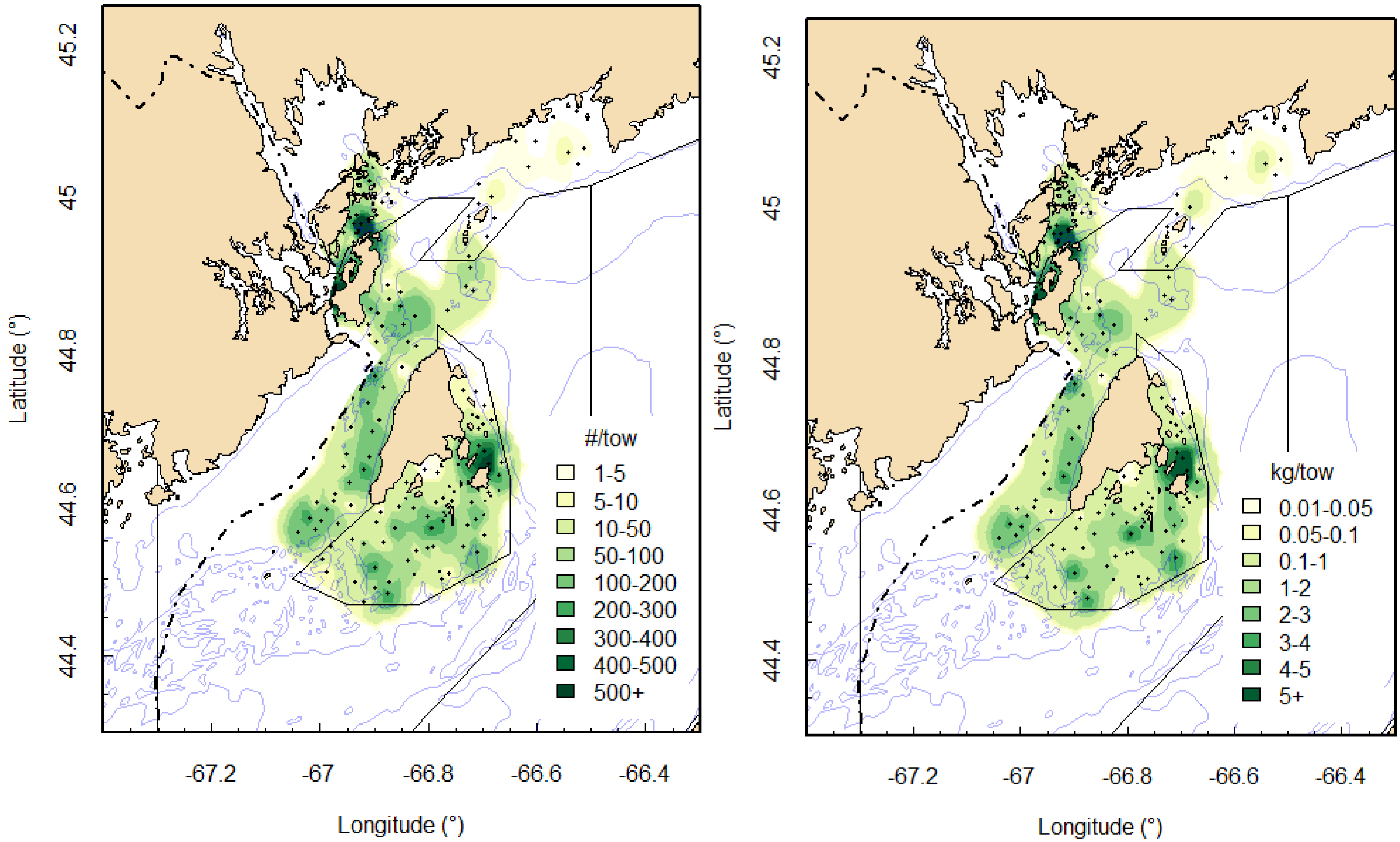

Figure 105. Spatial distribution of abundance (number/tow; left) and biomass (kg/tow; right) of commercial size (≥ 80 mm) scallop in Scallop Production Area 6 from the 2013 survey. Survey strata are shown.

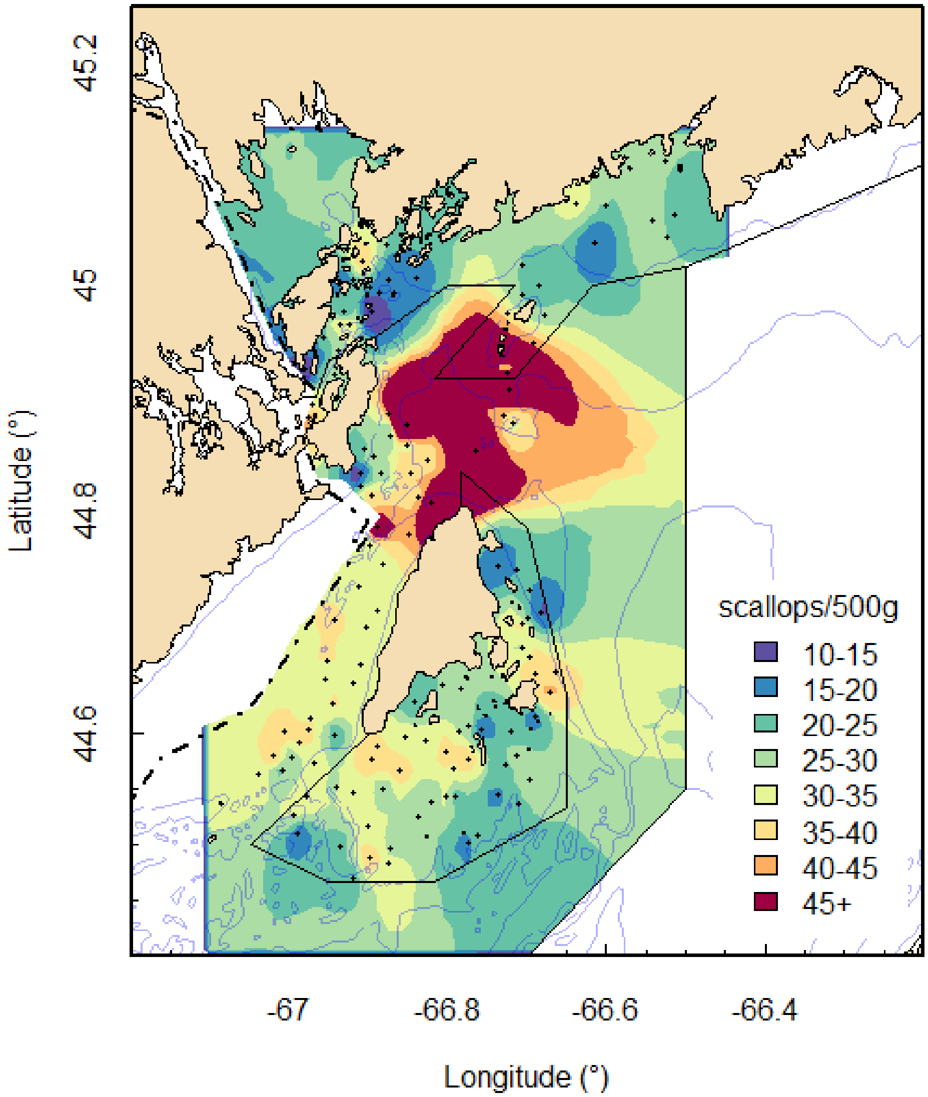

Figure 106. Spatial distribution of meat count (scallops/500 g) in Scallop Production Area 6 from the 2013 survey. Survey strata are shown. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

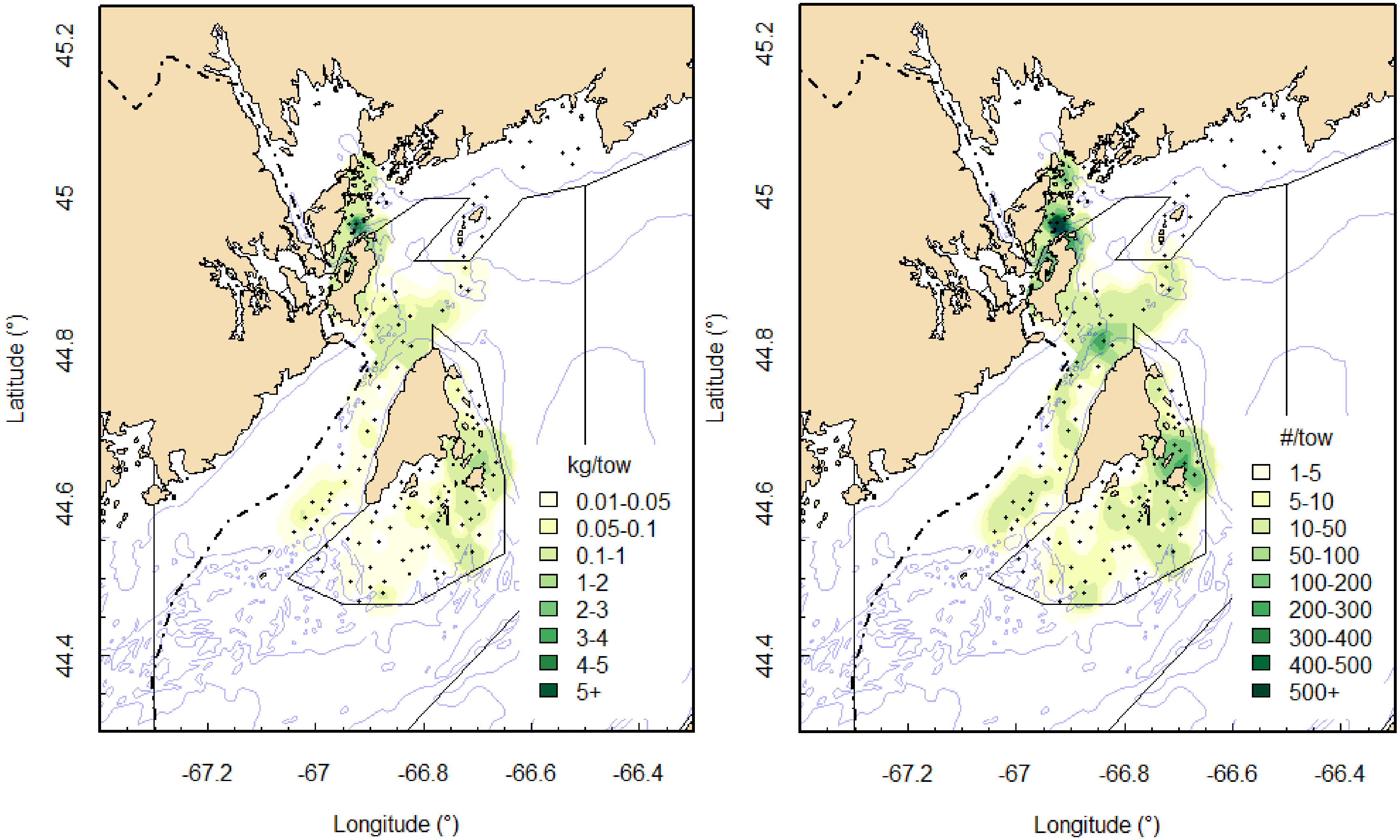

Figure 107. Spatial distribution of abundance (number/tow; left) and biomass (kg/tow; right) of recruit size (65-79 mm) scallop in Scallop Production Area 6 from the 2013 survey. Survey strata are shown.

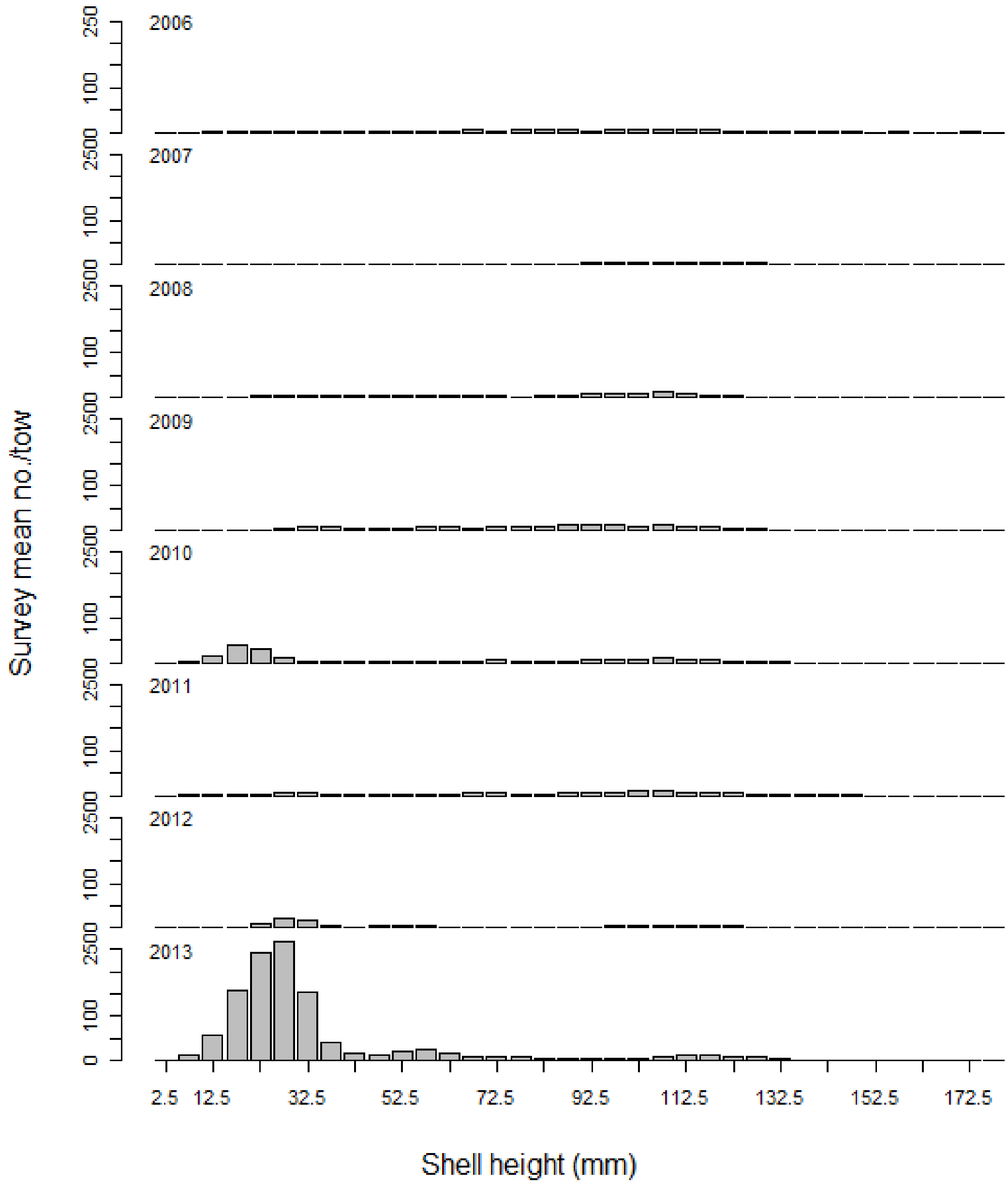

Figure 108. Zone 6A of Scallop Production Area 6 survey shell height (mm) frequencies (mean number/tow) from 2006-2013.

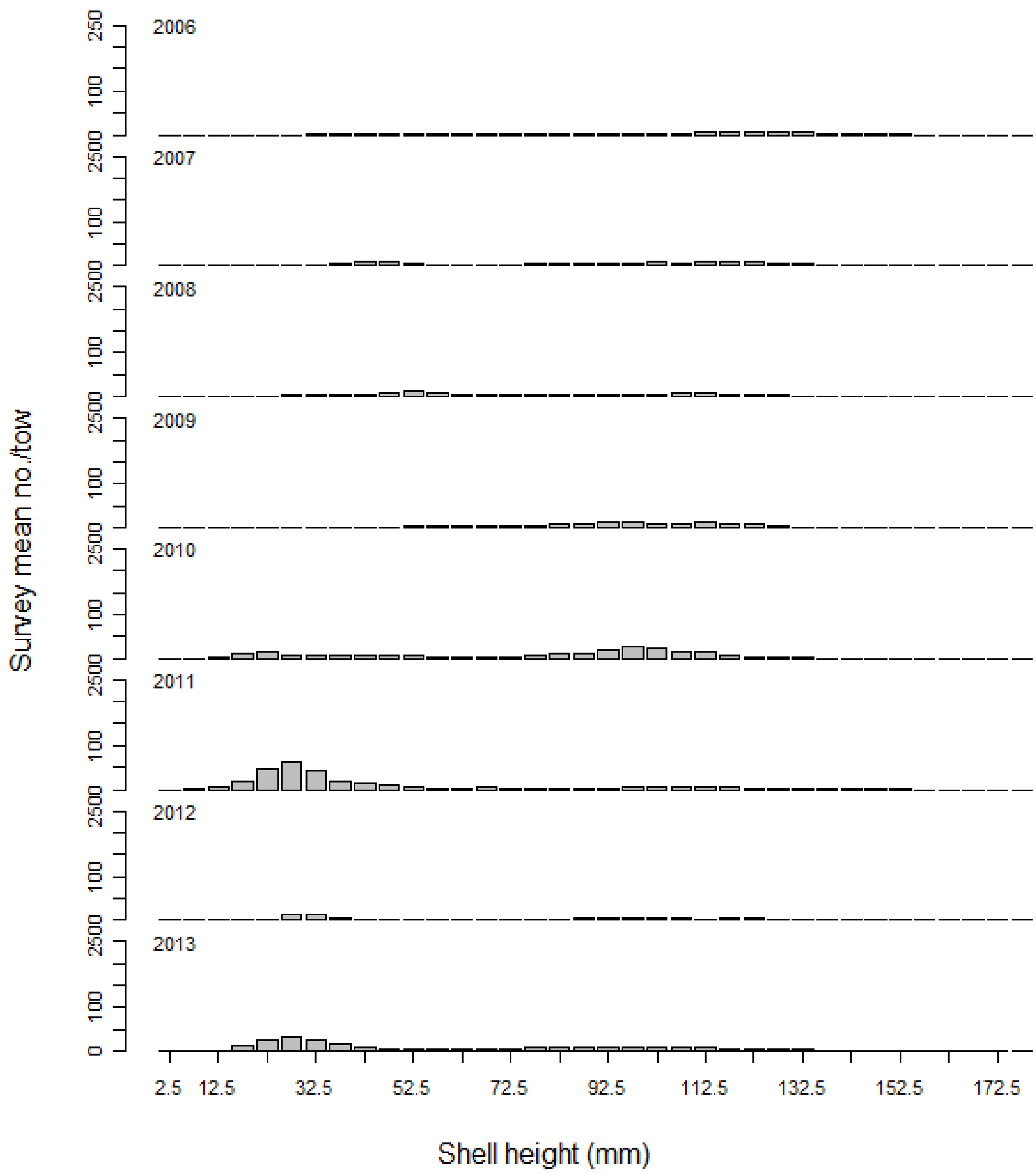

Figure 109. Zone 6B of Scallop Production Area 6 survey shell height (mm) frequencies (mean number/tow) from 2006-2014.

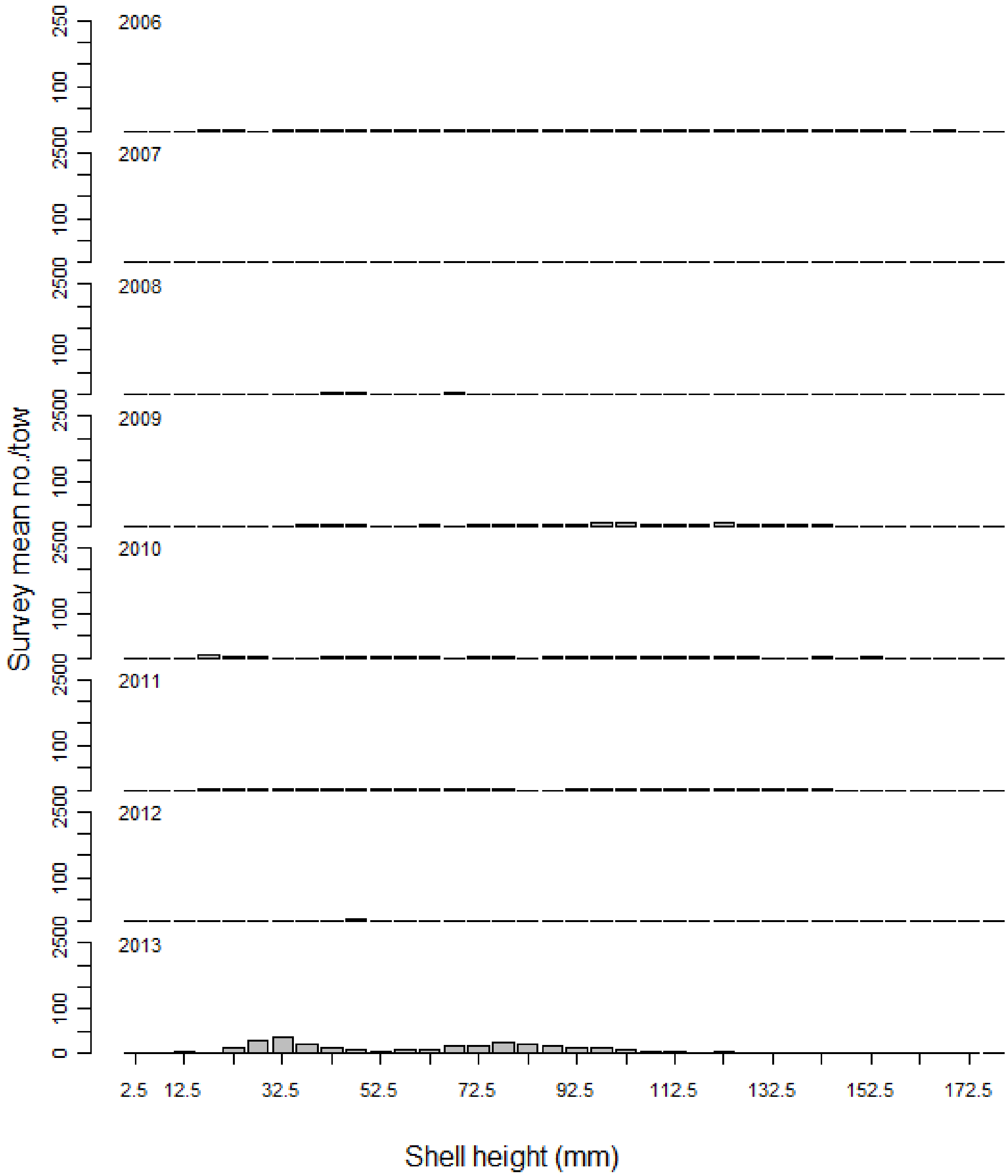

Figure 110. Zone 6C of Scallop Production Area 6 survey shell height (mm) frequencies (mean number/tow) from 2006-2013.

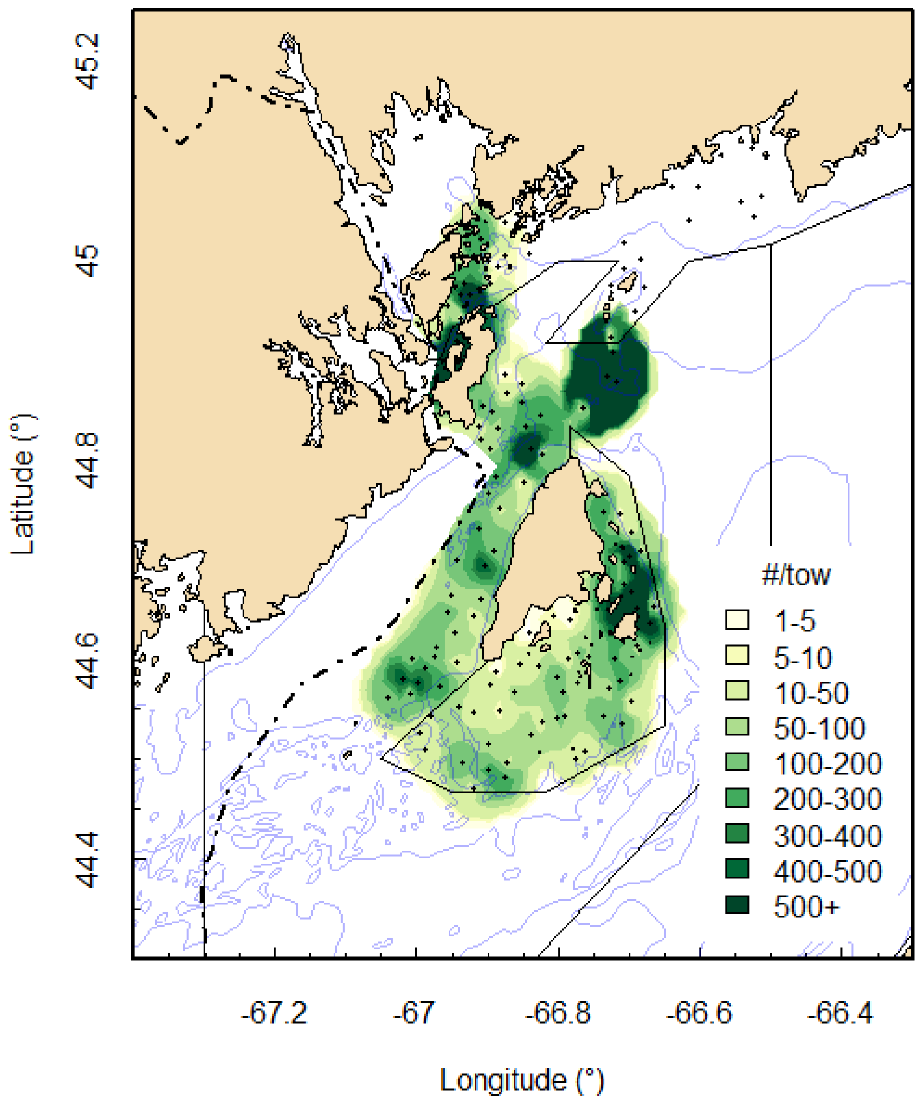

Figure 111. Spatial distribution of abundance (number/tow) of pre recruit size (<65 mm) scallop in Scallop Production Area 6 from the 2013 survey. Survey strata are shown.

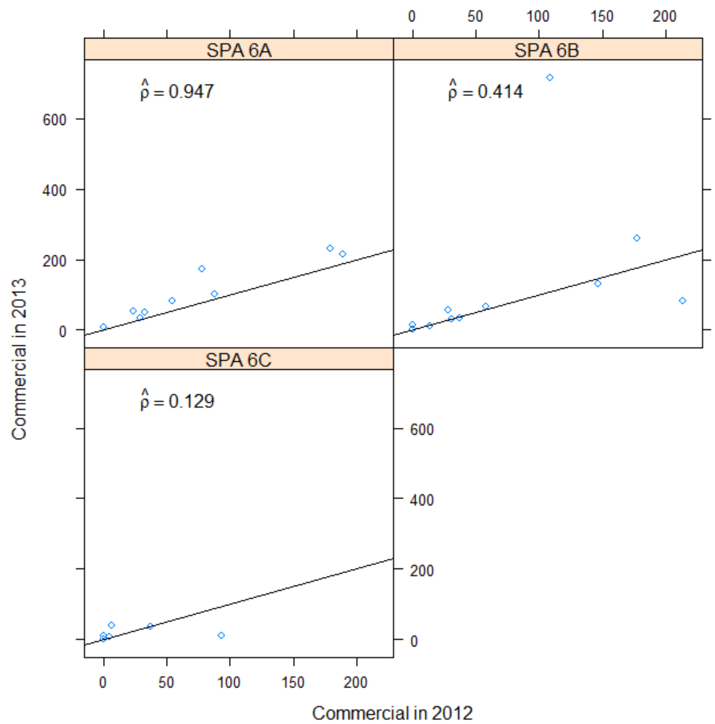

Figure 112. Comparing numbers of commercial (≥80 mm) scallop caught in 2012 and 2013 in the repeated survey stations in Scallop Production Area 6 for 6A (upper left), 6B (upper right) and 6C (lower). 1:1 line indicated.

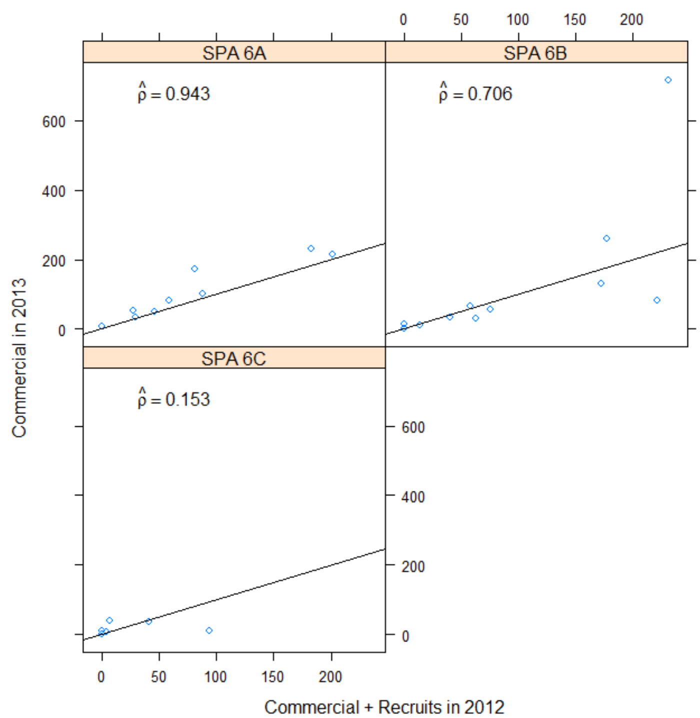

Figure 113. Comparing numbers of commercial and recruit (≥65 mm) scallop caught in 2012 and commercial scallop (≥80 mm) caught in 2013 in the repeated survey stations in Scallop Production Area 6 for 6A (upper left), 6B (upper right) and 6C (lower). 1:1 line indicated.

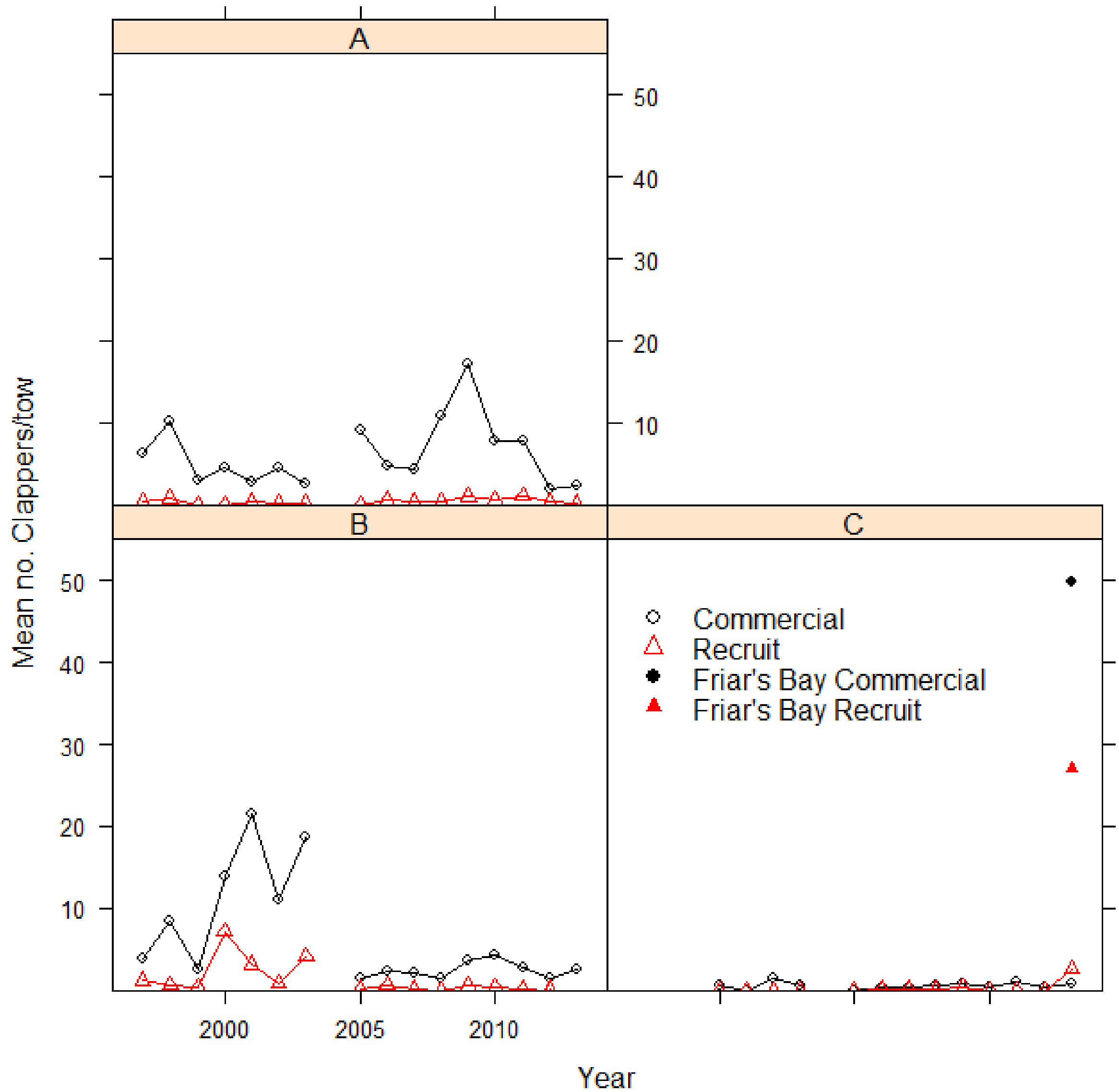

Figure 114. Scallop Production Area 6 trends in survey abundance of clappers (paired, dead shells) for commercial (≥ 80 mm; circles) and recruit (65-79 mm; crosses) size scallops in 6A (upper left) from 1997-2003,2005-2013, 6B (lower right) from 1997-2003, 2005-2013, 6C (lower right) from 2000-2003,2005-2013. Means from experimental tows from Friar's Bay are not part of the regular time series. If they are included in the calculations, they affect the average as shown in 6C for commercial (solid circle) and recruit (solid triangle) clappers.

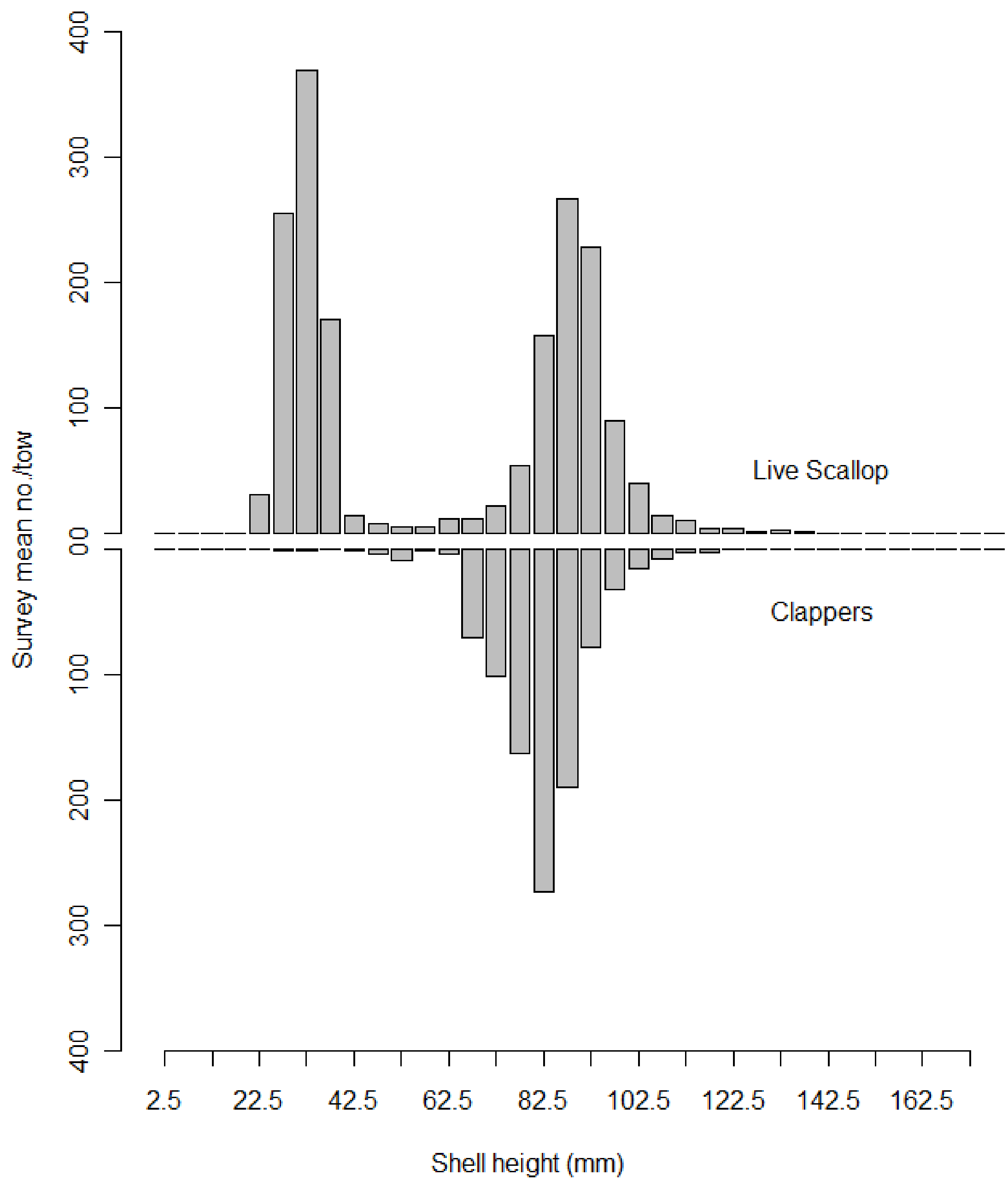

Figure 115. Friar's Bay experimental tows in 6C zone of Scallop Production Area 6 shell height (mm) frequencies (mean number/tow) for live (top panel) and dead (clappers; lower panel) scallops for 2013.

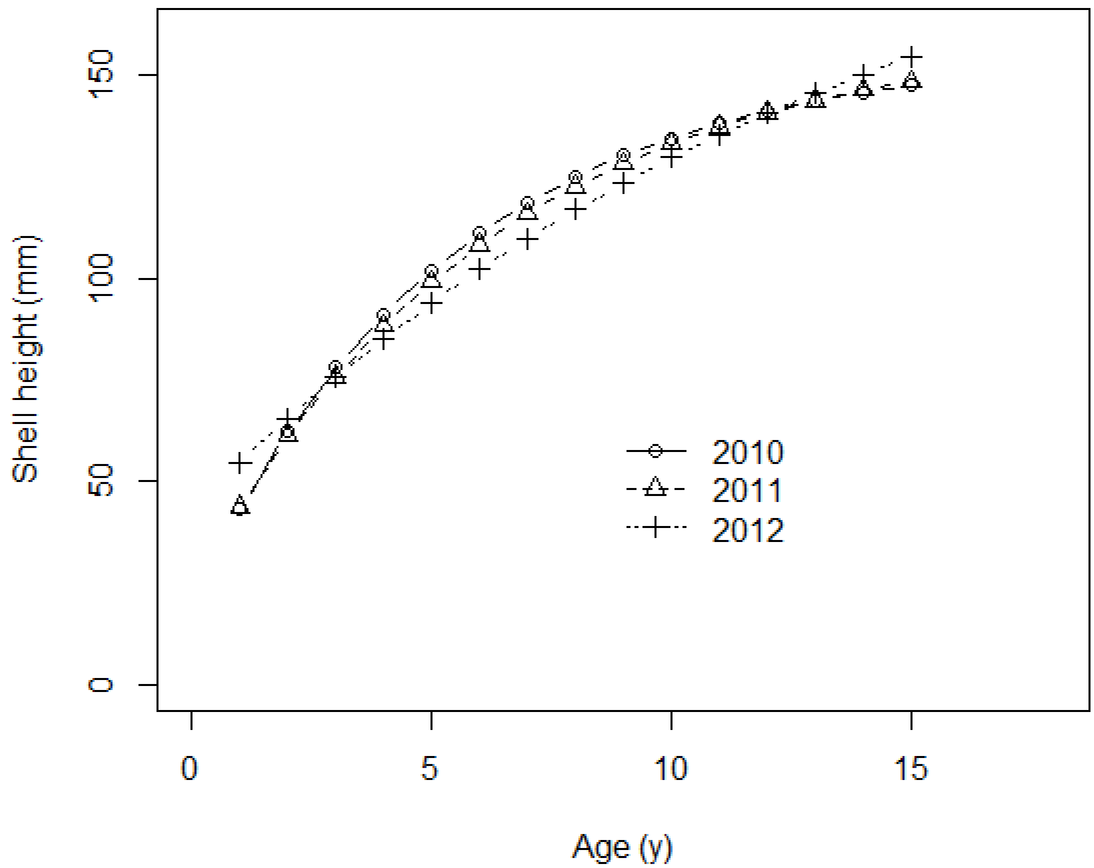

Figure 116. Growth curves fit to shell height (mm) and age (years) survey data for SPA 6C using the von Bertlanffy growth model. Data from 2010 (circles), 2011 (triangles) and 2012 (crosses) used.

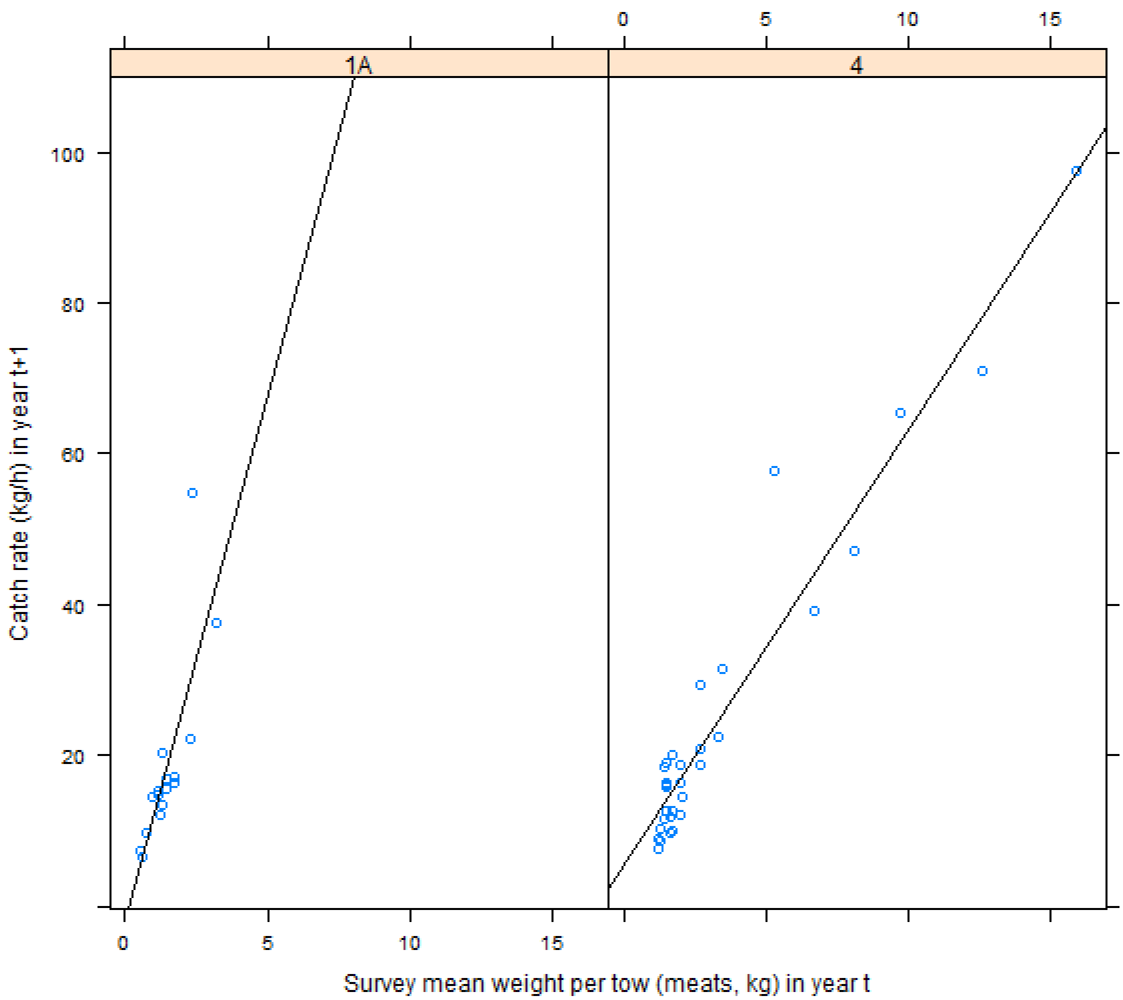

Figure 117. Examples of relationships between commercial catch rate (kg/h) and survey biomass estimates (meats, kg) in Scallop Production Area SPA 1A (left panel) and SPA 4 (right panel). Survey estimates are lined up with catch rate estimates in the following year. Solid lines refer to linear regressions fit to the data.

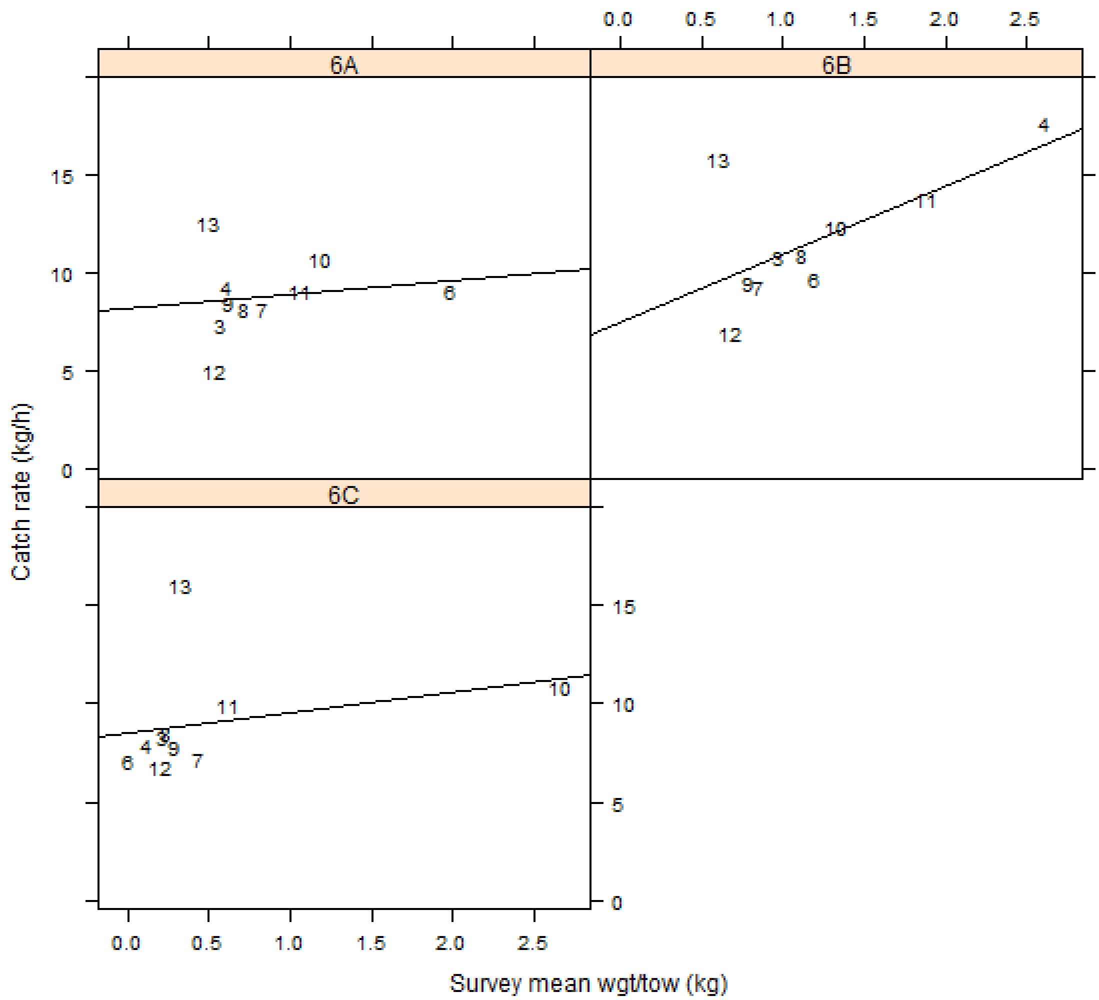

Figure 118. Relationships between survey biomass indices (kg/tow) and commercial catch rate (kg/h) from Scallop Production Areas 6A (upper left), 6B (upper right), and 6C (lower left). Points are labelled by fishing year while surveys have been lagged by one year. For example, the survey estimate for 2012 is lined up with the catch rate estimate for 2013. Solid lines refer to linear regressions fit to the data.

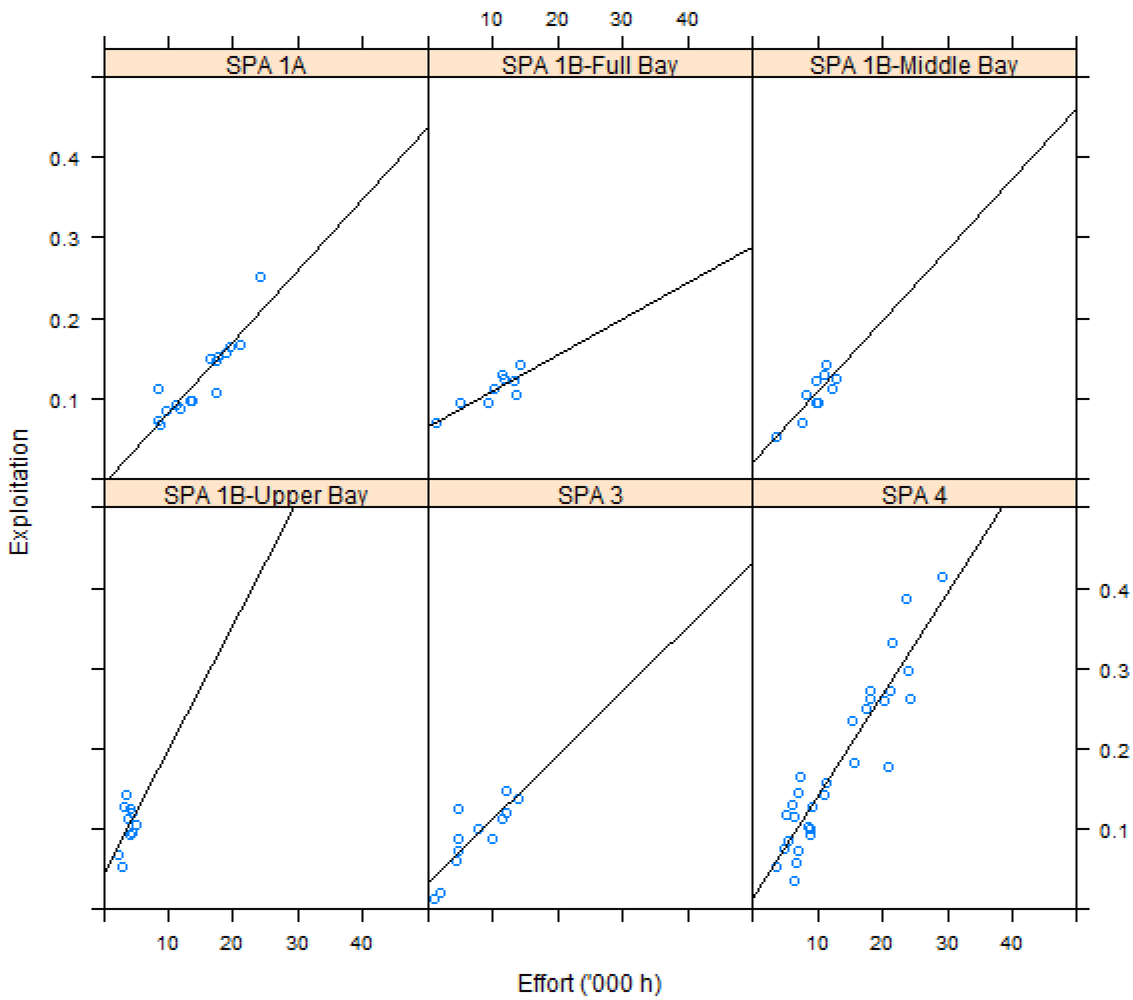

Figure 119. Relationships between exploitation estimated from the assessment models and commercial fishing effort (‘000 h) from logbooks for the Scallop Production Area 1A (upper left), 1B Full Bay fleet (upper middle), 1B Mid Bay fleet (upper right) 1B Upper Bay fleet (lower left), SPA 3 (lower middle) and SPA 4 (lower right). Solid lines represent linear regressions fit to the data.

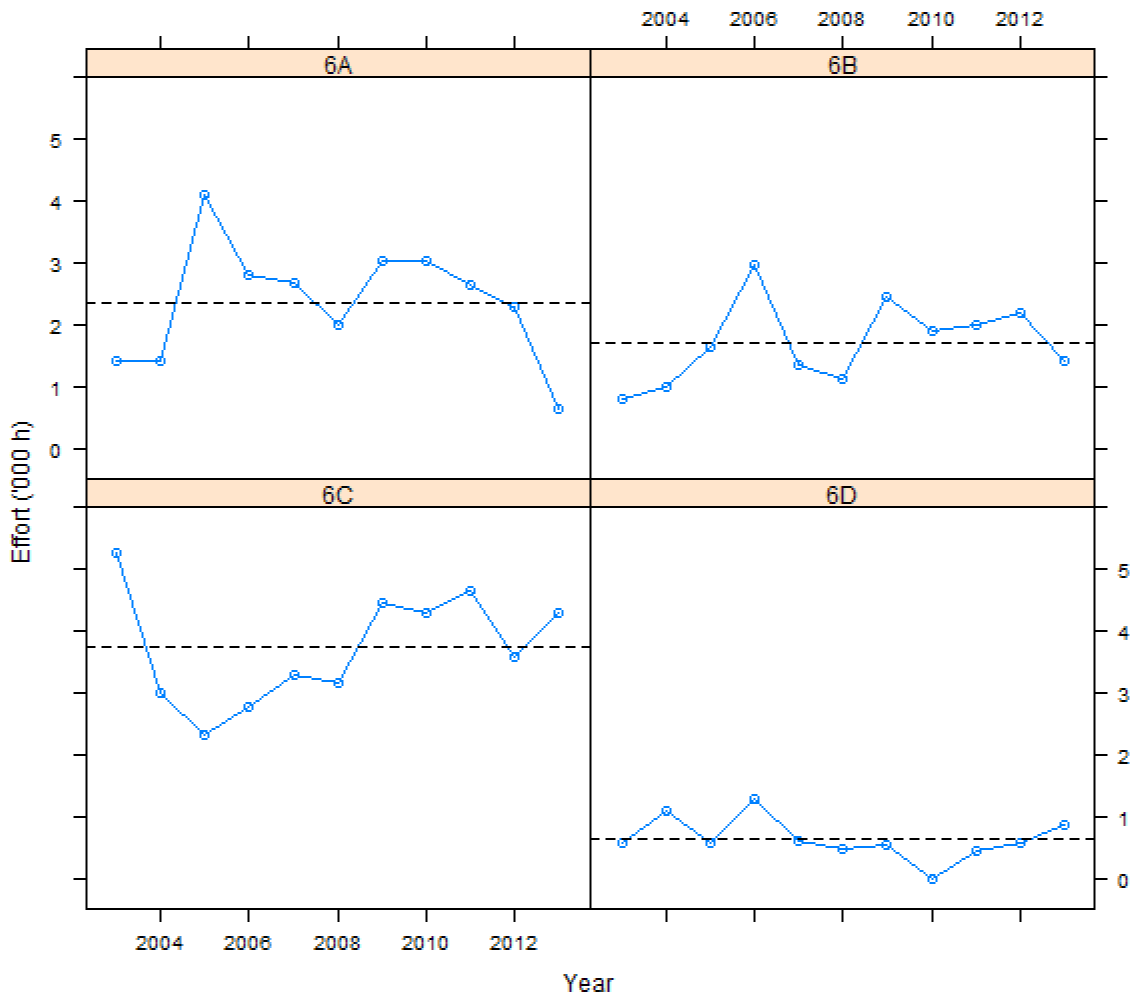

Figure 120. Trends for commercial effort ('000 h) in the four subareas of Scallop Production Area 6: 6A (upper left), 6B (upper right), 6C (lower left) and 6D (lower right) from 2003-2013. Horizontal dashed lines refer to the mean of the time series in each subarea.

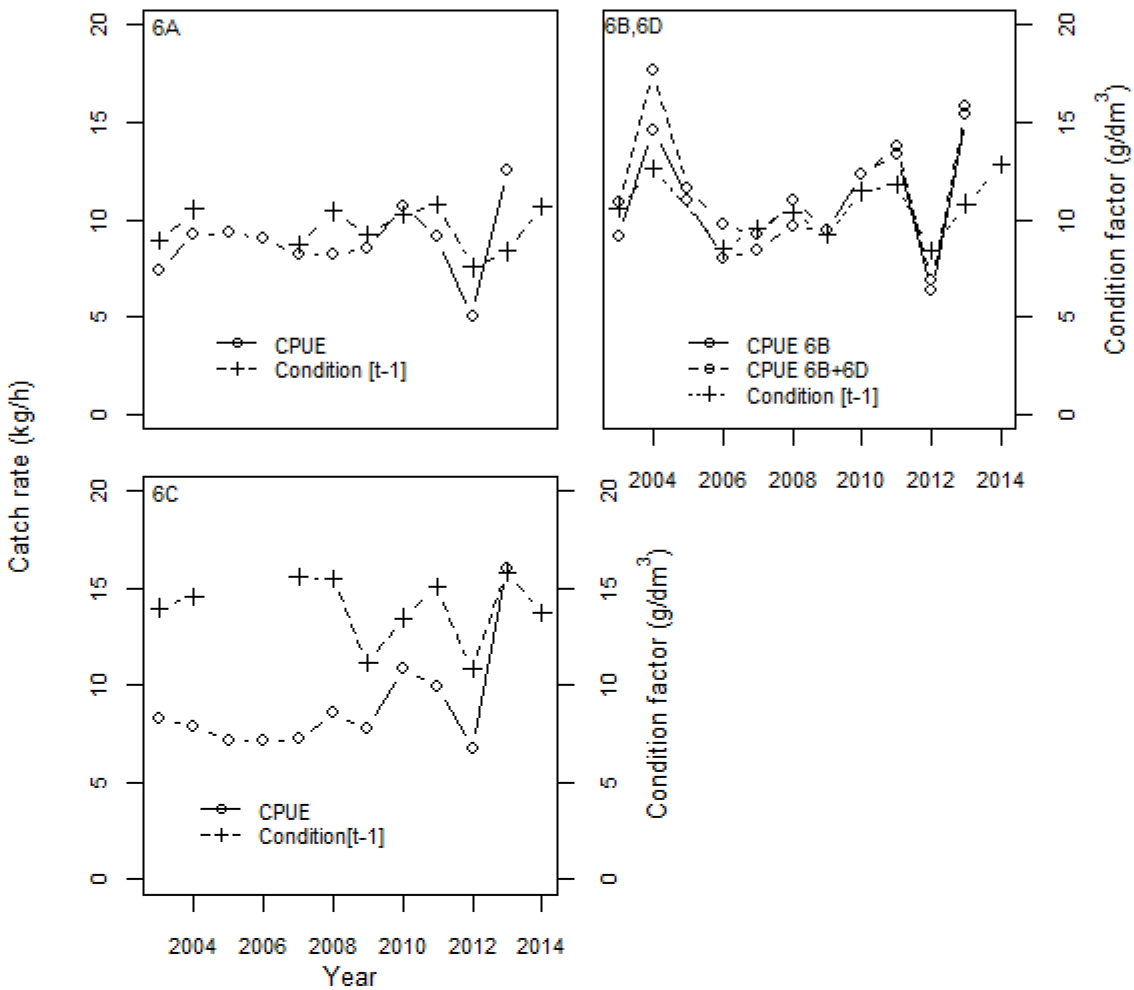

Figure 121. Annual commercial catch rate (kg/h; circles) and condition (g/dm^3; crosses) for Scallop Production Areas (SPAs) 6A (upper left), 6B and 6D (upper right), and 6C (lower left) from 2003-2014. Condition estimates, corresponding to the meat weight of a scallop with a 100 mm shell height, are from the annual scallop surveys in SPA 6 and are offset by one year. For example, the condition from the 2011 survey is lined up with the commercial catch rate in 2012.

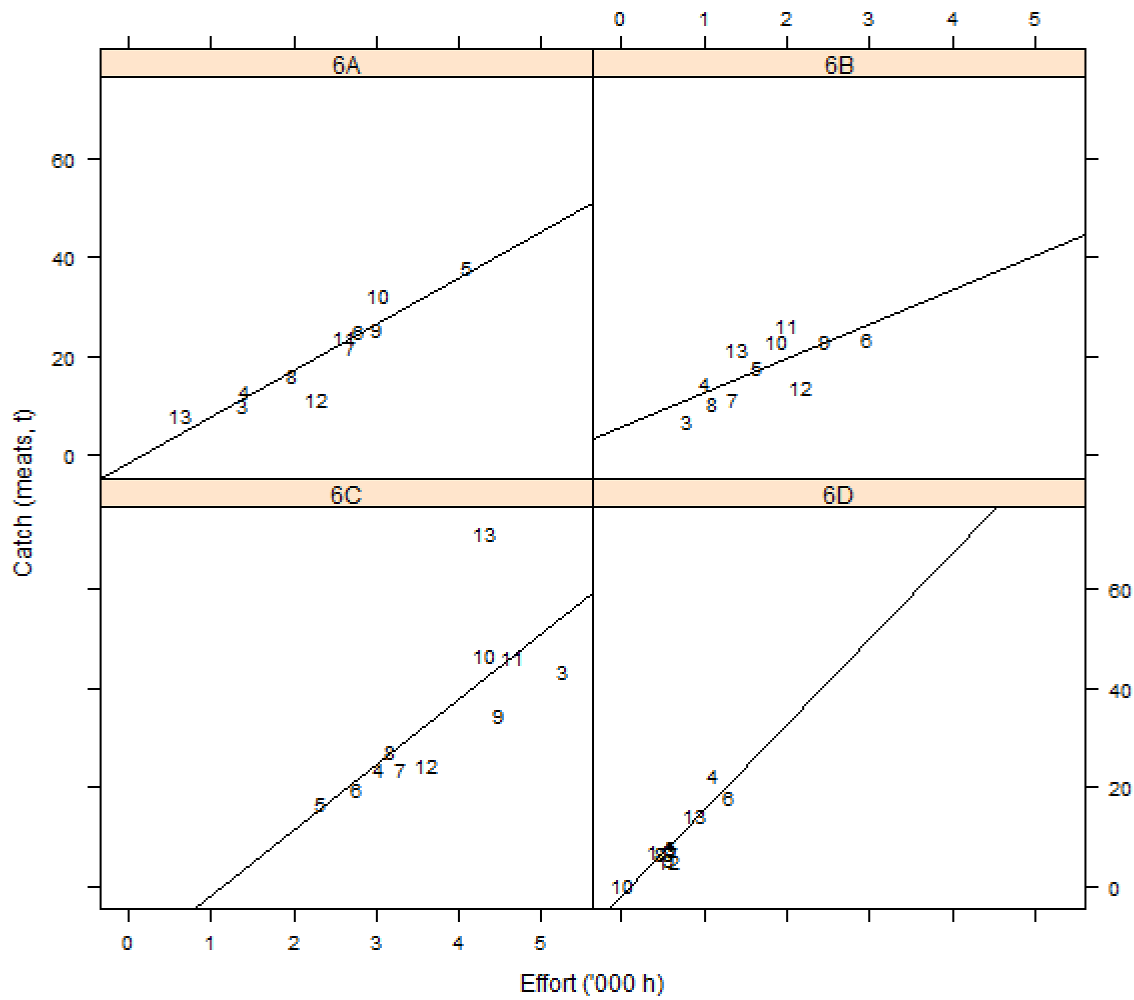

Figure 122. Relationships between commercial catch (meats, t) and effort ('000 h) in the four subareas of Scallop Production Area 6: 6A (upper left), 6B (upper right), 6C (lower left) and 6D (lower right). Solid lines refer to regression models fit to the data.

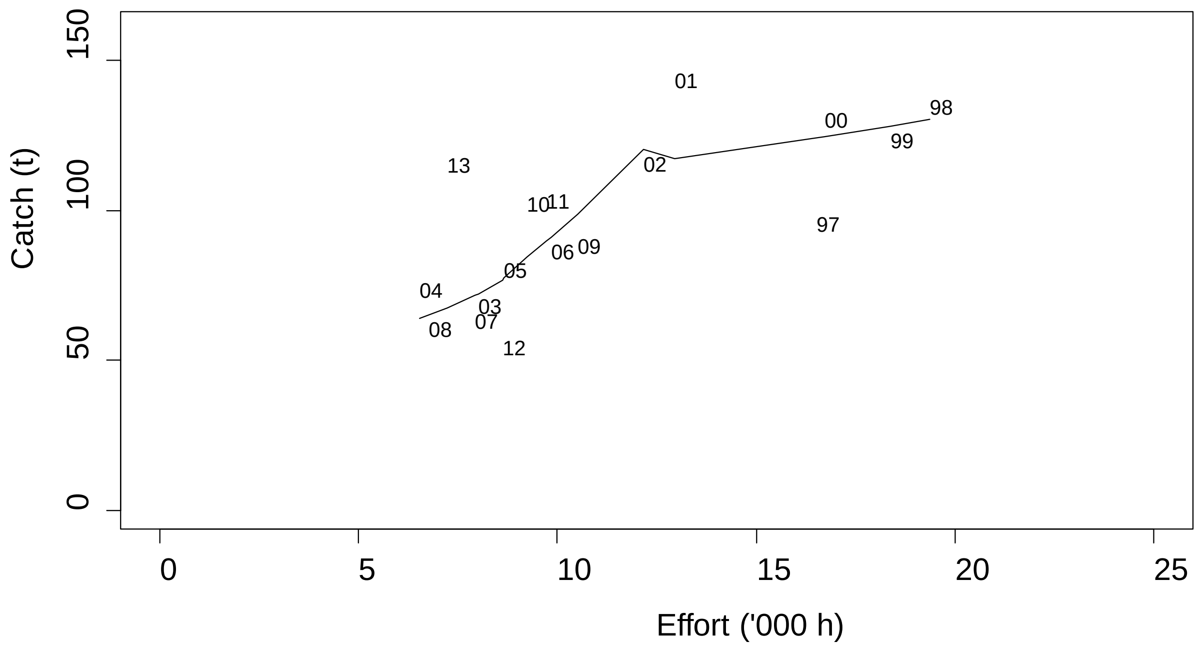

Figure 123. Relationship between commercial catch (meats, t) and effort ('000 h) in Scallop Production Area 6 for all subareas combined. Points are labelled by fishing year. Solid line refers to loess regression fit to the data.

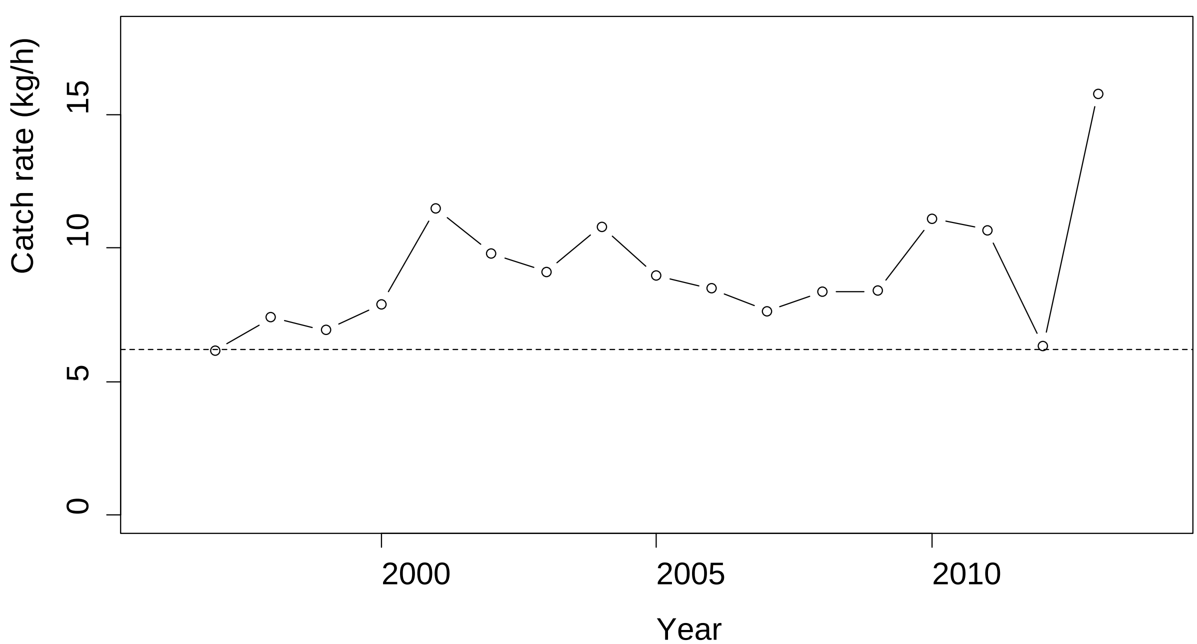

Figure 124. Annual commercial catch rate (kg/h) for Scallop Production Area 6 for all subareas combined. Horizontal dashed line indicates lowest catch rate in series, which is being proposed as a LRP for this fishery.