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Scallop Production Areas in the Bay of Fundy: Stock Status for 2015 and Forecast for 2016

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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 document reviews the status of scallop stocks in Scallop Production Areas (SPAs) 1A, 1B, and 3 to 6 (Bay of Fundy and Approaches) for 2014/2015 with advice for 2015/2016. The Bay of Fundy is fished by three separate scallop fishing fleets: Full Bay, Mid Bay, and Upper Bay.

Models used in this assessment have been reviewed and changes have been documented and reviewed. In 2015, the method of modelling meat weight-shell height (i.e., condition) changed, recruitment estimates for SPAs 1B, 3 and 6 were improved, and SPA 6 was modelled for the first time using the Bay of Fundy stock assessment model.

In SPA 1A, landings were 361.55 t against a Total Allowable Catch (TAC) of 350 t during the 2015 fishing year. Commercial catch rate in this area in 2015 was the highest in over a decade. Survey indices in this area showed an increase in commercial number and weight per tow in most subareas, and a decline in recruit number and weight per tow in all subareas. Population biomass estimated by the model was 3,790 t (meats) in 2015, an increase of 54% from the estimate of 2,462 t in 2014. This stock is currently in the healthy zone.

In SPA 1B, landings were 546.2 t against a TAC of 550 t during the 2015 fishing year. Catch rates for Full Bay in the SPA 1B subareas has been similar over the past few years. Catch rates for Mid Bay were variable among subareas, and Upper Bay fleet catch rates declined. The number and weight of commercial scallops per tow in 2015 increased overall in SPA 1B, although the trend differed among subareas. The number and weight per tow of recruit scallops decreased in most subareas of SPA 1B. Population biomass estimated by the model was 4,350 t (meats) in 2015, an increase of 27% from the estimate of 3,197 t in 2014. This stock is currently in the healthy zone.

In SPA 3, landings were 234.96 t against a TAC of 250 t during the 2015 fishing year. Catch rates in all subareas of SPA 3 have been similar over the past few years. The survey index of number and weight per tow of commercial and recruit scallops decreased in most subareas of SPA 3. Population biomass estimated by the model was 2,620 t (meats) in 2015, a decrease of 7% from the estimate of 2,814 t for 2014. This stock is currently in the healthy zone.

In SPA 4 and 5, landings were 132.35 t against a TAC of 135 t during the 2015 fishing year. The catch rate in SPA 4 has been similar over the past two years. The catch rate in SPA 5 declined in 2015. The survey index of number and weight per tow of commercial scallops increased in SPA 4 in 2015, and the number and weight per tow of recruit scallops decreased. In SPA 5, number and weight per tow of commercial and recruit scallops were above the long term median. Population biomass estimated by the model for SPA 4 was 2,213 t (meats) in 2015, an increase of 70% from the estimate of 1,300 t for 2014. This stock is currently in the healthy zone.

In SPA 6, landings were 231 t against a TAC of 240 t during the 2015 fishing year. Catch rates for Mid Bay decreased in 2015 and increased for Full Bay. Commercial and recruit numbers and weight per tow increased in all subareas of SPA 6. This is the first time the Bay of Fundy assessment model has been used in SPA 6. Population biomass estimated by the model was 1,361 t (meats) in 2015, an increase over the average (2006 to 2012) of 368 t. This stock is currently in the healthy zone.

Zones de production de pétoncles dans la baie de Fundy : État du stock en 2015 et prévisions pour 2016

RÉSUMÉ

Le présent document examine la situation des stocks de pétoncles dans les zones de production de pétoncles (ZPP) 1A, 1B et 3 à 6 (baie de Fundy et ses environs) pour 2014-2015, et fournit des conseils pour 2015-2016. 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.

Les modèles utilisés dans cette évaluation ont été examinés et les changements ont été documentés et examinés. En 2015, la méthode de modélisation du poids de la chair par rapport à la hauteur de la coquille (c.-à-d. l'état) a changé, les estimations de recrutement pour les ZPP 1B, 3 et 6 ont été améliorées et la ZPP 6 a été modélisée pour la première fois à l'aide du modèle d'évaluation du stock de la baie de Fundy.

Dans la ZPP 1A, les débarquements équivalaient à 361,55 tonnes (t), comparativement à un total autorisé des captures (TAC) de 350 t au cours de l'année de pêche de 2015. Le taux de capture commerciale dans cette zone en 2015 était le plus élevé depuis plus d'une décennie. Les indices des relevés effectués dans cette zone ont démontré une augmentation du nombre de captures commerciales et du poids par trait de chalut dans la plupart des sous-secteurs ainsi qu'une diminution du nombre de recrues et du poids par trait de chalut dans tous les sous-secteurs. La biomasse de la population estimée par le modèle était de 3790 t (chairs) en 2015, en augmentation de 54 % par rapport à l'estimation de 2462 t en 2014. Ce stock se situe actuellement dans la zone saine.

Dans la ZPP 1B, les débarquements équivalaient à 546,2 t, comparativement à un TAC de 550 t au cours de l'année de pêche 2015. Les taux de prise pour la flottille de la totalité de la baie dans les sous-secteurs de la ZPP 1B sont semblables à ceux des dernières années. Les taux de prise pour la flottille du milieu de la baie étaient variables parmi les sous-secteurs et les taux de prise de la flottille de la partie supérieure de la baie ont diminué. Le nombre et le poids des pétoncles de taille commerciale par trait en 2015 ont augmenté dans la ZPP 1B, bien que la tendance générale varie d'un sous-secteur à l'autre. Le nombre et le poids par trait des pétoncles de recrues ont diminué dans la plupart des sous-secteurs de la ZPP 1B. La biomasse de la population estimée par le modèle était de 4350 t (chairs) en 2015, en augmentation de 27 % par rapport à l'estimation de 3197 t en 2014. Ce stock se situe actuellement dans la zone saine.

Dans la ZPP 3, les débarquements équivalaient à 234,96 t, comparativement à un TAC de 250 t au cours de l'année de pêche 2015. Les taux de prise dans tous les sous-secteurs de la ZPP 3 ont été semblables au cours des dernières années. L'indice de relevé qui indique le nombre et le poids par trait des pétoncles de taille commerciale et de recrues a diminué dans la plupart des sous-secteurs de la ZPP 3. La biomasse de la population estimée par le modèle était de 2620 t (chairs) en 2015, en diminution de 7 % par rapport à l'estimation de 2814 t en 2014. Ce stock se situe actuellement dans la zone saine.

Dans les ZPP 4 et 5, les débarquements équivalaient à 132,35 t, comparativement à un TAC de 135 t au cours de l'année de pêche 2015. Le taux de prise dans la ZPP 4 a été semblable au cours des deux dernières années. Le taux de prise a diminué dans la ZPP 5 en 2015. L'indice du relevé montrant le nombre et le poids par trait des pétoncles de taille commerciale a augmenté dans la ZPP 4 en 2015, et le nombre et le poids par trait des pétoncles de recrues ont diminué. Dans la ZPP 5, le nombre et le poids par trait des pétoncles de taille commerciale et de recrues étaient supérieurs à la médiane à long terme. La biomasse de la population estimée par le modèle visant la ZPP 4 était de 2213 t (chairs) en 2015, en augmentation de

70 % par rapport à l’estimation de 1 300 t en 2014. Ce stock se situe actuellement dans la zone saine.

Dans la ZPP 6, les débarquements équivalaient à 231 t, comparativement à un TAC de 240 t au cours de l’année de pêche 2015. Les taux de prise pour la flottille du milieu de la baie ont diminué en 2015 et ont augmenté pour la flottille de la totalité de la baie. Le nombre et le poids par trait de pétoncles de taille commerciale et de recrues ont augmenté dans tous les sous-secteurs de la ZPP 6. C'est la première fois que le modèle d'évaluation de la baie de Fundy a été utilisé dans la ZPP 6. La biomasse de la population estimée par le modèle était de 1361 t (chairs) en 2015, en augmentation par rapport à la moyenne (2006 à 2012) de 368 t. Ce stock se situe actuellement dans la zone saine.

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, Nova Scotia. Mid Bay license holders can only fish for scallops on the northern side of the Mid Bay line (Figure 1), and traditionally the fleet has consisted 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 multi-species vessels based in either Nova Scotia or New Brunswick. 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 30 September season.

Details on the Scallop Production Areas (SPAs), fleet access, 2014/2015 fishing year Total Allowable Catch (TAC), landings, and years for which data is available for both the survey (strata shown in Figures 1 and 2) and commercial catch-per-unit-effort (CPUE) are given in Table 1.

Scallop removals accounted for in the assessment include landings from all three inshore scallop fleets and Food, Social and Ceremonial (FSC) catch by scallop drag, when applicable. Landed recreational and FSC catch by dip netting, diving, tongs, and hand are not available and not accounted for in the assessment. There was no FSC catch by scallop drag in the Bay of Fundy in the 2014/2015 fishing year.

The last formal assessment of the stock status and scientific advice on catch levels for the Bay of Fundy and Approaches was in 2013 (Nasmith et al. 2014), and stock information was updated in 2014 (DFO 2015).

ASSESSMENT METHODS

COMMERCIAL DATA

Commercial data in the form of catch, effort, and location are an important component of the assessment of scallop stocks in the Maritimes Region. These data are verified annually by Fisheries and Oceans Canada (DFO) Science Scallop Unit staff to ensure accuracy. In the 2013 assessment (Nasmith et al. 2014), a problem with the allocation of catch to its corresponding SPA was identified, especially as it pertained to catch in SPA 6. In 2014, the Scallop Unit, in coordination with the scallop Resource Manager, conducted a review of the Bay of Fundy SPA boundary definitions, as there were different versions in use by different groups within DFO. A definitive set of SPA boundaries for the Bay of Fundy and Approaches was created and distributed to, and implemented by, DFO Science, Resource Management, Commercial Data Division, Conservation and Protection, and the inshore scallop fleets. These boundaries came into effect 1 October 2014. This has improved issues with the allocation of catch to the numerous SPAs.

SURVEY

The Bay of Fundy is surveyed annually. Three survey designs are used for the purposes of assessment: simple random, stratified random, and sampling with partial replacement (SPR). For simple random, survey tows are distributed randomly within a survey area. For stratified random, survey tows are distributed proportionally to a number of strata and the tow placement within each stratum is random. The tows are then combined proportionally by strata area to obtain a single index value. For SPR, a subset of tows in a given year is a repeat of tows in the previous year. This differs from a fixed station design in that the subset of tows repeated changes from year-to-year. The 2015 survey in the Bay of Fundy and Approaches took place over 34 days between June 3 and August 19, 2015. A total of 593 tows were conducted. Survey protocol is that every live scallop and clapper (dead scallop with paired shell) are counted and binned into 5-mm shell height bins (e.g., 20-25 mm, 25-30 mm, etc). These data are used to estimate abundance and shell height frequencies. Detailed biological sampling is done on approximately every other tow or at the discretion of the lead DFO scientist aboard. A biological sample consists of three scallops per 5-mm size increment (>50 mm). Each scallop from the sample is shucked, the meat is weighed to the tenth of a gram, and the shell height is measured. Individual shells are also aged, although the current year's aging data was not available in time for the assessment.

In this report, scallops with a shell height of 80 mm and greater will be referred to as commercial size, and scallops with a shell height of 65 to 79 mm will be referred to as recruits, and are expected to grow to commercial size in the following year. Scallops less than 65 mm are defined as prerecruits. The size limit of the survey gear is approximately 40 mm (38 mm mesh liner), and counts of scallops smaller than this are considered to be qualitative.

GROWTH AND CONDITION

In the Bay of Fundy, detailed shell height and meat weight data has been regularly collected from the annual surveys since 1996. These data determine the meat weight-shell height relationships that are used to estimate biomass from numbers caught in the survey. The 2015 Bay of Fundy assessment used a new model for this relationship, following methods used in the 2015 Scallop Fishing Area 29W assessment (Sameoto et al. 2015). The progression of meat weight-shell height modelling methods over time in the Maritime Region scallop assessments was detailed in Sameoto et al. (2015).

As described in Sameoto et al. (2015), prior to 2012, the annual growth term for population biomass used in the assessment model assumed a temporally-constant relationship between meat weight and shell height (Smith and Lundy 2002). However, in many areas, there can be a large amount of inter-annual variability in the relationship between meat weight and shell height, which complicated the fit of the model (Smith et al. 2012). An alternative approach that used annual observed growth rates for biomass was adopted for the Bay of Fundy assessment in 2012 (Smith et al. 2012). This method calculated scallop condition as the ratio of meat weight over the cube of shell height assuming an isometric length weight relationship. This ratio was referred to as the condition factor (CF) (Eqn. 1; Smith et al. 2012).

$$CF = \frac{W}{L^3} \tag{1}$$

A linear mixed effects model was used to fit meat weight (w) and shell height (h) data collected for each scallop (i) in a given sample and the random effects estimated for the condition factor of each sample location (l) (i.e., using tow as the grouping variable). This resulted in a linear model of form (Eqn. 2):

$$w_{il} = (A - a_l){h_{il}}^3 + \varepsilon_{il} \tag{2}$$

The resulting fits of this model produce a fixed effect (A) or the overall condition factor and a random effect (a_l) or the sample specific condition factor, and error (ε_{il}). A generalized additive model was then used to predict the condition factor for those tows that were not sampled. Biomass was then estimated over all tows (Smith et al. 2012).

To estimate annual varying growth rates for the model, the average shell heights of commercial or recruit sized scallops were converted to a meat weight using the annual condition factor (Eqn. 3):

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

A von Bertalanffy growth equation (VB) was fit to the available age data as a nonlinear mixed effect model with random effects assigned for each sample location (i.e., using tow as the grouping variable) where L_∞, K, and t_0 are the fixed effects model parameters and l_∞ , $k_{l,}$ and t are the random effects for each sample location (l) (Eqn. 4).

$$L_t = \left(L_\infty - l_{\infty,l}\right)\left(1 - e^{(K-k_t)(t-t_0)}\right) \quad (4)$$

The fixed parameters from the VB were then used to determine the average height of the commercial or recruit sized scallops a year later ($\overline{h}_t$) (Eqn. 5):

$$\overline{h}_t = L_\infty\left(1 - e^{-K}\right) + e^{-K}\overline{h}_{t-1} \quad (5)$$

The average meat weight for the following year was then calculated as (Eqn. 6):

$$\overline{w}_t = CF_t\overline{h}_t^{3} \quad (6)$$

And the annual observed growth rate (g_t) was simply the ratio between the observed average meat weight of commercial or recruit sized scallops and the observed average meat weight of commercial or recruit sized scallops the following year (Eqn. 7):

$$g_{t-1} = \frac{\overline{w}_t}{\overline{w}_{t-1}} \quad (7)$$

The previous model (Smith et al. 2012, Nasmith et al. 2014, Sameoto et al. 2014, Smith et al. 2015) assumed that scallop condition was the ratio of meat weight over the cube of shell height. A detailed review of meat weight-to-shell height relationship data in SPA 6 has shown that the slope can vary significantly from 3 (unpublished data). Moreover, the prior model specification assumed an additive error structure. Examination of the variance of meat weight as a function of shell height in SPA 6 indicated a multiplicative error structure; therefore, condition for this assessment was calculated using a generalized linear mixed model (GLMM) using a Gamma family with a log link and tow as the grouping variable (Eqn. 8), and depth as a covariate. For further details see Smith and Sameoto (Unpublished Manuscript[1]).

$$\mathrm{E}\left(\mathrm{W_{ij}}\right) = \exp((\mathrm{B_{0t}} - \mathrm{b_{0i}}) + (\mathrm{B_{1t}} - \mathrm{b_{1i}})\log\left(\mathrm{H_{ij}}\right)) \quad (8)$$

The GLMM was fit to data separated into three areas: SPA 3 (1996 to present), Bay of Fundy (SPA 1A, 1B, and 4; 1997 to present), and SPA 6 (1997 to present) for each year. The weight at size was then multiplied by the numbers at size to get an estimate of biomass by scallop size bin for each tow. From the GLMM within each year, meat weight for tows that were not sampled were predicted using fixed effects, whereas fixed and random effects were used to predict the meat weight for those tows which were sampled.

The condition of a 100 mm shell height scallop was then estimated for each year using each year's parameter estimates and the average depth of each survey stratum (e.g. the depth of just Cape Spencer stratum to estimate Cape Spencer condition). The results are presented as the condition index. This new index is not directly comparable to the condition factor time series published in past documents (e.g., Nasmith et al. 2014). Although both represent the weight of a

[1] Smith, S.J., and Sameoto, J.A. (2016). Incorporating Habitat Suitability into Productivity Estimates for Sea Scallops in Scallop Fishing Area 29W. DFO Can. Sci. Advis. Sec. Unpublished Manuscript.

100 mm shell, the new method does not produce a factor; that is, it cannot be multiplied by a shell height to get the weight at that size as with the old method. Caution should be taken when comparing this aspect of the assessment to past documents.

To estimate annual growth rates for the model (g_t), the average shell height of commercial or recruit sized scallops was converted to a meat weight using the GLMM parameter estimates for each year and the VB growth equation was used to determine the average height of the commercial or recruit sized scallops a year later (Eqns. 4 and 5). The VB models were conducted on the same data sets as the meat weight-shell height modelling. The Bay of Fundy model used data from 1996 to 2014, the SPA 3 model had data from 1996, 1997, and 2005 to 2014, and the SPA 6 model had data from 2005 to 2014 (Figure 3). The SPA3 VB model differed slightly from the Bay of Fundy model in that only L_∞ and $\log K$ were modelled as random effects and not t as the full model did not converge. Although all the Bay of Fundy was modelled together for meat weight-shell height and VB parameters, the calculations for predicted meat weight and shell height growth rate used area-specific information. For example, the growth rate calculation in SPA 1A used the expected mean shell height for only SPA 1A, and predicted on that shell height data and mean area depth for SPA 1A. For SPA 3 and SPA 6, model parameters (e.g., growth rate) were calculated using data from only the areas used in the model. That is, data from the Outside Vessel Monitoring System (VMS) strata were not used to calculate growth rate.

RECRUITMENT

The sampling with partial replacement design in SPAs 1B, 3, and 6, uses repeated tows to correlate scallop abundances in the previous year with scallop abundances in the current year. In the case of commercial animals, commercial and recruit animals in year t are correlated with commercial animals in year $t+1$. In previous years, this method had not been used to estimate recruit numbers and weights, instead a simple mean from random tows in these areas was used. Using the VB relationship described above (Eqn. 4), prerecruit sizes were put into the model to determine what size they would grow to in the following year. For the three areas that use the partial replacement design, the size range of 50 to <65 mm grew into recruit size animals in one year (Table 2). Using this information, the recruit index series were recalculated using the sampling with partial replacement method, correlating prerecruits of 50 to <65 mm in year t to recruit animals in year $t+1$. This improved the recruit estimates for these subareas and decreased the variance around the estimates.

POPULATION MODEL

This assessment models the population dynamics for all SPAs (excluding 5) using a simplified version of the assessment model (Quinn and Deriso 1999) with modifications presented in Smith et al. (2012) and Smith and Hubley (2013),

$$B_{t+1} = \left(e^{-m_t} g_t \left(B_t - C_t\right) + e^{-m_t} g_{Rt} R_t\right)\tau_t \tag{9}$$

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 $t+1$. Ct 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).

Starting in 2015, the model was run using an R program created by Stephen Smith (in 2015) called SSModel (v. 1.0-3), which runs the model in WinBugs using R. In working to create this program, some changes were made to the prior distributions assigned to the proportionality constants K, S, and variance term kappa tau. In recent years, the prior for K (population scaling factor) was a normal distribution of logK:

$$logK \sim dnorm(8.21034, 3.418) \quad (10)$$

in the current assessment, K is used instead of logK, with a log normal distribution:

$$K \sim dlnorm(8.006, 0.6339) \quad (11)$$

In recent years, the prior for S (clapper dissolution rate) used a beta distribution:

$$S \sim dbeta(8,11) \quad (12)$$

and in the current assessment it is a uniform distribution:

$$S \sim dunif(0.1,0.99). \quad (13)$$

The variance term kappa tau (variance of the clapper estimate), used a gamma distribution in recent years:

$$kappa\ tau \sim dgamma(3, 0.44629) \quad (14)$$

and now uses a uniform distribution:

$$kappa\ tau \sim dunif(0, 2). \quad (15)$$

PRECAUTIONARY APPROACH

In 2012, biomass reference points in terms of a Lower Reference Point (LRP) were proposed and adopted through an Inshore Scallop Advisory Committee (ISAC) working group process for SPAs 1A, 1B, 3, and 4 (excluding 5). In 2013, Upper Stock References (USR) were proposed for SPAs 1A, 1B, 3, and 4 (excluding 5; Nasmith et al. 2014), and these were accepted at an ISAC meeting in December 2013. In SPA 6, there was no model established to estimate biomass, and in 2014 an LRP was proposed based on the catch rate time series (Nasmith et al. 2014). An USR based on the same catch rate time series was later adopted through an ISAC working group process in December 2014. At the time reference points were established it was the intention of DFO Science that they would be reviewed and revised as necessary. Where there have been changes to the meat-weight shell height model, slight changes to the model processes in terms of priors, and changes to recruitment biomass estimates, the perception of the Bay of Fundy stocks has changed slightly and reference points will need to be revaluated for all the SPAs. However, given the work to improve the model, and in the case of SPA 6, fit the model for the first time, there was no time to conduct a reassessment of reference points for the current assessment. Advice is therefore presented here with respect to the established reference points, and although some changes are expected, the current reference points as they stand are still reflective of the overall productivity and status of these stocks.

SCALLOP PRODUCTION AREA 1A

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 361.55 t against a TAC of 350 t during the 2015 fishing year in SPA 1A (Table 3). Annual trends for landings and TAC are presented in Figure 4.

In the 2015 fishing year, there were 53 vessels, and almost 100% of the 1,392 fishing log records were usable after review by DFO Science (Table 4). Commercial catch rate in this area has been increasing since 2012; the catch rate in 2015 of 25.9 kg/h was the highest in over a decade (Figure 5). Effort has been increasing since 2013, and in 2015 was near the long-term median (1997/1998 to 2013/2014) of 14,700 h (Figure 5). The increase in catch rates can be seen in the spatial plots of CPUE (Figure 6). Relative to the previous fishing year, there was more fishing in the 8 to 16 mile zone, especially in the southernmost strata 12, 13 and 19 (see Figure 2 for strata locations). Fishing in Middle Bay South was more concentrated in 2015, and there was less fishing in the “inside” portion of SPA 1A, near the shore (SPA 1A 0 to 2 miles in Figure 2). There was more fishing in the near shore area to the south of the survey strata, along Digby Neck, Nova Scotia, in 2015.

SURVEY

SPA 1A is subdivided into three subareas for the purposes of assessment (Figure 2): the 2 to 8 mile zone (strata 6 and 7), the 8 to 16 mile zone (strata 12 to 20), and Middle Bay South. In 2015, 11 tows were conducted in the 2 to 8 mile zone, 70 in the 8 to 16 mile zone, and 42 in Middle Bay South. Stations were allocated randomly within each subarea, with commercial variance from the previous year’s survey data used to determine the number of stations within the individual stratum of the 8 to 6 mile zones. The survey indices for the 2 to 8 and 8 to 16 mile zones are based on stratified means, and the index for Middle Bay South is a simple mean.

Most of SPA 1A has benefitted from recruitment in 2015. The number per tow of commercial scallop in the survey increased in both 2 to 8 and 8 to 16 mile subareas, with a large increase over 2014 in the 8 to 16 mile zone (Figure 7). In Middle Bay South there was a decrease in the number per tow in 2015, but this subarea did not see the increased number of recruits in 2014 as in other parts of SPA 1A. The recruitment happening in the 8 to 16 mile can be seen clearly in the shell height frequency plots for this sub area (Figure 8), with a similar event happening, with lesser magnitude, in the 2 to 8 mile subarea (Figure 9). In Middle Bay South, the shell height frequency shows lower abundances and generally poor recruitment (Figure 10). The average size of commercial scallops in SPA 1A has been increasing steadily since the last large recruitment event in 2000 (Figure 11); however, in 2015, the mean size of commercial animals in the 8 to 16 mile subarea decreased as a result of the recent recruitment. The spatial distribution of high densities of commercial scallop is similar to that in 2014 (Figure 12). Densities are highest in the 8 to 16 mile, especially along the border with SPA 1B, and densities are lowest and patchy in Middle Bay South.

The number per tow of recruit size scallops in 2015 is less than in 2014 for all subareas of SPA 1A (Figure 7). In 2 to 8 mile and Middle Bay South, the recruit number per tow in 2015 (1.2/tow and 0.7/tow, respectively) is the lowest in these subareas since the early-1990s. Although abundance of recruit scallops is less than in 2015, the distribution in the 8 to 16 mile zone is similar to 2014, with recruits found throughout most of the subarea (Figure 13). In 2015, prerecruits were seen in the same areas as in 2014, but were not as widespread in the 2 to 8 mile zone (Figure 14).

The condition in this area, presented as predicted weight in grams for a 100 m shell height at mean subarea depth (92.4 m for 8 to 16 mile, 67.8 m for 2 to 8 mile, and 59.1 m for Middle Bay South), increased in all subareas (Figure 15). This increase can be seen throughout all of 2 to 8 mile and Middle Bay South, and the northern half of 8 to 16 mile (Figure 16).

Weight per tow of commercial scallop increased along with abundance in the 2 to 8 and 8 to 16 mile subarea (Figure 17). In both 2 to 8 mile and 8 to 16 mile, the weight per tow in 2015 (3.4 kg and 5.75 kg/tow, respectively) was the highest in the time series. In Middle Bay South, weight per tow tends to be lower than other parts of SPA 1A, and in 2015 it was 1.5 kg/tow, a slight decrease from 2014. The increase in biomass occurred in all the strata in 2 to 8 and 8 to 16 mile, and was patchy in Middle Bay South (Figure 18).

Weight per tow of recruits in 2015 was less than in 2014 for all subareas of SPA 1A (Figure 17). In 2 to 8, weight per tow of recruits in 2015 was the lowest in the time series (0.007 kg/tow), and in Middle Bay South it was 0.003 kg/tow; among the lowest in the time series for this subarea. Recruit biomass is relatively better in the 8 to 16 mile zone, and even though weight per tow of recruits decreased by almost half (from 0.31 kg/tow in 2014 to 0.17 kg/tow in 2015), current levels are still high for this subarea. The recruit biomass is distributed throughout the 8 to 16 mile strata, with the highest biomass densities near the border with SPA 1B; in contrast, recruit biomass in 2 to 8 mile and Middle Bay South is highly localized (Figure 19).

Meat counts (scallops per 500g) decreased in SPA 1A as condition increased (Figure 20); the highest count (40-45 meats/500g) was found inshore in Middle Bay South, but generally counts in SPA 1A were 30-35 or lower. While meat counts are a management measure used in this fishery, the meat count values presented in this document are based on survey information and are meant to be illustrative.

Number of clappers (paired, dead shells) per tow in SPA 1A is generally low for 2 to 8 mile and Middle Bay South, with more clappers in 8 to 16 mile (Figure 21).

POPULATION MODEL

For SPA 1A, the stock assessment model was fit to the survey and catch data from 1997 to 2015. 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 600,000 samples long with the first 300,000 discarded for burn-in. Retained samples were thinned by 30 to give 20,000 samples from which to estimate the posterior distribution. Model diagnostics indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 22). The model fits the survey mean estimates well in this area in general; the uncertainty around the survey estimates is reduced due to the inclusion of the sample variances from the survey time series (Figure 23), although there is increased uncertainty around the large recruitment event in 2001.

STOCK STATUS AND FORECAST

Estimates of survival (i.e, exp(–*m*), *m* being instantaneous natural mortality from Eqn. 9), began decreasing slightly from 2009 to 2013, but has since been increasing, to 0.93 in 2015 (Figure 24). Exploitation (calculated in the model as $Catch_t$ / ($Biomass_{t+1}$ + $Catch_t$)) from 2013 to 2015 has ranged from 0.091 to 0.105, a decrease from the recent high of 0.19 in 2010 (Figure 24). Population biomass estimated by the model was 3,790 t (meats) in 2015, an increase of 54% from the estimate of 2,462 t for 2014 (Figure 25). This large biomass increase was preceeded by large, relative to the recent series, recruit biomass in 2014 of 233 t (Figure 25). In 2015, the recuit biomass estimate decreased to 83.6 t, which is high relative to recent years in this area, but below the long-term (1997 to 2014) mean of 176.5 t.

Harvest scenarios for 2015/2016, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 in the following year (2016/2017), are presented in Table 5. For example, Table 5 is interpreted as follows: a catch of 180 t corresponds to an exploitation 0.05, and is projected to result in a 0.9% decrease in biomass, the probability of biomass increase is neutral (46%), the probability that a catch of 180 t will result in the population remaining above the LRP is >99%, and the probability of the population remaining above the USR is >99%. In the following fishing year (2016/2017), a catch of 333 t would have a probability of 10% of exceeding a reference exploitation 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 (e.g., 2010) to year $t+1$ (e.g., 2011) with the estimates of biomass from fitting the model to data up to year $t+1$ (Figure 26, upper panel). For three of the six years evaluated (2010 to 2012), the median of the posteriors fell within the 50% credible interval of the projection, and 2014 was very close. In 2013 and 2015, the median of the posterior fell in the upper credible limits. At the time the projections are made, conditions in the following year are unknown. When projecting forward, the meat weight-shell height relationship (i.e., growth) in the current year is used, and mortality is estimated from the mean of the previous three years. If growth had been known at the time, the projections for 2013 and 2015 would have been improved relative to the actual estimate for those years (Figure 26, lower panel). From 2012 to 2013 a decline in biomass was predicted, but the growth rate of commercial scallops was 16% greater than predicted. From 2014 to 2015, the model projected an increase, but it was underestimated in part due to a 20% difference in predicted versus actual growth of recruit size scallops.

SCALLOP PRODUCTION AREA 1B

COMMERCIAL FISHERY

Scallop Production Area 1B is fished by three separate fleets each with a share of the TAC (Figure 27). The Full Bay fleet caught a total of 303.96 t against a quota of 301.8 t in the 2015 fishing year (Table 6). The Mid Bay fleet caught 164.02 t against a quota of 175.6 t, and Upper Bay caught 78.2 t against a quota of 72.7 t (Table 7). In 2007/2008, a TAC sharing formula for the three fleets in SPA 1B was implemented that allocated shares by three subareas: Scallop Fishing Area (SFA) 28B, SFA 28C, and SFA 28D.

In the 2015 fishing year in SPA 1B, there were 140 vessels and 99% of the 2,509 fishing log records were usable after review by DFO Science (Table 4). Catch rates varied among fleets and subareas in SPA 1B (Figure 28). In 28B, catch rates for the Full Bay fleet have been similar over the last three years, approximately 26 kg/h, while Mid Bay fleet catch rates declined in 2015 to 21 kg/h from a time series (since 2002) high of 27.96 kg/h in 2014. In 28C, Mid Bay catch rates have been increasing since 2012, and in 2015 were 27.4 kg/h, among a high in the time series for this subarea. Catch rates for the Upper Bay fleet in 28C decreased from 20.5 kg/h in 2014 to 17.9 kg/h in 2015. In 28D, the Upper Bay fleet catch rate decreased, from 19.8 kg/h in 2015 to 17.0 kg/h in 2015. The Full Bay fleet fished in both 28C and 28D in the 2015 fishing year, but there were not enough records to present these data consistent with *Privacy Act* considerations. The fleets in SPA 1B tend to cover the same areas from year-to-year, especially in 28B and 28C (Figure 29; see Figure 2 for strata locations). The fishing pattern in 28D in 2015 was different from 2014. Notably, with little to no fishing in the Scotts Bay and Spencer’s Island areas in 2015, and more in 28D Outer Bay.

SURVEY

Scallop Production Area 1B is subdivided into seven subareas for the purposes of assessment (Figure 2) with a total of 128 tows conducted over all subareas combined in 2015. Tow stations are allocated randomly in Cape Spencer (29 tows in 2015), Spencer’s Island (5 tows) and Scots Bay (4 tows). The other subareas have used a SPR survey design since 2009, in which 25% of the tow stations are repeats from the previous survey year: Middle Bay North (34 random and 10 repeat tows in 2015), Upper Bay 28C (17 random and 10 repeats), 28D Outer (8 random and 4 repeats), and Advocate Harbour (4 random and 4 repeats).

The number of commercial scallops per tow increased in Cape Spencer, was similar to 2014 in Middle Bay North, Upper Bay 28C, Outer Bay, and decreased from 2014 in Advocate Harbour, Scots Bay, and Spencer’s Island (Figure 30). In Cape Spencer, the number per tow in 2015 was

330.9, the highest in the time series for this subarea. This subarea is benefitting from a new year class recruiting, which can be seen clearly in the shell height frequency (Figure 31), that was large enough to decrease the mean commercial shell height (Figure 32). In fact, the recruit number per tow in 2014 (134.4) was the highest in the time series for Cape Spencer, and in 2015 the number of recruits per tow (72.3) is second highest for this subarea (Figure 30). In Middle Bay North, number per tow of commercial scallops has increased slowly since 2012, due to steady recruitment (Figure 33). Mean commercial shell height has been increasing since 2007, and Middle Bay North currently has the largest mean shell height in SPA 1B (Figure 32). Recruit number per tow in 2015 was 12.9, which was greater than 2014 (5.07/tow; Figure 30). Commercial scallops in Upper Bay 28C have been steady at approximately 92-100/tow since 2012, and there is also steady recruitment of year classes in this subarea, averaging 14.6/tow since 2012, but decreasing to 7.9/tow in 2015 (Figures 30 and 34). Mean shell height in this subarea increased in 2015 and is similar to Cape Spencer (Figure 32). 28D Outer tends to be a patchy subarea with lower abundances than other parts of SPA 1B; with 22 scallops/tow in 2015, it was the lowest commercial index in SPA 1B. The shell height frequencies for this subarea show low abundances at all sizes (Figure 35). Recruitment in 28D Outer tends to be very low, the recruit number per tow in 2015 (3/tow) is typical for this subarea. Abundance of commercial scallop in the survey for Advocate Harbour, Scots Bay, and Spencer's Island tends to vary greatly. The annual survey tracks year classes very well for Advocate Harbour (Figure 36). Scots Bay (Figure 37) and Spencer's Island (Figure 38) also show steady recruitment of recent year classes, and a commercial population that is, on average, smaller in terms of mean shell height, than in other parts of SPA 1B (Figure 32). Number per tow of recruit scallops in Advocate Harbour since 2013 has been among the highest of the time series (Figure 30). In Scots Bay and Spencer's Island, the number of recruit per tow decreased in 2015 from 2014.

Cape Spencer tends to have good distribution of commercial scallops, and Middle Bay North has persistent beds, most notably along the border with Upper Bay 28C (Figure 12). The subareas in 28D (Outer, Advocate, Scots Bay and Spencer's Island) are patchier. Recruit scallops were distributed throughout Cape Spencer in 2015, and were more widespread in Middle Bay North in 2015 than 2014, and similar between years in the other subareas of SPA 1B (Figure 13). Prerecruit scallops had a similar distribution in 2015 to 2014, although were less abundant (Figure 14).

Condition, presented as predicted weight in grams for a 100 m shell height at mean depth for a subarea (76.6 m for Cape Spencer, 45.4 m for Middle Bay North, 33.6 m for Upper Bay 28C and 46 m for 28D), increased in 2015, in all subareas of SPA 1B, after decreasing in 2014 (Figure 39). Condition is highest in Cape Spencer and lowest in Upper Bay 28C and 28D (Outer, Advocate Harbour Scots Bay and Spencer's Island combined). The increase in condition can be seen as general increases over all subareas of SPA 1B (Figure 16).

Commercial weight (kg) per tow increased in Cape Spencer from 2014, was similar to 2014 in Middle Bay North and Upper Bay 28C, and decreased from 2014 in Outer Bay, Advocate, Scots Bay, and Spencer's Island (Figure 40). In Cape Spencer, weight per tow was approximately 2 kg/tow from 2000 to 2012, then began increasing in 2013 and in 2015 is at a time series high of 5.9 kg/tow. In Middle Bay North, weight per tow has been stable, ranging from 1.2 to 1.9 kg/tow since 2006. Weight per tow in Upper Bay 28C has also been stable, ranging from 1.2 to 1.6 kg/tow since 2008. Weight per tow in 28D Outer is generally lower than in the rest of SPA 1B, and, in 2015, was 0.4 kg/tow; a decrease from 0.9 kg/tow in 2014. Weight per tow in Advocate Harbour increased from 2012-2014 (1.9 kg/tow to 3.8 kg/tow) and it decreased in 2015 to 3.3 kg/tow. In Scots Bay, weight per tow increased from 0.1 kg/tow in 2011 to 2.6 kg/tow in 2013, and has been declining since, to 1.1 kg/tow in 2015. The time series high for weight per tow in Scots Bay was in 2007 (5.0 kg/tow). Since, weight/tow has generally declined to a series low in 2013 of 0.002 kg/tow. In 2015 the weight/tow was 0.5 kg/tow. The increase in commercial biomass can be seen in the spatial plot (Figure 18), especially in Cape Spencer; in all subareas, biomass distribution is similar to 2014.

With the exception of Middle Bay North, weight per tow of recruit scallops decreased (Upper Bay 28C, Advocate Harbour, Scots Bay and Spencer's Island) from, or was similar (28D Outer) to, 2014 in all subareas of SPA 1B (Figure 40). In 2014, recruit weight per tow in Middle Bay North was 0.038 kg/tow, and in 2015 that doubled to 0.076 kg/tow. In Cape Spencer, although weight per tow of recruits is less than in 2014, the 2015 value (0.37 kg/tow) is the second highest value in the time series. Recruit biomass is distributed more evenly in Cape Spencer in 2015 than in 2014, with similar patchy distributions in the other subarea of SPA 1B (Figure 19).

Areas of high meat counts (scallops per 500 g) were similar between 2014 and 2015 (Figure 20), with the highest counts in Upper Bay, Advocate, Spencer's Island and Scots Bay. Better meat counts (lower number of meats per 500 g) were in Middle Bay North and Cape Spencer. While meat counts are a management measure used in this fishery, the meat count values presented in this document are based on survey information and are meant to be illustrative.

The number of clappers per tow tends to be greatest in Advocate Harbour, Spencer's Island, and Scots Bay, and Upper Bay 28C (Figure 41).

POPULATION MODEL

Survey indices for each subarea in SPA 1B (Cape Spencer, Middle Bay North, Upper Bay 28C, Outer Bay, Advocate, Spencer's Island, and Scots Bay) were combined to form a time series from 1997 to 2015. 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. 28D Outer 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 Harbour, Spencer's Island, and Scots Bay were the same as Middle Bay North from 1997 to 2000. 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.

Two chains were generated, each 500,000 samples long with the first 250,000 discarded for burn-in. Retained samples were thinned by 30 to give 16,666 samples from which to estimate the posterior distribution. Model diagnostics indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 42). The model fits the survey mean estimates well in this area and the uncertainty around the estimates have been relatively low, with the exception of the commercial biomass in 2009, which had increased uncertainty due to relatively large survey variance in that year (Figure 43).

STOCK STATUS AND FORECAST

Estimates of survival (i.e, exp(–*m*), *m* being instantaneous natural mortality from Eqn. 9) decreased from 2010 (0.90) to 2012 (0.81), it was similar in 2012 and 2013, and in 2014 there was a slight increase to 0.84, where it remained in 2015 (Figure 44). Exploitation (calculated in the model as $Catch_t$ / ($Biomass_{t+1}$ + $Catch_t$)) from 2011 to 2013 was relatively steady, ranging between 0.12 and 0.13, exploitation increased in 2014 to 0.148, and decreased to 0.116 in 2015 (Figure 44). Population biomass estimated by the model was 4,350 t (meats) in 2015, an increase of 27% from the estimate of 3,197 t for 2014 (Figure 45). This area is benefiting from recent recruitment. Recruit biomass estimated by the model in 2014 was 455.8 t, in 2015 the estimate of recruit biomass was lower, at 242.9 t, which is still above the long-term (1997 to 2014) average for this area of 186 t.

Harvest scenarios for 2015/2016, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 in the following year (2016/2017), are presented in Table 8. For example, Table 8 is interpreted as follows: a catch of 200 t corresponds to an exploitation of 0.04, and is projected to result in a 6.8% postive change in biomass, the probability of biomass increase is 59%, the probability that a catch of 200 t will result in the population remaining above the LRP is >99%, and the probability of the population remaining above the USR is >99%. In the following fishing year (2016/2017), a catch of 445 t would have a probability of 10% of exceeding a reference exploitation 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 (e.g., 2010) to year $t+1$ (e.g., 2011), with the estimates of biomass from fitting the model to data up to year $t+1$ (Figure 46, upper panel). For four of the six years evaluated, the median of the posteriors falls within the 50% credible interval of the projection. In the other two years (2013 and 2015), the median of the posterior falls in the upper credible limits. At the time these projections are made, assumptions are made about growth, condition, and mortality. When projecting forward, the meat weight-shell height relationship (i.e., growth) in the current year is used, and mortality is estimated from the mean of the previous 3 years. Knowing growth would have improved the 2015 estimate. In that year actual growth was 17-19% greater than predicted growth for commercial and recruit scallops (Figure 46, lower panel). Knowing growth would have improved the prediction in 2013, but it would still be within the upper credible limit bounds. In 2013, actual growth was 13% greater than predicted, and it is likely that the estimate of recruit biomass for 2012 was lower than what it actually was, so that the growth of the actual recruit biomass was underestimated.

SCALLOP PRODUCTION AREA 3

COMMERCIAL FISHERY

The Full Bay fleet caught a total of 234.96 t against a TAC of 250 t in the 2015 fishing year (Table 9). Trends in landings and TAC can be seen in Figure 47.

In the 2015 fishery, there were 52 vessels and almost 100% of the 934 records were useable after review by DFO Science (Table 4). Catch rates in St. Mary’s Bay have been very similar over the last 3 years, approximately 26.6 kg/h (Figure 48). Catch rates in the Brier/Lurcher area, both in the summer and fall, have been similar as well, for the last three years at approximately 22.5 kg/h (Figure 48). Mean daily catch rates from fall versus the spring/summer fishery are shown in Figure 49. The fishery in spring/summer 2015 lasted longer than in the previous year, and catch rates were more variable.

The opening of the fishery in SPA 3 in the fall is restricted to the Brier/Lurcher area outside St. Mary’s Bay. While there is some annual change in the spatial pattern, fishing tends to be concentrated in the inshore part of this area as identified previously using VMS data (see Survey Section below; Figure 50). There was a more noticeable change in the spatial pattern in the spring/summer fishery, with more area fished in the Brier/Lurcher area and less in St. Mary’s Bay than in the previous summer (Figure 51).

SURVEY

Scallop Production Area 3 consists of three subareas for the purposes of survey and assessment. These subareas have been in effect since the 2011, when two previous survey strata known as Brier/Lurcher were restratified based on VMS data to create two strata (Smith et al. 2012). The Inside VMS stratum represents areas historically fished, the Outside VMS stratum represents areas rarely fished (e.g., see red strata lines in Figure 50), and the third survey subarea is St. Mary’s Bay. All three subareas have used a SPR design since 2007, in which 25% of tows are repeats of stations from the previous year's survey: Inside VMS (44 random and 17 repeated tows), Outside VMS (40 random and 14 repeated tows), and St. Mary's Bay (17 random and 3 repeat tows).

Number per tow of commercial scallops decreased in 2015 relative to 2014 in all subareas of SPA 3 (Figure 52). In St. Mary's Bay, the number per tow of commercial scallop increased from 2011 (38.3/tow) to 2014 (89.7 tow) and in 2015 decreased to 58/tow. The decline in commercial scallop can be seen in the shell height frequency, with decreased abundance at all sizes (Figure 53). In St. Mary's Bay, the number of recruit per tow from 2011 to 2014 ranged from 9.1 to 12.8/tow. In 2015, the number of recruit per tow decreased to 2.9/tow; however, the steady recruitment has resulted in St. Mary's having the smallest mean commercial shell size in SPA 3 (Figure 54). Number per tow of commercial scallop is generally greatest in the Inside VMS stratum, and has decreased from 2013 (159.7/tow) to 2015 (146.9/tow), while recruitment has increased from 2013 (9.6/tow) to 2015 (19.9/tow). The Inside VMS stratum often sees a large abundance of prerecruit scallops (Figure 55). Commercial number per tow in the Outside VMS stratum tends to be lower than the Inside VMS stratum. In 2014, the number per tow of commercial scallop in the Outside VMS stratum (96.4) was the highest in the series since 1998. In 2015, the number per tow in the Outside VMS stratum decreased to 58.4. Recruitment in this subarea is inconsistent (Figure 56). In 2015, the number of recruits per tow was 4.3, which is an increase from 2014 (2.9/tow). The Outside VMS stratum has the largest mean size of commercial scallop in SPA 3, as the population ages and no large year classes have recruited recently (Figure 54). The distribution of commercial scallop in SPA 3 was similar in 2015 to 2014, with higher densities in the Inside VMS stratum (Figure 57). Recruits in 2015 are more widespread in the Outside VMS strata than in 2014, and almost absent from the western portion of the Inside VMS stratum in 2015 (Figure 58). There were noticeably less prerecruits in the western portion of the Inside VMS stratum in 2015 than in 2014, and prerecruits were less widespread in general in 2015 (Figure 59).

Condition, presented as predicted weight in grams for a 100 mm shell height at mean depth for a subarea (24.6 m for St. Mary's Bay, 61.1 m for Inside VMS, and 89.7 for Outside VMS), increased in 2015 for all of SPA 3 (Figure 60). St. Mary's Bay has consistently better condition than the VMS strata, and in 2015 the increase in condition in the Inside VMS stratum was mostly seen in the eastern portion, with the spatial pattern of condition in the western portion being similar to 2015 (Figure 61).

Weight per tow of commercial scallops decreased in St. Mary's Bay and the Outside VMS stratum in 2015, and increased slightly in the Inside VMS stratum (Figure 62). In St. Mary's Bay, weight per tow decreased from 3.4 to 2.1 kg/tow, which is the second highest value in the time series. Recruit weight per tow also decreased from 0.07 to 0.02 kg/tow. In the Inside VMS stratum, commercial weight per tow in 2015 (2.8 kg) was similar to 2014 (2.5 kg). Weight per tow of recruits increased in the Inside VMS stratum, from 0.05 kg in 2014 to 0.16 in 2015. Weight per tow in the Outside VMS stratum reached a time series high in 2014 at 1.5 kg/tow and declined slightly to 1.1 kg/tow in 2015. Recruit weight per tow in the Outside VMS in 2015 was 0.02 kg/tow, similar to 2014. Similar to commercial abundance, commercial biomass density tends to be greatest in the Inside VMS stratum (Figure 63). The greatest density of recruit biomass in 2015 was almost all within the inside VMS stratum, with widespread low biomass density in the Outside VMS stratum (Figure 64).

From 2014 to 2015, meat count (meats per 500 g) improved in St. Mary's Bay and the western portion of the Inside VMS stratum. Meat count increased in the eastern portion of the Inside VMS stratum and throughout the Outside VMS stratum (Figure 65). While meat counts are a management measure used in this fishery, the meat count values presented in this document are based on survey information and are meant to be illustrative.

The number of commercial size clappers per tow in St. Mary's Bay declined slightly to 1.8/tow in 2015 from 2.3/tow in 2014. In the Inside VMS stratum, clappers per tow in 2015 were similar to 2014, and in the Outside VMS stratum, clappers per tow decreased from 6.7 in 2014 to 3.4 in 2015 (Figure 66).

POPULATION MODEL

The stock assessment model was fit to the survey and catch data. Survey indices from both St. Mary's Bay and Inside VMS stratum were used, with the missing years filled in using simple interpolation. Two chains were generated, each 600,000 samples long with the first 300,000 discarded for burn-in. Retained samples were thinned by 30 to give 20,000 samples from which to estimate the posterior distribution. Model diagnostics indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 67). The model fits the survey mean estimates well in this area, and uncertainty around the estimates is relatively small, especially in the years since the SPR design was implemented (2007; Figure 68).

STOCK STATUS AND FORECAST

Estimates of survival (i.e, exp($-m$), m being instantaneous natural mortality from Eqn. 9) decreased, from 0.91 in 2013 to 0.85 in 2015 (Figure 23), which is around the long-term (1996 to 2014) average for this area of 0.84 (Figure 67). Exploitation (calculated in the model as $Catch_t$ / ($Biomass_{t+1}$ + $Catch_t$)) decreased in this area from 0.148 in 2012 to 0.08 in 2014, and in 2015 it increased slighly to 0.095 (Figure 69). Population biomass estimated by the model was 2,620 t (meats) in 2015, a decrease of 7% from the estimate of 2,814 t for 2014 (Figure 70). In 2015 the recuit biomass was estimated at 123 t, which is above the long-term (1996 to 2014) average for this area of 116 t.

Harvest scenarios for 2015/2016, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 in the following year (2016/2017), are presented in Table 10. For example, Table 10 is interpreted as follows: a catch of 150 t corresponds to an exploitation of 0.05, and is projected to result in a 1.4% decrease in biomass, the probability of biomass increase is 43%, the probability that a catch of 150 t will result in the population remaining above the LRP is >99%, and the probability of the population remaining above the USR is 99%. In the following fishing year (2016/2017), a catch of 220 t would have a probability of 10% of exceeding a reference exploitation 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 (e.g., 2010) to year $t+1$ (e.g., 2011) with the estimates of biomass from fitting the model to data up to year $t+1$ (Figure 71, upper panel). For two of the six years evaluated, the median of the posteriors fell within the 50% credible interval of the projection. In the other four years, the mediation of the posterior falls in the 50-90% credible limits. At the time these projections are made, assumptions are made about growth, condition, and mortality. When projecting forward, the meat weight-shell height relationship (i.e., growth) in the current year is used, and mortality is estimated from the mean of the previous three years. However, using actual growth did not improve the estimates (Figure 71, lower panel). One potential reason for the model fit not improving with actual growth estimates is that recruitment is being underestimated. Given the patchy nature of recruitment in this area (e.g., Figure 58), it it possible the survey design does not capture the entire recruitment signal. Work to investigate this issue is ongoing, with the inclusion of the SPR recruit estimates being used in this assessment as a first step in improving the estimates (see Assessment Methods: Recruitment). An additional potential reason for the model fit not improving with actual growth estimates is that biomass has increased rather rapidly in this area, tripling from 2010 to 2014. In such cases of rapid increase, the model can tend to underpredict the increases (National Research Council 1998).

SCALLOP PRODUCTION AREAS 4 AND 5

COMMERCIAL FISHERY

Before the start of the 2013/2014 fishing, SPAs 4 and 5 were joined under one TAC. In 2014/2015, the Full Bay Fleet caught a total of 124.09 t in SPA 4 and 8.26 t in SPA 5 against a combined TAC of 135 t (Figure 72, Table 11). Historic trends in TAC and landings for SPA 4 and SPA 5 before 2014 can be seen in Tables 12 and 13, and Figure 73.

In the 2015 fishery in SPA 4, there were 47 vessels and almost 100% of the 633 records were usable after review by DFO Science. In SPA 5, there were 23 vessels and 60 of the 61 records were useable after review by DFO Science (Table 4). The 2015 catch rate in SPA 4 was 22.5 kg/h, virtually unchanged from the catch rate of 22.8 kg/h in 2014 (Figure 74). Effort increased from 4,048 hours in 2014 to 5,441 hours in 2015, which is below the long term (1982/83 to 2014/15) median (Figure 74). The 2015 catch rate in SPA 5 declined, from 22.5 kg/h in 2014 to 19.9 kg/h in 2015, which is close to the long-term (1976/77 to 2014/15) median (Figure 75). Effort decreased in SPA 5 by about 100 hours to 418.8 hours in 2015, which is close to the long-term (1976/77 to 2014/15) median (Figure 75). The similar catch rates between 2014 and 2015 in SPA 4 and the slight decline in SPA 5 are evident in the spatial plots (Figure 76). In SPA 4, there was more fished area in strata 3, 9, and 10 (see Figure 2 for strata locations), along the border with SPA 1A.

SURVEY

Scallop Production Area 4 consists of eight strata (1 to 5, and 8 to 10 in Figure 2) that are assessed using a stratified random design. In 2015, 82 stations were randomly allocated among the SPA 4 strata, with the number of stations in a given stratum determined by the commercial variance in the previous year's survey. The inshore portion of SPA 4 (SPA 4 0 to 2 miles in Figure 2) is not included in the modelled area for SPA 4, but exploratory tows have been conducted occasionally in this stratum since 1981. In 2015, three exploratory tows were conducted based on location of commercial fishing activity in the previous fishing year. The annual survey in SPA 5 started in 1990, was discontinued in 2009, and survey tows were conducted again in this area in 2014 and 2015. In 2015, five tows were randomly assigned within an area designated by fishing effort over the last three years. The survey results for SPA 5 are presented with reference to the historic means of the survey series. The population model only uses data from SPA 4.

The number per tow of commercial scallop in SPA 4 increased greatly, from 98/tow in 2014 to 153/tow in 2015 (Figure 77). This increase is due, in part, to the large number of recruit scallops seen in 2014, which were first seen in 2013 as prerecruits (Figure 78). The mean shell size of commercial animals had been increasing in this area since the last large year class recruited in 2000. The new recruitment in 2015 decreased the mean shell height from 125.8 to 121.7 mm (Figure 79), which is the largest decrease since 2000. The numbers of recruit scallops per tow in 2014 (26.9) was the highest in this area since 2001/2002 (Figure 77); in 2015 the number per tow decreased to 6.8/tow. The increase in commercial scallops can be seen in all strata of SPA 4 (Figure 12). Recruit scallops are less widespread than in 2015, with a decreased density in strata 2-3 and 8-10 (Figure 13; see Figure 2 for strata locations and names). Prerecruit scallops were distributed more through strata 3 and 10 in 2015, and less in strata 1 (Figure 14). Condition, presented as predicted weight in grams for a 100 mm shell height at mean depth for SPA 4 (82.6 m), increased in SPA 4 from 2014 and is currently the highest in the time series (Figure 80); in the spatial plots, this increase is seen in all strata (Figure 16). Weight per tow of commercial scallop increased in 2015, at 4.4 kg/tow, and is the highest value in the series since 2003 (Figure 77). Recruit weight per tow decreased from 0.12 kg/tow in 2014 to 0.04 kg/tow in 2015. The increase in commercial biomass was seen in all strata of SPA 4 (Figure 18), and the decline in recruit biomass is evident in survey strata 1, 4, and 5 (Figure 19; see Figure 2 for survey strata locations and names).

Meat count (scallops per 500 g) was generally low in SPA 4 in 2014 and stayed low in 2015 (Figure 20). Most of SPA 4 was 10-15 count, and the highest observed counts were in the 4 and 5 survey strata. While meat counts are a management measure used in this fishery, the meat count values presented in this document are based on survey information and are meant to be illustrative.

The number of clappers (paired, dead shells) per tow in SPA 4 has been increasing steadily since 2010 (Figure 81), and in 2015 there was 7.2 clappers/tow. These clappers were predominately large, older scallops with a mean shell height of 131.9 mm.

Exploratory tows in the 0 to 2 mile stratum of SPA 4 (see Figure 2 for location) showed an increase in the number per tow of commercial scallop, similar number per tow of recruit scallops, and there is evidence of recent recruitment in the shell height frequency (Figure 82). However, with only three tows in 2015, there is large variance around the estimates (see Figure 83).

The annual survey in SPA 5 was discontinued in 2009 after consultation with industry, and the sampling effort was redirected to other areas in the Bay of Fundy. In the 2014 and 2015 surveys, exploratory tows were conducted in SPA 5. In 2014, the shell height frequency suggested recent recruitment to commercial size, and in 2015 there is a large number of new recruit size scallops (Figure 84). The number per tow and weight per tow of commercial scallop in SPA 5 has been above the medians determined from the original survey series (1990 to 2008), while recruit number per tow and weight per tow was near the median in 2014 and increased in 2015 (Figure 85).

POPULATION MODEL

For SPA 4, the stock assessment model was fit to the stratified survey index and catch data from 1983 to 2015. Detailed meat-weight shell height data has only been available since 1996, so the meat weight from 1983 to 1995 was estimated using the fixed effects from the model described above (Eqn. 8), with data from detailed sampling obtained from 1996 to 2001 combined. This same time period was used in the VB model (Eqn. 4) to model growth to get growth rates for those years. This time period was thought to be reflective of conditions from 1983-1995, and was first used by Smith and Lundy (2002) to fill in this missing information. 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 untypically favourable growth conditions that year (Smith and Lundy 2002). To correct this problem, the recruit index was adjusted for 2000 so that scallops between 40-79 mm were considered recruits. Two chains were generated, each 100,000 samples long, with the first 50,000 discarded for burn-in. Retained samples were thinned by 20 to give 5000 samples to estimate the posterior distribution. Model diagnostics indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 86).The model fits the survey mean estimates quite closely in this area, the uncertainty around the survey estimates is reduced due to the inclusion of the sample variances from the survey time series (Figure 87), although there is increased uncertainty around the large recruitment events in 1987 and 2001.

STOCK STATUS

Estimates of survival (i.e, exp(–*m*), *m* being instantaneous natural mortality from Eqn. 9), show the very high levels of natural mortality that occurred from 1989-1991 as the result of a catastrophic mortality event. Natural mortality began increasing slightly from 2010 to 2013 and, since then, has been approximately 0.90 (Figure 88). Exploitation (calculated in the model as $Catch_t$ / ($Biomass_{t+1}$ + $Catch_t$)) has been decreasing from 2011, when it was 0.154, to 0.054 in 2015 (Figure 88). Population biomass estimated by the model was 2,213 t (meats) in 2015, an increase of 70% from the estimate of 1,300 t for 2014 (Figure 89). This large biomass increase was preceeded by large, relative to the recent series, recruit biomass in 2014, of 97.5 t. In 2015 the recuit biomass estimate decreased to 23.6 t, which is near the recent time series mean in this area (Figure 89). The long-term (1983-2014) mean for recruitment in SPA 4 is 235 t, but the mean from 2003 to 2014 is only 29 t.

Harvest scenarios for 2015/2016, as well as the catches that correspond to various probabilities of exceeding an exploitation rate of 0.15 in the following year (2016/2017), are presented in Table 14. For example, Table 14 is interpreted as follows: a catch of 80 t corresponds to an exploitation of 0.03, and is projected to result in a 5.7% postive change in biomass, the probability of biomass change is neutral (49%), the probability that a catch of 80 t will result in the population remaining above the LRP is >99%, and the probability of the population remaining above the USR is 99%. In the following fishing year (2016/2017), a catch of 194 t would have a probability of 10% of exceeding a reference exploitation 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 (e.g., 2010) to year $t+1$ (e.g., 2011) with the estimates of biomass from fitting the model to data up to year $t+1$ (Figure 90, upper panel). For four of the six years evaluated (2010 to 2012, 2014), the median of the posteriors fell within the 50% credible interval of the projection. In 2013 and 2015, the median of the posterior fell in the 90% credible limits. At the time these projections are made, assumptions are made about growth, condition, and mortality. When projecting forward, the meat weight-shell height relationship (i.e., growth) in the current year is used, and mortality is estimated from the mean of the previous three years. If growth had been known at the time, the projection for 2013 and 2015 would have been improved relative to the actual estimate in 2013 and 2015, respectively (Figure 90, lower panel). From 2012 to 2013, a decline in biomass was predicted, but the growth rate of commercial scallops was 19% greater than predicted. From 2014 to 2015 an increase was predicted, but it was underestimated in part due to a 16% difference in actual versus predicted commercial growth and a 24% difference in predicted versus actual recruit growth.

SCALLOP PRODUCTION AREA 6

COMMERCIAL FISHERY

A total of 231 t was landed against a TAC of 240 t in SPA 6 in 2014/2015. The Mid Bay fleet reported a total of 207.01 t against a quota of 202.23 t and the Full Bay reported a total of 23.99 t against a quota of 37.77 t (Table 15, Figure 91). Broken down further within SPA 6, Mid Bay landings were 17.7 t, 57.57 t, 114.86 t, and 16.88 t for SPAs 6A, 6B, 6C, and 6D, respectively, whereas Full Bay landings were 14.31 t, 7.71 t, 1.89 t, and 0.08 t for SPAs 6A, 6B, 6C, and 6D, respectively (Table 15).

In the 2015 fishery, there were 116 vessels, and 96% of the 1598 records were useable after review by DFO Science (Table 4). The catch rate for all of SPA 6 increased significantly from 2012 to 2014 (from 6.7 kg/h to 25.4 kg/h), but declined in 2015 to 20.2 kg/h (Figure 92). Effort in SPA 6 had remained relatively constant between 2012 and 2014 (average 8,418 hours), but increased in 2015 to 11,421 hours (Figure 92). When looking at catch rates by the various subareas, catch rates decreased in 2015 for Mid Bay across all subareas but are still at the second highest level observed over the Mid Bay time series. For Full Bay, catch rates increased in subareas 6A, 6B, and 6C in 2015 relative to 2014; catch rate for 6D cannot be presented as there were not enough records to present these data consistent with *Privacy Act* considerations (Figure 93). When interpreting catch rates, it is important to note that Mid Bay records constitute the majority of the total catch records in SPA 6 (95% vs. 5%, Mid Bay vs. Full Bay records, respectively).

The spatial pattern of fishing, as derived from the logbook data, was similar between 2013/2014 and 2014/2015, with catch rates between 15 and 30 kg/h relatively common throughout the fished area. The extent of the area fished increased slightly with more area fished between Northern Grand Manan and Campobello Island and to the West of Grand Manan in 2014/2015 (Figure 94).

INDUSTRY SAMPLES

Total allowable catches set in SPA 6 since 1997 have varied, reflecting average catch trends, and were not based on an assessment model or any other indicator of productivity (Nasmith et al. 2014). Advice presented for the 2013/2014 season was provided from commercial catch and effort data assuming that effort tracks changes in exploitation rate and that changes in catch rate track changes in population biomass. However, in SPA 6 and other areas in the Bay of Fundy, catch rates can be influenced by fluctuations in the meat weight to shell height relationship (referred to as the condition) between years.

As a result of the use of catch rate to provide advice, and the potential influence of condition on catch rates, a number of Mid Bay associations proposed conducting meat weight-shell height sampling during the SPA 6 season. In 2014 and 2015, scientific licences were provided to two associations to conduct in-season sampling of commercial size scallops. In 2014, six samples were taken consisting of 50 commercial size scallop. In 2015, 23 samples were taken consisting of between 31 and 74 commercial size scallop. For both years, all samples were collected in January.

A GLMM, as detailed in Eq. 8, was fit separately for each year’s data using vessel as the grouping variable. Depth was not available for all sampled locations and was therefore not used in the model (as it is for the model based on survey data).

Condition in January 2014 was 17.2 g for a 100 mm shell height scallop compared to the value obtained from the survey in August 2013 of 11.3 g. Condition in January 2015 was 16.6 g for a 100 mm shell height scallop compared to the value obtained from the survey in August 2014 of 10.9 g. These observations are not unexpected as the meat weight-shell height relationship fluctuates seasonally. Moreover, given that for both years an increase of approximately 5.8 g was observed between the summer survey and winter fishery, the seasonal fluctuation between late summer and January has been relatively consistent. However, in the context of the provision of advice, now that SPA 6 has a model, seasonal changes in condition are inherently captured though the relative change in condition between survey years. Therefore the continuation of in-season industry meat-weight shell height sampling is no longer required in the context of augmenting data from which to provide TAC advice.

SURVEY

Until 2014, SPA 6 was assessed based on management areas: 6A, 6B, and 6C. In 2014, the survey was restratified based on two areas defined by VMS fishing patterns from 2002 to 2014 (DFO 2015), following the method used in SPA 3 (Smith et al. 2012). Here, the survey index has been further improved by restratifying the survey according to VMS “fishing” intensity from 2002 to 2014 and defining two VMS strata; an Inside VMS stratum defined by a threshold of greater than or equal to 21 hours of fishing per km^2 over the period 2002 to 2014 and an Outside VMS stratum defined by a combination of the historical survey extent and historical survey index (Figure 95). Recent work has shown that the productivity of scallops is tied closely to habitat suitability and. in the absence of detailed habitat information, the spatial distribution of fishing effort can be a good indicator of suitable habitat (Smith et al. 2009, Brown et al. 2012, Sameoto et al. 2014, Smith et al. 2015). The survey in SPA 6 has used the SPR design since 2006. In 2015, the survey continued using SPR, but was designed using the Inside and Outside VMS strata. Stations were allocated between strata proportionally to area; this resulted in 75 stations in the Inside VMS stratum and 45 stations in the Outside VMS stratum. As part of the SPR design, 25% of tows within each stratum are repeats of previous years' stations. This resulted in 56 random and 19 repeated tows in the Inside VMS stratum, and 33 random and 12 repeated tows in the Outside VMS stratum. Survey tows from 1997 to 2014 were reassigned to correspond to the new VMS strata design.

The number per tow of both commercial and recruit size scallop in SPA 6 has increased greatly in the Inside VMS stratum since 2012 for commercial size, and since 2013 for recruit size (Figure 96). In 2015, commercial and recruit numbers per tow in the Inside VMS stratum were the highest of the survey time series, which started in 1997, at 250 and 65 per tow, respectively. Weight per tow of commercial size scallop has also increased since 2012 in the Inside VMS stratum, and is currently at its highest in the time series at 3.8 kg/tow, whereas recruit weight per tow has increased slightly since 2012 and is at 0.4 kg/tow (Figure 96).

In the Outside VMS stratum, commercial and recruit numbers have also been increasing since 2012, although this increase has not been as great as observed in the Inside VMS stratum. In 2015, commercial and recruit numbers in the Outside VMS stratum were at a time series high of 156 and 41 per tow, respectively (Figure 97). Weight per tow has also increased for both commercial and recruit sizes, which are currently at 2.4 and 0.4 kg/tow, respectively.

This increase in commercial and recruit size can clearly be seen from the shell height frequencies, as the high abundance of prerecruit size scallop approximately 15 to 50 mm in shell height observed in 2013 grew into recruit and commercial size in subsequent years. However, this high abundance of prerecruit scallop was mainly observed in the Inside VMS stratum, with much lower densities observed in the Outside VMS stratum (Figures 98, 99). In 2015, the majority of scallops were commercial size with low abundances observed below 55 mm for both strata. The recruitment of newer, younger scallops to commercial size resulted in a corresponding decline in the mean shell height of the commercial size scallops from 2012 to 2014 in the Inside VMS stratum and since 2013 in the Outside VMS stratum (Figure 100).

The increased abundance in commercial size scallops is evident throughout the survey area of SPA 6, as observed from the spatial plots. In 2014, the majority of survey tows had over 50 commercial scallops per tow. In 2015, the proportion of tows with over 100 per tow increased, and these tows are located throughout the survey area (Figure 101). Recruit size scallop were also observed throughout the survey area in both 2014 and 2015 (Figure 102). Extremely high abundances (> 500 per tow) of prerecruits were observed North of Grand Manan, New Brunswick, and around Campobello Island, New Brunswick, in 2014. In 2015, prerecruit abundances of 10 to 100 per tow were found throughout the survey area, including a few localized patches of >200 per tow (Figure 103).

Condition, presented as predicted weight in grams for a 100 mm shell height at mean depth for the Inside VMS stratum of SPA 6 (54.7 m), remained relatively similar between 2014 and 2015 (Figure 104). Spatially, condition exhibited a similar pattern in 2014 and 2015, with high condition found in and around Campobello Island and to the east of Grand Manan around subarea SPA 6D (Figure 105). Spatially, commercial biomass was ≥0.1 kg/tow throughout most of the survey area in 2014 and 2015 and, in 2015, there were numerous high patches where commercial biomass was >3 kg/tow (Figure 106). Recruit biomass remained between 0.1-1 kg/tow throughout most of the survey area in both 2014 and 2015 (Figure 107).

Meat count (scallops per 500 g) ranged throughout the survey area of SPA 6, with the majority of area having a count between 25 and 35 in 2014. In 2015, the spatial pattern in meat count was similar to 2014, although the overall area with count ≥35 increased. In both years, the area North of Grand Manan had meat counts >45 (Figure 108). This is due to a large proportion of commercial sized scallops in this area just being commercial size (>80 mm); in 2014, 66% of commercial sized scallops in this area were <100 mm, and in 2015, 74% of commercial sized scallops in this area were <100 mm. While meat counts are a management measure used in this fishery, the meat count values presented in this document are based on survey information and are meant to be illustrative.

The number of clappers per tow for the Inside VMS stratum had increased for both commercial and recruit size from 2012 to 2014, but declined in 2015. In the Outside VMS stratum, clappers per tow increased slightly in 2015 relative to 2014 (Figure 109). However, any observed increased in clappers per tow should be considered in combination with the proportion of clappers observed, as the number of clappers per tow would be expected to increase in relation to an increase in overall population abundance. The clapper index, presented as a proportion of the number of clappers to the combined total of clappers plus live scallops, is shown in Figure 110. For the Inside VMS stratum, the proportion of clappers had increased in 2014 for commercial sized scallops to approximately 10%, but has since declined in 2015 to levels similar to those observed between 2007 and 2012 (approximately 4%). The proportion of recruit size clappers has remained relatively consistent and low throughout the time series (average 2%). In the Outside VMS stratum, both the commercial and recruit size clappers have been remained relatively consistent since 2008 (average of 5% and 1%, respectively; Figure 110).

POPULATION MODEL

For SPA 6, the stock assessment model was fit to the new survey index for the Inside VMS Stratum only and the catch data associated with this Inside VMS stratum. As catch is reported by subarea, usable logbook data was spatially-allocated by its reported latitude and longitude to either the Inside VMS stratum, Outside VMS stratum, or designated as not falling within a strata (Figure 95). The catch associated with each area (Inside VMS stratum, Outside VMS stratum, no strata) was converted to a proportion of the overall usable catch from SPA 6 in that year and then multiplied by the official landings in SPA 6 in that year to determine the total catch associated with each area. The proportion of landings associated with the Inside VMS stratum ranged from 64-81% between 2006 and 2015. The Outside VMS stratum accounted for between 2% and 9% of the landings between 2006 and 2015. Although the catches assigned to the Inside VMS stratum represent the majority of the landings for SPA 6, there were numerous logbook locations that were located outside both VMS strata (assigned to 'no strata') that were also in locations that seem unlikely to be scallop habitat (i.e. overlapping with areas of depth >150 m). Further work to investigate the spatial distribution of landings from SPA 6 will assist with future model refinement.

As this was the first attempt to fit the current model to SPA 6, the time series was restricted to 2006-2015, as there was no survey of SPA 6 in 2004 and the survey conducted in 2005 was relatively limited (45 tows total of which 38 overlap with the Inside VMS stratum). It is possible that in the future these years could be filled in; however, this will take further investigation. Two chains were generated, each 1,000,000 samples long with the first 500,000 discarded for burn-in. Retained samples were thinned by 10 to give 100,000 samples from which to estimate the posterior distribution. All priors used were the same as per the other Bay of Fundy areas except the upper bound on kappa tau was increased to 2.5 due to the posterior from initial model runs falling up against the initial upper bound of 2. Model diagnostics indicated full mixing of chains and convergence. The comparison of posterior distributions with the priors indicated that the priors were not highly influential (Figure 111). The model fits the survey mean estimates well and uncertainty around the estimates was relatively small, although it has increased for commercial biomass since 2012 and for the recruit biomass since 2013 (Figure 112).

STOCK STATUS

Estimates of survival (i.e, exp(–*m*), *m* being instantaneous natural mortality from Eqn. 9) have range from from 0.81 in 2009 to 0.93 in 2015 (Figure 113). Exploitation (calculated in the model as $Catch_t$ / ($Biomass_{t+1}$ + $Catch_t$)) has varied between 0.11 and 0.25 from 2007 to 2015, with exploitation in 2015 being at 0.12 (Figure 113). Population biomass estimated by the model was an average of 368 t (meats) from 2006 to 2012 and has since increased to 1361 t in 2015 (Figure 114). In 2015, the recuit biomass was estimated at 158 t (Figure 114).

Harvest scenarios for 2015/2016 are presented in Table 16. For example, Table 16 is interpreted as follows: a catch of 140 t corresponds to an exploitation of 0.08, and is projected to result in a 12.4% increase in biomass. The probability of biomass increase is 53%.

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 (e.g., 2011) to year $t+1$ (e.g., 2012), with the estimates of biomass from fitting the model to data up to year $t+1$ (Figure 115, upper panel). For one (2012) of the four years evaluated, the median of the posteriors fell within the 50% credible interval of the projection. In the other three years, the median of the posterior fell within the 90% credible limits. At the time these projections are made, assumptions are made about growth, condition, and mortality. When projecting forward, the meat weight-shell height relationship (i.e., growth) in the current year is used, and mortality is estimated from the mean of the previous three years. However, using actual growth did not improve the estimates greatly (Figure 115, lower panel). This was likley due to the actual growth being relatively similar to the predicted growth rate (<25% difference). Biomass has increased significantly in this area since 2012, tripling from 2012 to 2015.In such cases of rapid increase, the model can tend to underpredict the increases (National Research Council 1998).

Although the application of the delay difference model to SPA 6 is new, it performed relatively well with reasonable parameter estimates. Other areas in the Bay of Fundy have defined reference points based on the population biomass estimates from the model; however, SPA 6 has reference points defined in terms of commercial catch rate. This is due to the fact that this assessment (November 2015) was the first year in which the assesment model has been used in SPA 6, but reference points were required for this fishery in January 2015. Reference points were, therefore, previously adopted using catch rate as an indicator of stock status. Further work and consultation with Industry will be required if reference points are to be defined in terms of population biomass rather than the current approach of using commercial catch rate. The catch rate index is the overall catch rate for all of SPA 6 for both fleets combined. The LRP is 6.2 kg/h, the lowest catch rate observed in the time series since 1997, and the USR is 9.1 kg/h and is based on the average catch rate from 2005 to 2011. In 2015, catch rates were well above the USR at 20.2 kg/h, but were down from 2014 (25.4 kg/h; Figure 116).

ECOSYSTEM CONSIDERATIONS

In the 2014/2015 fishing year, there were no fishery observer trips in the Bay of Fundy; therefore, refer to Sameoto and Glass (2012) for past analysis of discards from the inshore scallop fishery.

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TABLES

Table 1. Summary of Bay of Fundy catch in 2015 fishing year, and available commercial and science survey data for assessment. Survey strata are shown in Figures 1 and 2. Fishing in SPA 2 can take place subject to special license conditions. n/a: not applicable, SPA: Scallop Production Area, CPUE: catch-per-unit-effort, Decision indicates what methods are used to provide advice on the stock.

SPA	Fleets	TAC (meats,t)	Landings (meats, t)	CPUE	Survey (strata)	Decision
1A	Full Bay	350	361.55	1976-2015	1981-2015 (8 to 16), 1984-2015 (2 to 8), 1997-2002, 2004-2015 (MBS)	Model, Reference Points
1B	Full Bay	301.77	303.96	1982-2015	1997-2015 (Cape S., MBN), 2002-2003, 2005-2015 (UB)	Model, Reference Points
	Mid Bay	175.59	164.02	1992-2015		
	Upper Bay	72.68	78.19	1997-2015		
2	Marginal Area	n/a	n/a	n/a	n/a	n/a
3	Full Bay	250	234.9	1996-2015	1996-2015	Model, Reference Points
4,5	Full Bay	135	132.34	1976-2015	1981-2015; 1997-2008 (5)	Model,Trends Reference Points
6	Full Bay	37.77	23.99	1976-2015	1997-2003, 2005-2015	Model, Trends, Reference Points
	Mid Bay	202.23	207.0	1993-2015		
Total		1525.04	1514.96			

Table 2. Predicted growth over one year for scallops of various shell heights, based on von Bertalanffy growth modelling for three separate areas.

Area	40 mm	45 mm	50 mm	55 mm	60 mm	65 mm
SPA 1A,1B,4 and 5	60.58	64.6	68.61	72.63	76.65	80.67
SPA 3	59.68	63.77	67.86	71.96	76.06	80.15
SPA 6	57.79	62.02	66.24	70.47	74.69	78.92

Table 3. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 1A, 2002 to 2015 fishing year. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.

Commercial Data (t)	Avg. 02–09	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015
TAC	433	300	300	200	200	275	350
Landing	355.9	297	278.1	206.4	206.02	274.49	361.55

Table 4. Summary of commercial fishing log data available by fishing area in the Bay of Fundy for fishing year 2015. 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	54	-	-	53	1392	1389	99.8
1B	52	94	15	140	2509	2488	99.2
3	55	-	-	52	934	931	99.7
4	47	-	-	47	633	629	99.8
5	23	-	-	23	61	60	98.4
6A	7	38	-	43	217	209	96.3
6B	5	43	-	44	416	401	96.4
6C	4	73	-	76	886	847	95.6
6D	2	28	-	28	79	78	98.7
6 (all subareas)	11	112	-	116	1598	1535	96.1

Table 5. Harvest scenario table for Scallop Production Area 1A to evaluate 2015/2016 catch levels in terms of exploitation (e), expected change in biomass (%), probability (Pr) of biomass increase, probability that after the 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 2016/2017 are evaluated in terms of the posterior probability of exceeding an exploitation rate of 0.15.

2015/2016						Potential catch (t) 2016/2017					
						***Pr* ($e_{2016/2017}$) > 0.15**					
Catch (t)	e	***% Change***	***Pr Increase***	***Pr > LRP***	***Pr > USR***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
180	0.05	-0.9	0.46	>0.99	>0.99	333	395	443	488	532	581
200	0.05	-1.4	0.46	>0.99	>0.99	331	394	441	486	531	578
225	0.06	-1.6	0.46	>0.99	>0.99	329	392	441	485	531	579
250	0.06	-2.0	0.45	>0.99	>0.99	327	390	439	483	528	576
275	0.07	-2.5	0.44	>0.99	>0.99	326	387	436	481	525	574
300	0.08	-3.1	0.43	>0.99	>0.99	323	384	431	476	520	569
325	0.08	-3.5	0.42	>0.99	>0.99	320	381	430	475	520	567
350	0.09	-4.2	0.41	>0.99	>0.99	318	377	426	472	517	564
375	0.09	-4.6	0.41	>0.99	>0.99	315	376	425	469	512	560
400	0.1	-4.9	0.40	>0.99	>0.99	313	375	423	466	511	561
425	0.11	-5.6	0.39	>0.99	>0.99	309	371	419	463	507	556
450	0.11	-6.1	0.39	>0.99	>0.99	309	368	416	461	505	552
610	0.15	-9.3	0.33	>0.99	>0.99	293	353	401	445	488	534

Table 6. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 1B, 2002 to 2015 fishing year. Full Bay TAC was split into SPA 1A and SPA 1B in 2002/2003.

Commercial Data (t)	Avg. 02–09	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015
TAC	185	205.5	203	152.3	190.3	228.4	301.8
Landing	189	151.9	84.2	159.9	202.8	229.4	303.96

Table 7. Mid Bay (MB) fleet and Upper Bay (UP) fleet total allowable catch (TAC) and landings in Scallop Production Area 1B, 2002 to 2015 fishing year. The TAC for MB and UB was combined from 2002-2007.

Commercial Data (t)	Avg. 02–09	2010	2011	2012	2013	2014	2015
MB TAC[1]	159	144.7	142.9	107.2	133.95	160.74	175.6
MB Landing	140	138.6	123.3	103.1	162.7	197.7	164.02
UB TAC	138	54.8	54.1	40.6	50.7	60.9	72.7
UB Landing	66.4	54.4	54.7	39.97	57.4	68.9	78.2

Table 8. Harvest scenario table for Scallop Production Area 1B to evaluate 2015/2016 catch levels in terms of exploitation (e), expected change in biomass (%), probability (Pr) of biomass increase, probability that after the 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 2016/2017 are evaluated in terms of the posterior probability of exceeding an exploitation rate of 0.15.

2015/2016						Potential catch (t) 2016/2017					
						Pr ($e_{2016/2017}$) > 0.15					
Catch (t)	e	***% Change***	***Pr Increase***	***Pr > LRP***	***Pr > USR***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
200	0.04	6.8	0.59	>0.99	>0.99	445	507	562	611	661	716
250	0.05	5.8	0.56	>0.99	>0.99	437	501	554	604	653	709
300	0.06	4.7	0.55	>0.99	>0.99	433	497	547	596	645	699
350	0.07	3.5	0.53	>0.99	>0.99	424	491	542	590	640	695
400	0.08	2.6	0.51	>0.99	0.99	419	483	537	584	632	686
450	0.09	0.7	0.48	>0.99	0.99	414	475	527	574	622	676
500	0.10	0.1	0.47	>0.99	0.99	410	471	521	569	617	669
550	0.11	-1.3	0.44	>0.99	0.99	400	462	512	561	609	662
600	0.12	-2.6	0.41	>0.99	0.99	395	456	507	553	602	654
650	0.13	-3.6	0.40	>0.99	0.99	389	451	500	546	595	647
700	0.14	-4.8	0.37	>0.99	0.99	380	443	494	541	588	640
727	0.15	-5.8	0.35	>0.99	0.99	378	438	486	535	582	633

Table 9. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 3, 2002 to 2015 fishing year.

Commercial Data (t)	Avg. 02-09	2009/ 2010	2010/ 2011	2011/ 2012	2012/ 2013	2013/ 2014	2014/ 2015
TAC	190	50	50	300	260	260	250
Landing	147	56	72.96	264.8	261	265.1	234.96

Table 10. Harvest scenario table for Scallop Production Area 3 to evaluate 2015/2016 catch levels in terms of exploitation (e), expected change in biomass (%), probability (Pr) of biomass increase, probability that after the 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 2016/2017 are evaluated in terms of the posterior probability of exceeding an exploitation rate of 0.15.

2015/2016						Potential catch (t) 2016/2017					
						Pr **($e_{2016/2017}$) > 0.15**					
Catch (t)	e	***% Change***	***Pr Increase***	***Pr > LRP***	***Pr > USR***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
150	0.05	-1.4	0.43	>0.99	0.99	220	265	299	331	364	399
175	0.06	-2.1	0.42	>0.99	0.98	218	261	296	329	361	397
200	0.07	-2.9	0.42	>0.99	0.98	217	259	294	326	361	395
225	0.08	-3.8	0.39	>0.99	0.98	215	256	289	322	355	390
250	0.09	-4.8	0.38	>0.99	0.98	210	252	286	319	351	387
275	0.1	-6.2	0.36	>0.99	0.98	207	248	283	314	346	382
300	0.11	-6.8	0.35	>0.99	0.98	206	247	280	312	344	380
325	0.12	-7.7	0.34	>0.99	0.98	202	242	277	309	341	376
350	0.13	-8.4	0.33	>0.99	0.97	200	241	274	305	338	373
375	0.14	-9.6	0.31	>0.99	0.97	197	238	269	301	333	369
400	0.15	-10.5	0.29	>0.99	0.97	194	235	267	298	330	364

Table 11. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 4 and 5. SPAs 4 and 5 were joined under one TAC starting in the 2013/2014 fishing year.

Commercial Data (t)	2013/ 2014	2014/ 2015
TAC	110	135
SPA 4 Landing	90.2	124.09
SPA 5 Landing	12.3	8.26
Total Landing	102.5	132.35

Table 12. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 4, 2001/2002 to 2012/2013 fishing year. SPAs 4 and 5 were joined under one TAC starting in the 2014 fishing year (Table 11).

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

Table 13. Full Bay Fleet total allowable catch (TAC) and landings in Scallop Production Area 5, 2001/2002 to 2012/2013 fishing year. SPAs 4 and 5 were joined under one TAC starting in the 2014 fishing year (Table 11).

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

Table 14. Harvest scenario table for Scallop Production Area 4 to evaluate 2015/2016 catch levels in terms of exploitation (e), expected change in biomass (%), probability (Pr) of biomass increase, probability that after the removal the stock will be above the LRP and above the USR. These calculations assume a USR of 750 t and a LRP of 530 t. Potential catches in 2016/2017 are evaluated in terms of the posterior probability of exceeding an exploitation rate of 0.15.

2015/2016						Potential catch (t) 2016/2017					
						Pr ($e_{2016/2017}$) > 0.15					
Catch (t)	e	***% Change***	***Pr Increase***	***Pr > LRP***	***Pr > USR***	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
80	0.03	5.7	0.49	>0.99	0.99	194	230	263	292	323	359
100	0.04	5.1	0.48	>0.99	0.99	191	230	260	292	325	357
125	0.05	3.5	0.47	>0.99	0.99	190	229	258	288	315	349
150	0.06	1.9	0.46	>0.99	0.99	182	220	250	280	314	345
175	0.07	1.4	0.44	>0.99	0.99	185	221	251	282	311	344
200	0.08	-1.7	0.41	>0.99	0.99	173	213	242	272	303	336
225	0.09	-1.5	0.41	>0.99	0.99	180	216	245	273	300	332
250	0.10	-2.4	0.40	>0.99	0.99	176	210	240	268	297	333
275	0.12	-4.2	0.39	>0.99	0.99	170	206	236	264	296	328
300	0.13	-5.5	0.37	>0.99	0.98	170	205	233	259	289	320
360	0.15	-7.7	0.35	>0.99	0.98	163	198	228	257	287	317

Table 15. Full Bay fleet and Mid Bay fleet total allowable catch (TAC) and landings by subarea in Scallop Production Area 6, 2002 to 2015 fishing year.

Fleet/Subarea	Avg 02-09	2010	2011	2012	2013	2014	2015
Mid Bay TAC (t)	145	119	119	119	119	184.45	202.23
6A	20.7	32.3	23.9	11.4	39.2	56.6	17.70
6B	17.1	23.2	26.5	13.6	20.1	51.3	57.57
6C	31.2	46.7	46.5	25.3	51.8	67.2	114.86
6D	11.3	0.3	7.0	4.4	6.5	18.7	16.88
Mid Bay Total	74.76	102.5	103.9	54.7	117.5	196.8	207.01
Full Bay TAC (t)	26	21	21	21	21	32.55	37.77
6A	3.1	0.07	0	0.37	2.6	11.95	14.31
6B	1.4	0	0	0.18	0.3	4.0	7.71
6C	2.1	0	0	0.33	4.6	0.45	1.89
6D	1.2	0	0	0	0.63	1.75	0.08
Full Bay Total	7.5	0.07	0	0.88	8.1	18.2	23.99

Table 16. Harvest scenario table for Scallop Production Area 6 to evaluate 2015/2016 catch levels in terms of exploitation (e), expected change in biomass (%), and probability (Pr) of biomass increase. Note that a removal reference of exploitation of 0.15 applies to SPA 6; however, harvest scenarios above 0.15 have also been included to show expected stock dynamics (see: italicized rows in table).

2015/2016			
Catch (t)	*e*	***% Change***	***Pr Increase***
140	0.08	12.4	0.53
160	0.09	11.4	0.52
180	0.11	10.0	0.51
200	0.12	8.9	0.50
220	0.13	7.6	0.49
240	0.14	6.4	0.48
260	0.15	5.4	0.47
280	*0.16*	*4.0*	*0.46*
300	*0.17*	*2.6*	*0.45*
320	*0.19*	*1.3*	*0.44*
340	*0.20*	*0.3*	*0.43*

FIGURES

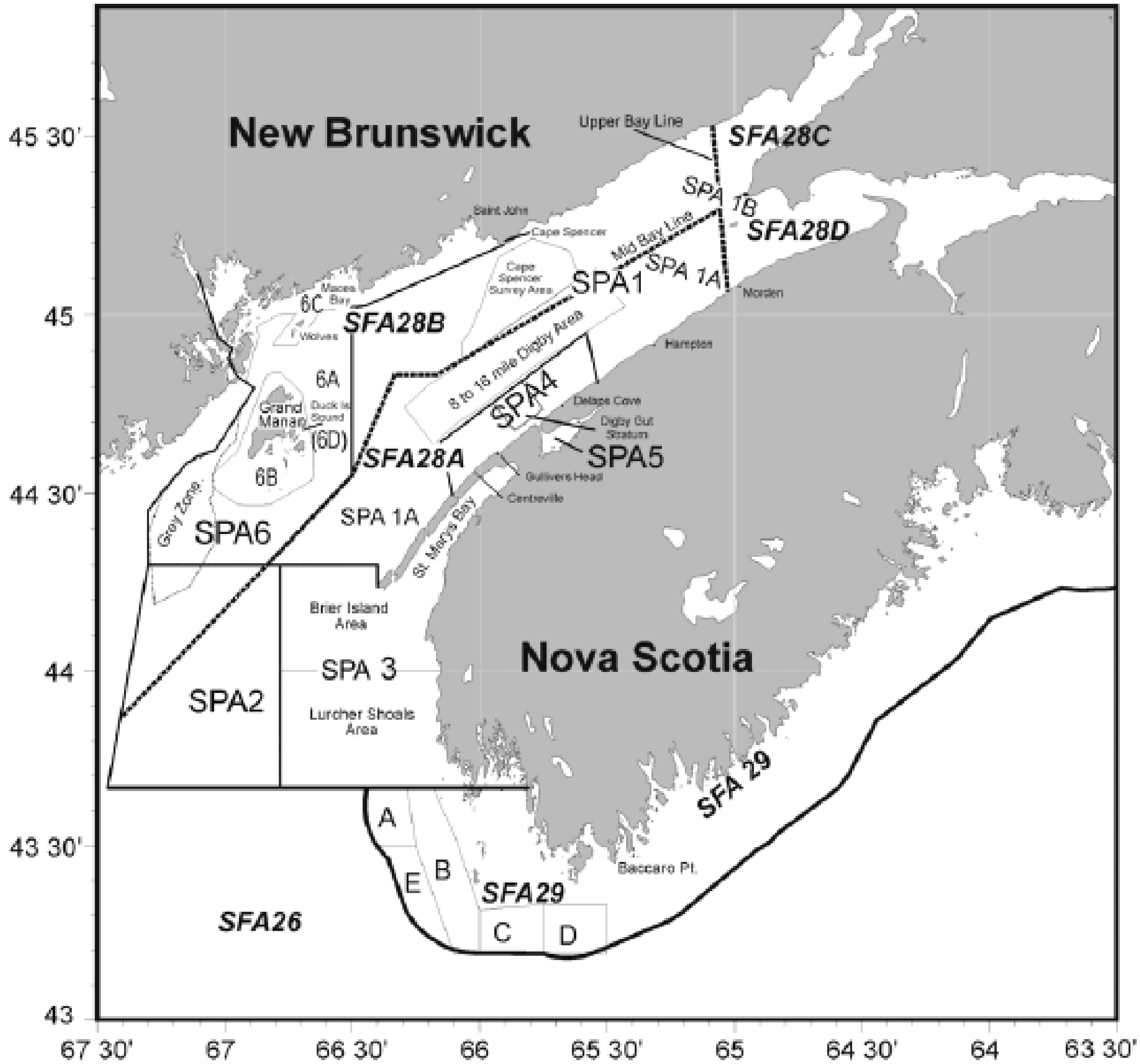

Figure 1. Map of Scallop Production Areas (SPA) and Scallop Fishing Areas (SFA) in the Bay of Fundy and Approaches.

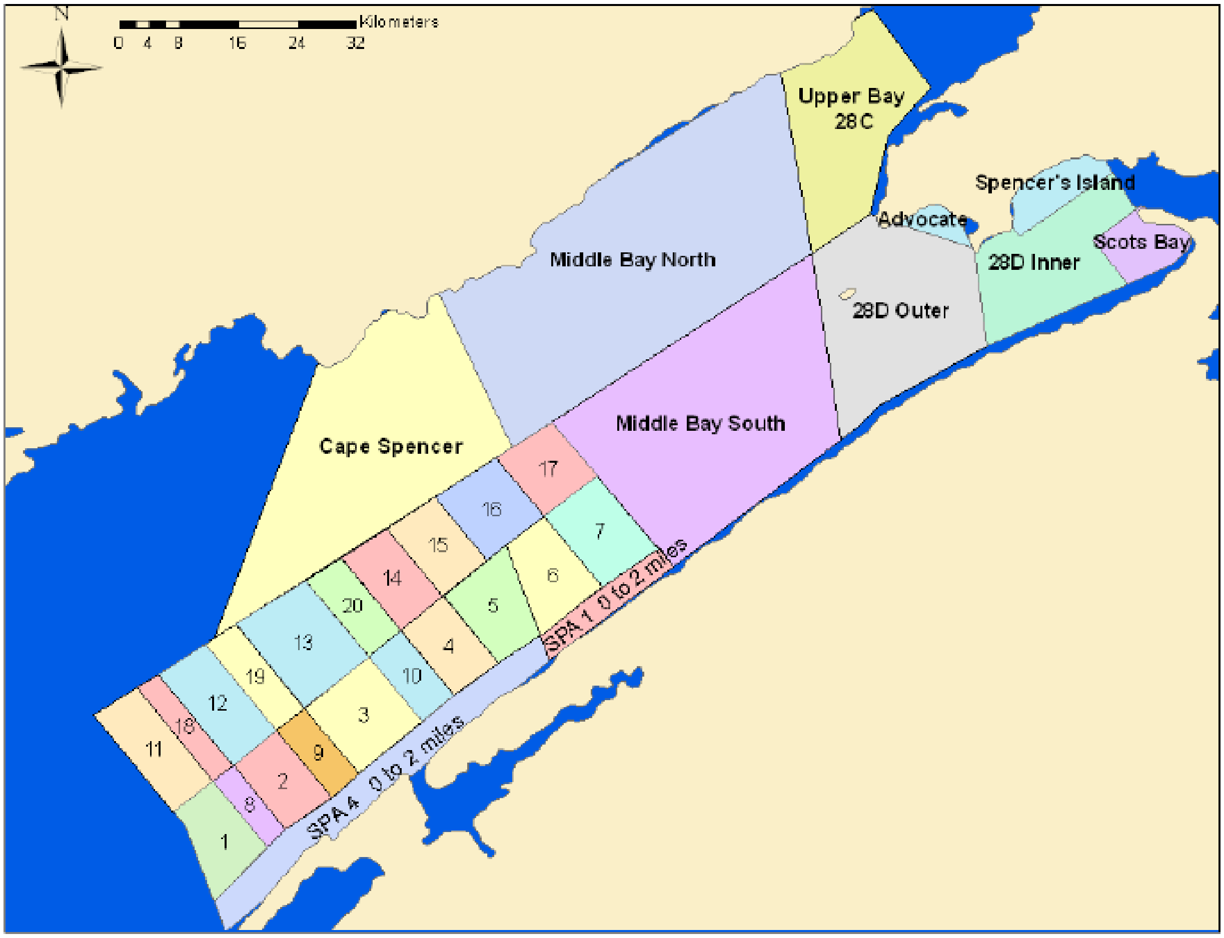

Figure 2. Map of strata in Scallop Production Areas (SPAs) 1A, 1B, and 4 used for the annual scallop survey. For SPA boundaries see Figure 1.

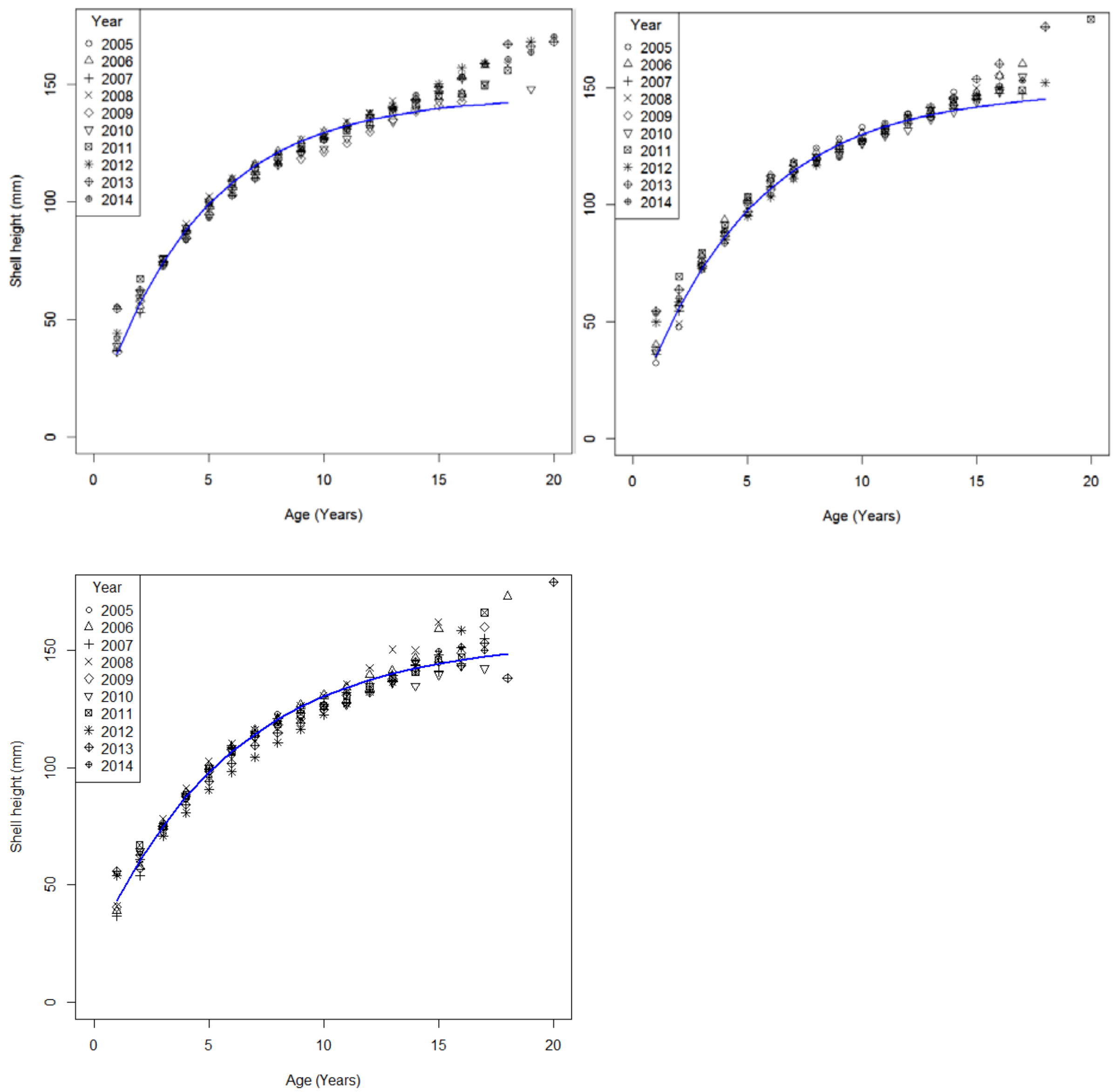

Figure 3. Shell height at age von Bertalanffy growth modelling results for the Bay of Fundy (Scallop Production Area (SPA) 1A, 1B, and 4; top left), SPA 3 (top right), and SPA 6 (bottom left). Not all years shown.

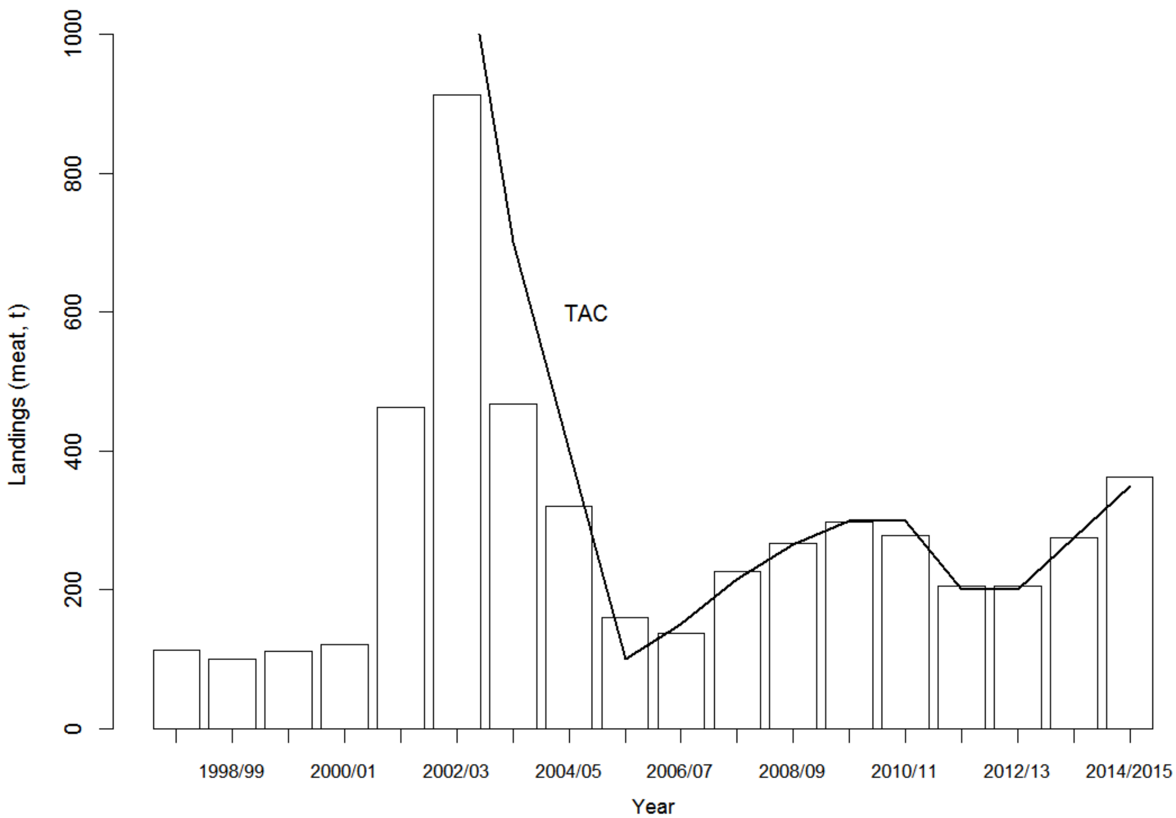

Figure 4. Total Allowable Catch (TAC, t; black line) and landings (bars, t) in Scallop Production Area 1A from 1997/1998 to 2014/2015.

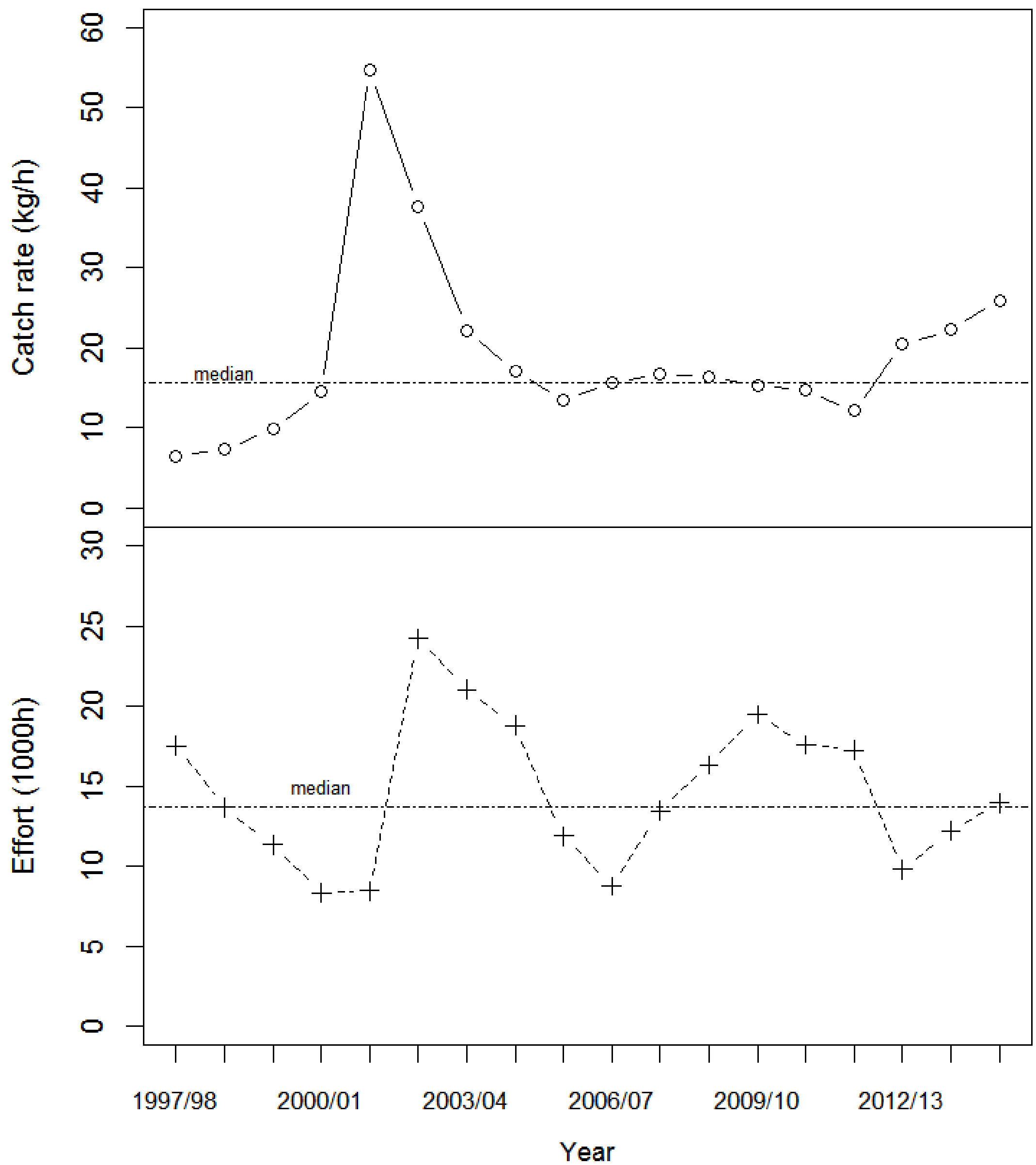

Figure 5. Catch per unit effort (CPUE, kg/h; top panel) and effort (1000 h; bottom panel) in the Scallop Production Area 1A fishery from 1997/1998 to 2014/2015.

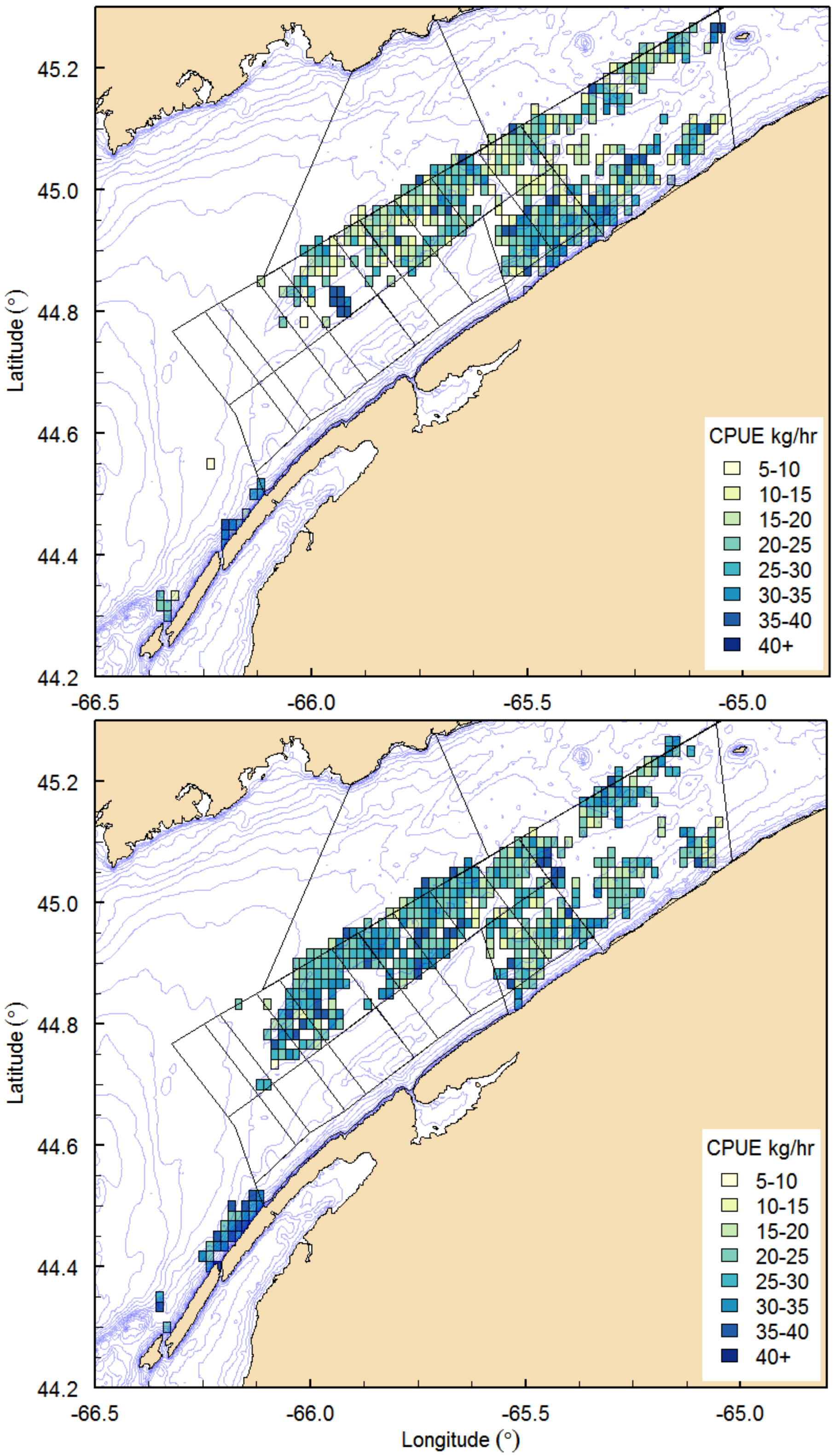

Figure 6. Spatial distribution of catch per unit effort (CPUE, kg/h) in the Scallop Production Area 1A fishery for the 2014 (top panel) and 2015 (bottom panel) fishing years. Black lines represent survey strata.

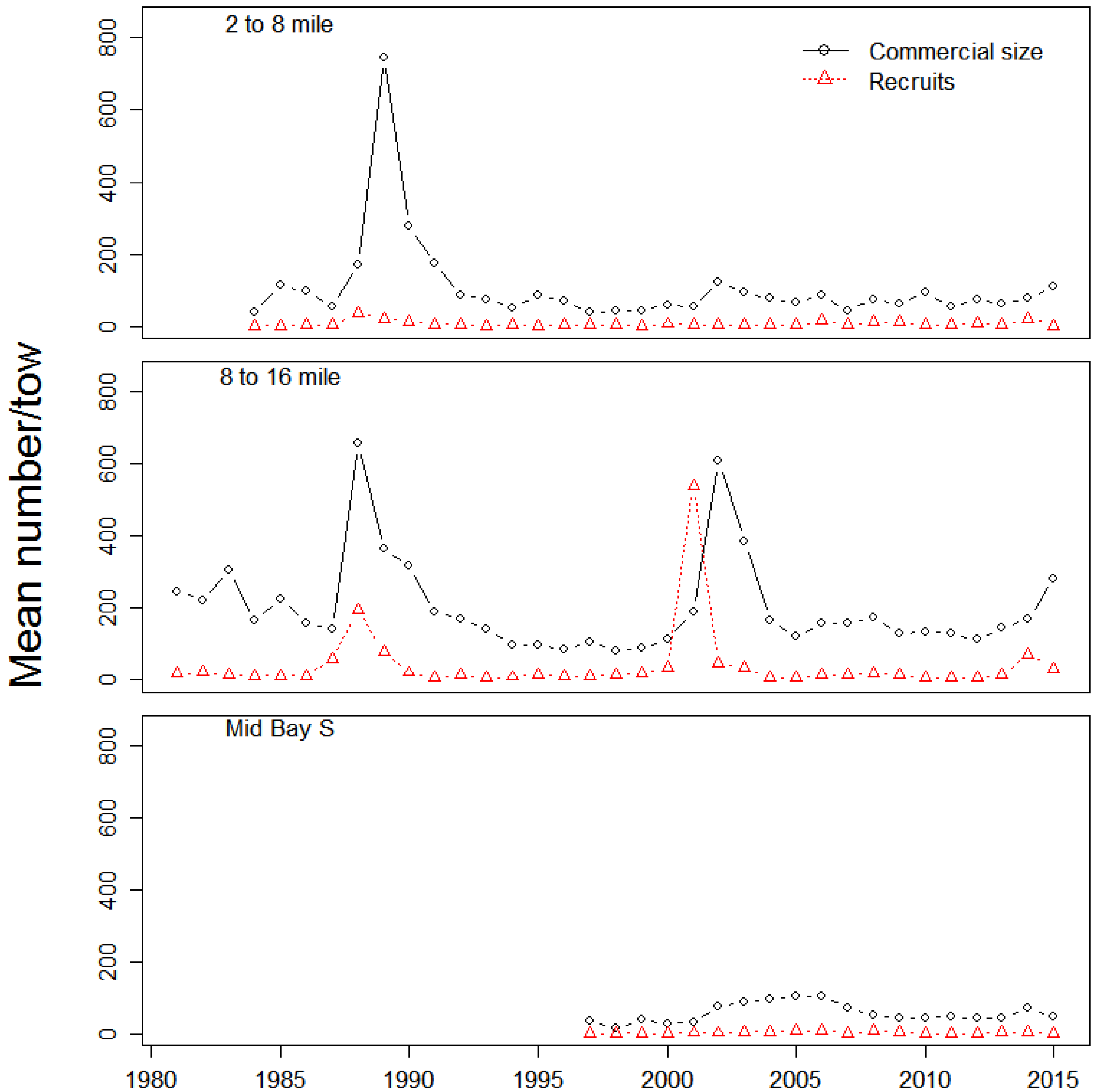

Figure 7. Mean number per tow of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 1A: 2 to 8 mile (top panel; 1984 to 2015), 8 to 16 mile (middle panel; 1981 to 2015), and Middle Bay South (bottom panel; 1997 to 2015).

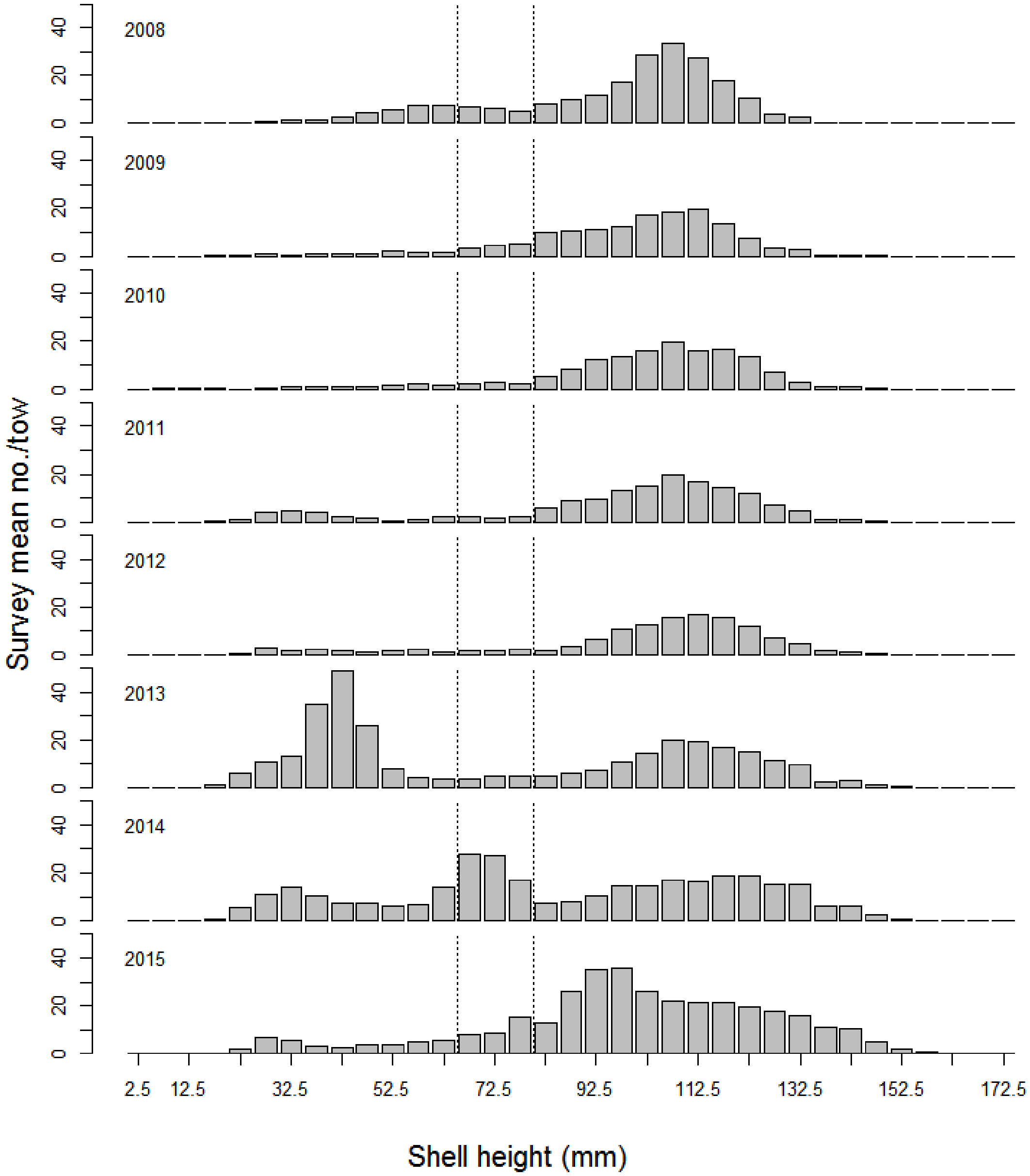

Figure 8. Shell height (mm) frequency (mean number/tow) for the 8 to 16 mile zone of Scallop Production Area 1A, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

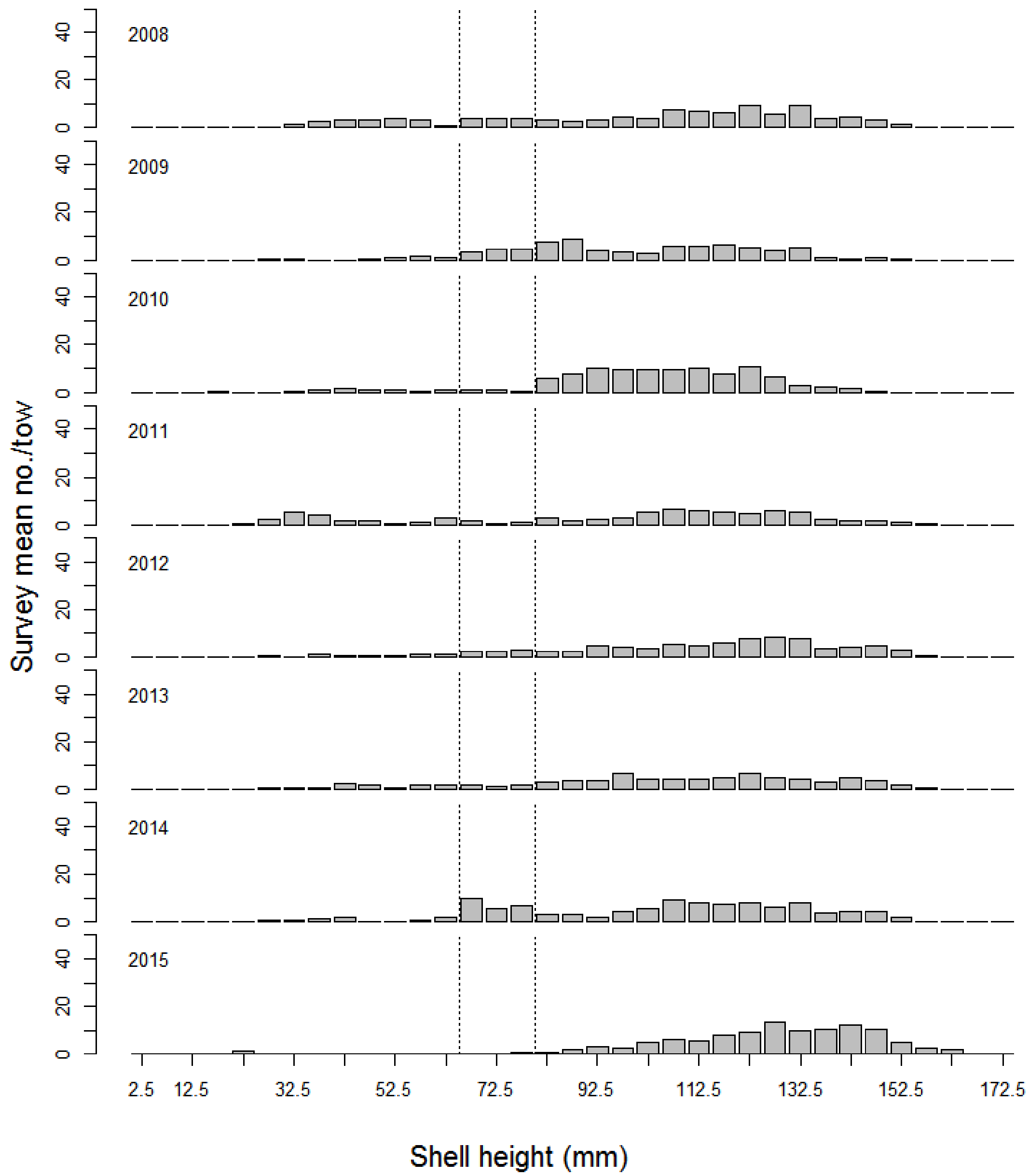

Figure 9. Shell height (mm) frequency (mean number/tow) for the 2 to 8 mile zone of Scallop Production Area 1A, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

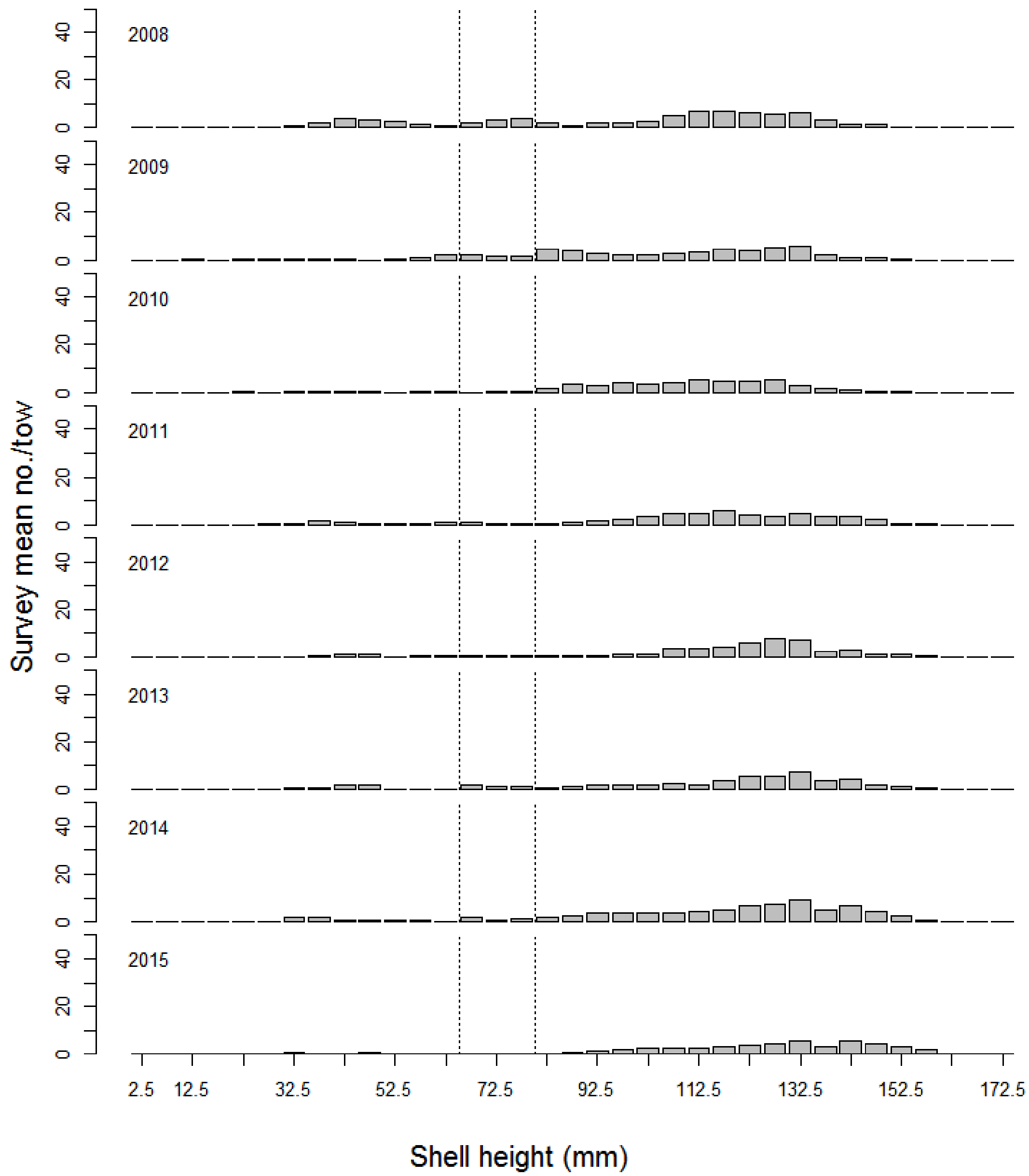

Figure 10. Shell height (mm) frequency (mean number/tow) for the Middle Bay South area of Scallop Production Area 1A, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

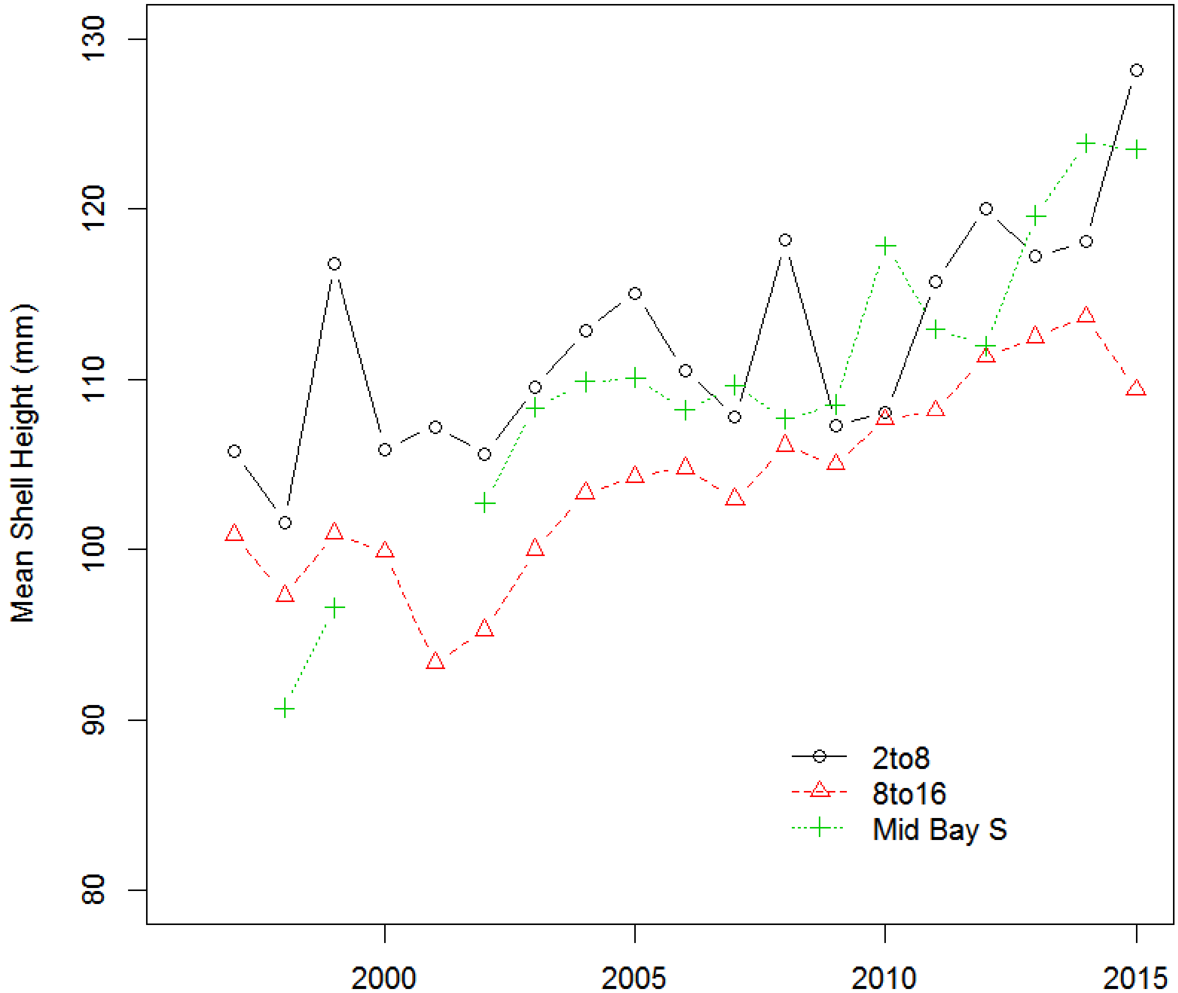

Figure 11. Mean shell height (mm) of commercial size scallops in the three subareas of Scallop Production Area 1A: 2 to 8 mile (black circles), 8 to 16 mile (red triangles), and Middle Bay South (green crosses) from 1997 to 2015.

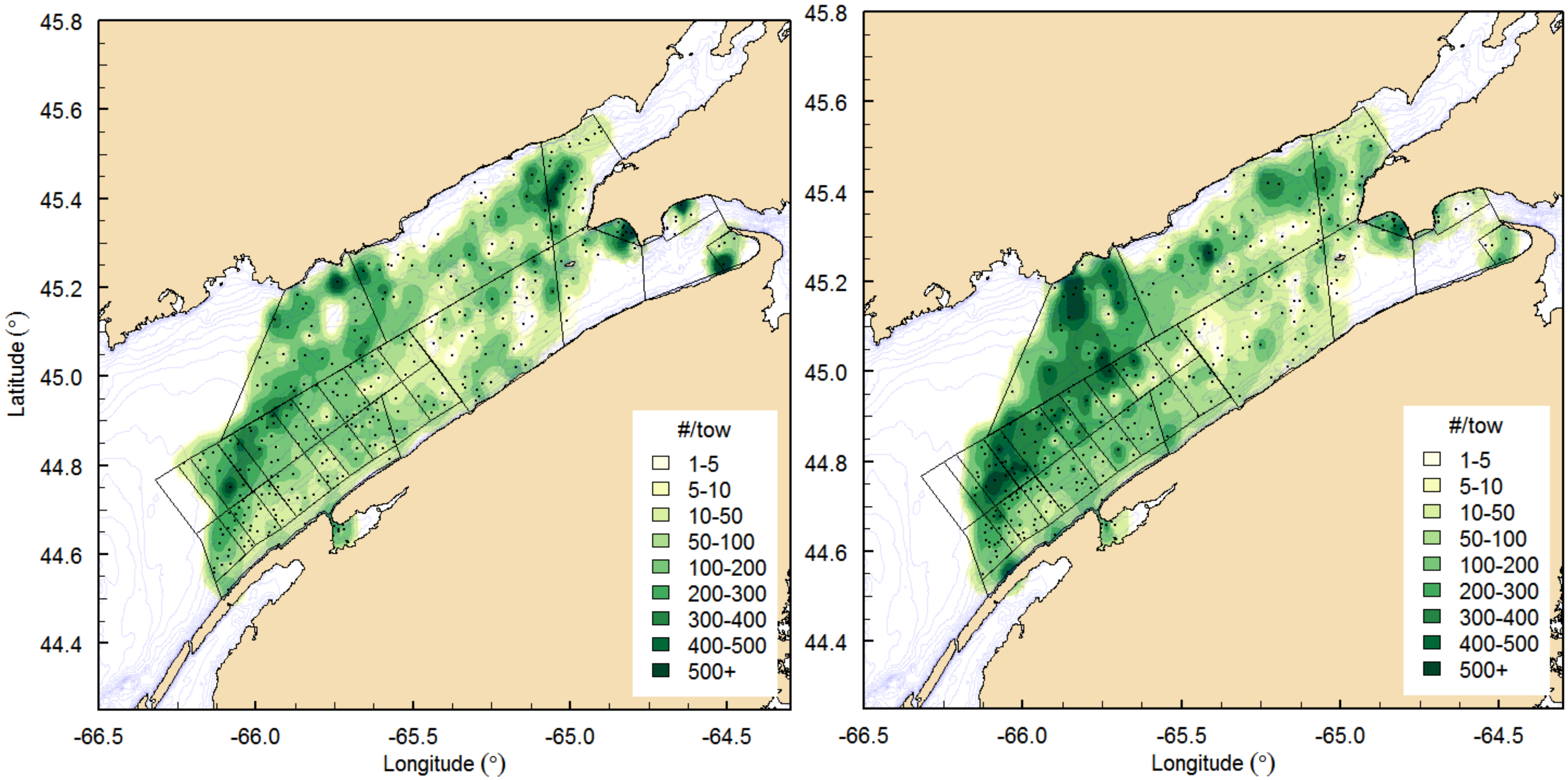

Figure 12. Spatial distribution of abundance (number/tow) of commercial scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata.

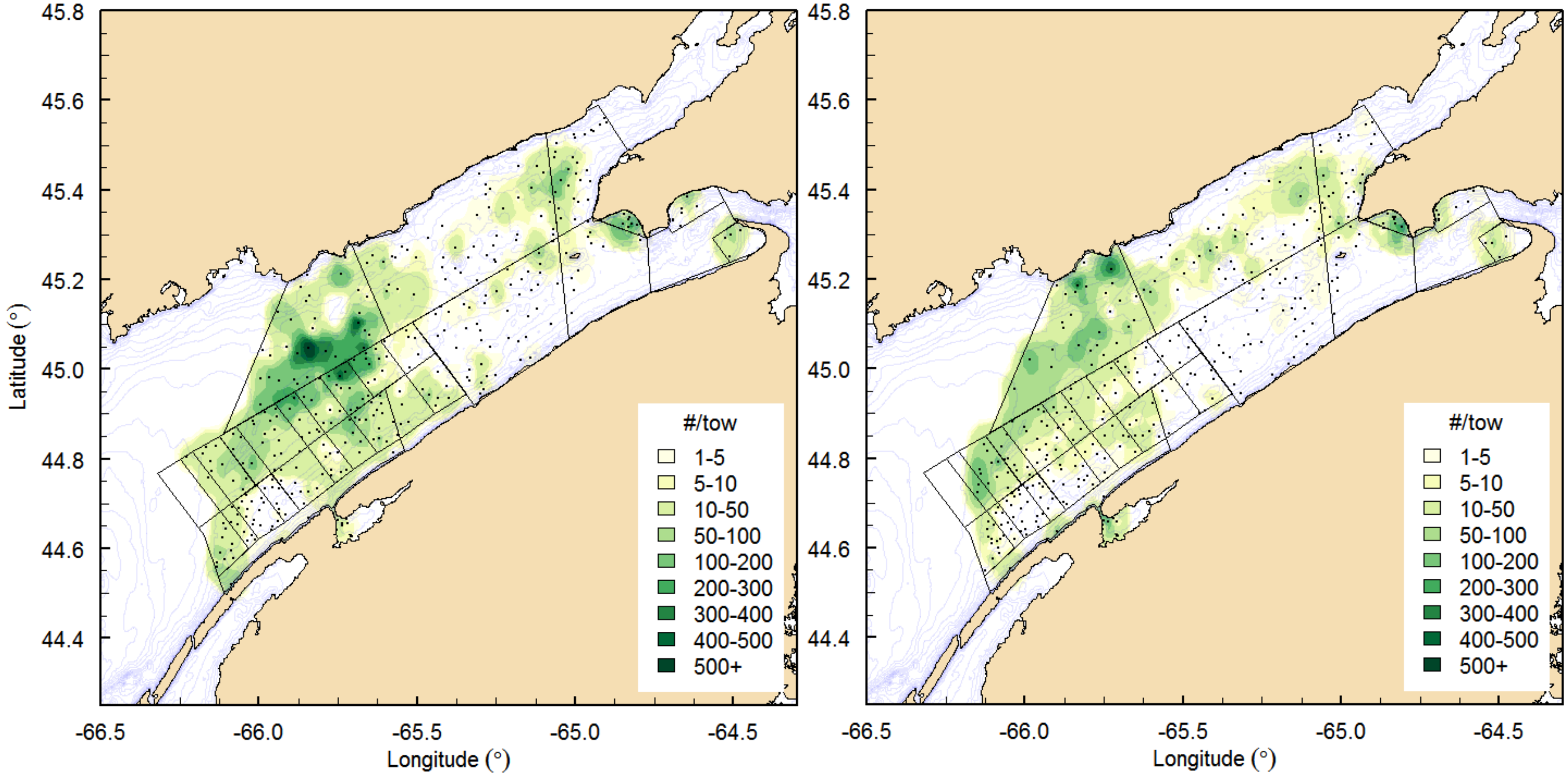

Figure 13. Spatial distribution of abundance (number/tow) of recruit scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata.

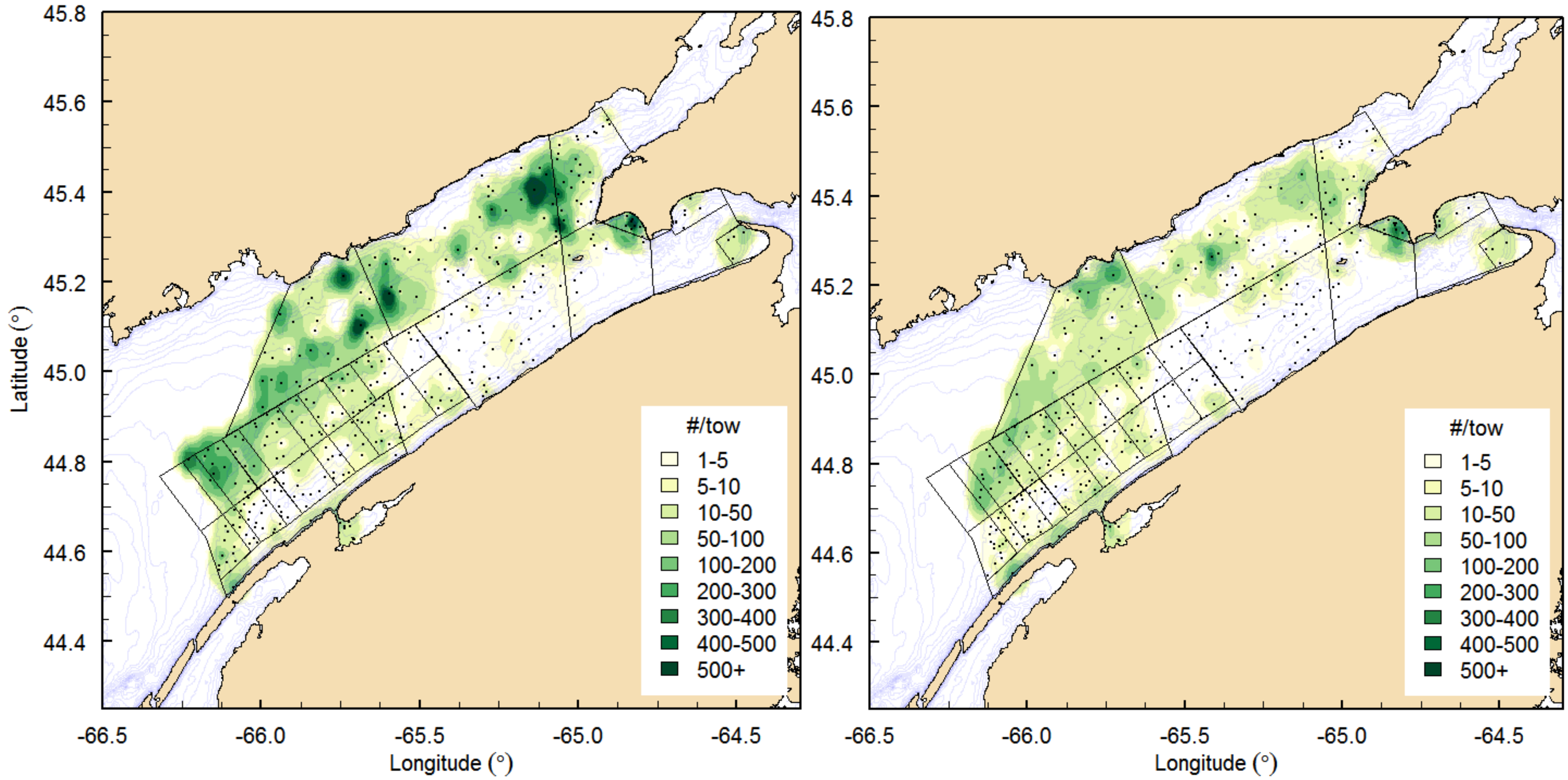

Figure 14. Spatial distribution of abundance (number/tow) of prerecruit scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel).Black lines represent survey strata.

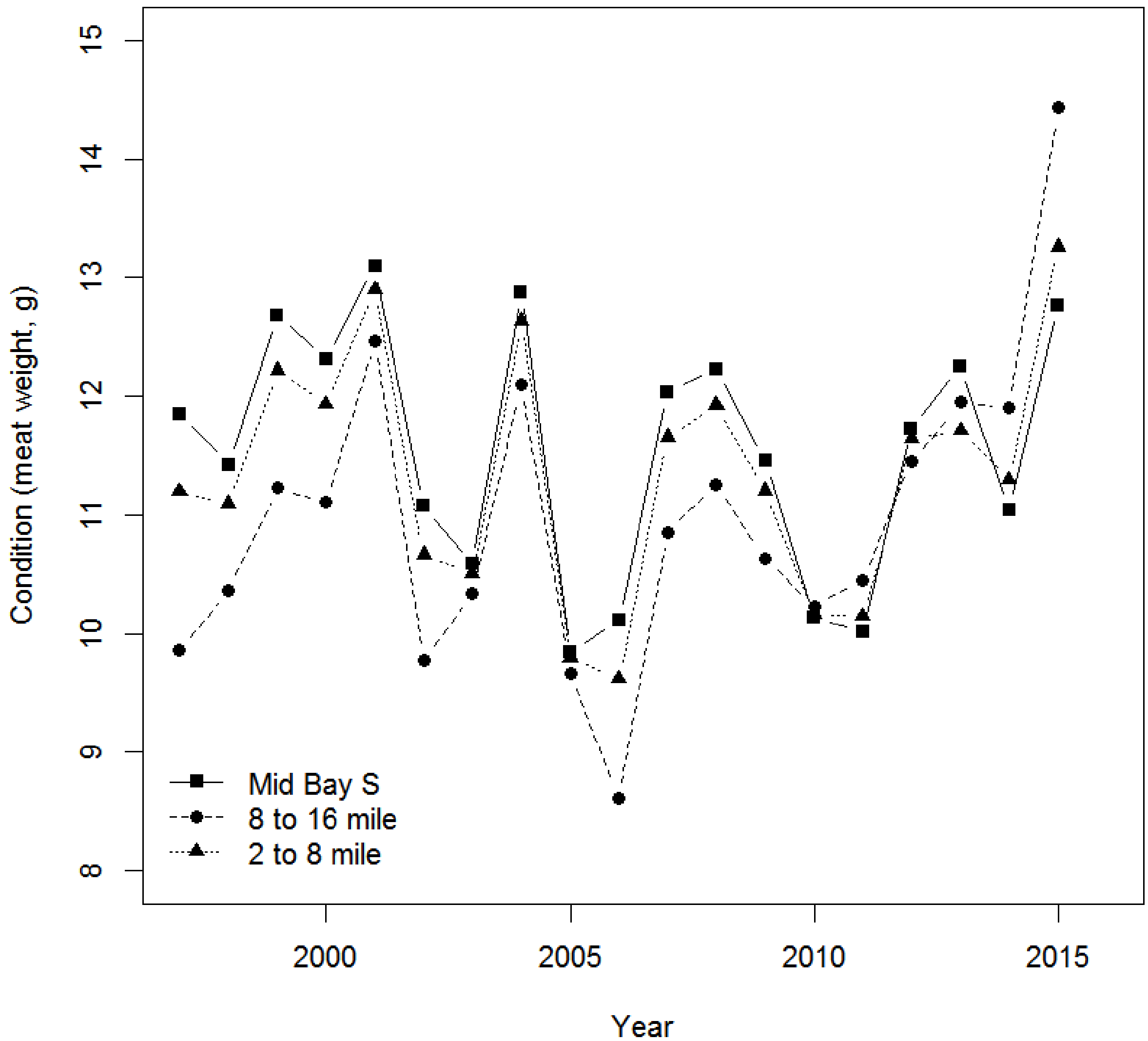

Figure 15. Condition (meat weight, g) for a shell of 100 mm in the three subareas of Scallop Production Area 1A: 2 to 8 mile (triangle), 8 to 16 mile (circle), and Middle Bay South (square) from 1997 to 2015.

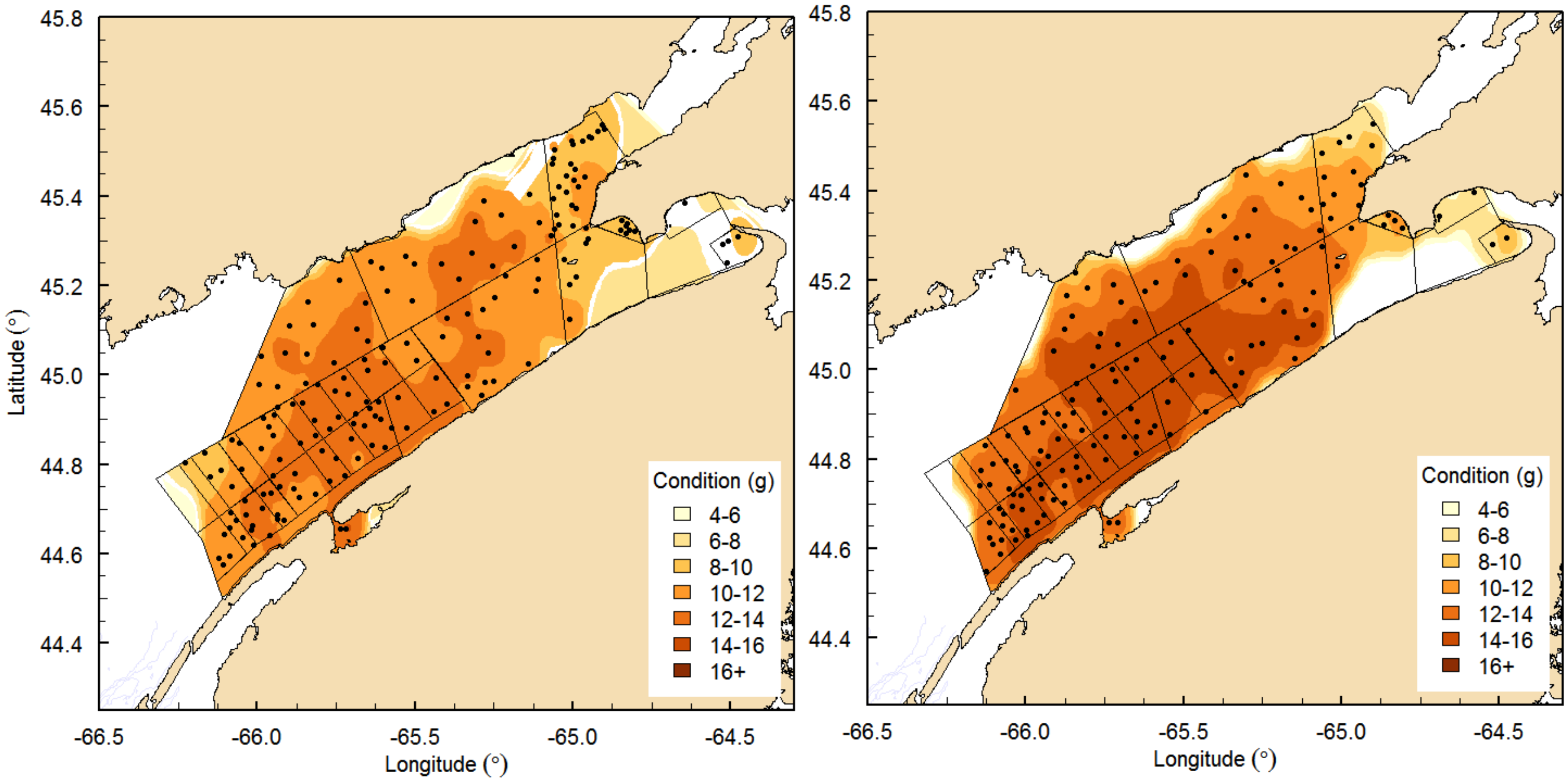

Figure 16. Spatial distribution of condition, weight in grams of a 100 mm scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata.

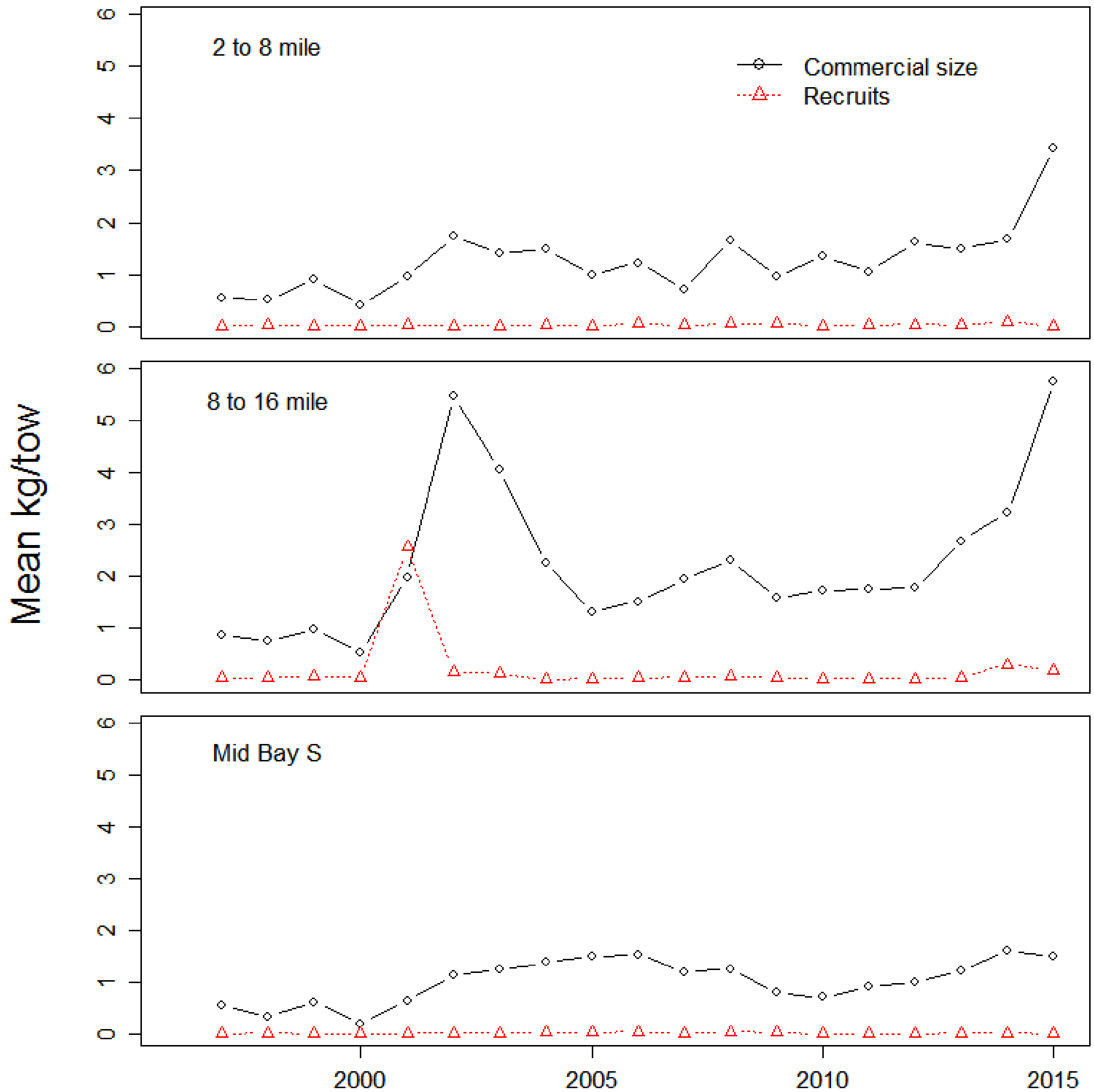

Figure 17. Mean weight (kg) per tow of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 1A: 2 to 8 mile (top panel), 8 to 16 mile (middle panel), and Middle Bay South (bottom panel) from 1997 to 2015.

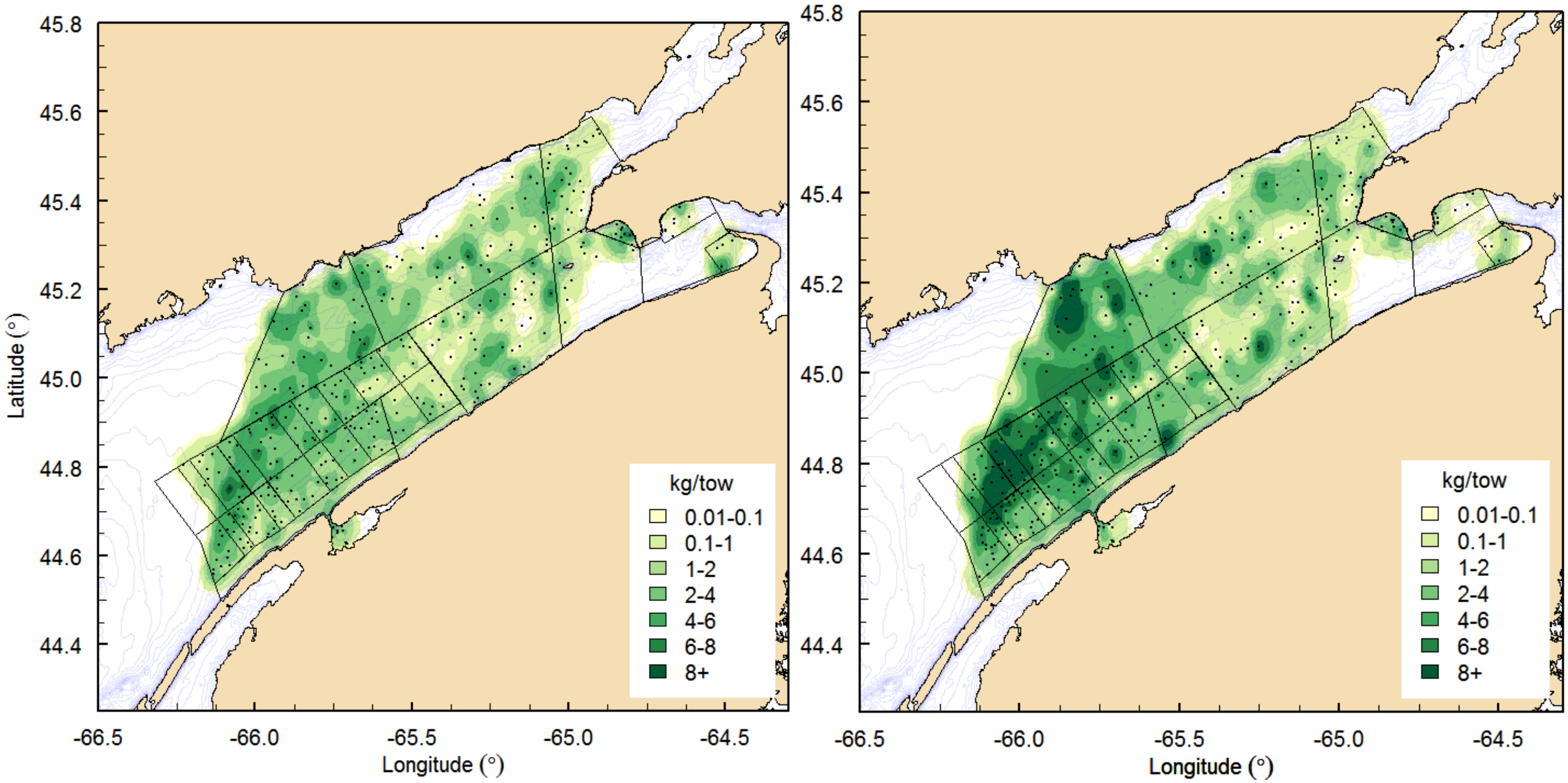

Figure 18. Spatial distribution of biomass (kg/tow) of commercial scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata.

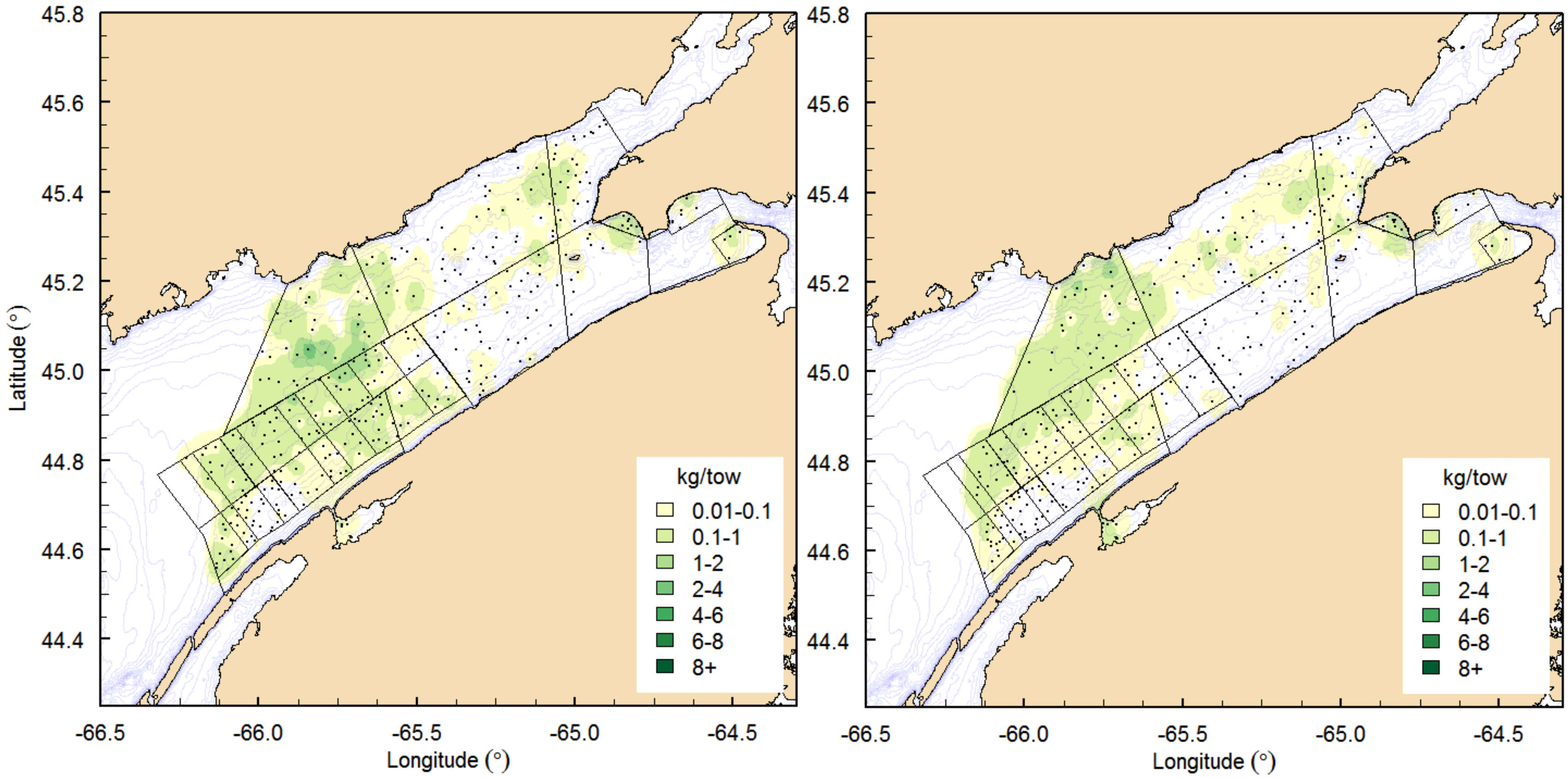

Figure 19. Spatial distribution of biomass (kg/tow) of recruit scallop in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata.

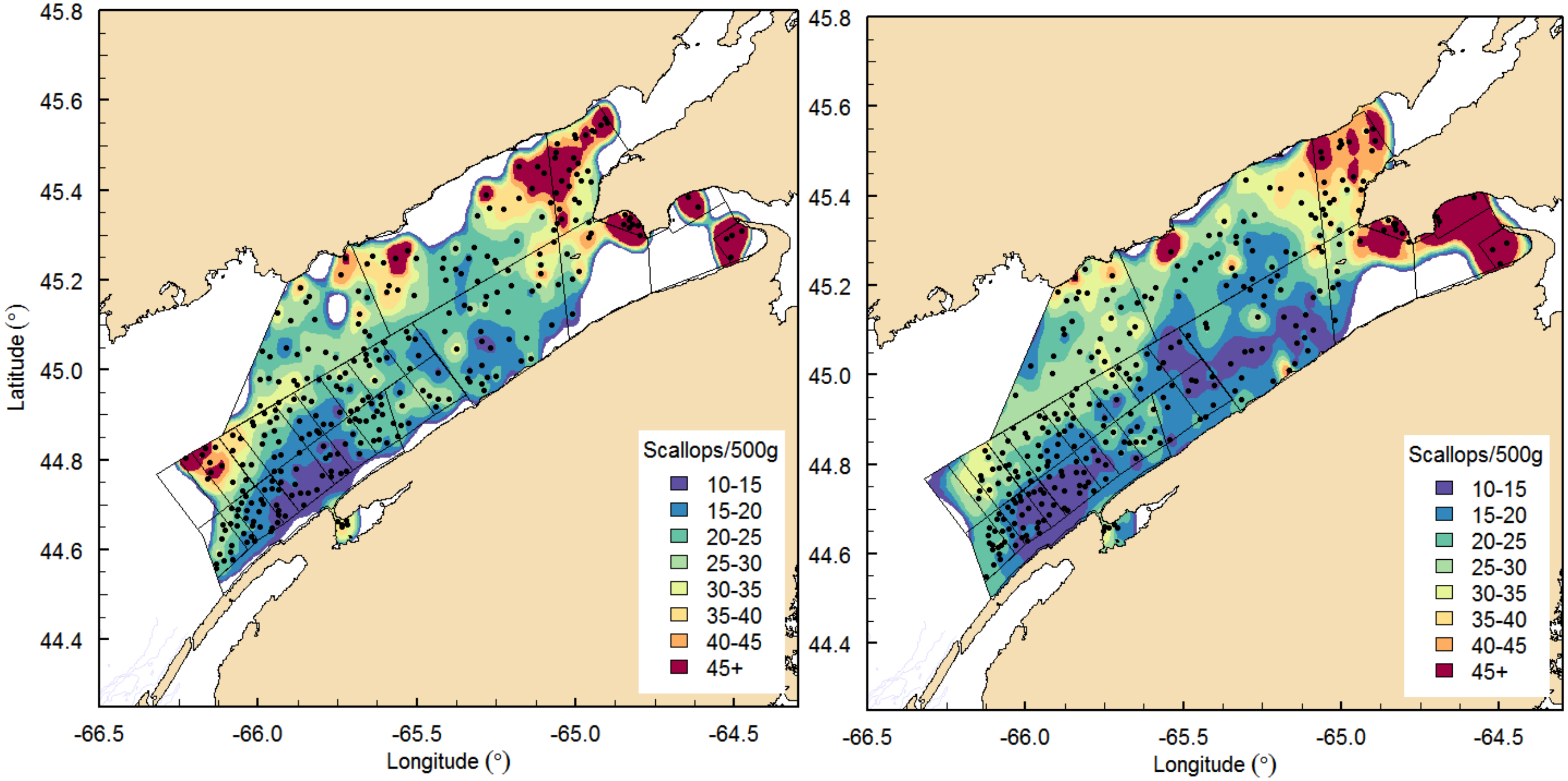

Figure 20. Spatial distribution of meat count (scallops/500 g) in Scallop Production Areas 1A, 1B, 4 and 5 in 2014 (left panel) and 2015 (right panel). Black lines represent survey strata. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

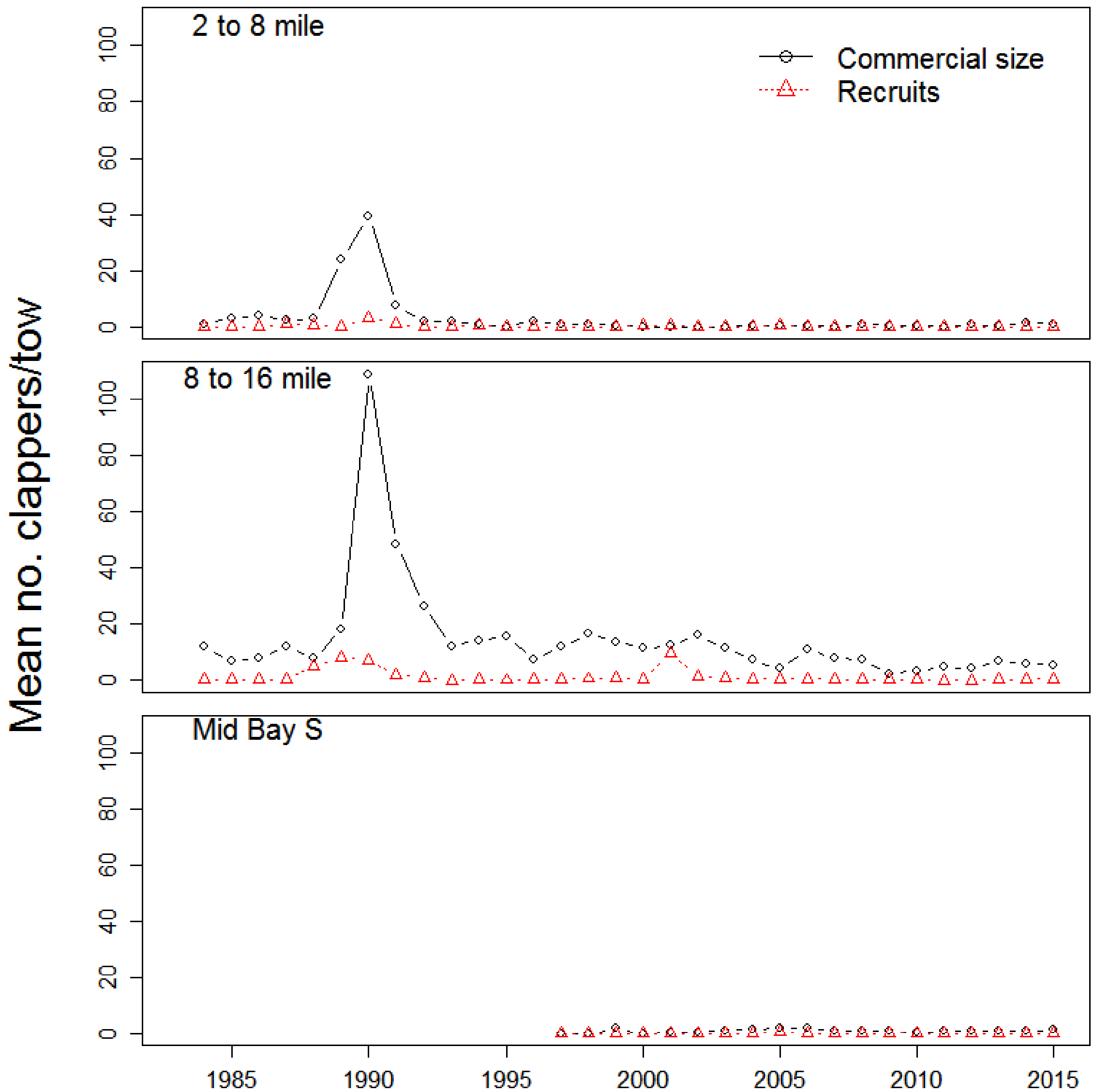

Figure 21. Mean number per tow of clappers (paired, dead shells) of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 1A: 2 to 8 mile (top panel), 8 to 16 mile (middle panel), and Middle Bay South (bottom panel) from 1997 to 2015.

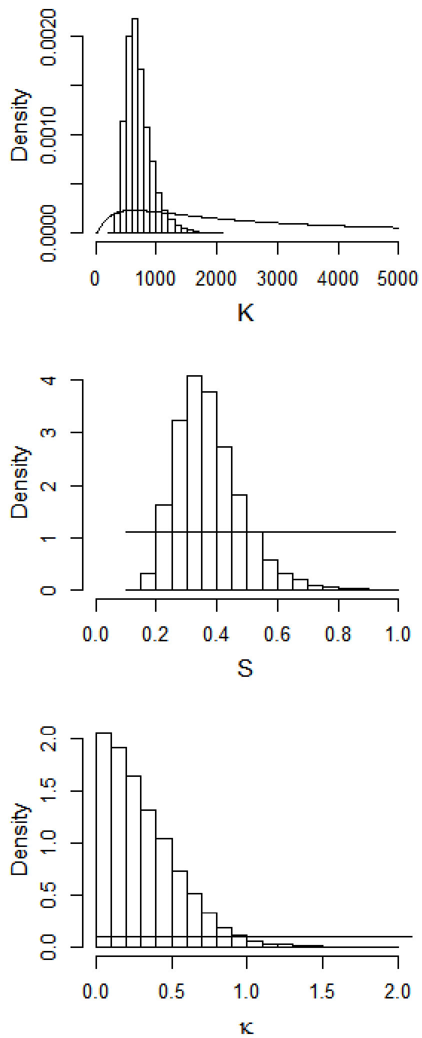

Figure 22. Comparison of prior (lines) and posterior densities (histogram) from the Bayesian state-space assessment model in Scallop Production Area 1A.

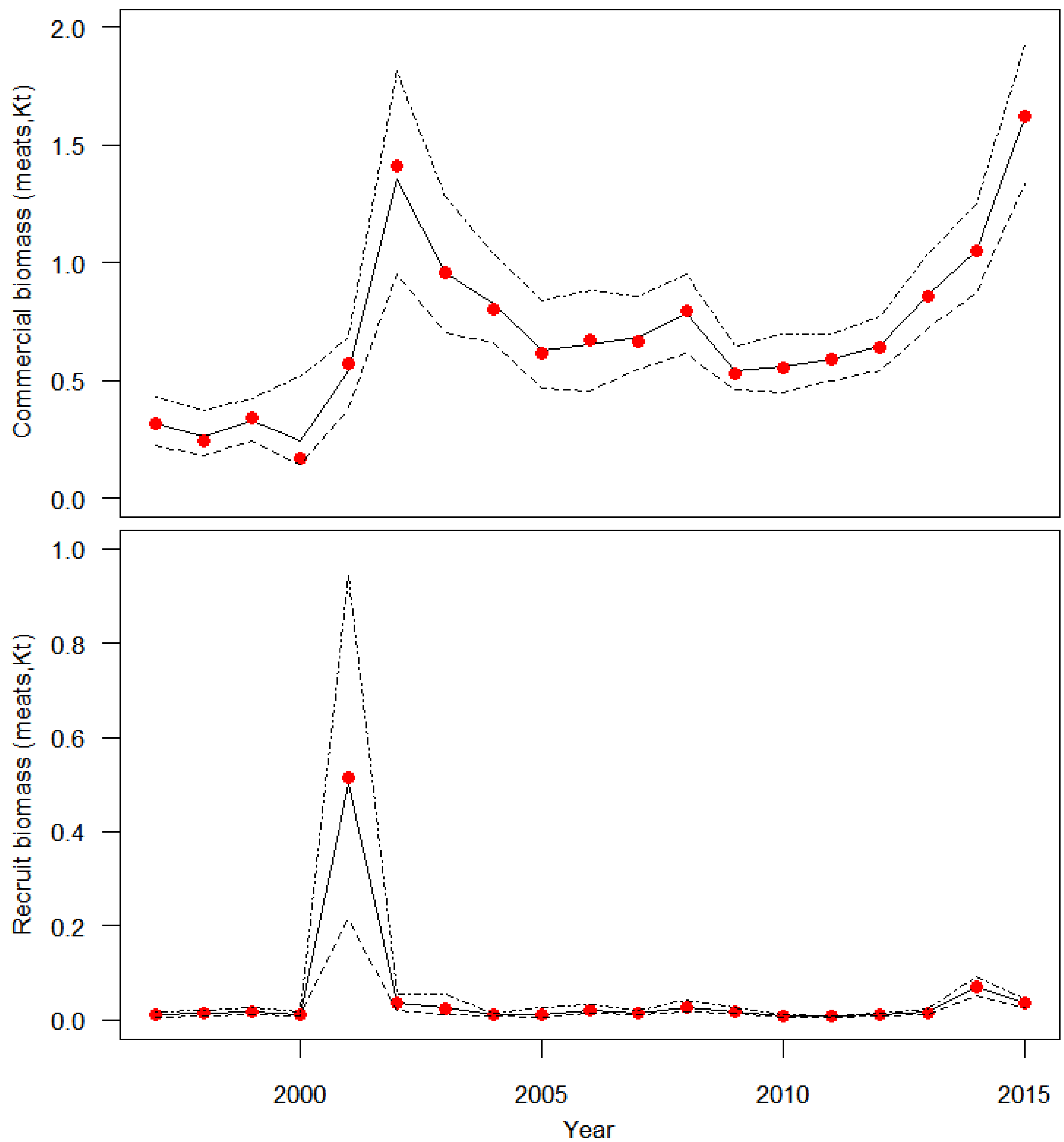

Figure 23. Posterior mean fit (solid black line) to the survey biomass series (red circles) of commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 1A from 1997 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

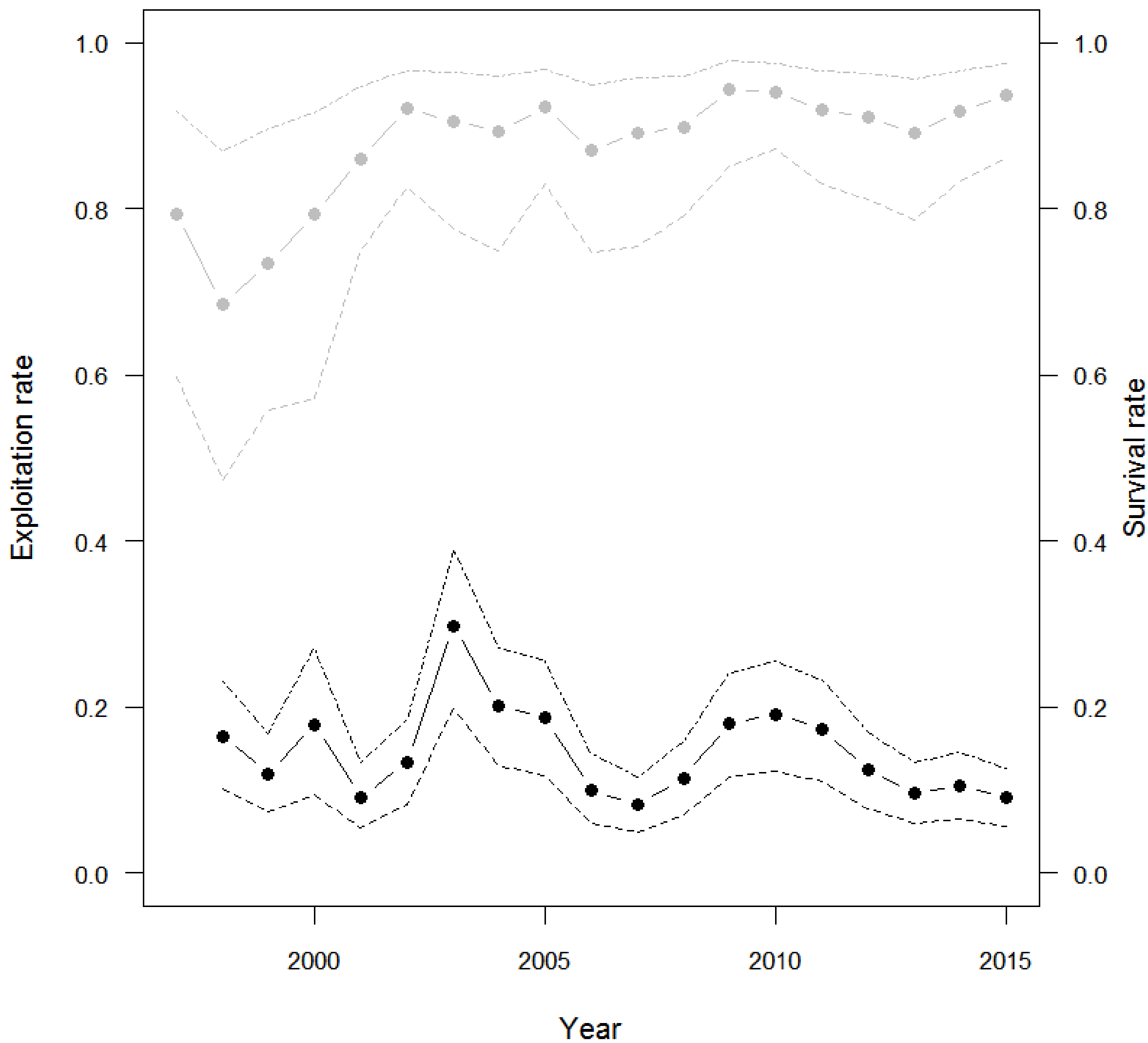

Figure 24. Annual trends (1997 to 2015) in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey circles) from the Bayesian state-space assessment model in Scallop Production Area 1A. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

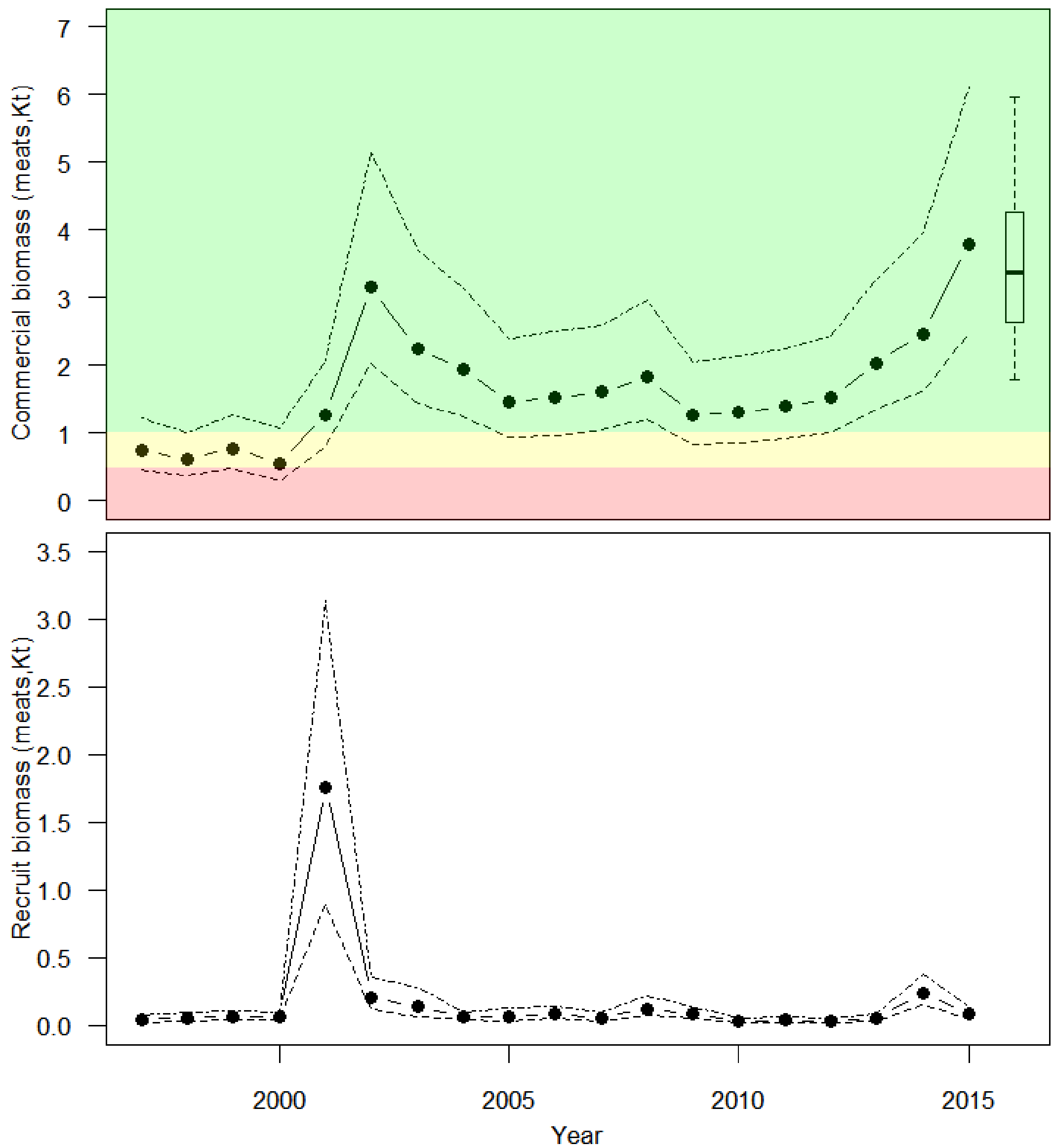

Figure 25. Biomass estimates for commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 1A, fit to survey and commercial data from 1997 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits on the estimates. The predicted commercial biomass for 2016 is displayed as a box plot with median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). This prediction assumes the initial total allowable catch of 180 t for this area is caught. The green-shaded area represents the healthy zone (based on an upper stock reference of 1000 t), yellow area represents the cautious zone (based on a lower reference point (LRP) of 480 t) and the red is the critical zone (< LRP).

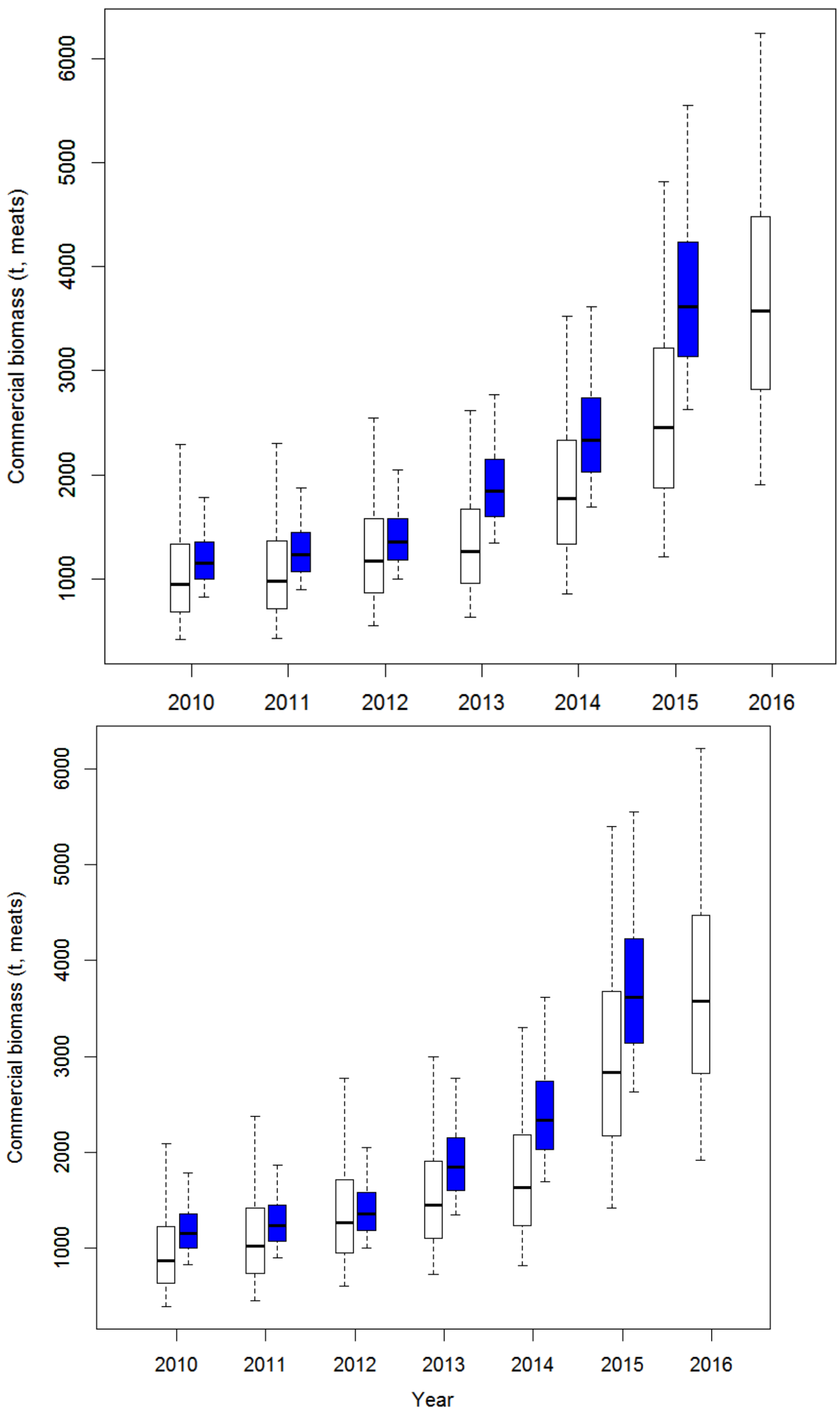

Figure 26. Evaluation of the model projection performance from 2010 to 2015 in Scallop Production Area 1A. White box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2010 predictions based on data up to 2009). Blue box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t. Upper panel projections use estimated weight from year t to t+1, and lower panel projections use actual growth rate from year t to t+1 to evaluate projections if growth had been known. Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projection for 2016 assumes the initial total allowable catch of 180 t for this area is caught.

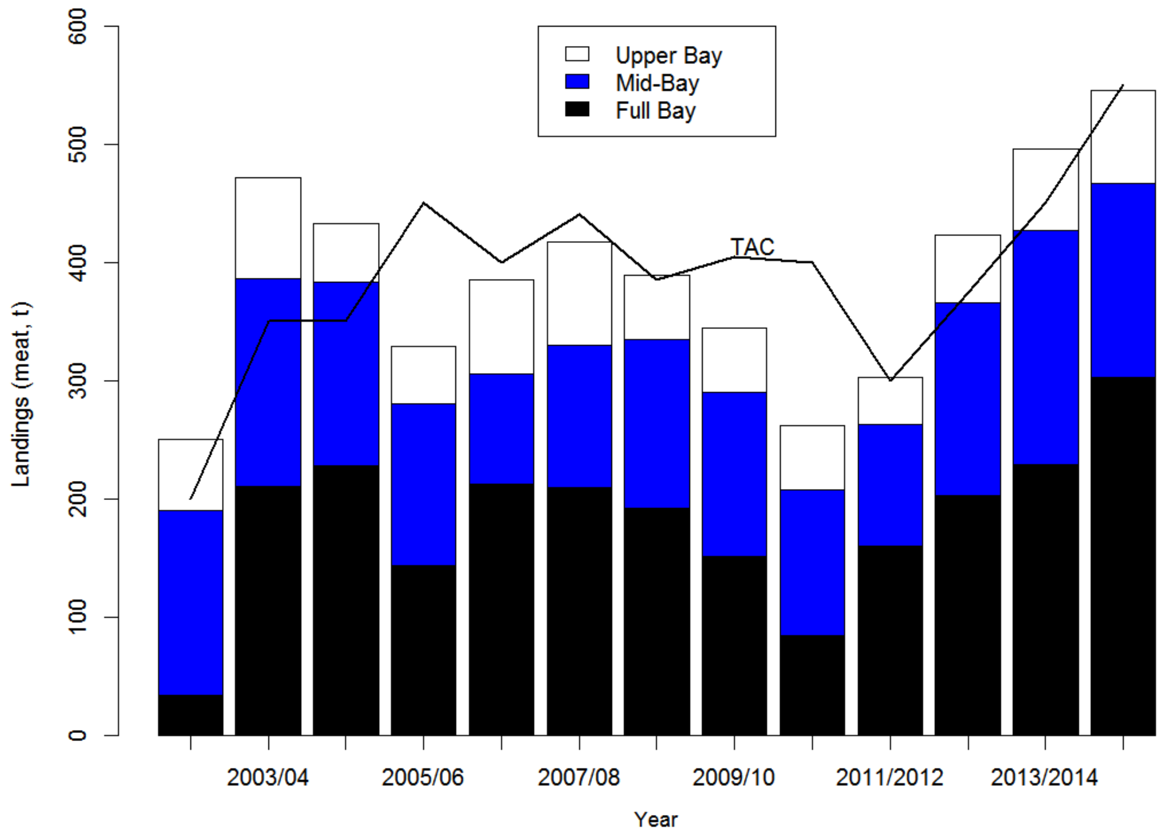

Figure 27. Combined total allowable catch (TAC, t; black line) and landings (bars, t) in Scallop Production Area 1B for the Full Bay fleet (black bars), Mid Bay fleet (blue bars), and Upper Bay fleet (white bars), from 2002/2003 to 2014/2015.

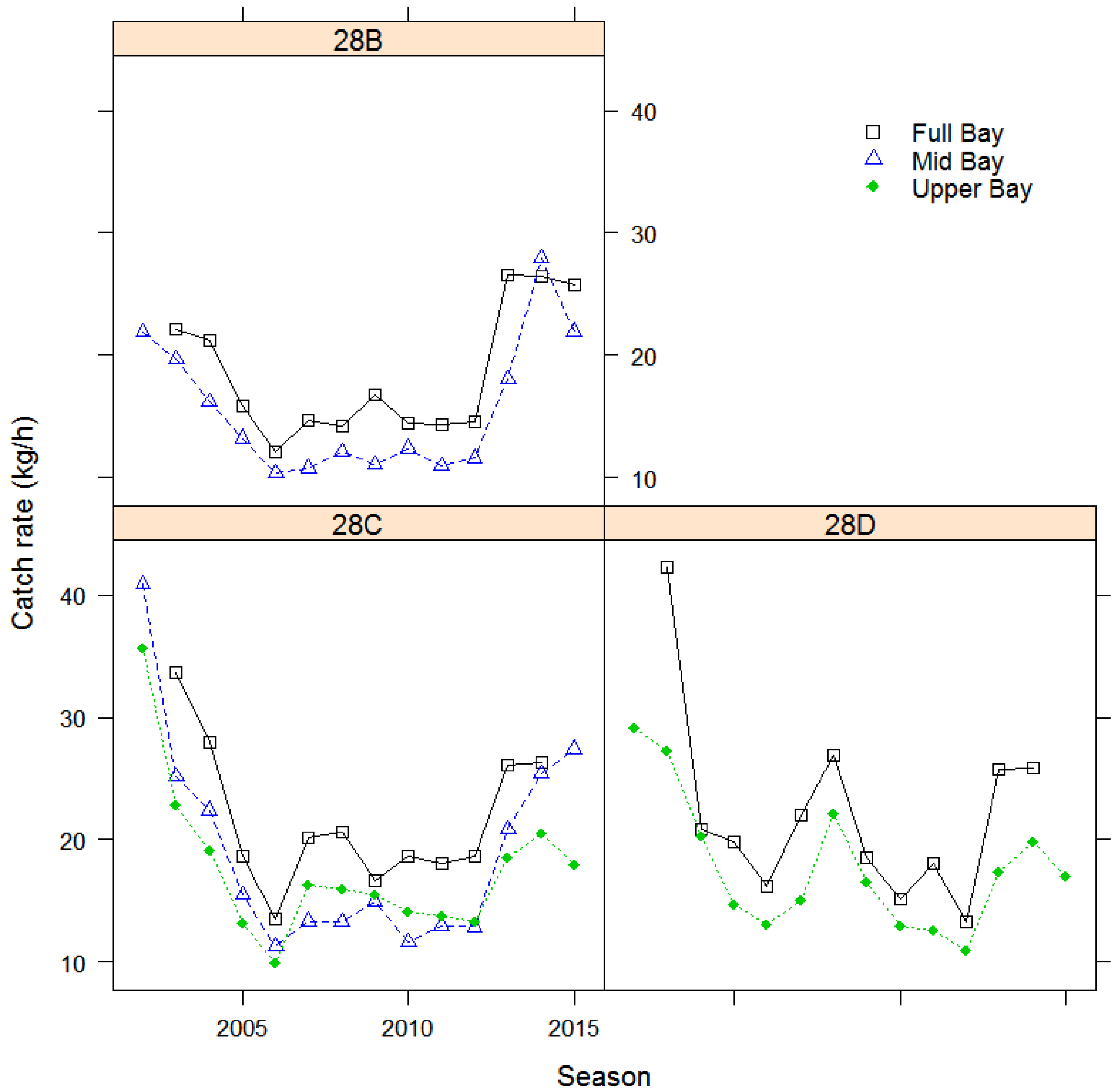

Figure 28. Catch per unit effort (CPUE, kg/h) for the three fleets in Scallop Production Area 1B: Full Bay (black squares), Mid Bay (blue triangles), and Upper Bay (solid green diamond) fishery from 2002 to 2015 in 28B (top panel), 28C (bottom left panel), and 28D (bottom right panel). Note Full Bay fished in 28C and 28D in 2015 however there were too few records to display.

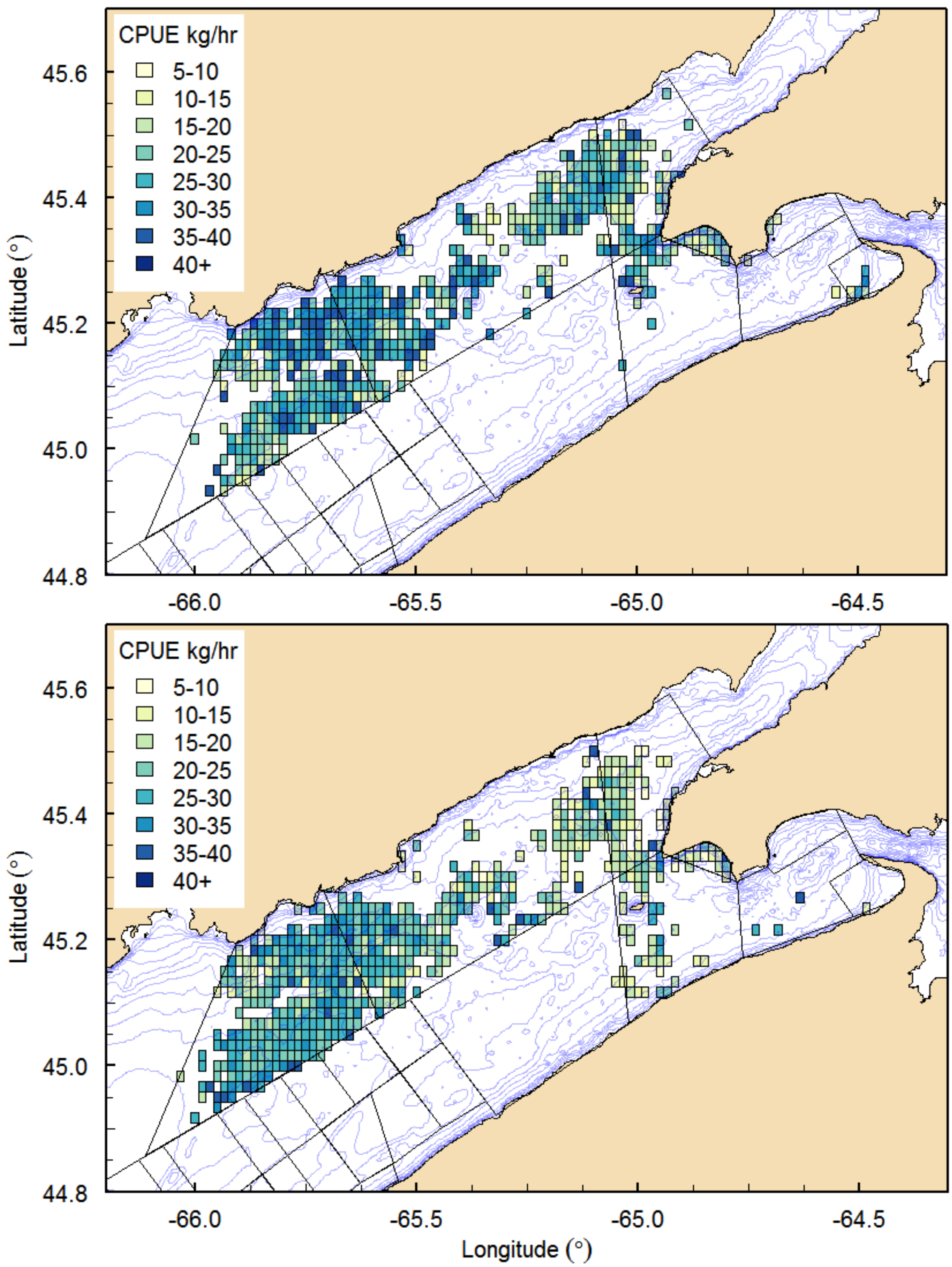

Figure 29. Spatial distribution of catch per unit effort (CPUE, kg/h) in the Scallop Production Area 1B fishery for the 2014 (top panel) and 2015 (bottom panel) fishing years. Black lines represent survey strata.

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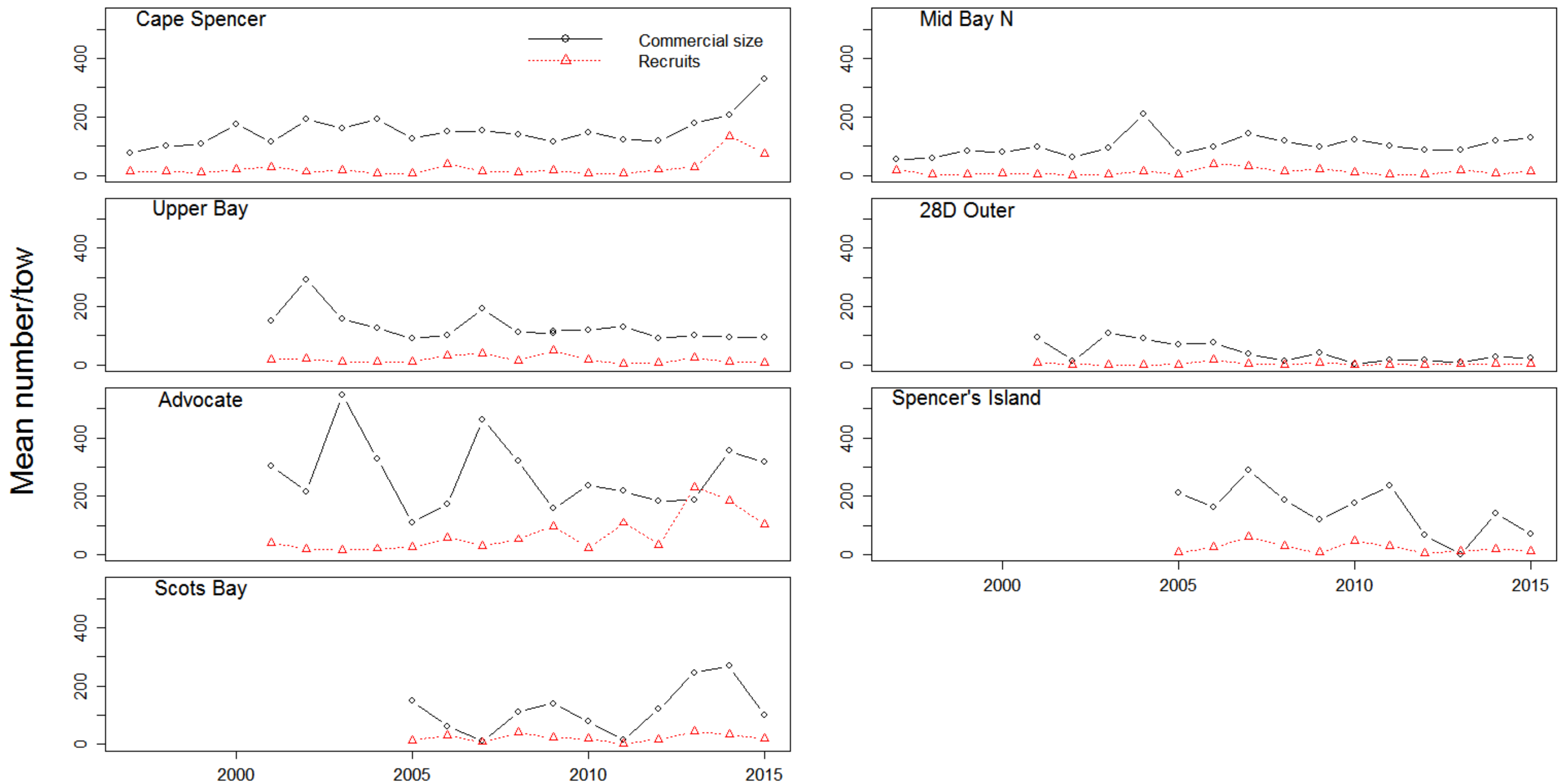

Figure 30. Mean number per tow of commercial (black circles) and recruit (red triangle) sized scallops in the seven subareas of Scallop Production Area 1B; left side panels from top to bottom: Cape Spencer (1997 to 2015), Upper Bay 28C (2001 to 2015), Advocate Harbour (2001 to 2015), Scots Bay (2005 to 2015), and right side panels top to bottom: Middle Bay North (1997 to 2015), 28D Outer (2001 to 2015) and Spencer's Island (2005 to 2015).

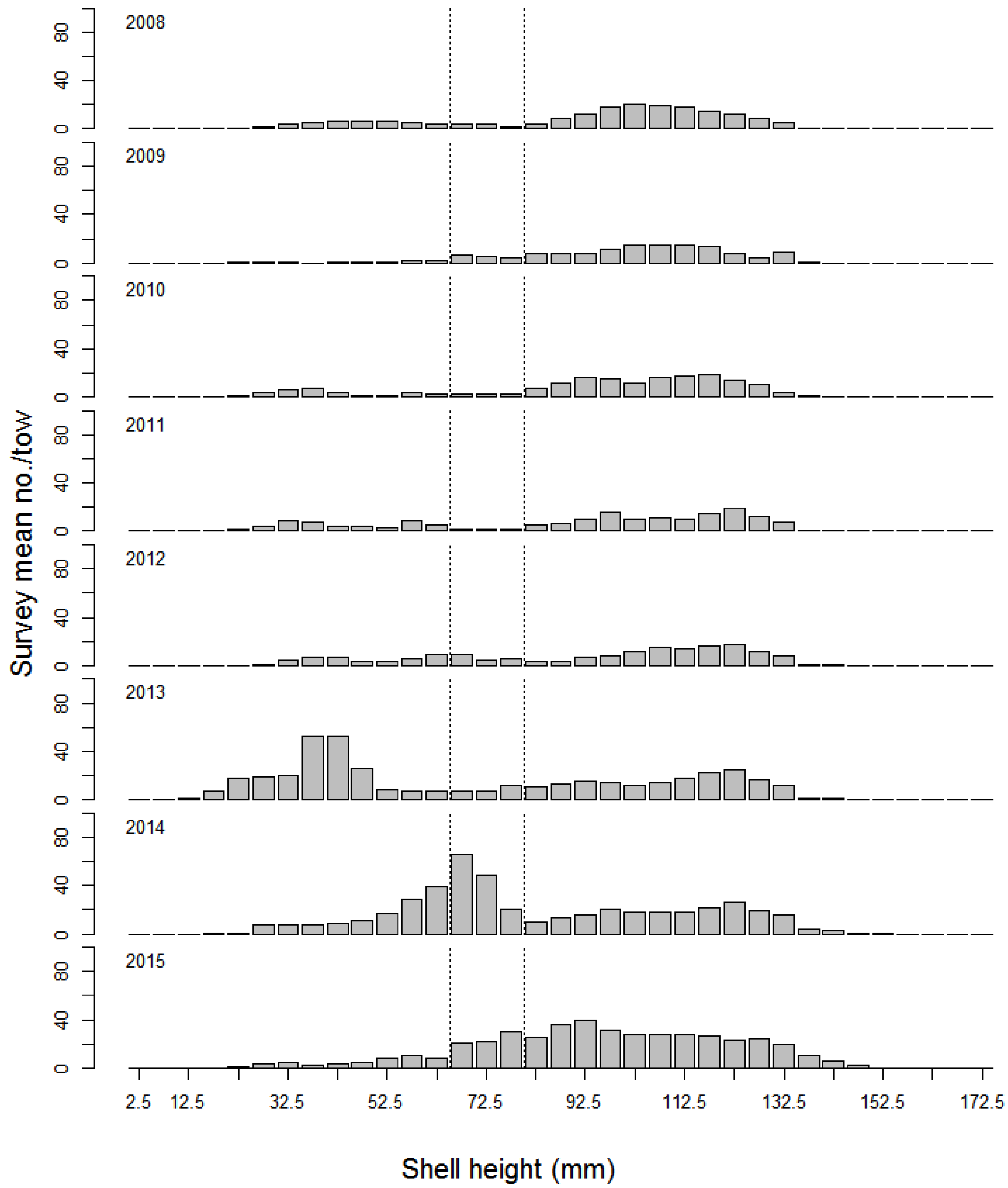

Figure 31. Shell height (mm) frequency (mean number/tow) for the Cape Spencer subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

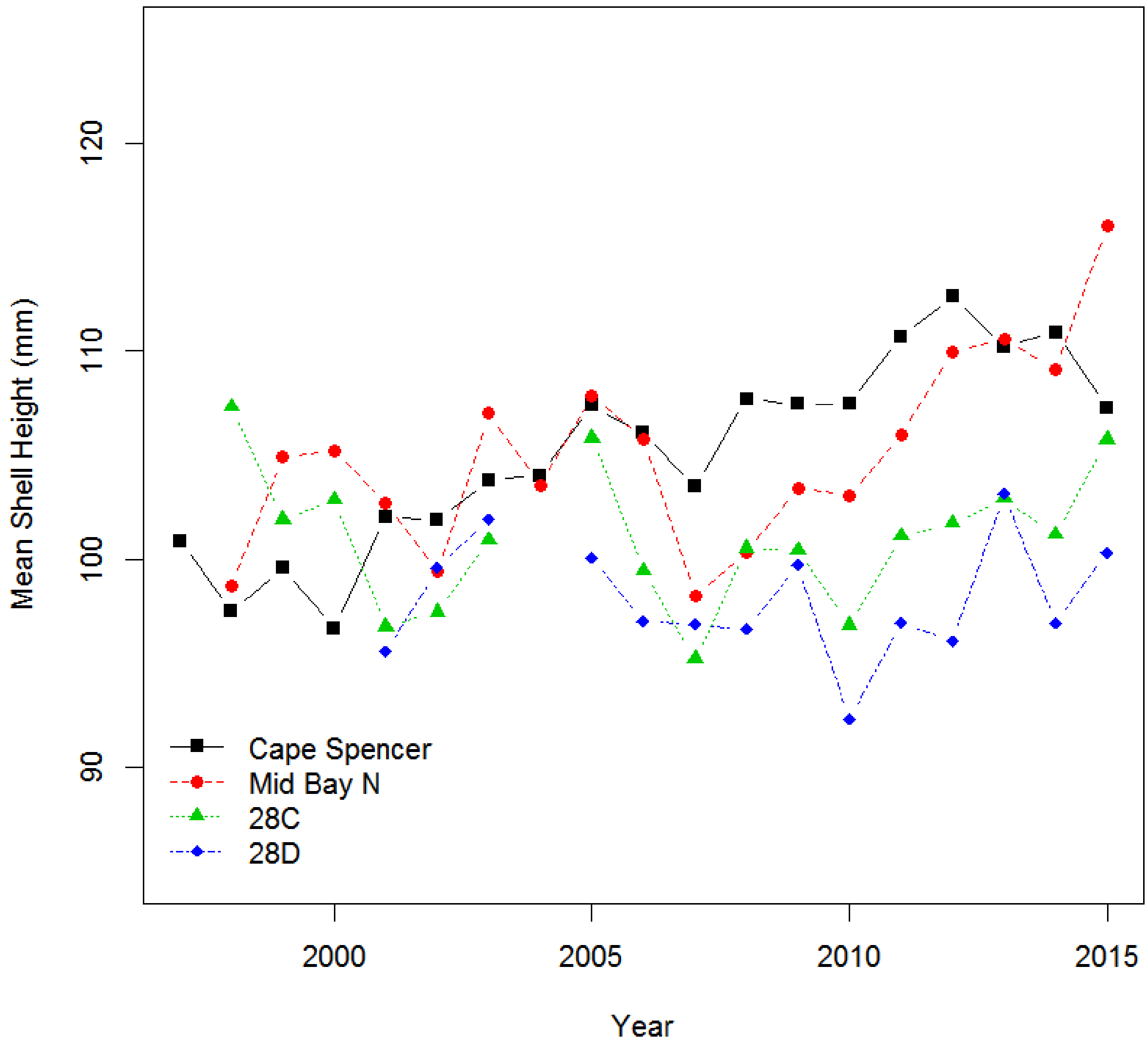

Figure 32. Mean shell height (mm) of commercial size scallops in four subareas of Scallop Production Area 1B: Cape Spencer (black square), Middle Bay North (red circle), Upper Bay 28C (green triangle), and 28D (Outer, Advocate Harbour, Scots Bay and Spencer's Island; blue diamond) from 1997 to 2015.

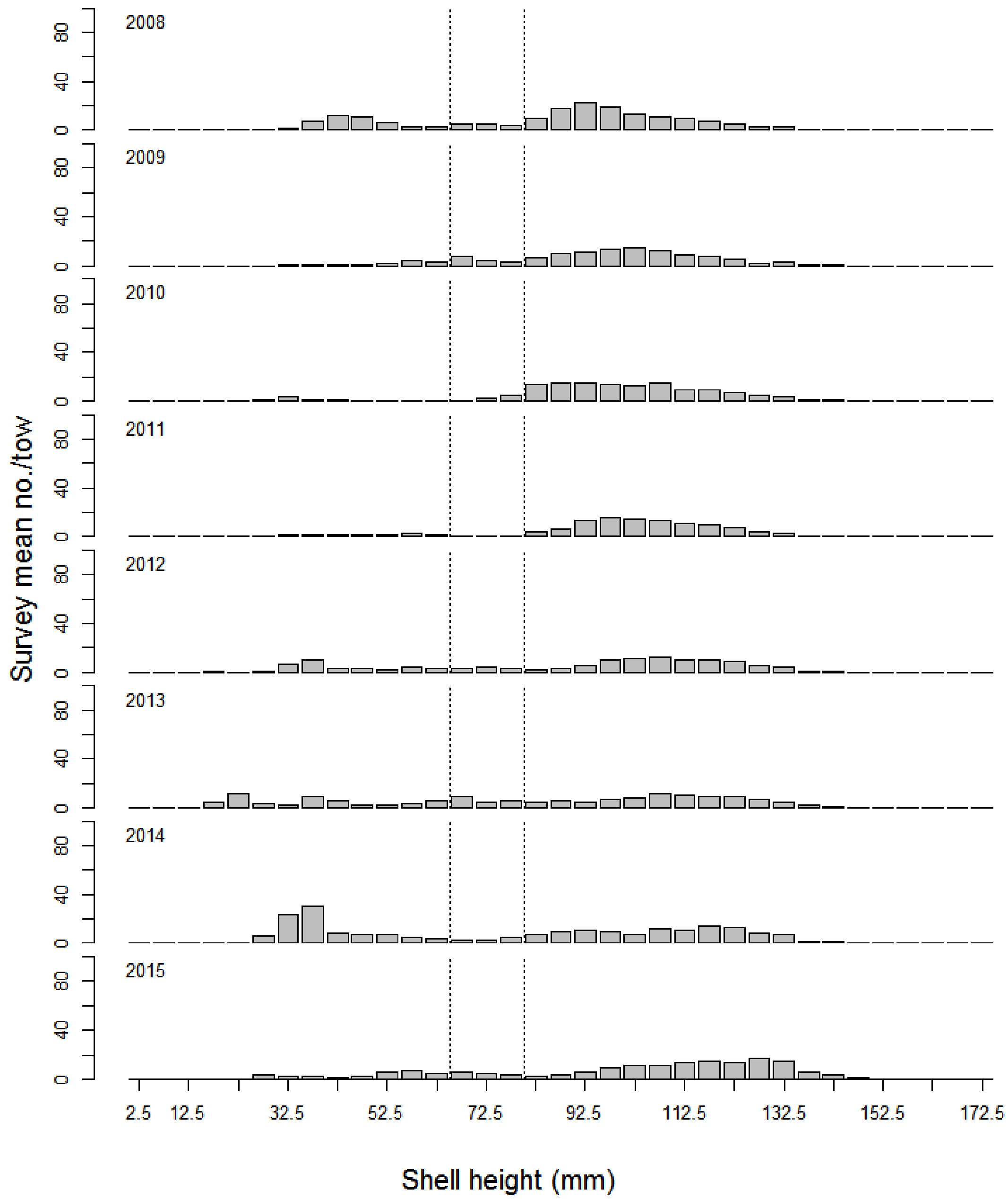

Figure 33. Shell height (mm) frequency (mean number/tow) for the Middle Bay North subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

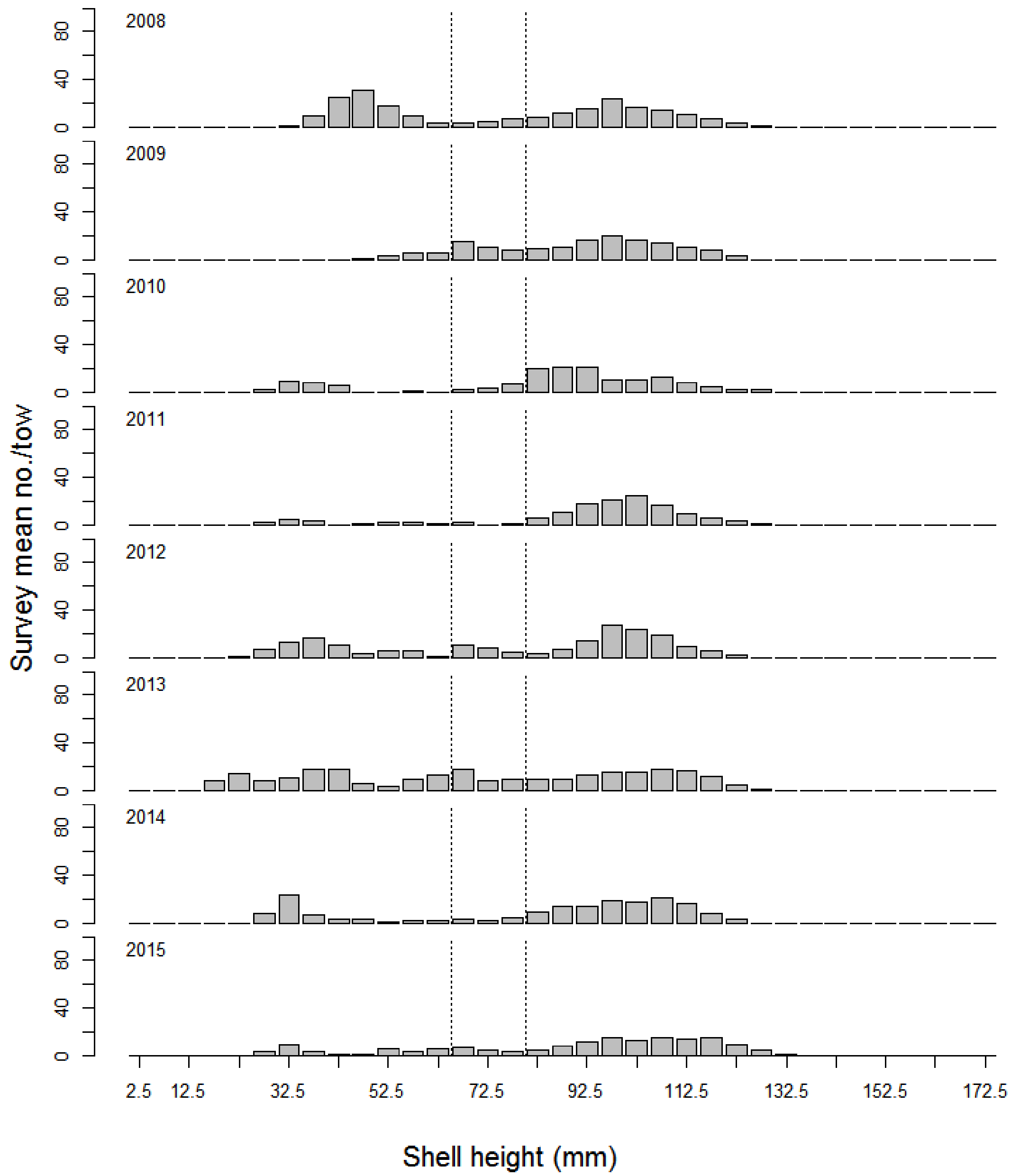

Figure 34. Shell height (mm) frequency (mean number/tow) for the Upper Bay 28C subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

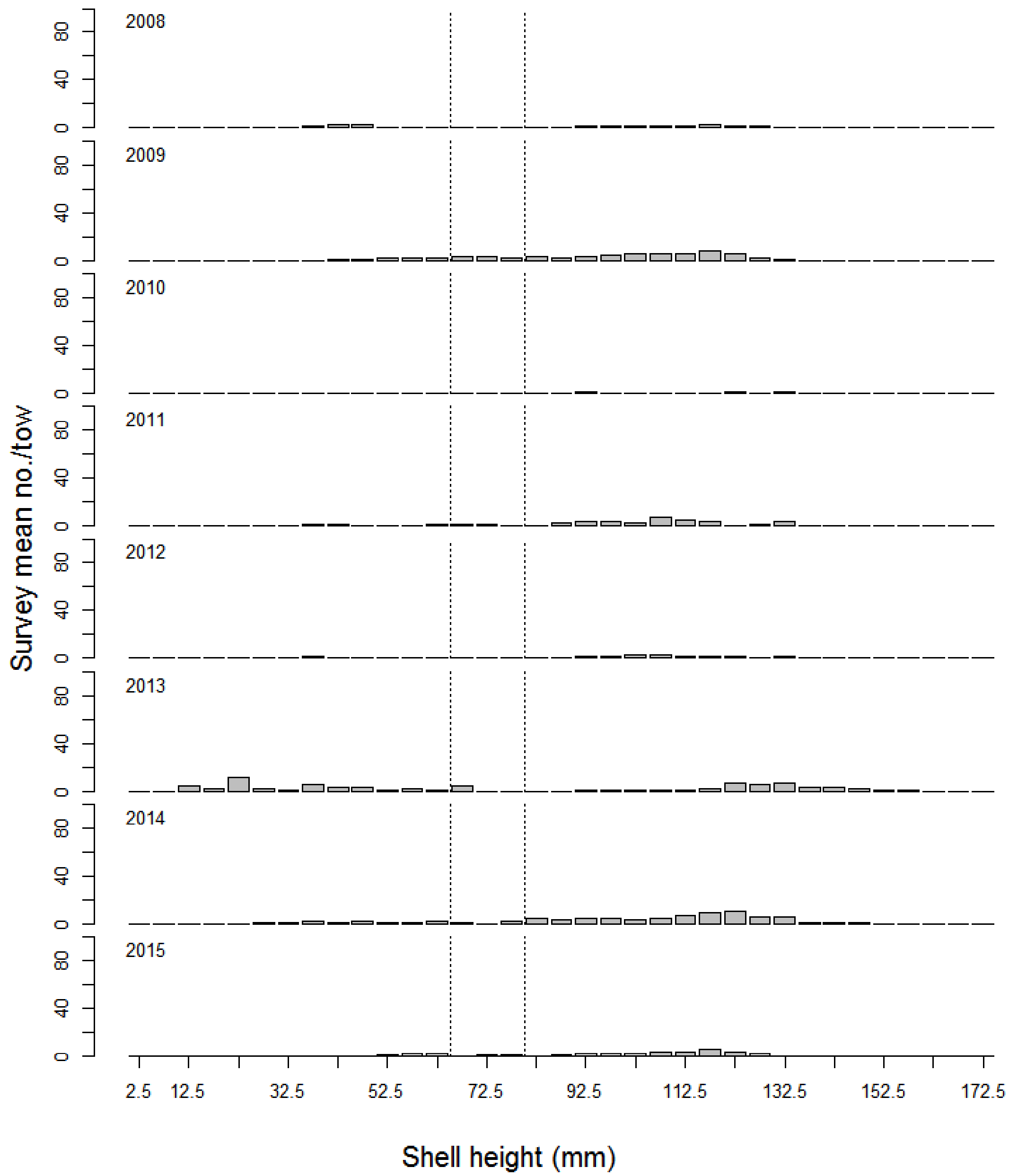

Figure 35. Shell height (mm) frequency (mean number/tow) for the 28D Outer subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

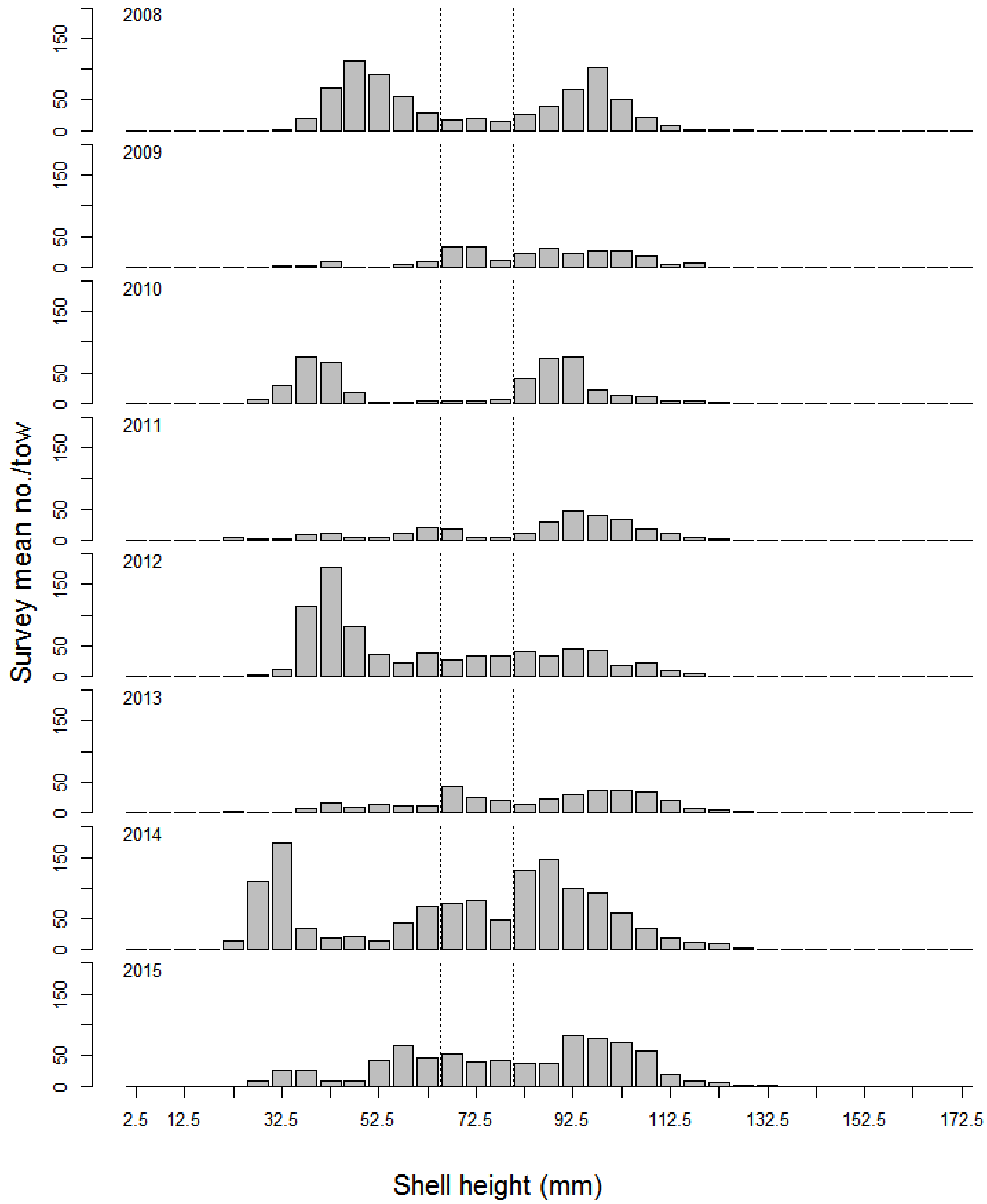

Figure 36. Shell height (mm) frequencies (mean number/tow) for the Advocate Harbour subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

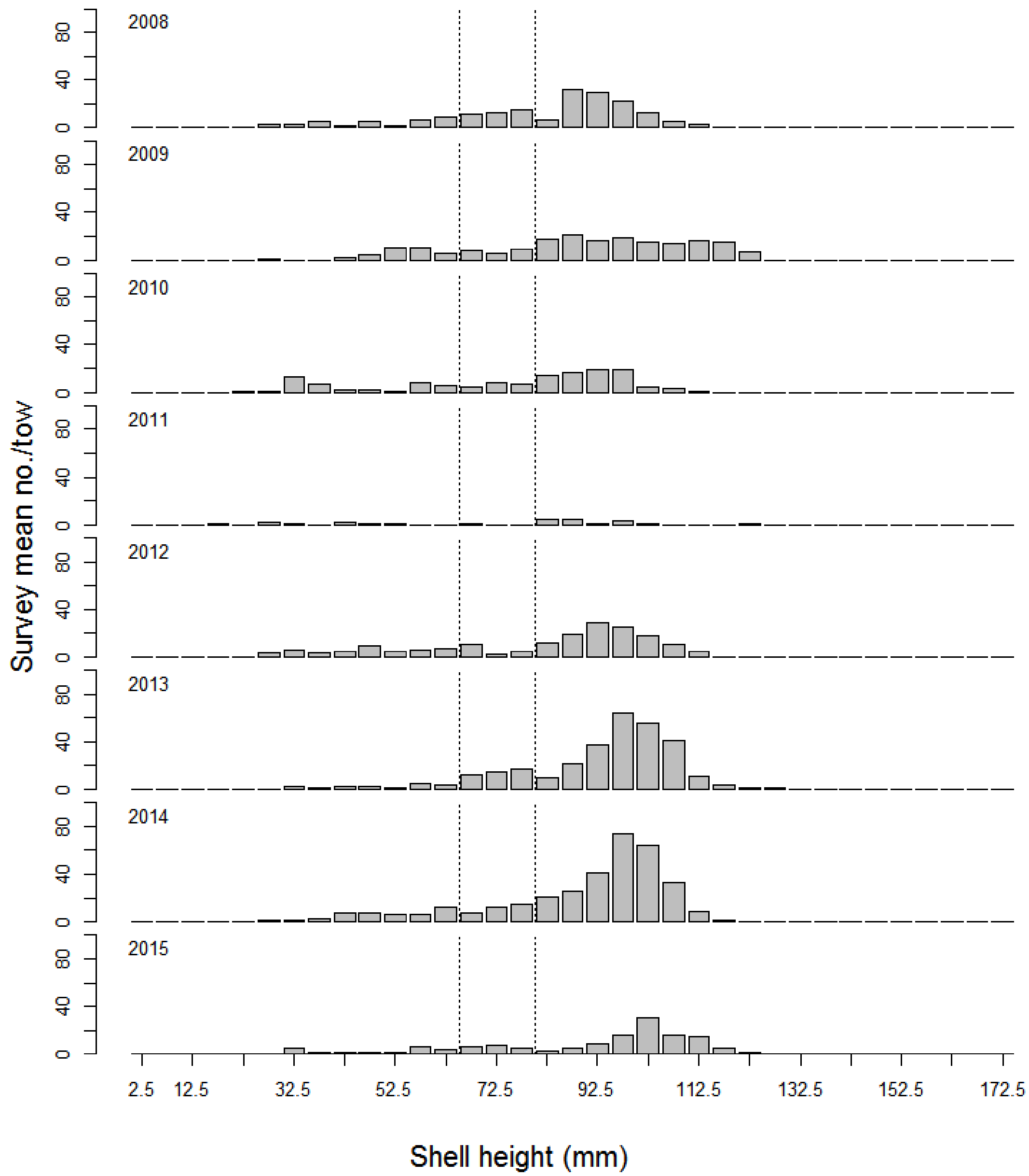

Figure 37. Shell height (mm) frequency (mean number/tow) for the Scots Bay subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

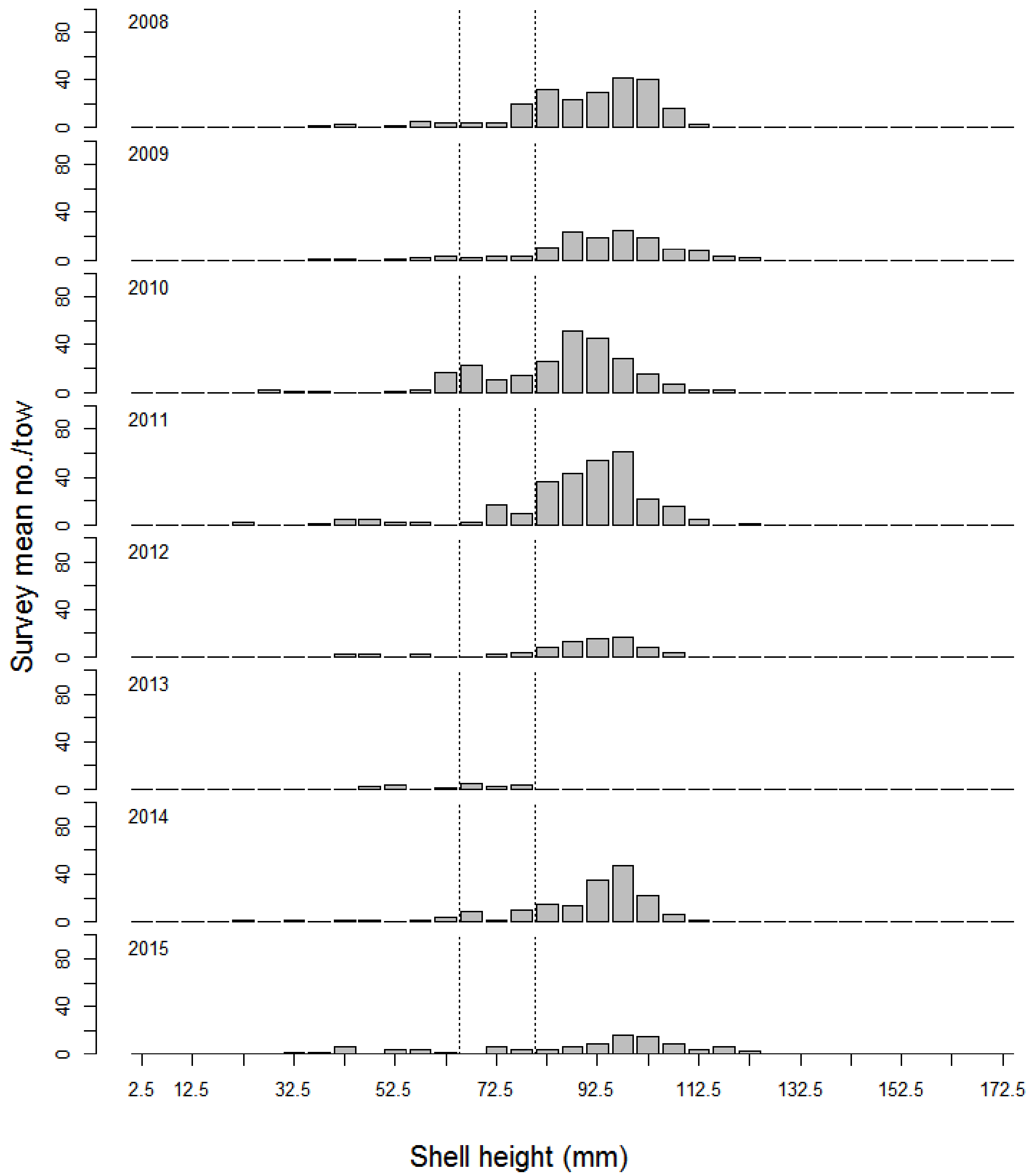

Figure 38. Shell height (mm) frequency (mean number/tow) for the Spencer's Island subarea of Scallop Production Area 1B, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

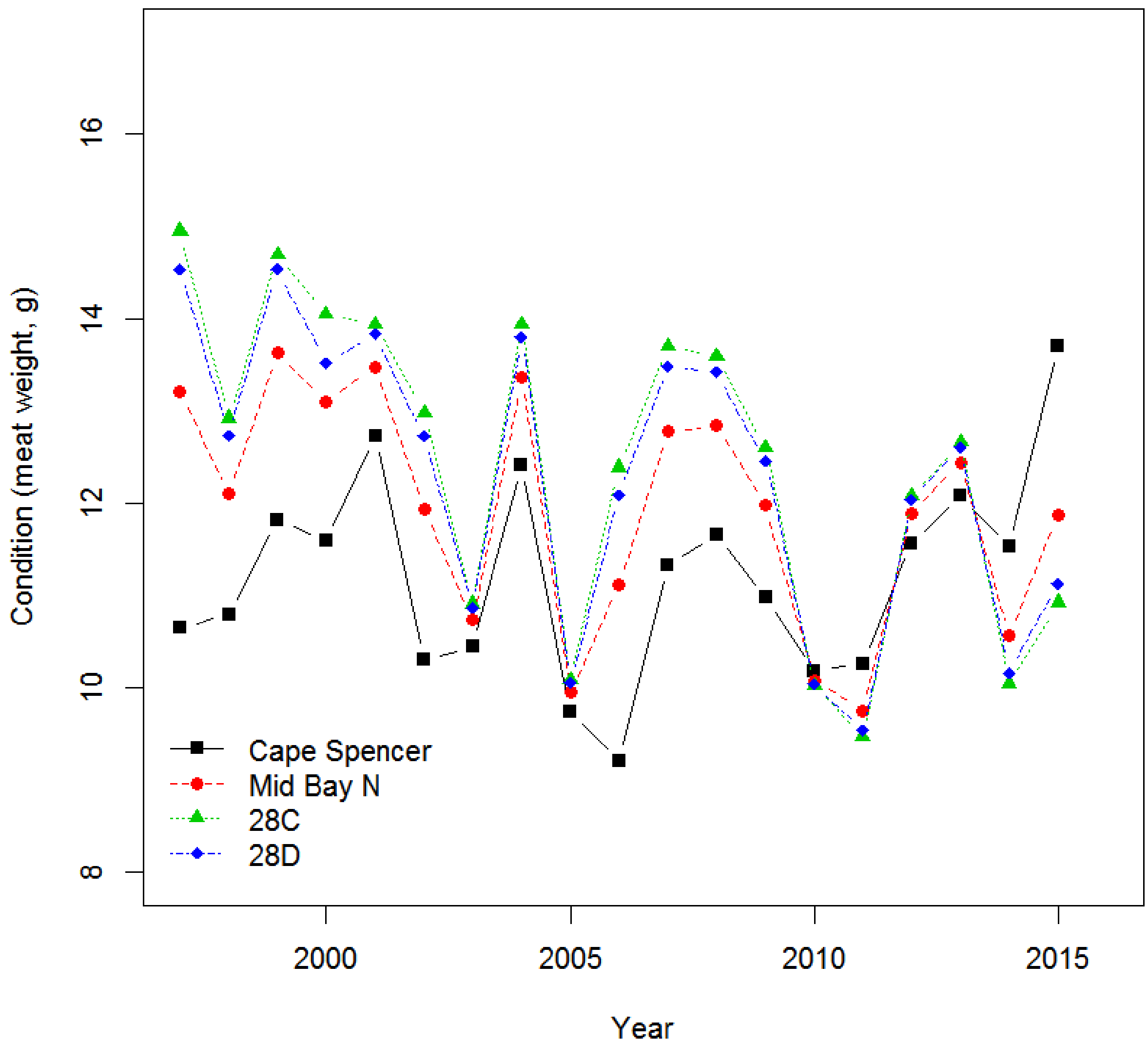

Figure 39. Condition (meat weight, g) for a shell of 100 mm in four subareas of Scallop Production Area 1B: Cape Spencer (black square), Middle Bay North (red circle), Upper Bay 28C (green triangle), and 28D (Outer, Advocate Harbour, Scots Bay and Spencer's Island; blue diamond) from 1997 to 2015.

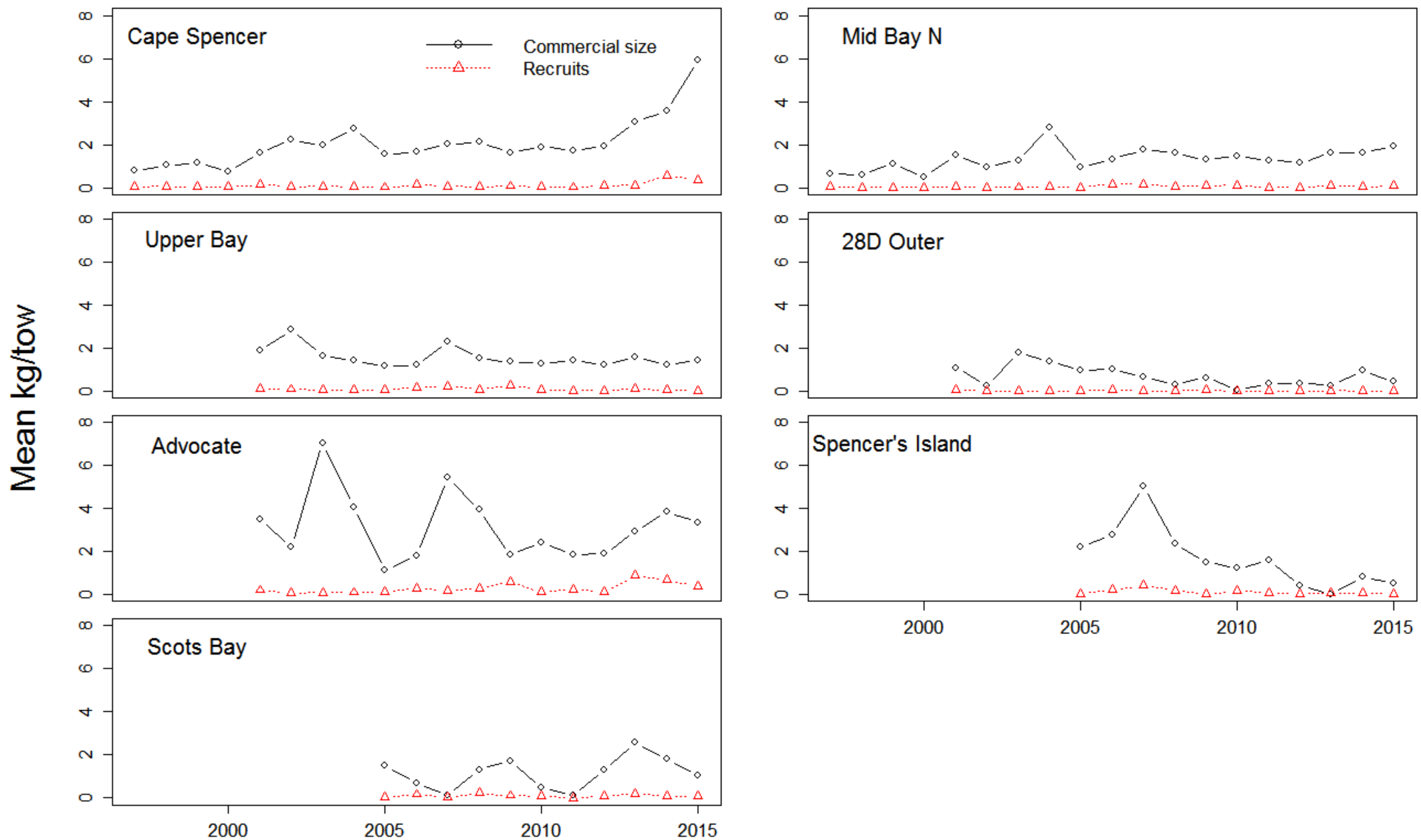

Figure 40. Mean weight (kg) per tow of commercial (black circles) and recruit (red triangle) sized scallops in the seven subareas of Scallop Production Area 1B; left side panels from top to bottom: Cape Spencer (1997 to 2015), Upper Bay 28C (2001 to 2015), Advocate Harbour (2001 to 2015), Scots Bay (2005 to 2015), and right side panels top to bottom: Middle Bay North (1997 to 2015), 28D Outer Bay (2001 to 2015) and Spencer's Island (2005 to 2015).

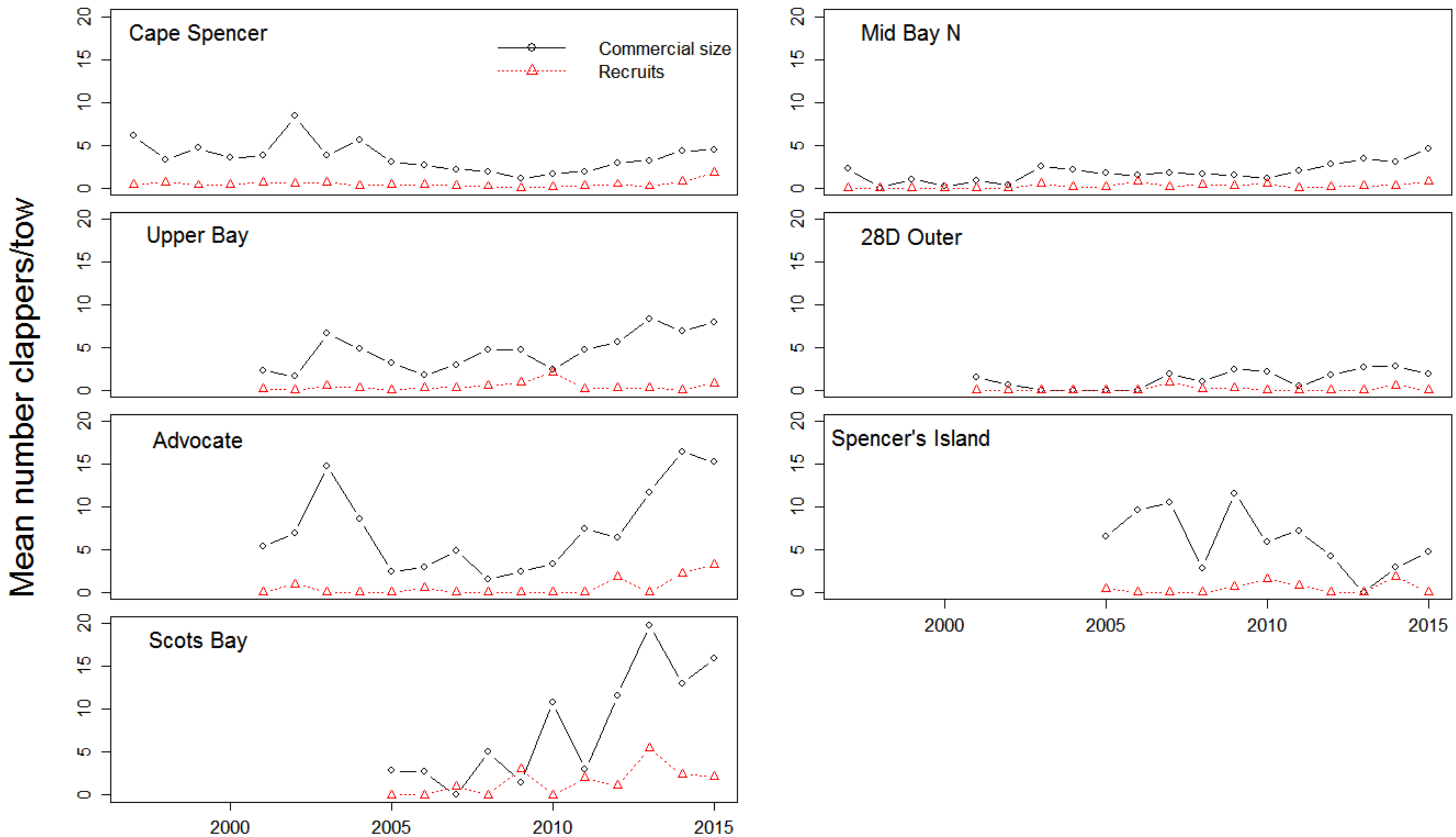

Figure 41. Mean number per tow of clappers (paired, dead shells) of commercial (black circles) and recruit (red triangle) sized scallops in the seven subareas of Scallop Production Area 1B; left side panels from top to bottom: Cape Spencer (1997 to 2015), Upper Bay 28C (2001 to 2015), Advocate Harbour (2001 to 2015), Scots Bay (2005 to 2015), and right side panels top to bottom: Middle Bay North (1997 to 2015), 28D Outer Bay (2001 to 2015) and Spencer's Island (2005 to 2015).

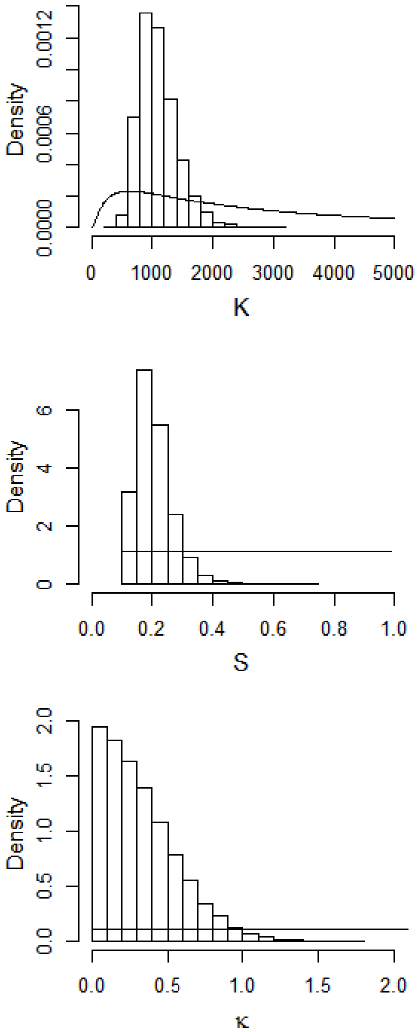

Figure 42. Comparison of prior (lines) and posterior densities (historgram) from the Bayesian state-space assessment model in Scallop Production Area 1B.

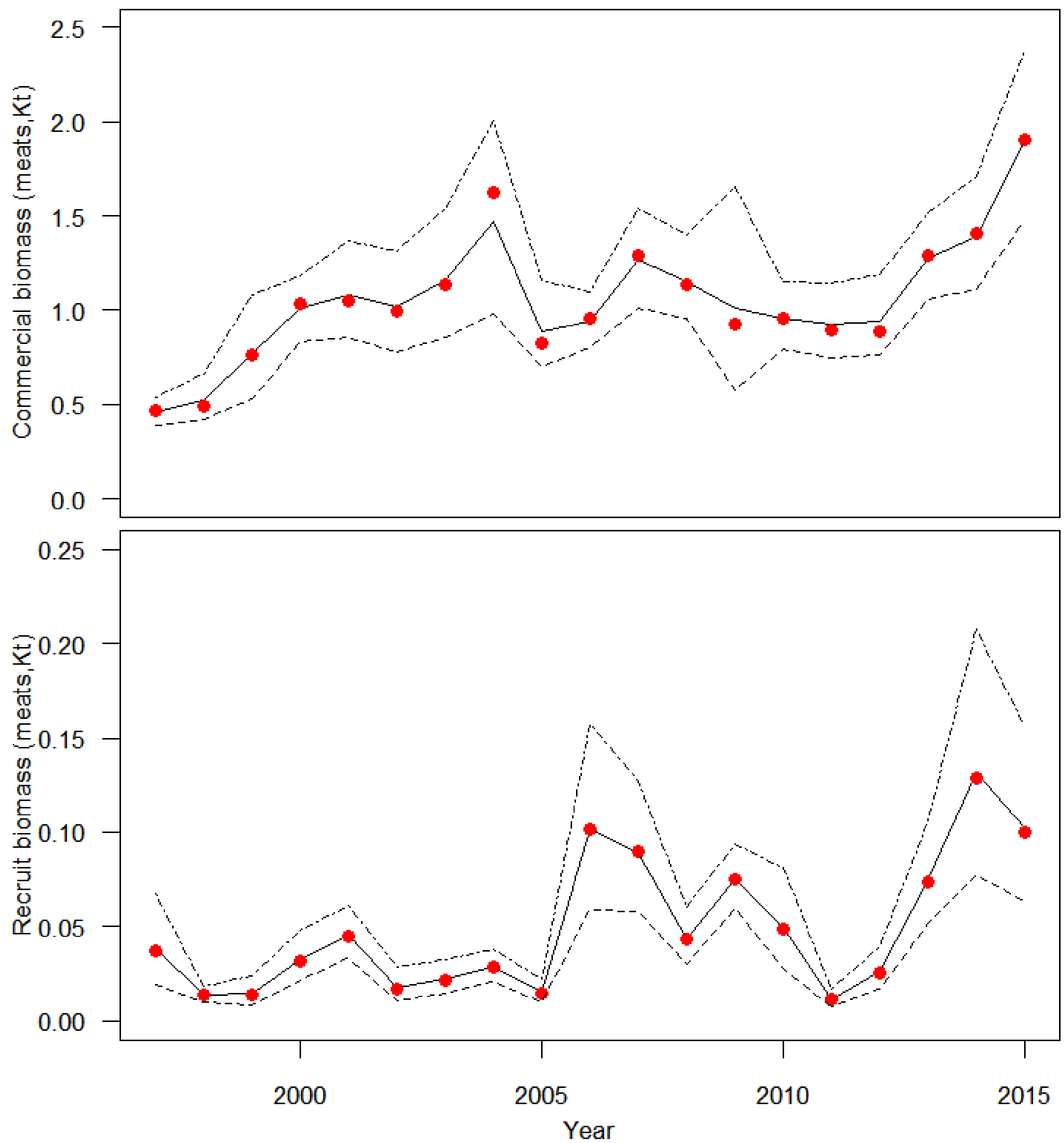

Figure 43. Posterior mean fit to the survey biomass series of commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 1B from 1997 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

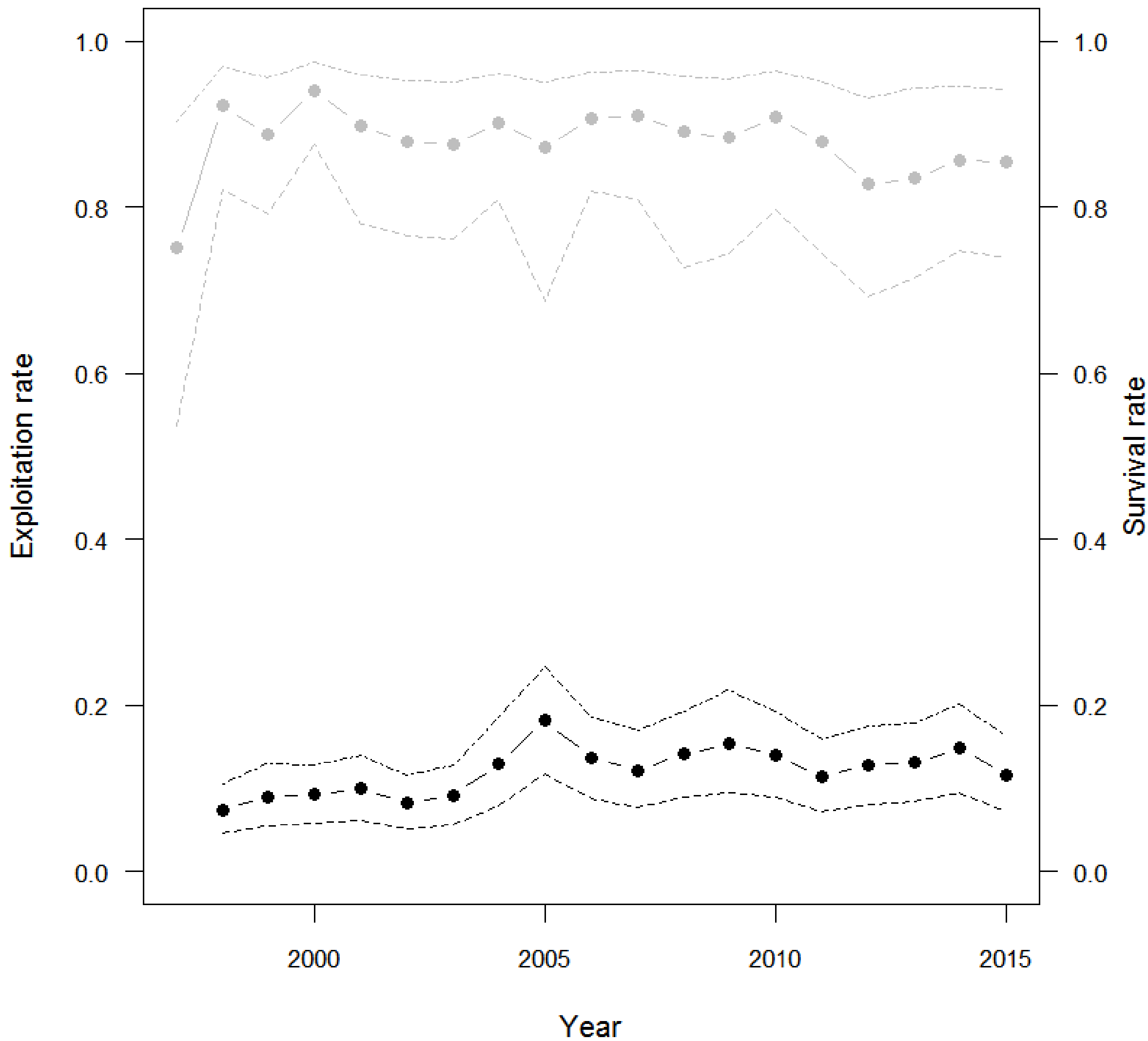

Figure 44. Annual trends (1997 to 2015) in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey circles) from the Bayesian state-space assessment model in Scallop Production Area 1B. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

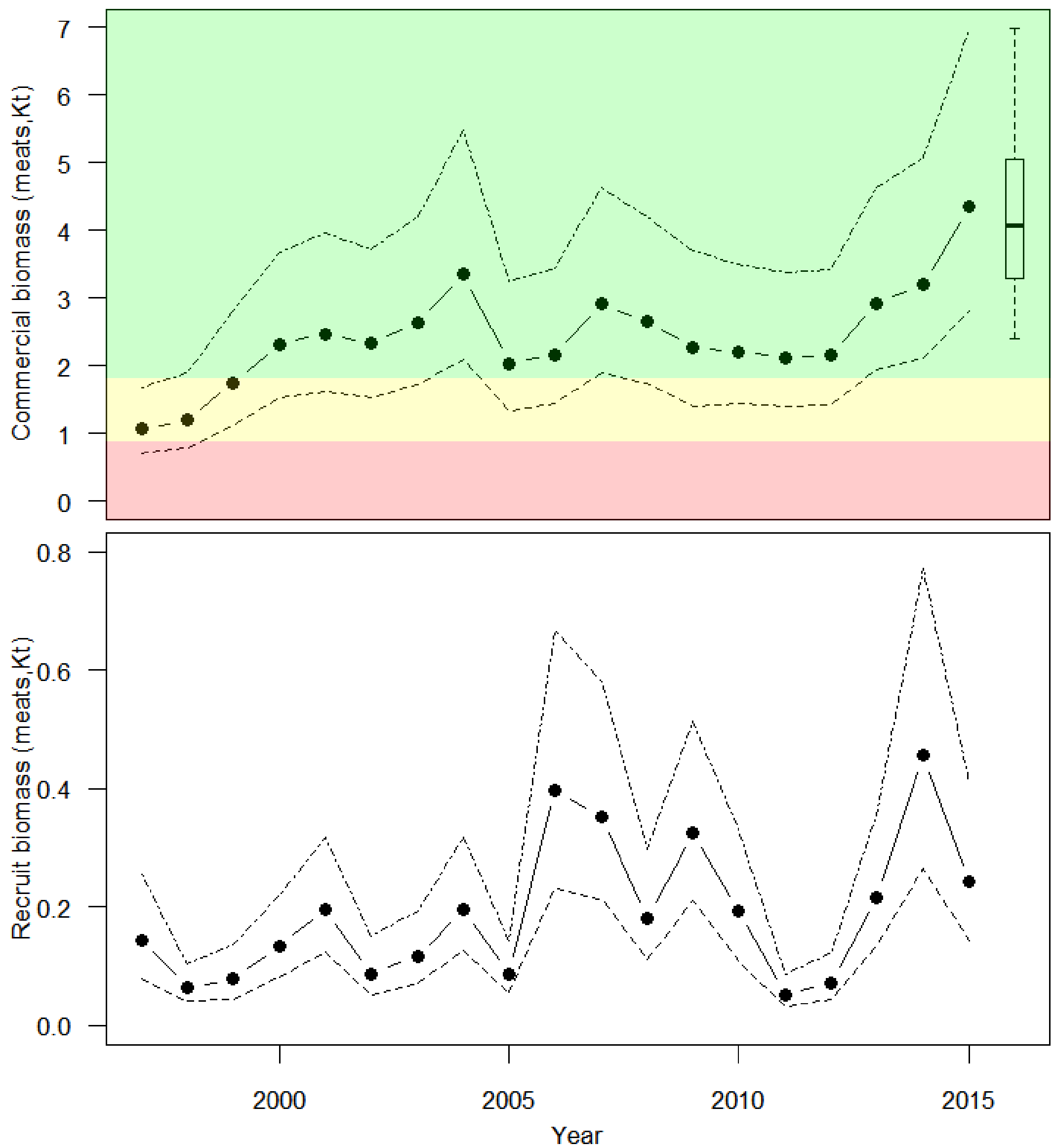

Figure 45. Biomass estimates for commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 1B, fit to survey and commercial data from 1997 to 2015. Dashed lines are the upper (dotted) and lower (dashed) 95% credible limits on the estimates. The predicted commercial biomass for 2016 is displayed as a box plot with median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). This prediction assumes the initial total allowable catch of 200 t for this area is caught. The green-shaded area represents the healthy zone (based on an upper stock reference of 1800 t), yellow area represents the cautious zone (based on a lower reference point (LRP) of 880 t) and the red is the critical zone (< LRP).

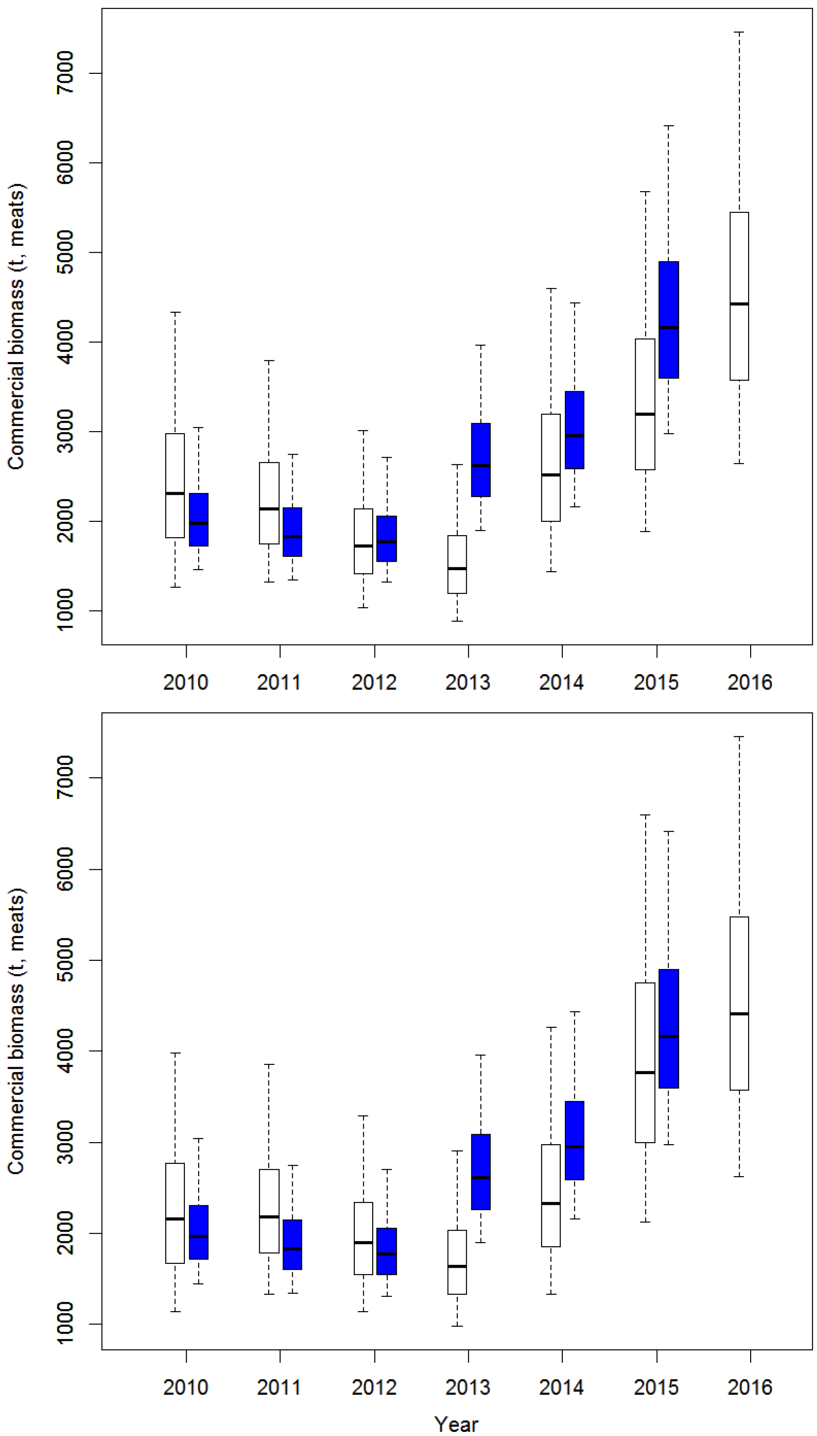

Figure 46. Evaluation of the model projection performance from 2010 to 2015 in Scallop Production Area 1B. White box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2010 predictions based on data up to 2009). Blue box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t. Upper panel projections use estimated weight from year t to t+1, and lower panel projections use actual growth rate from year t to t+1 to evaluate projections if growth had been known. Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projection for 2016 assumes the initial total allowable catch of 200 t for this area is caught.

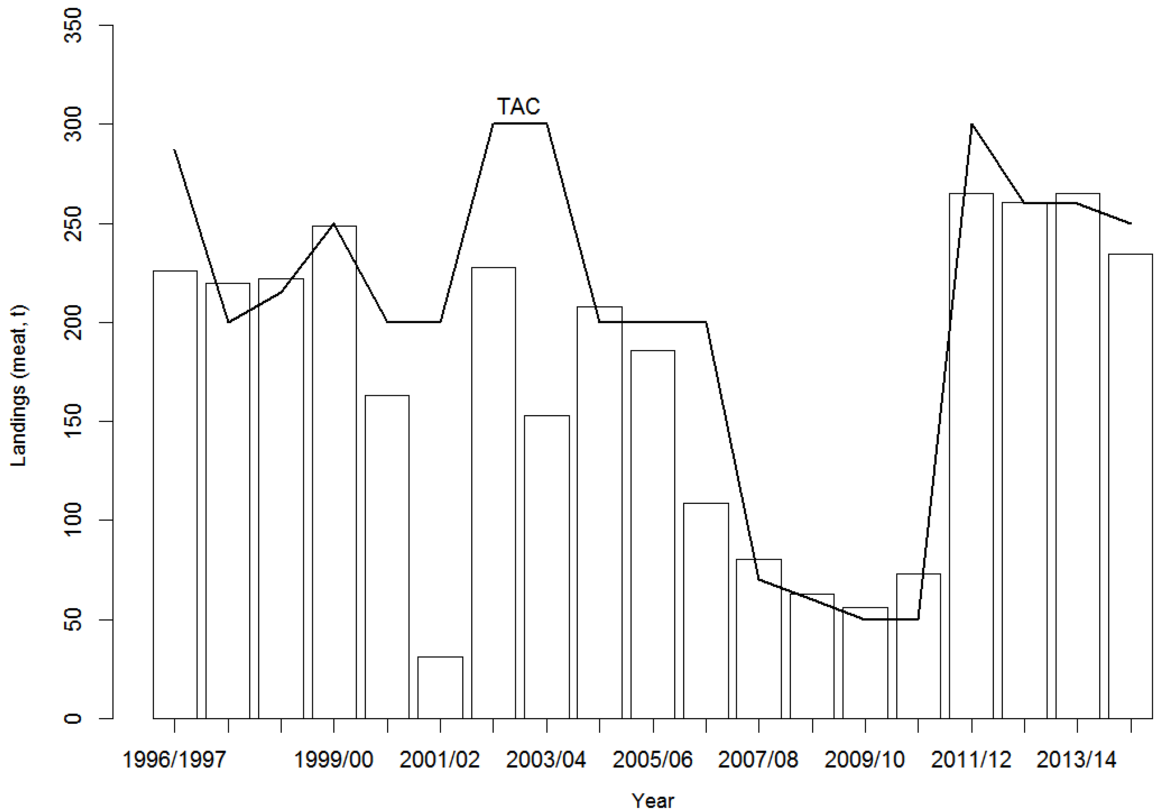

Figure 47. Total Allowable Catch (TAC, t; black line) and landings (t, bars) in Scallop Production Area 3 from 1996/1997 to 2014/2015.

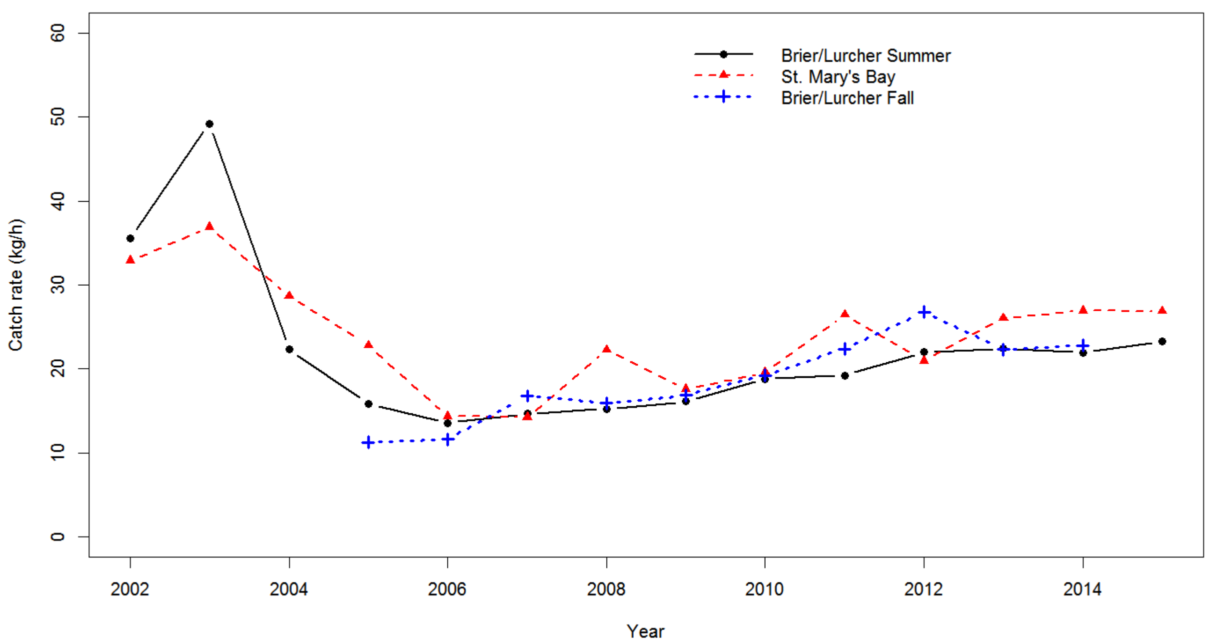

Figure 48. Catch per unit effort (CPUE, kg/h) in the Scallop Production Area 3 fishery for the Full Bay fleet. Catch rate is separated as Brier/Lurcher summer (black circles; 2002 to 2015), St. Mary's Bay (red triangle; 2002 to 2015), and Brier/Lurcher Fall (blue crosses; 2005 to 2014).

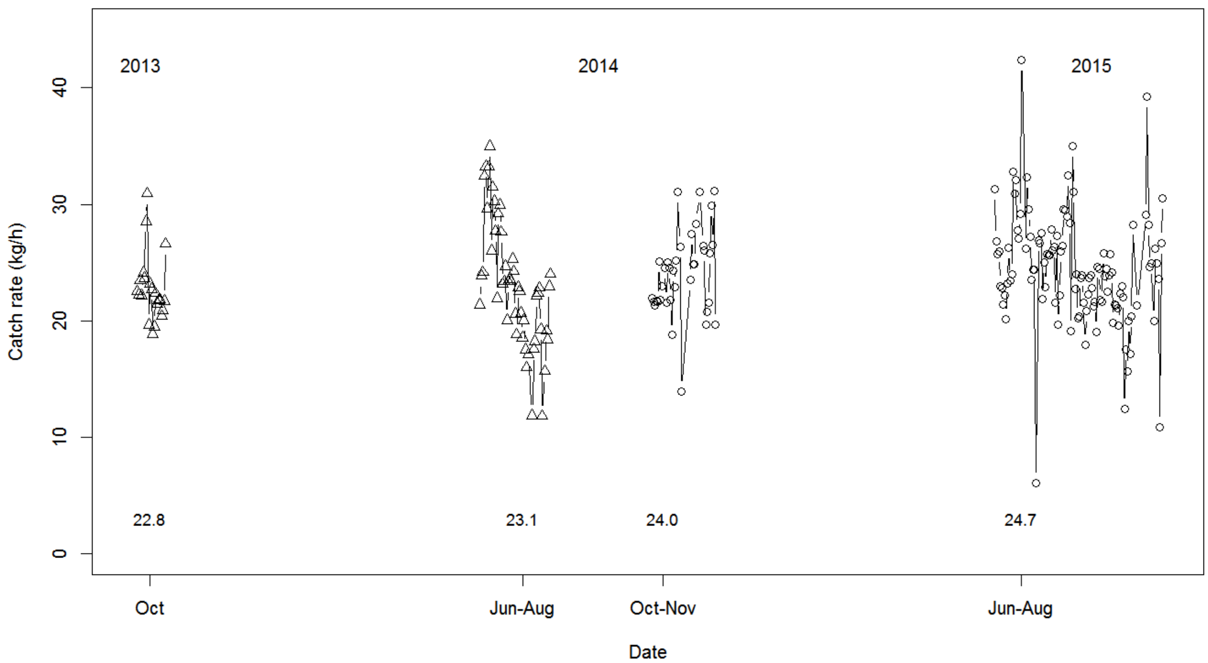

Figure 49. Mean daily catch per unit effort (CPUE, kg/h) in the Scallop Production Area 3 fishery for the Full Bay fleet for the 2013/2014 (triangles) and 2014/2015 (circles) fishing years.

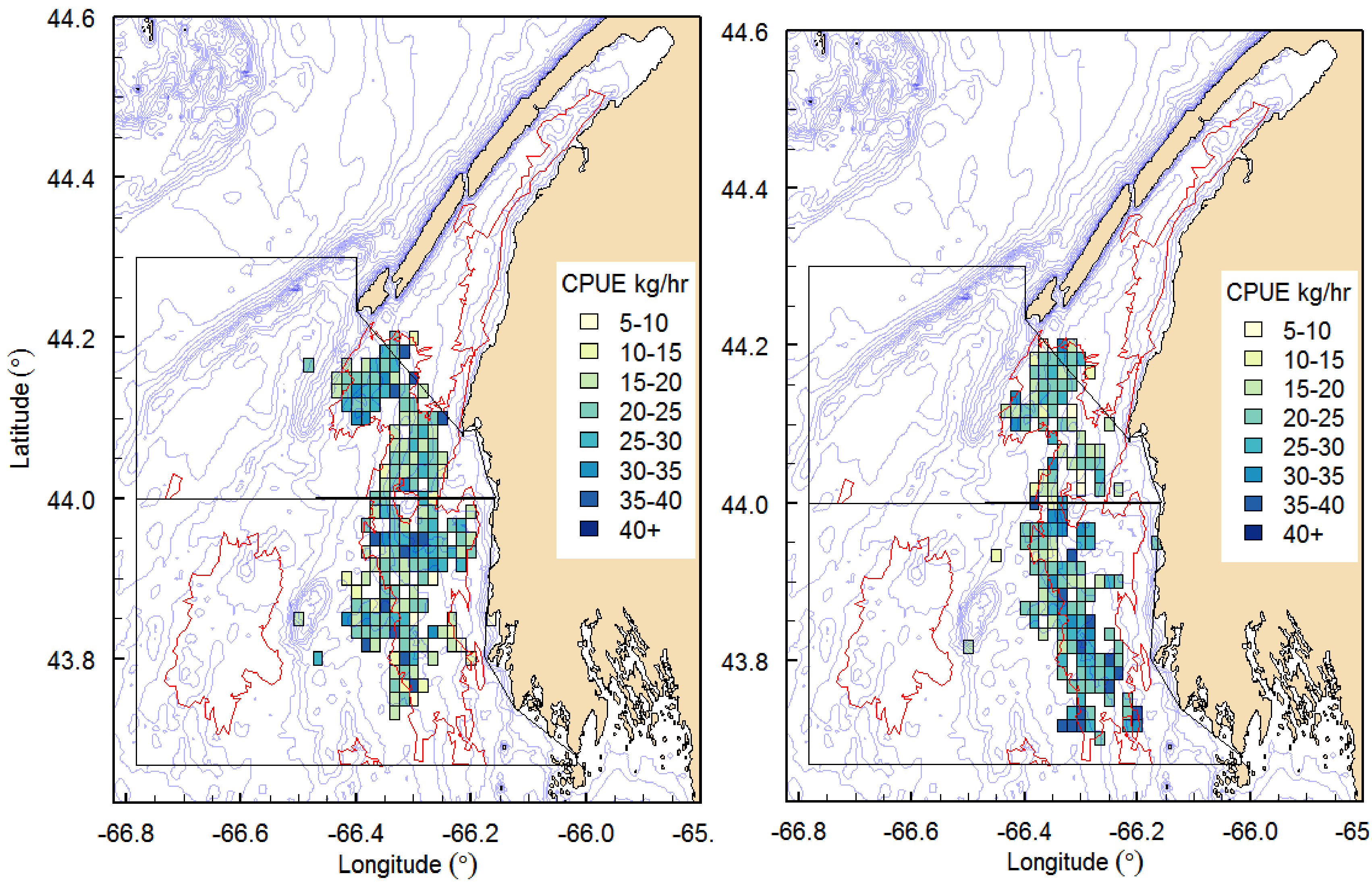

Figure 50. Spatial distribution of catch per unit effort (CPUE, kg/h) in the fall portion of the Scallop Production Area (SPA) 3 fishery for the 2014 (left panel) and 2015 (right panel) fishing years. VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

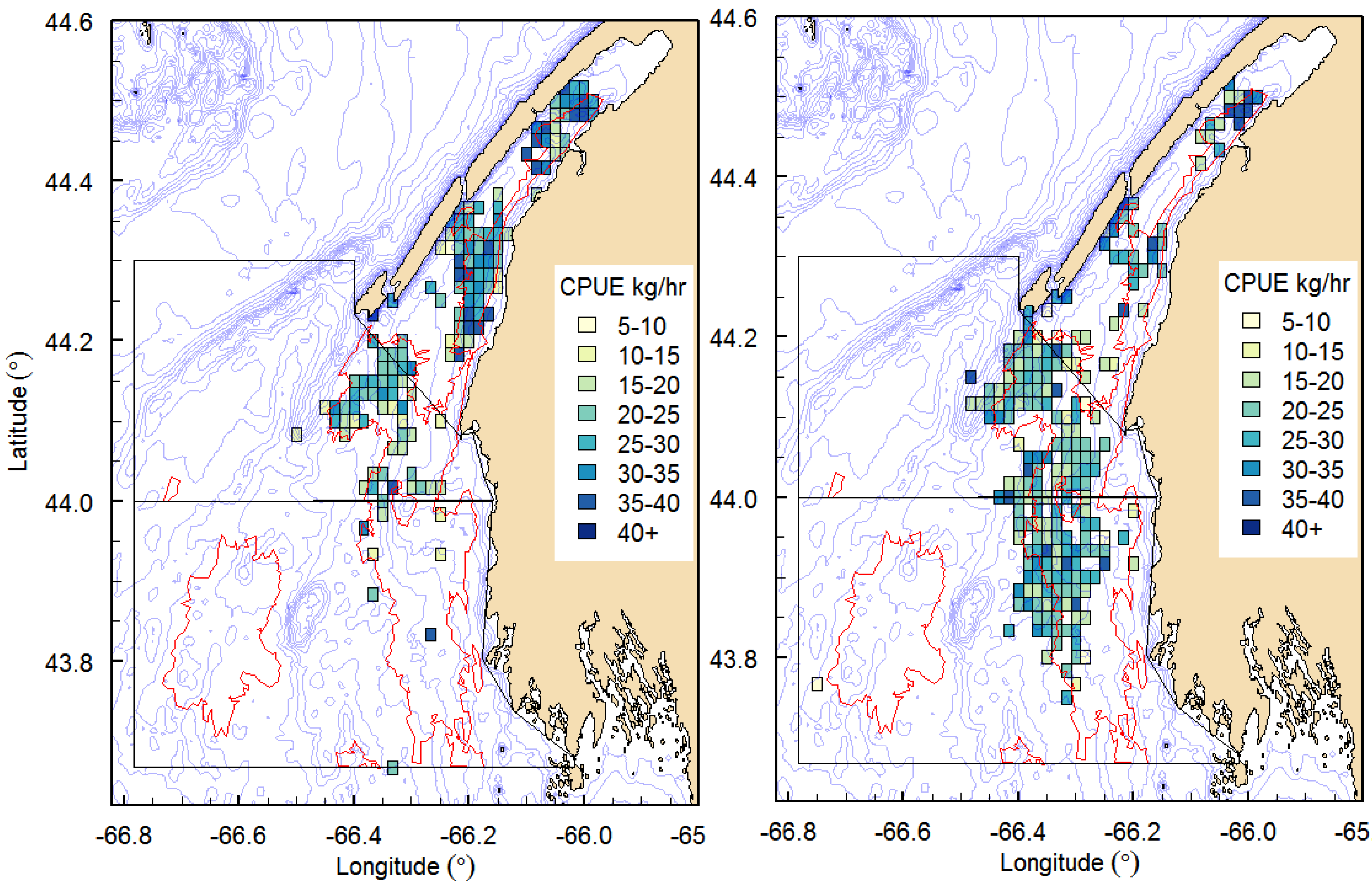

Figure 51. Spatial distribution of catch per unit effort (CPUE, kg/h) in the summer portion of the Scallop Production Area (SPA) 3 fishery for the 2014 (left panel) and 2015 (right panel) fishing years. VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

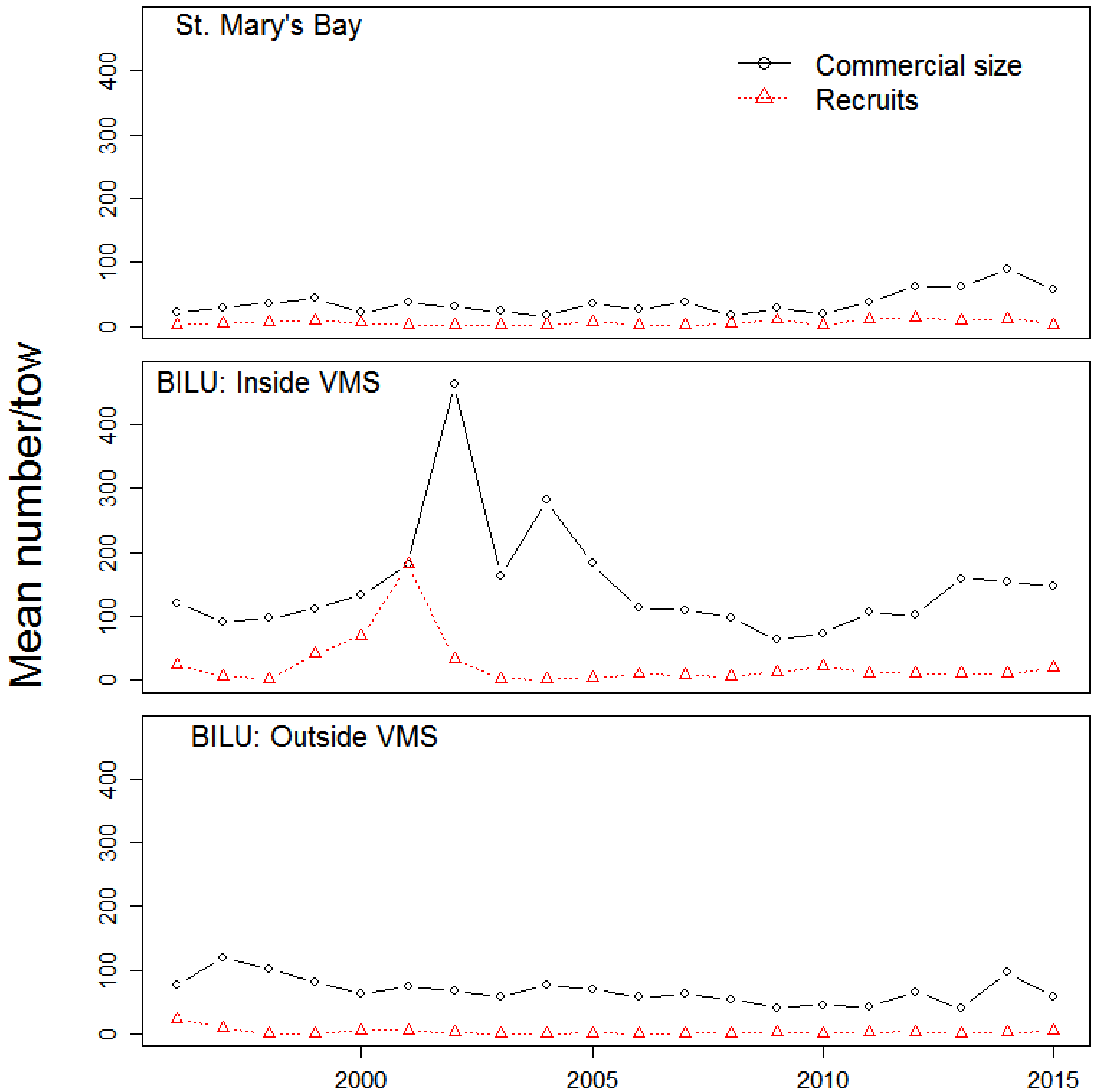

Figure 52. Mean number per tow of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 3: St. Mary's Bay (top panel; 1996 to 2015), Inside VMS stratum of Brier/Lurcher (middle panel; 1996 to 2015), and Outside VMS stratum of Brier/Lurcher (bottom panel; 1996 to 2015).

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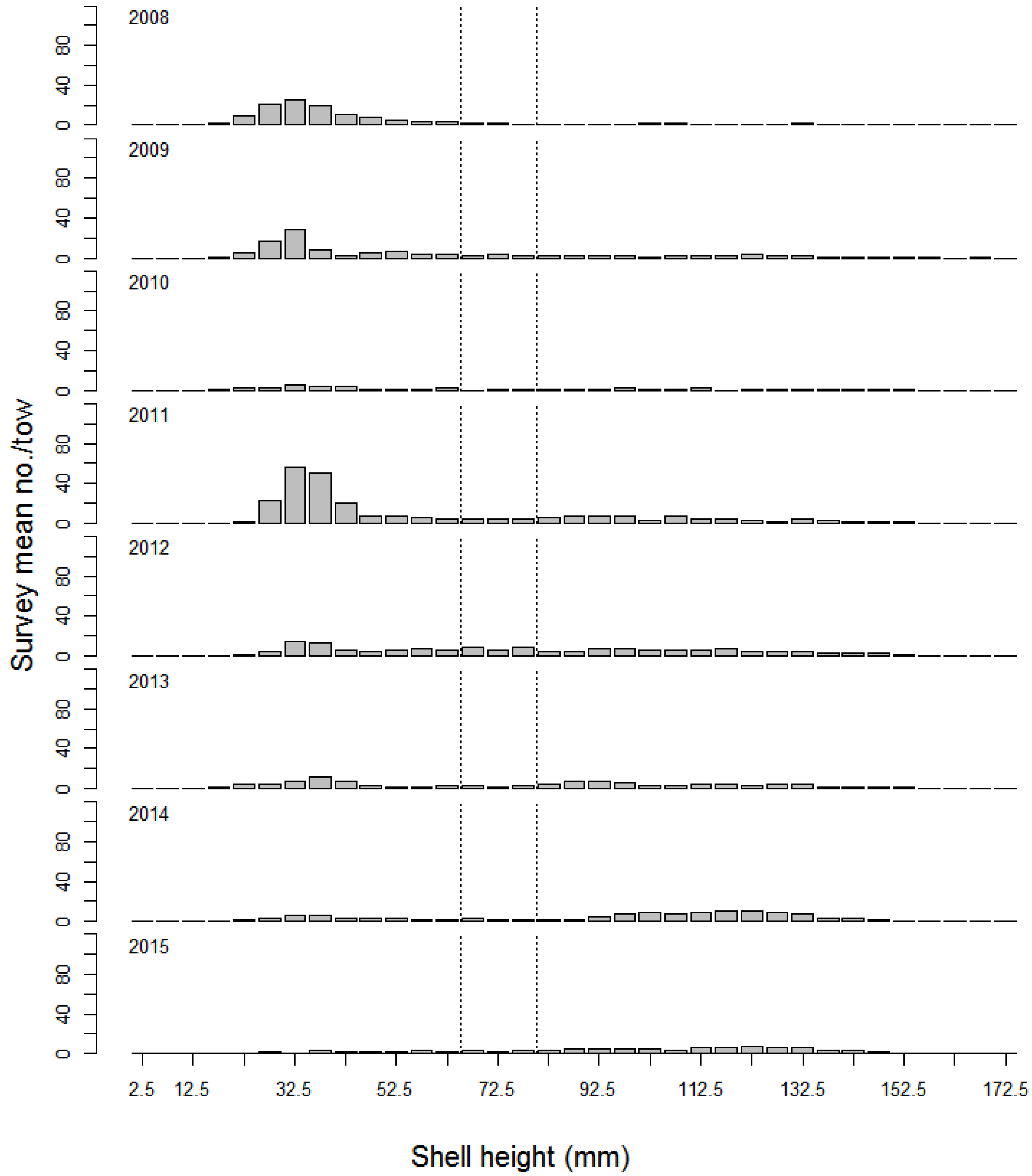

Figure 53. Shell height (mm) frequency (mean number/tow) for St. Mary's Bay in Scallop Production Area 3, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

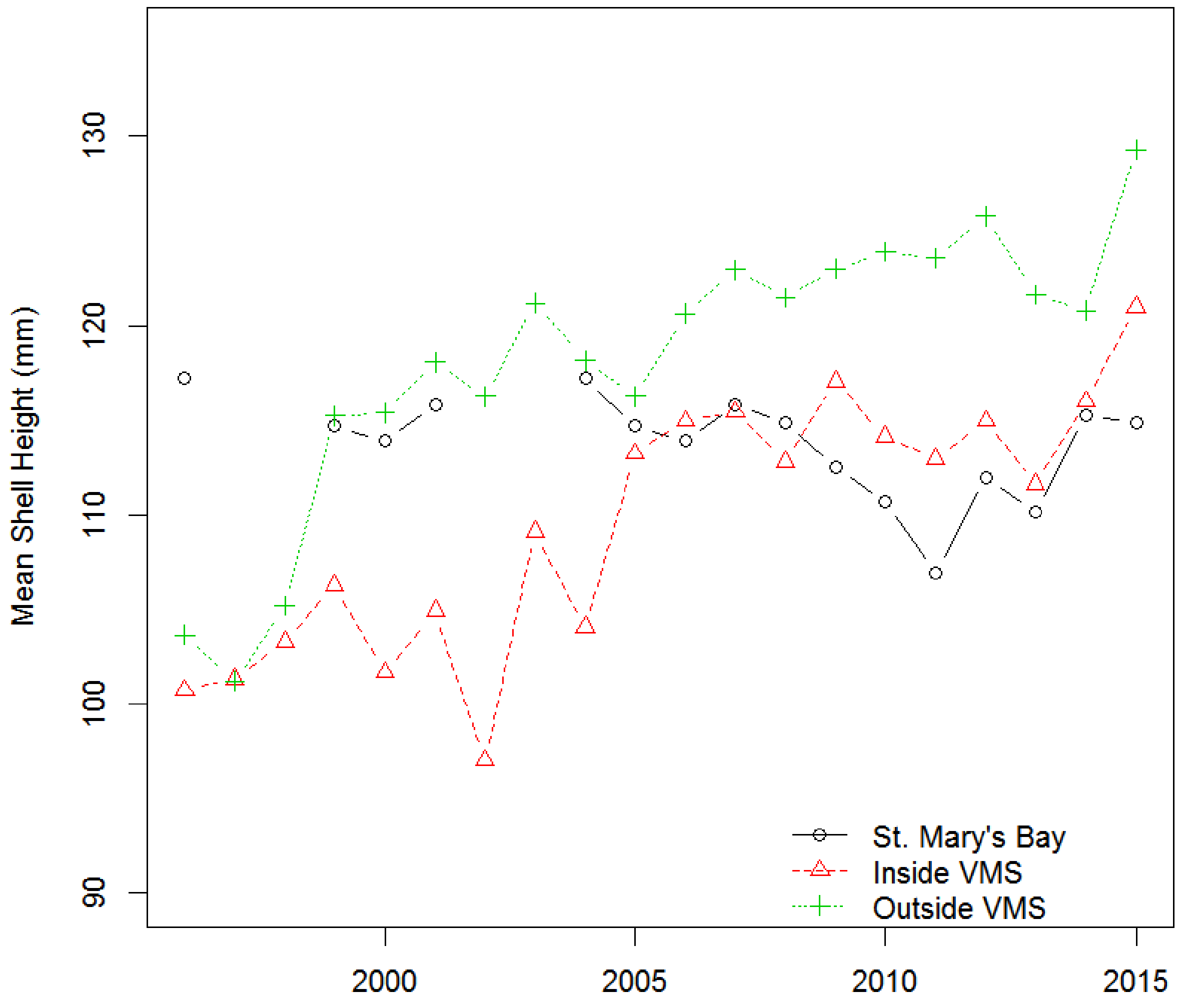

Figure 54. Mean shell height (mm) of commercial size scallops in the three subareas of Scallop Production Area 3: St. Mary's Bay (black circles), Inside VMS stratum (red triangles), and Outside VMS stratum (green crosses) from 1997 to 2015.

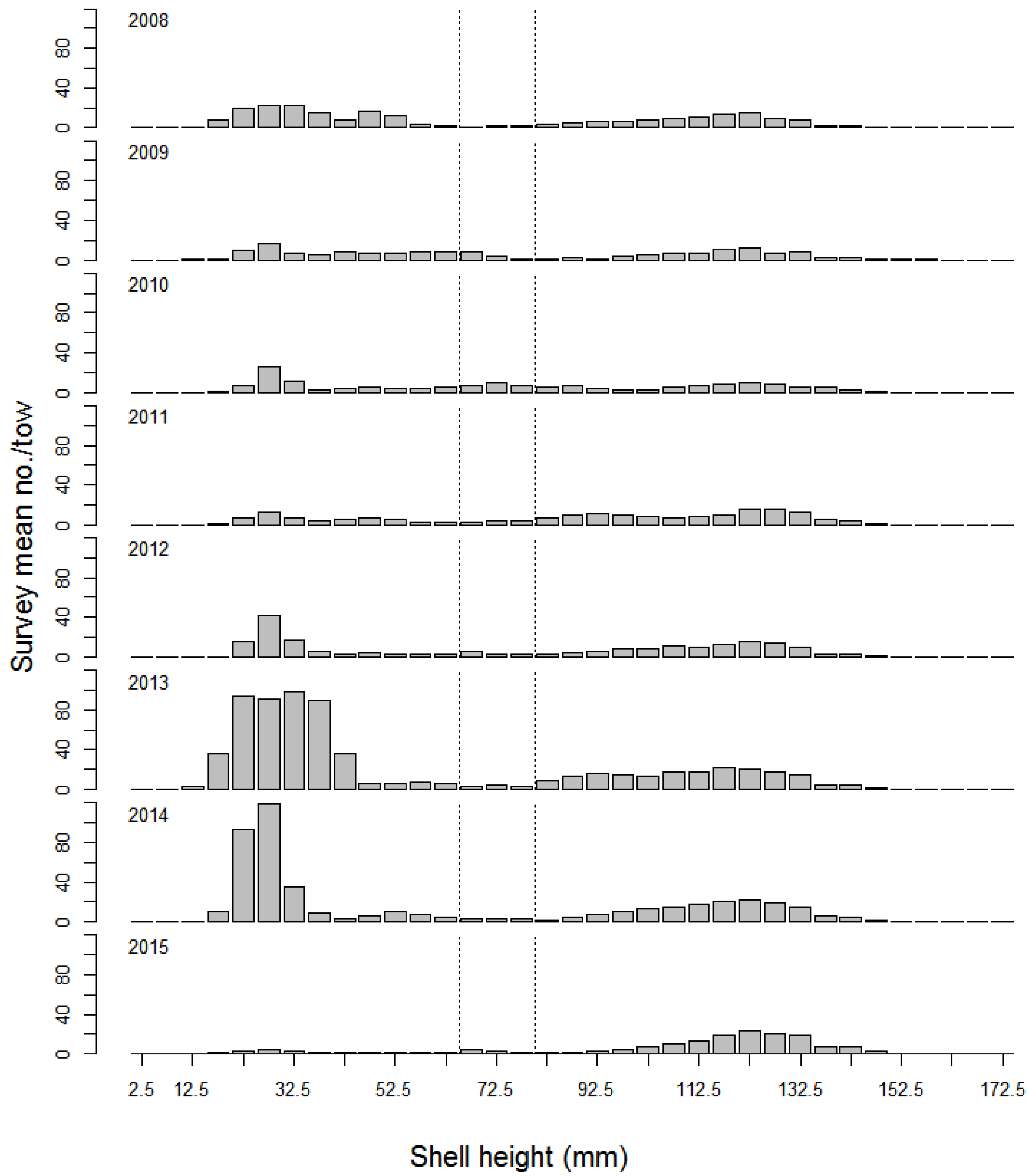

Figure 55. Shell height (mm) frequency (mean number/tow) for the Inside VMS stratum of Brier/Lurcher in Scallop Production Area 3, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

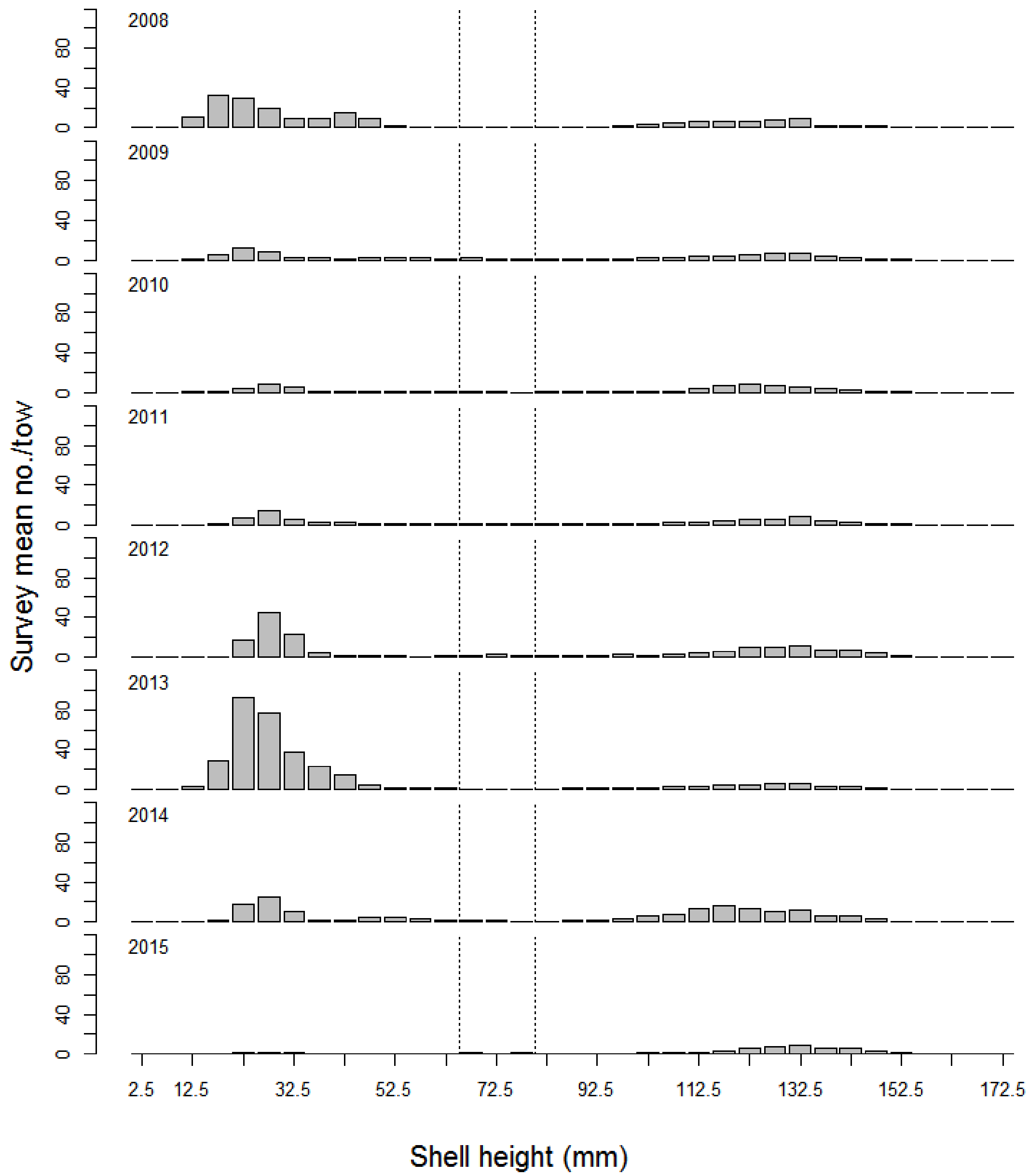

Figure 56. Shell height (mm) frequency (mean number/tow) for the Outside VMS stratum of Brier/Lurcher in Scallop Production Area 3, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

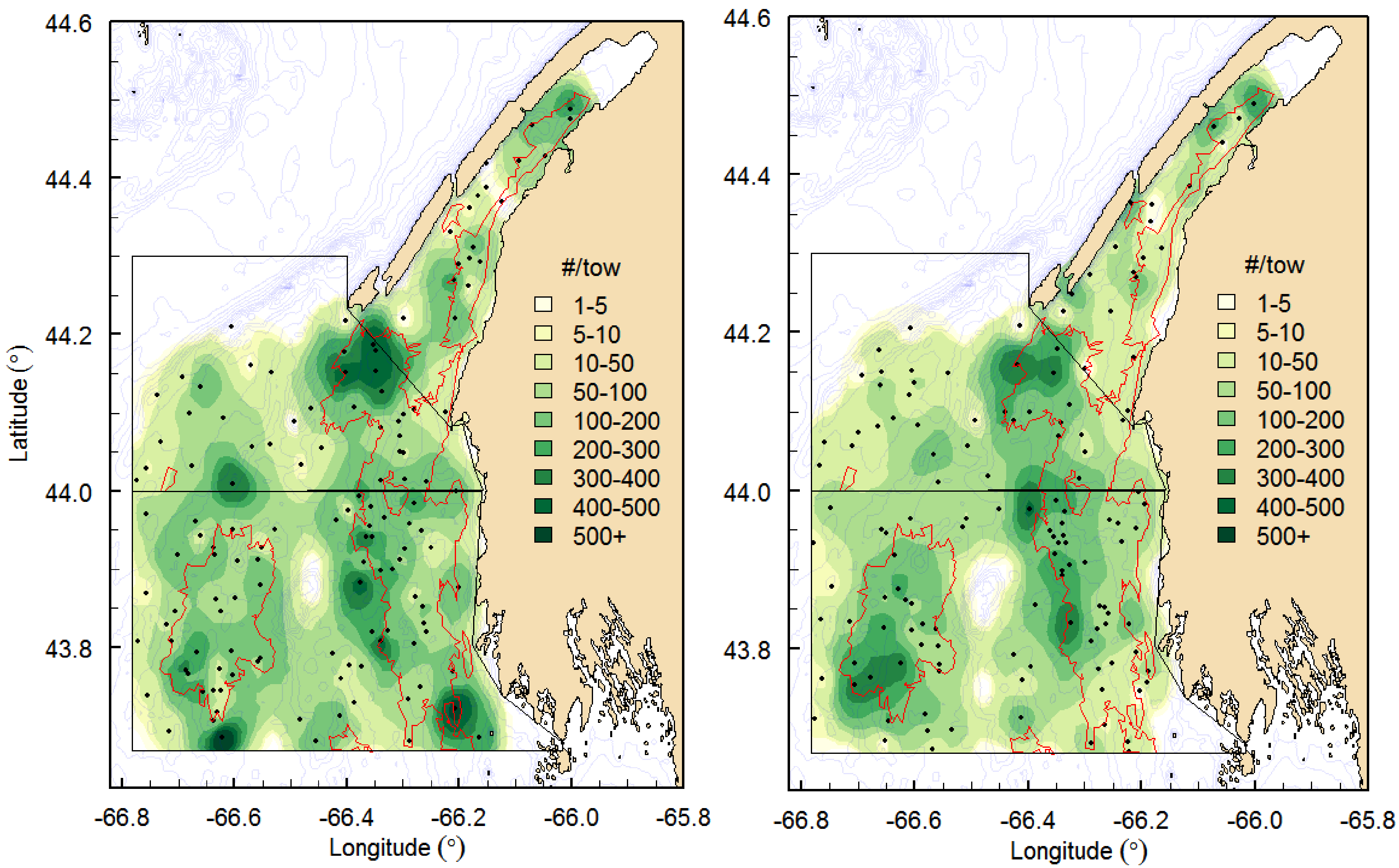

Figure 57. Spatial distribution of abundance (number/tow) of commercial scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

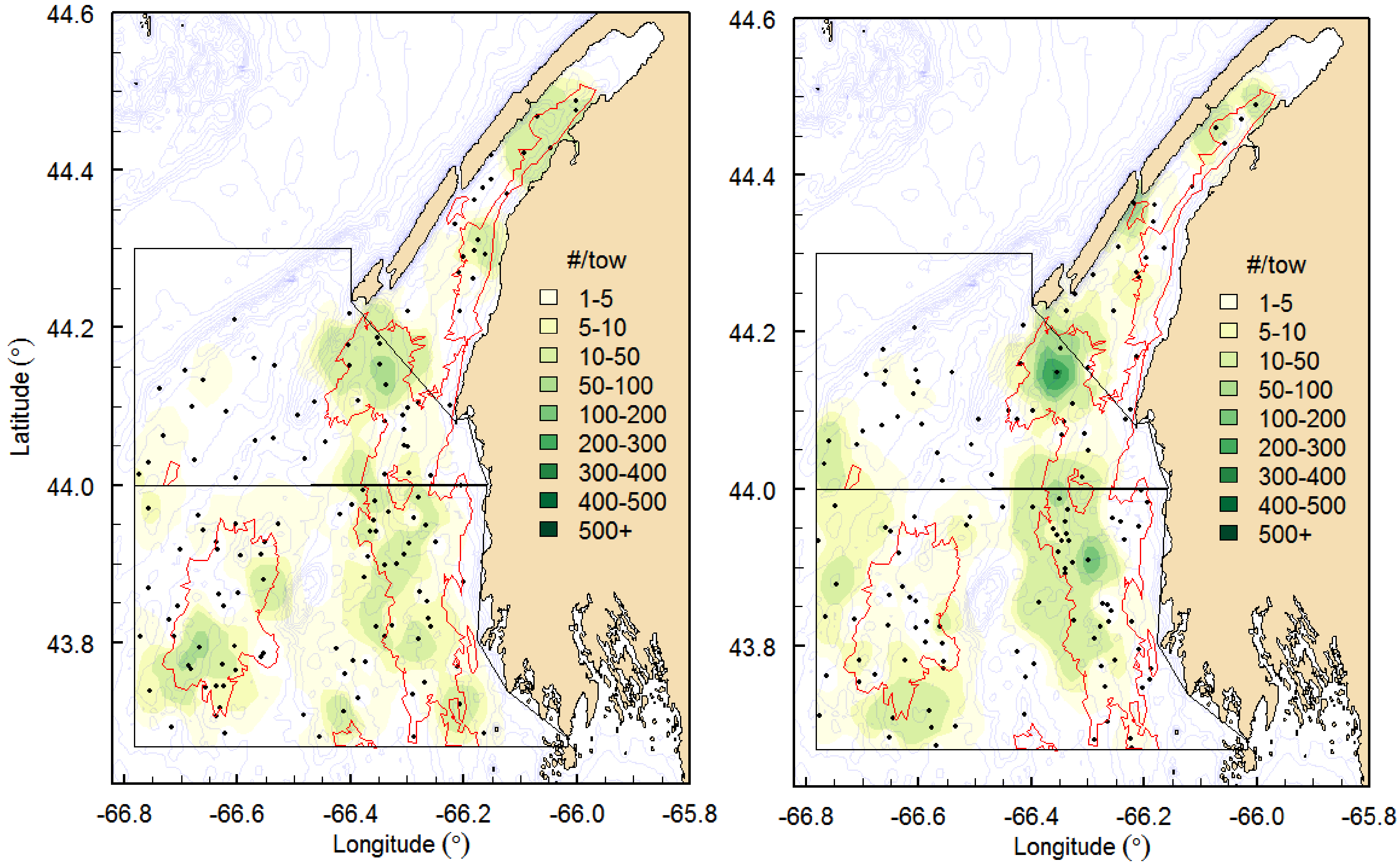

Figure 58. Spatial distribution of abundance (number/tow) of recruit scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

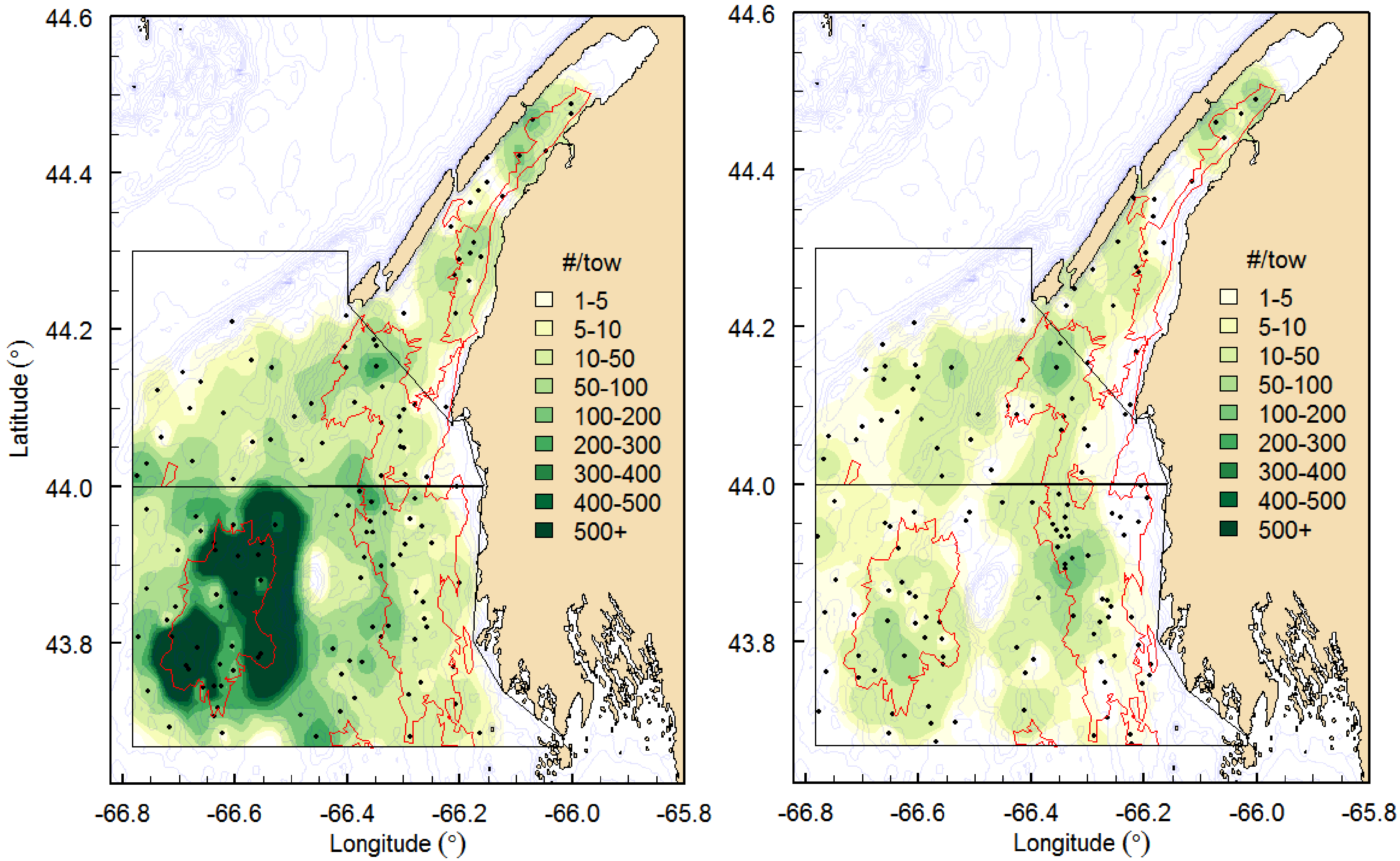

Figure 59. Spatial distribution of abundance (number/tow) of prerecruit scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

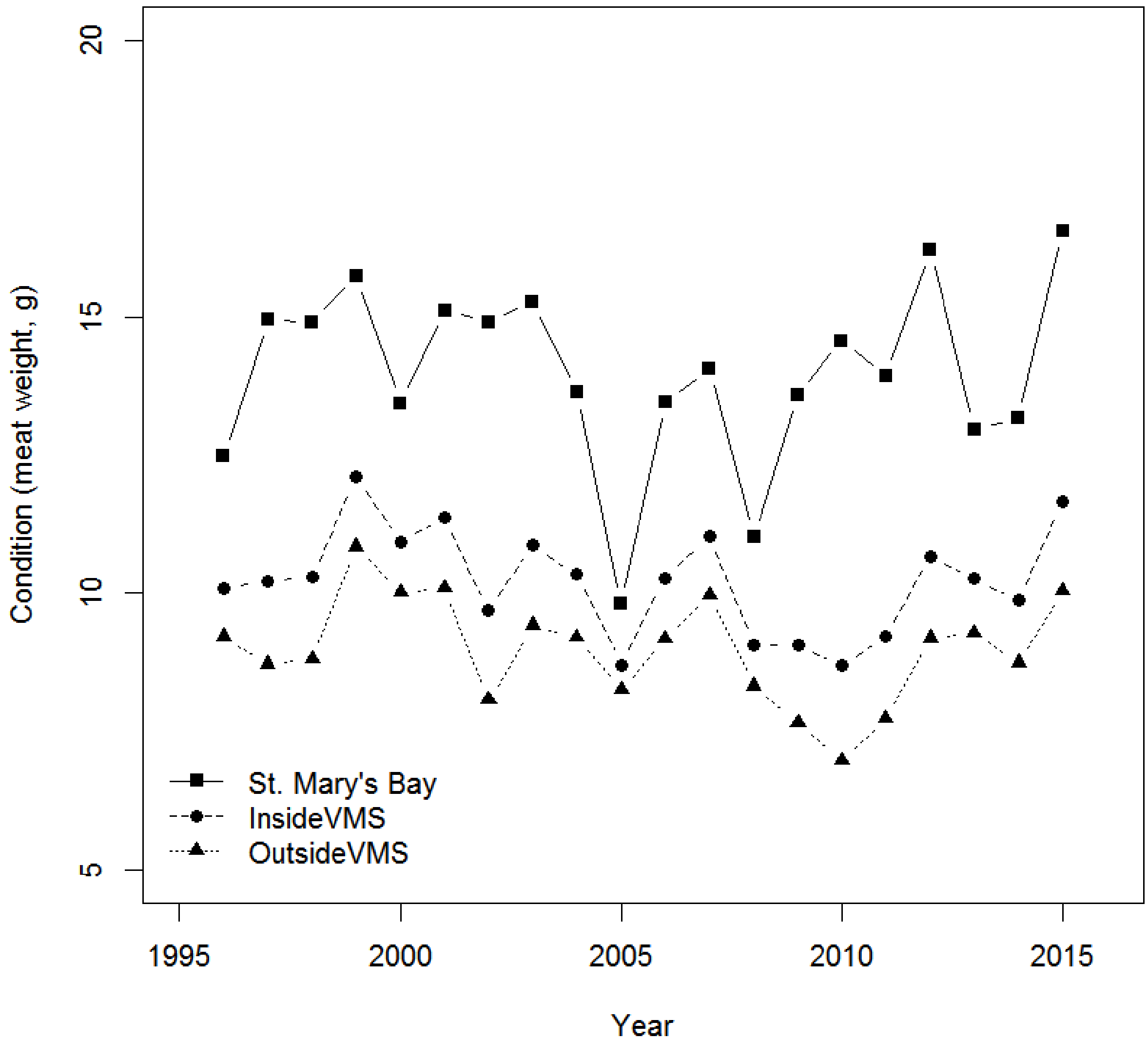

Figure 60. Condition (meat weight, g) for a shell of 100 mm in the three subareas of Scallop Production Area 3: St. Mary's Bay (squares), Inside VMS stratum (circle), and Outside VMS stratum (triangle) from 1997 to 2015.

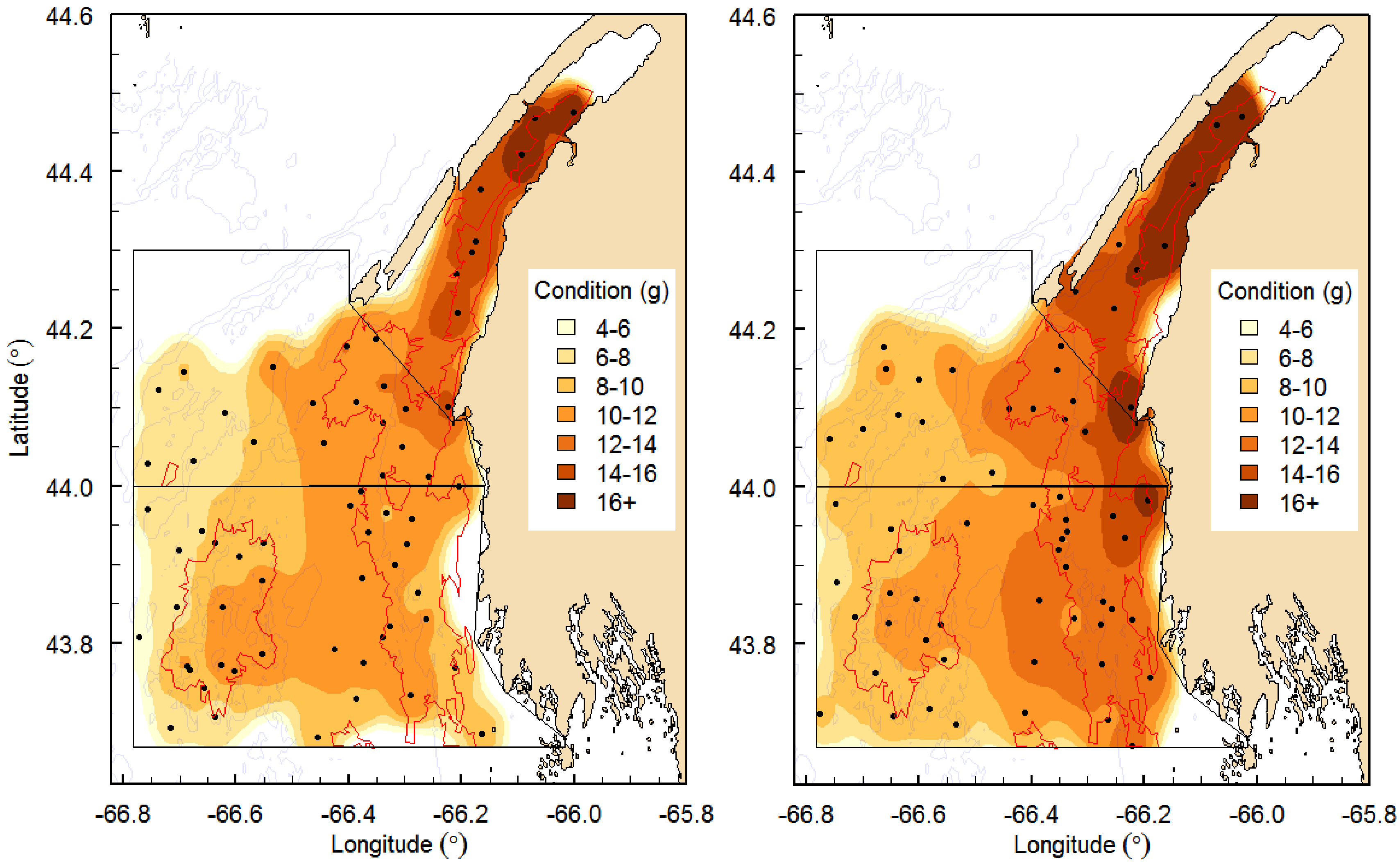

Figure 61. Spatial distribution of condition, weight in grams of a 100 mm scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

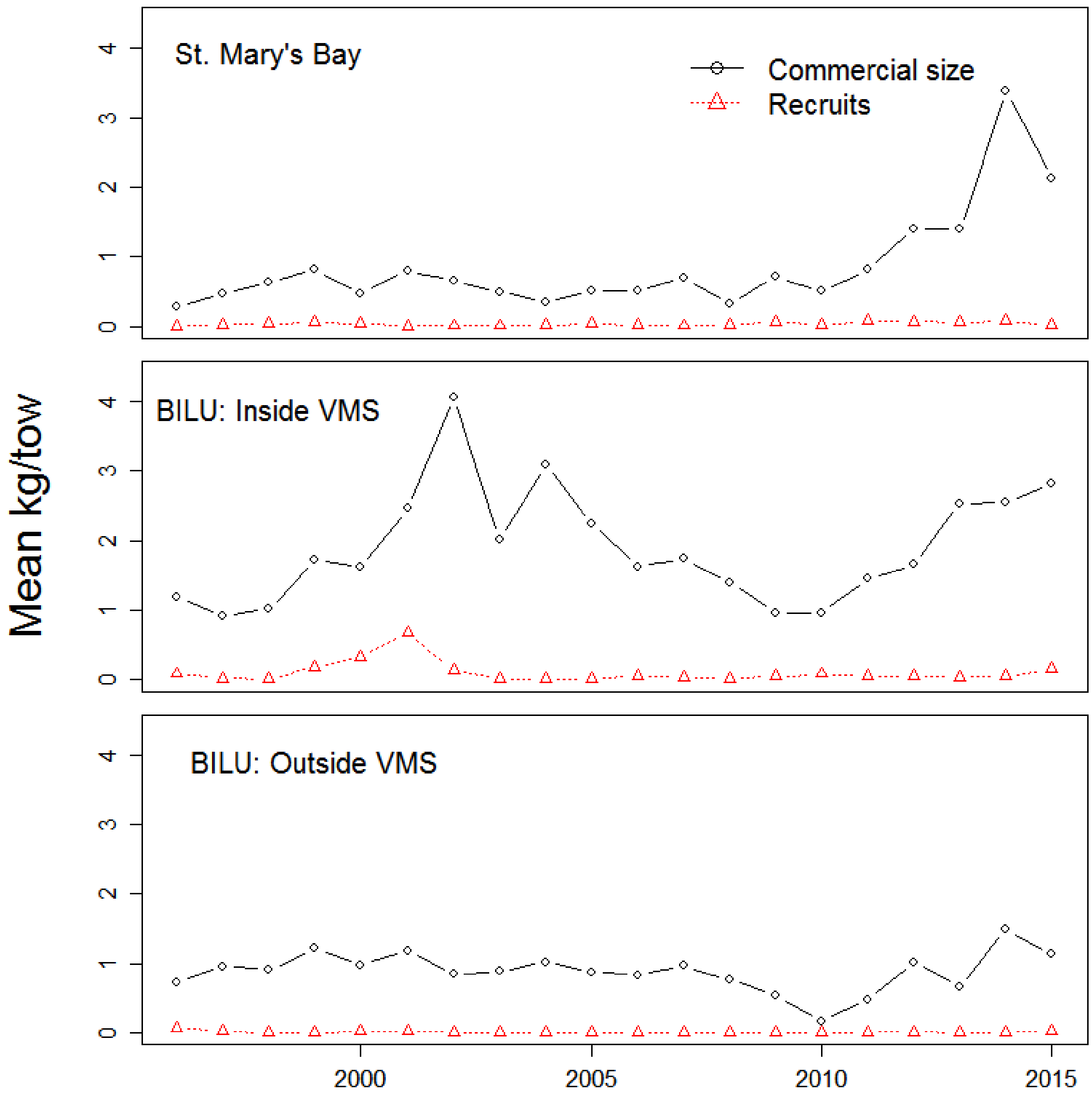

Figure 62. Mean weight (kg) per tow of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 3: St. Mary's Bay (top panel; 1996 to 2015), Inside VMS stratum of Brier/Lurcher (middle panel; 1996 to 2015), and Outside VMS stratum of Brier/Lurcher (bottom panel; 1996 to 2015).

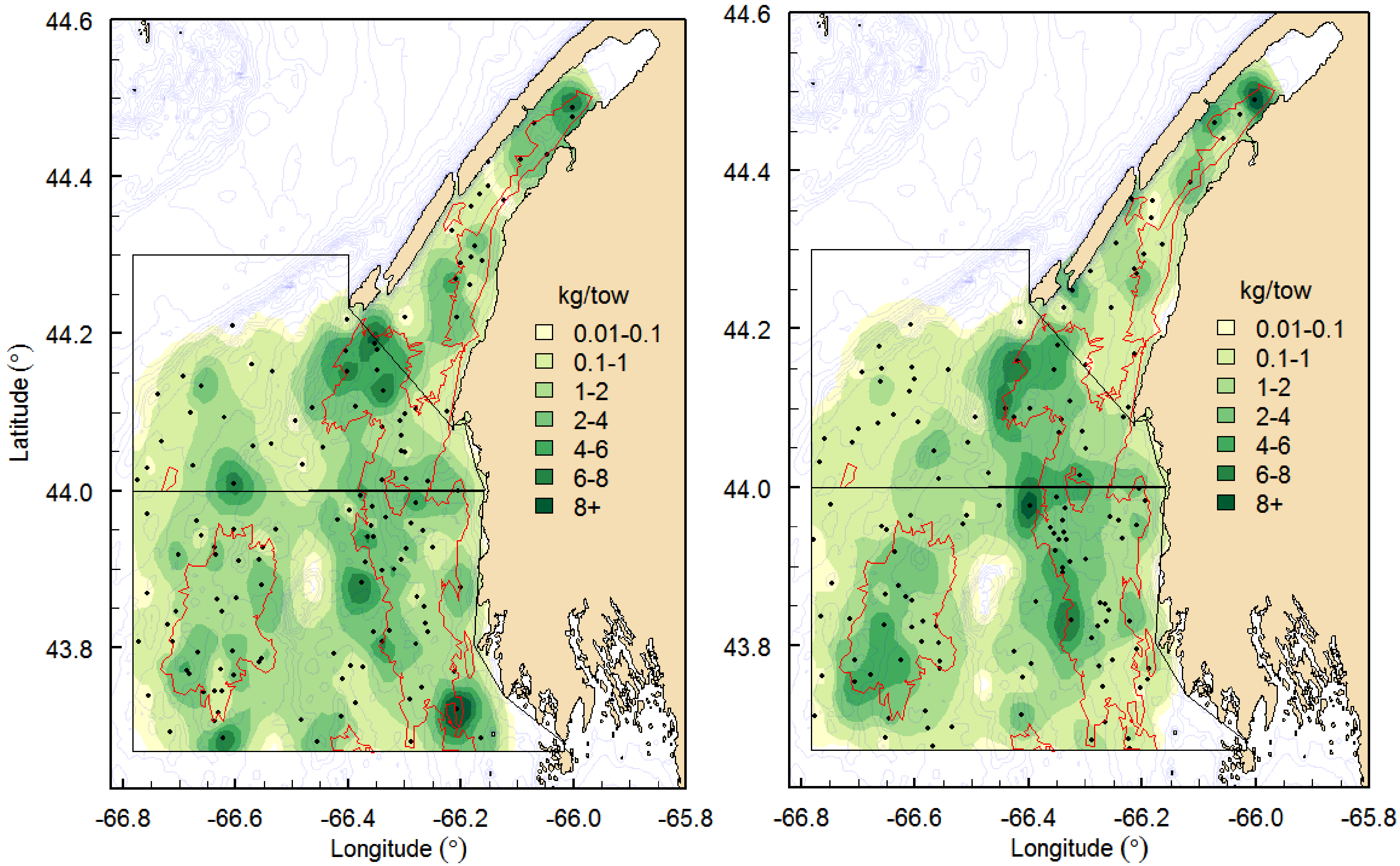

Figure 63. Spatial distribution of biomass (kg/tow) of commercial scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

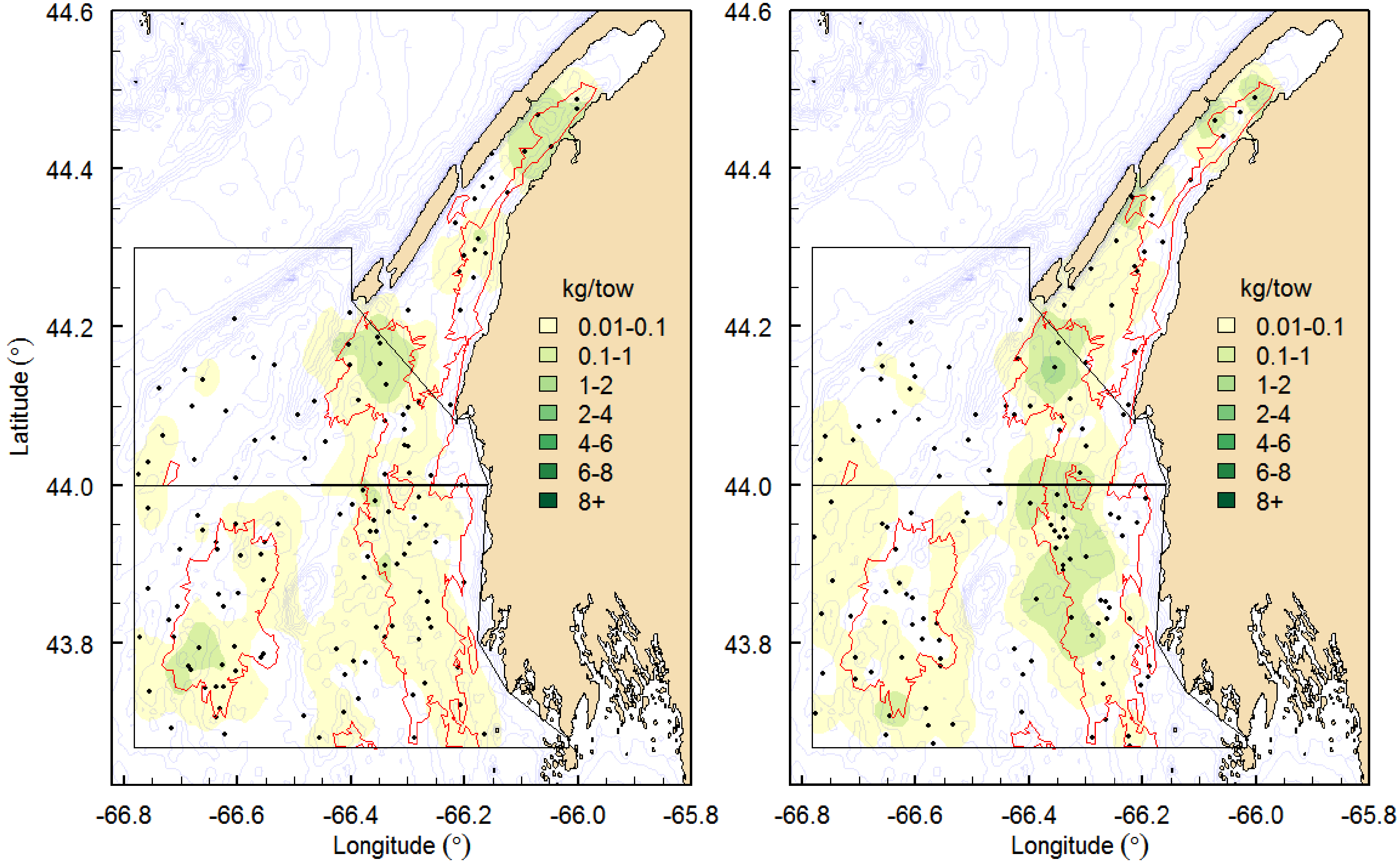

Figure 64. Spatial distribution of biomass (kg/tow) of recruit scallop in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black.

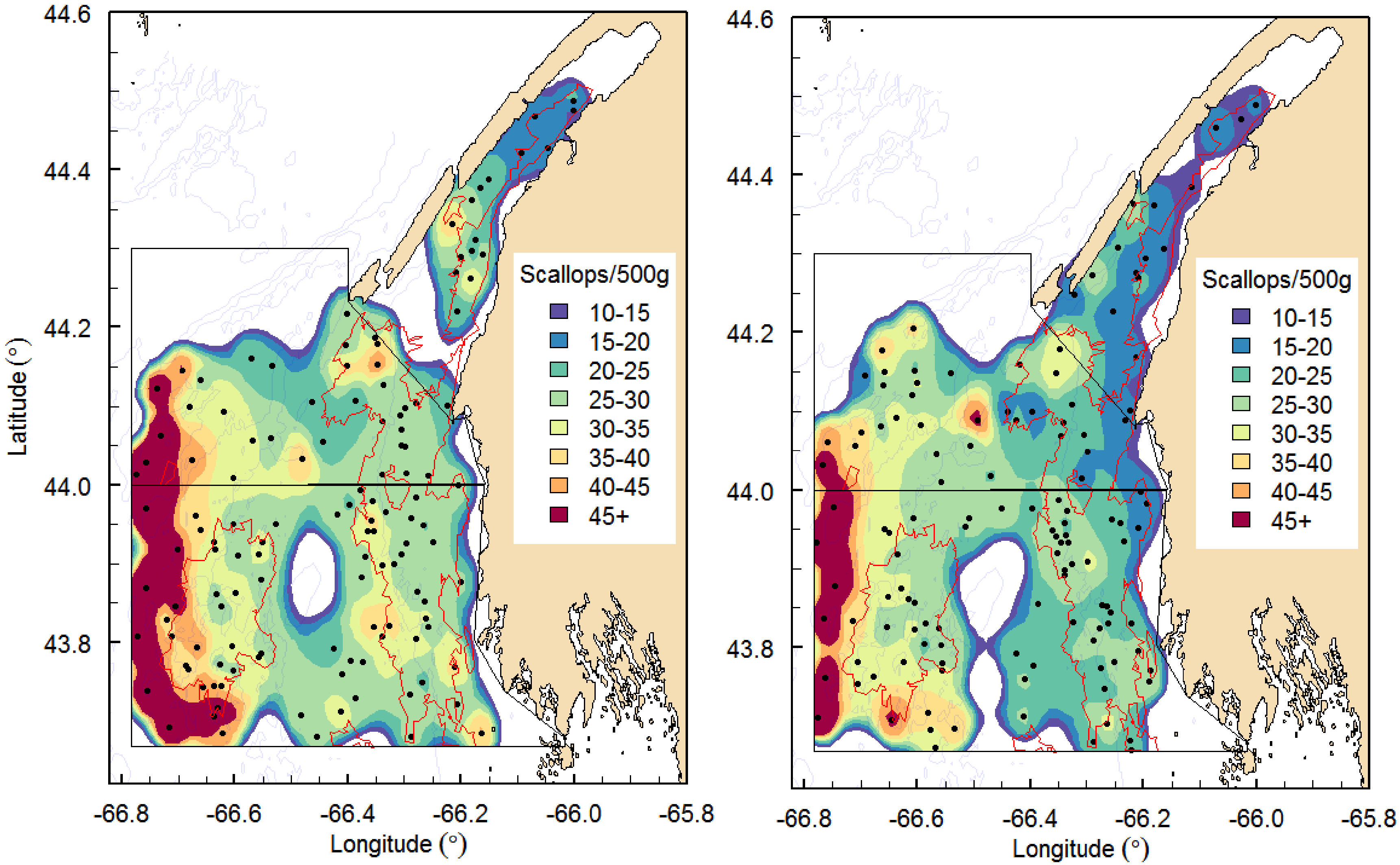

Figure 65. Spatial distribution of meat count (scallops/500 g) in Scallop Production Area (SPA) 3 in 2014 (left panel) and 2015 (right panel). VMS survey strata shown in red. Extent of SPA 3 and historic survey strata shown in black. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

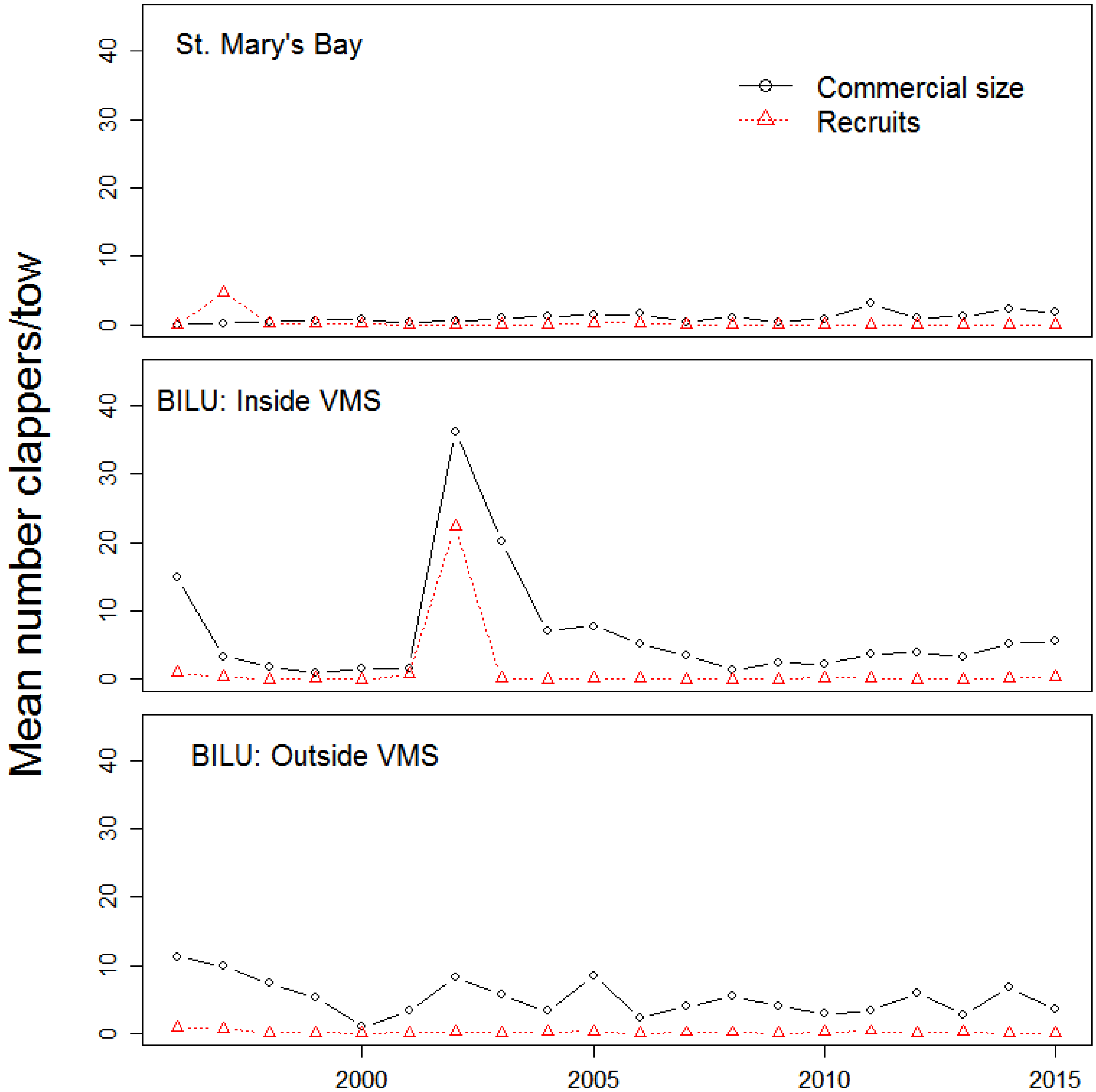

Figure 66. Mean number per tow of clappers (paired, dead shells) of commercial (black circles) and recruit (red triangle) sized scallops in the three subareas of Scallop Production Area 3: St. Mary's Bay (top panel; 1996 to 2015), Inside VMS stratum of Brier/Lurcher (middle panel; 1996 to 2015), and Outside VMS stratum of Brier/Lurcher (bottom panel; 1996 to 2015).

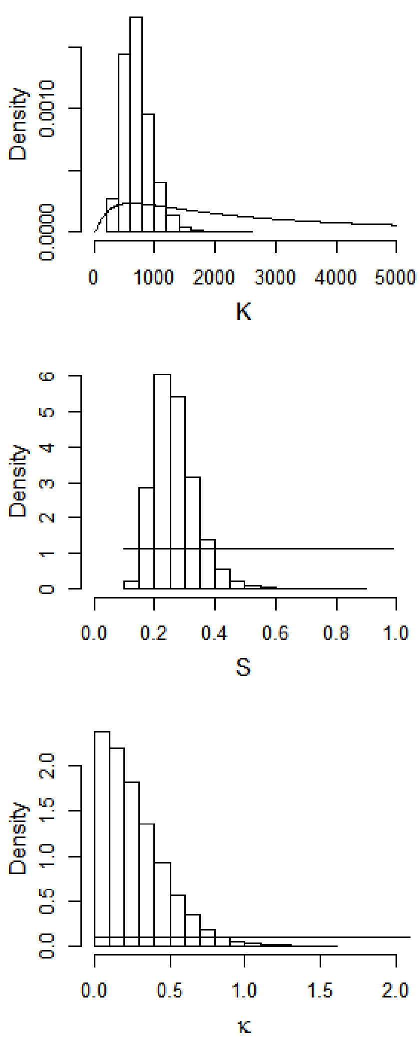

Figure 67. Comparison of prior (lines) and posterior densities (histogram) from the Bayesian state-space assessment model in Scallop Production Area 3.

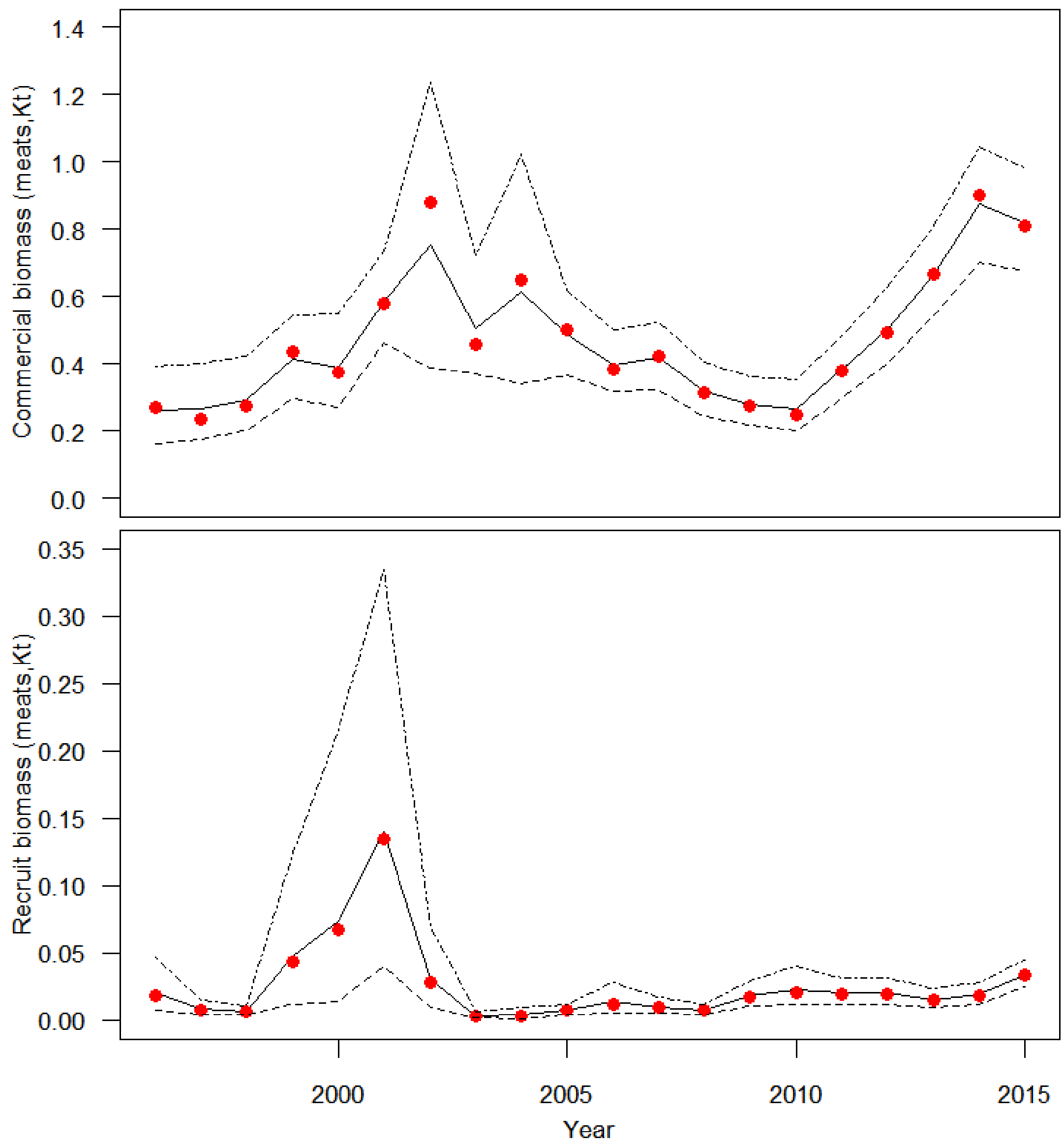

Figure 68. Posterior mean fit to the survey biomass series of commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 3 from 1996 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

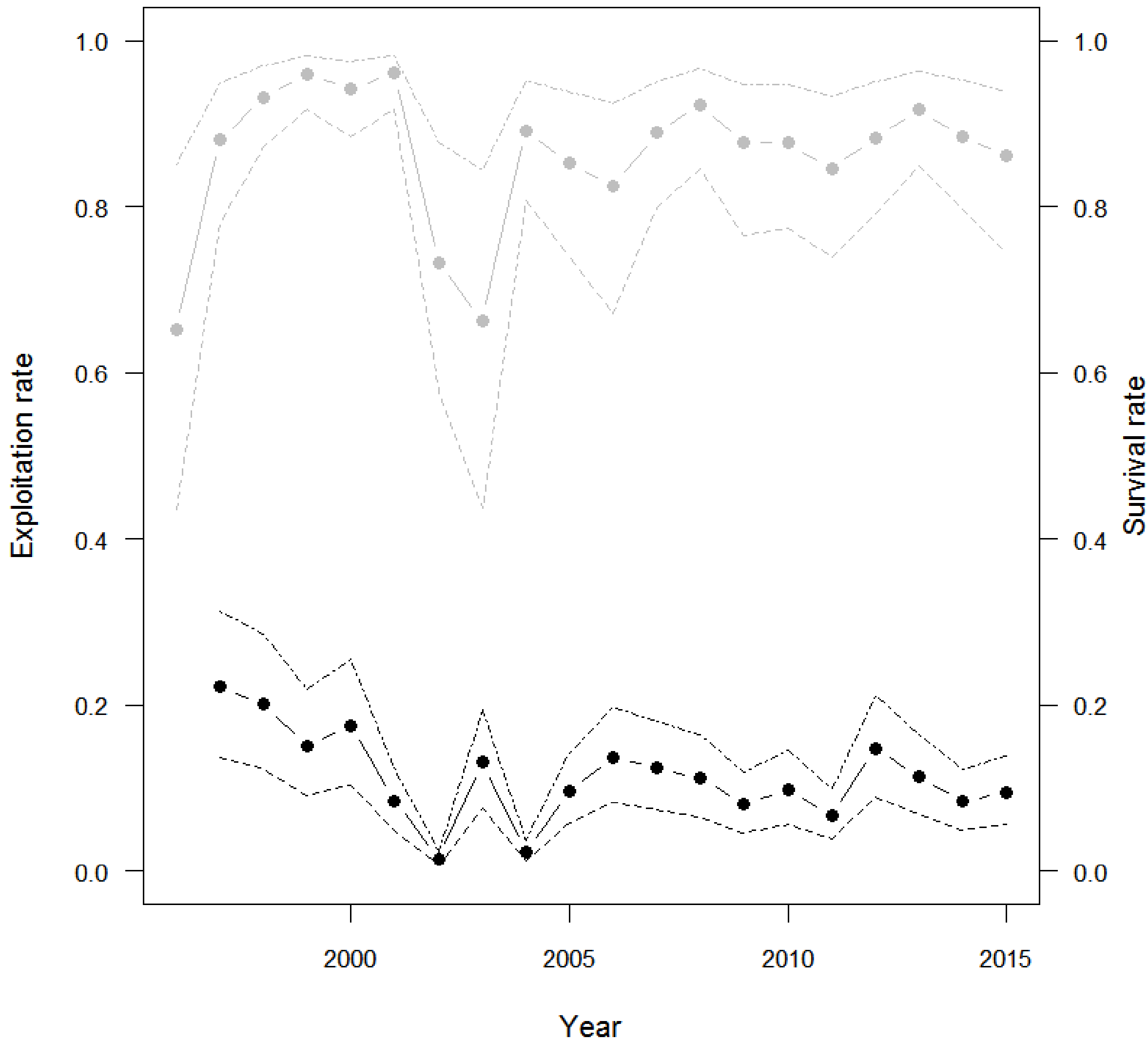

Figure 69. Annual trends (1996 to 2015) in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey circles) from the Bayesian state-space assessment model in Scallop Production Area 3. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

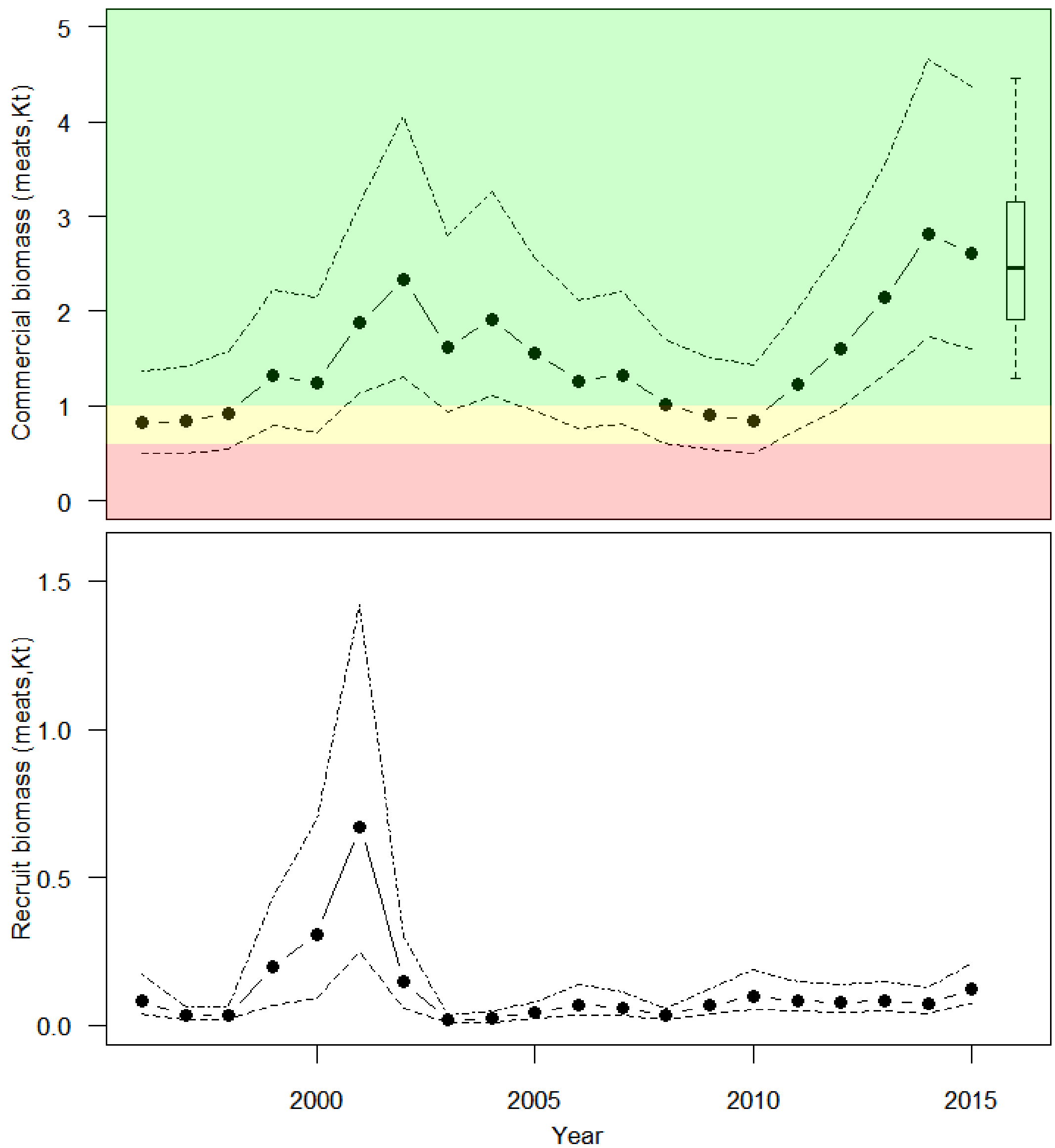

Figure 70. Biomass estimates for commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 3, fit to survey and commercial data from 1996 to 2015. Dashed lines are the upper (dotted) and lower (dashed) 95% credible limits on the estimates. The predicted commercial biomass for 2016 is displayed as a box plot with median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). This prediction assumes the initial total allowable catch of 150 t for this area is caught. The green-shaded area represents the healthy zone (based on an upper stock reference of 1000 t), yellow area represents the cautious zone (based on a lower reference point (LRP) of 600 t) and the red is the critical zone (< LRP).

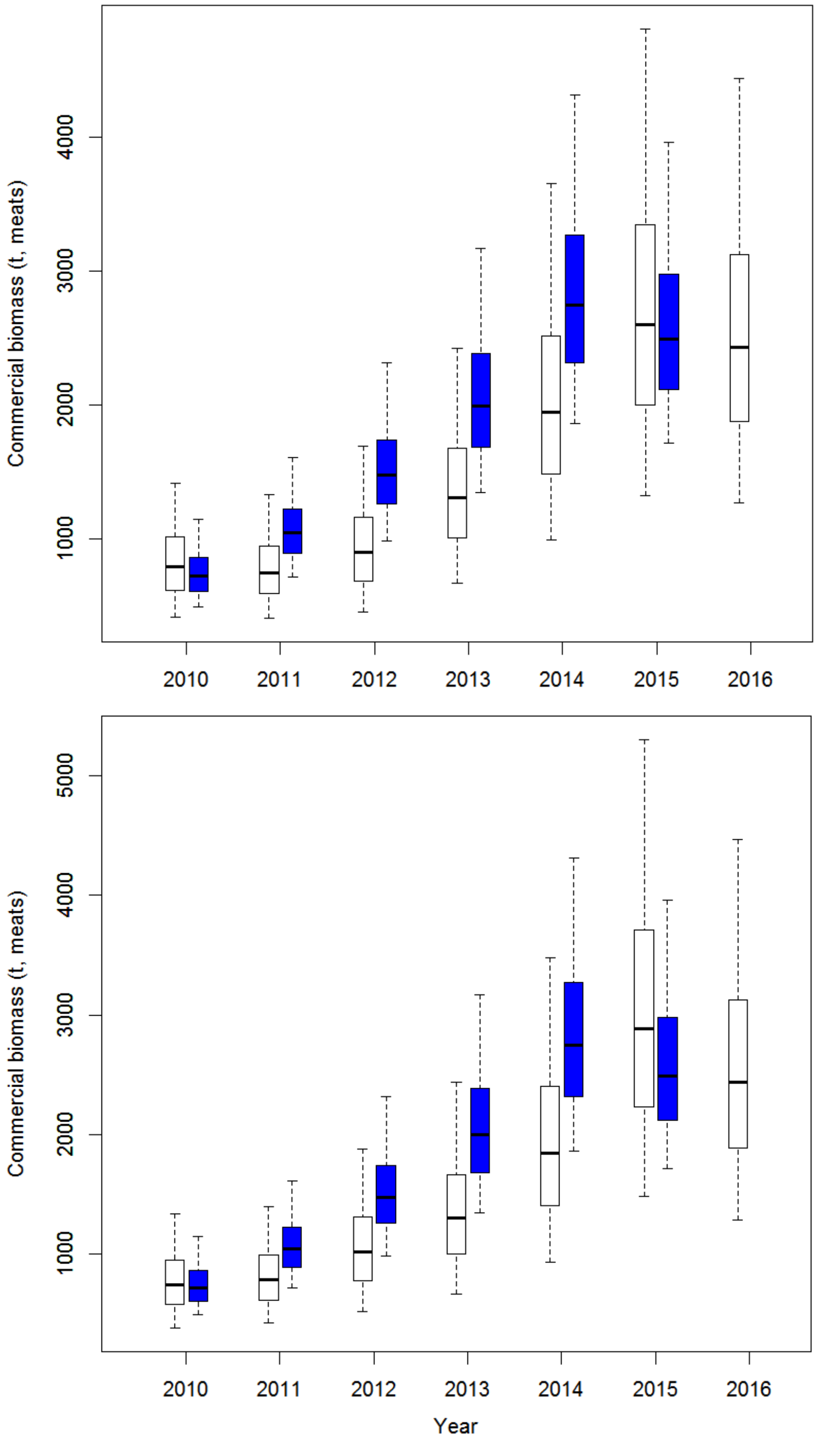

Figure 71. Evaluation of the model projection performance from 2010 to 2015 in Scallop Production Area 3. White box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2010 predictions based on data up to and including 2009). Blue box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t. Upper panel projections use estimated weight from year t to t+1, and lower panel projections use actual growth rate from year t to t+1 to evaluate projections if growth had been known. Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projection for 2016 assumes the initial total allowable catch of 150 t for this area is caught.

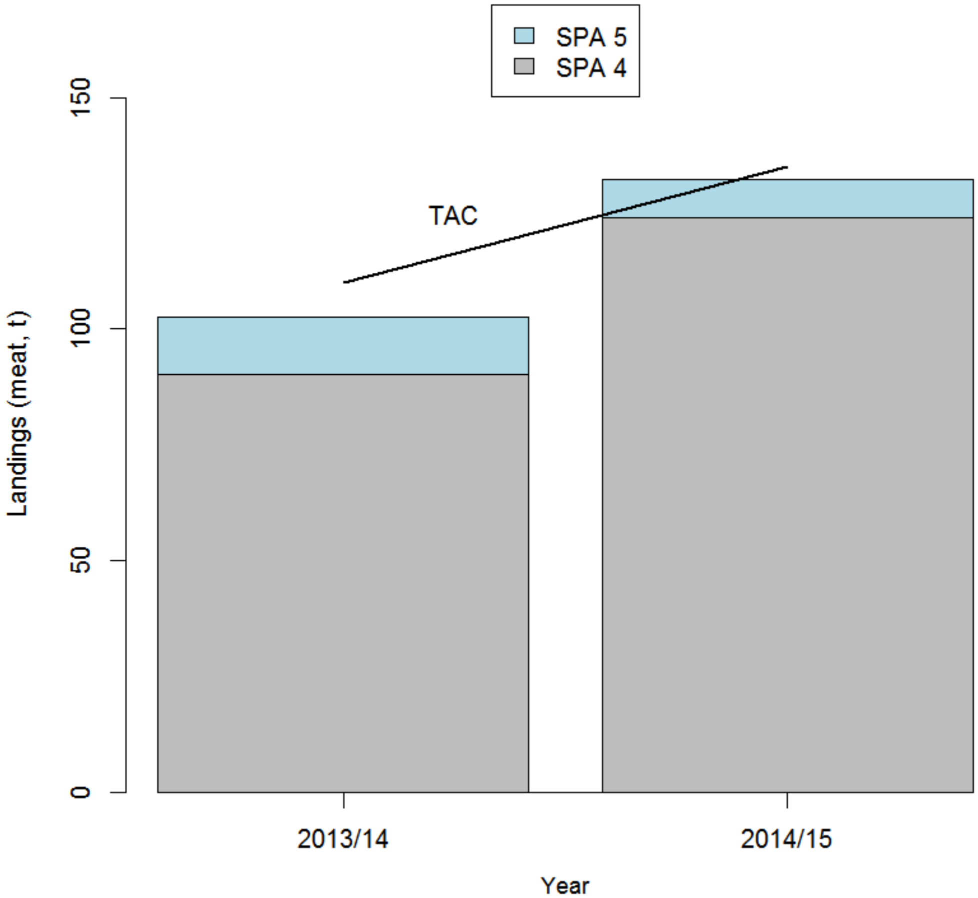

Figure 72. Total Allowable Catch (TAC, t; black line) and landings (t, bars) in Scallop Production Area 4 (gray bars) and 5 (blue bars) for the 2014 and 2015 fishing years. SPA 4 and 5 were joined under one TAC starting in the 2014 fishing year (see Figure 73 for historic values).

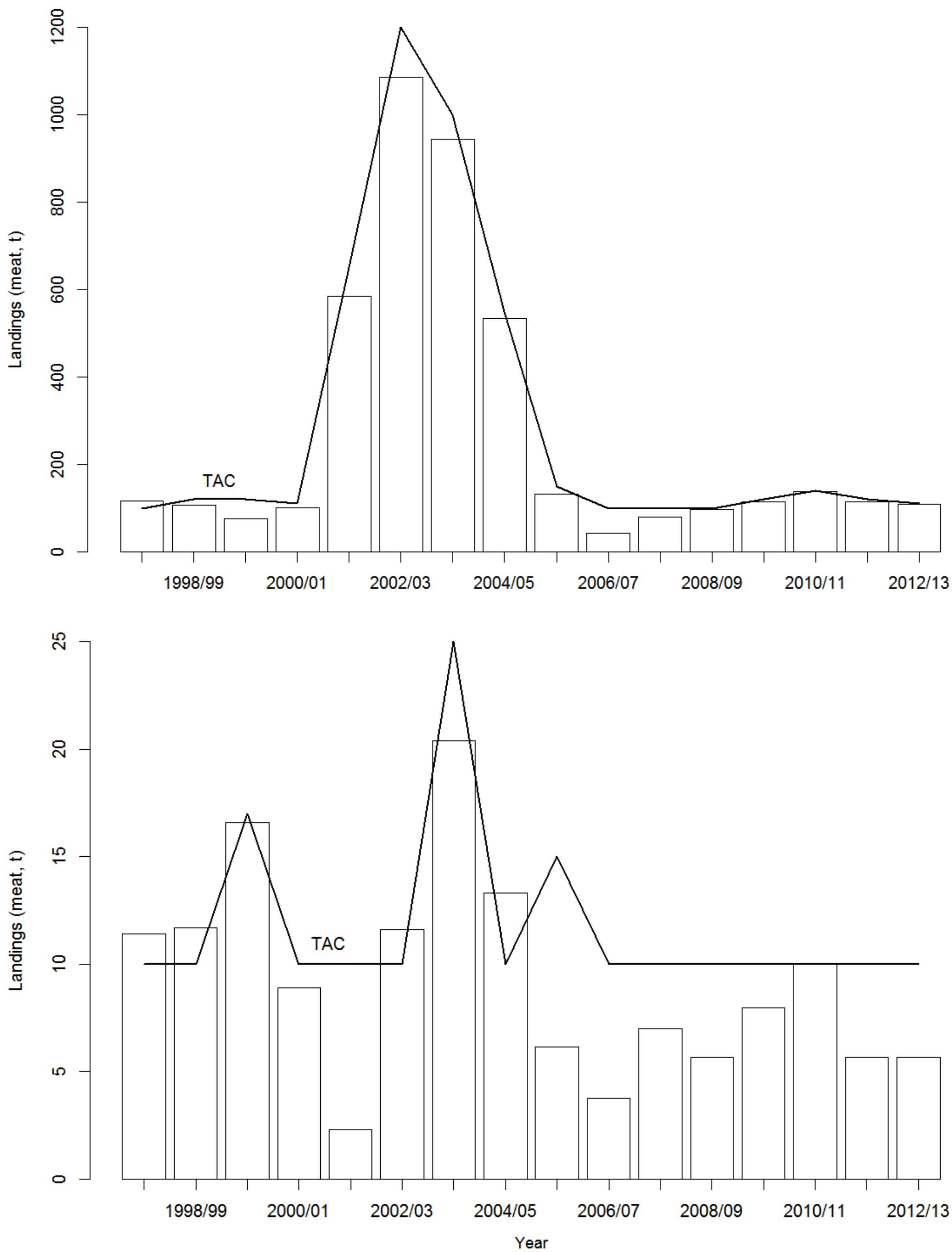

Figure 73. Total Allowable Catch (TAC, t; black line) and landings (t, bars) in Scallop Production Area 4 (upper panel) and 5 (bottom panel) from 1997/1998 to 2012/2013. SPAs 4 and 5 were joined under one TAC starting in the 2013/2014 fishing year (see Figure 72 for recent values).

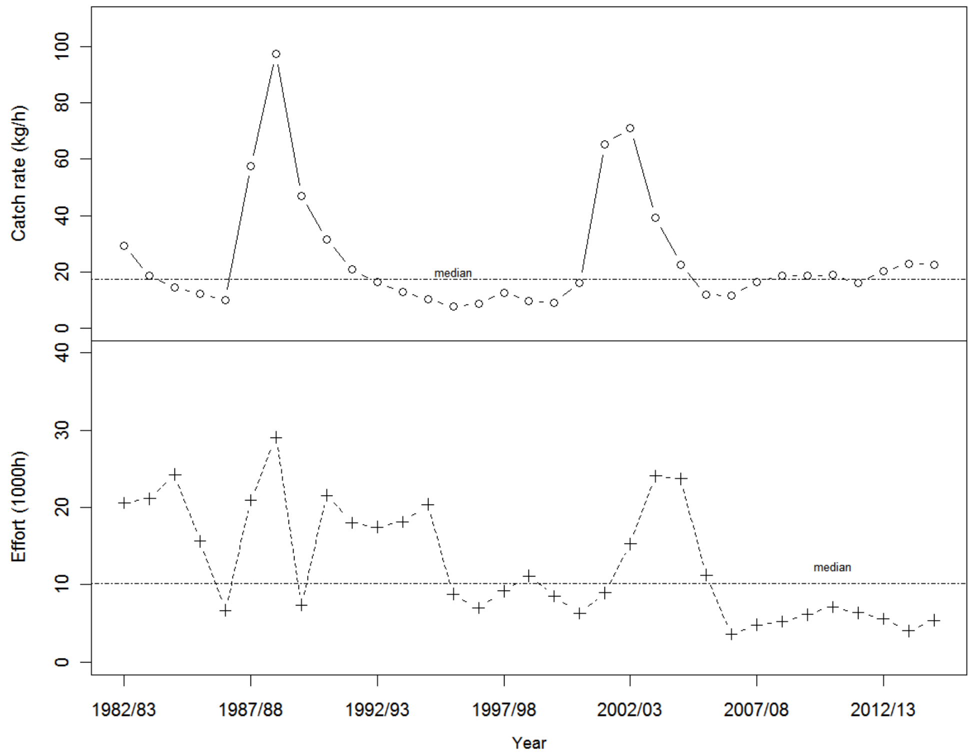

Figure 74. Catch per unit effort (CPUE, kg/h; top panel) and effort (1000 h; bottom panel) in the Scallop Production Area (SPA) 4 portion of the SPA 4 and 5 fishery from 1982/1983 to 2014/2015. Median rates from 1982/1983 to 2013/2014 indicated by dashed line.

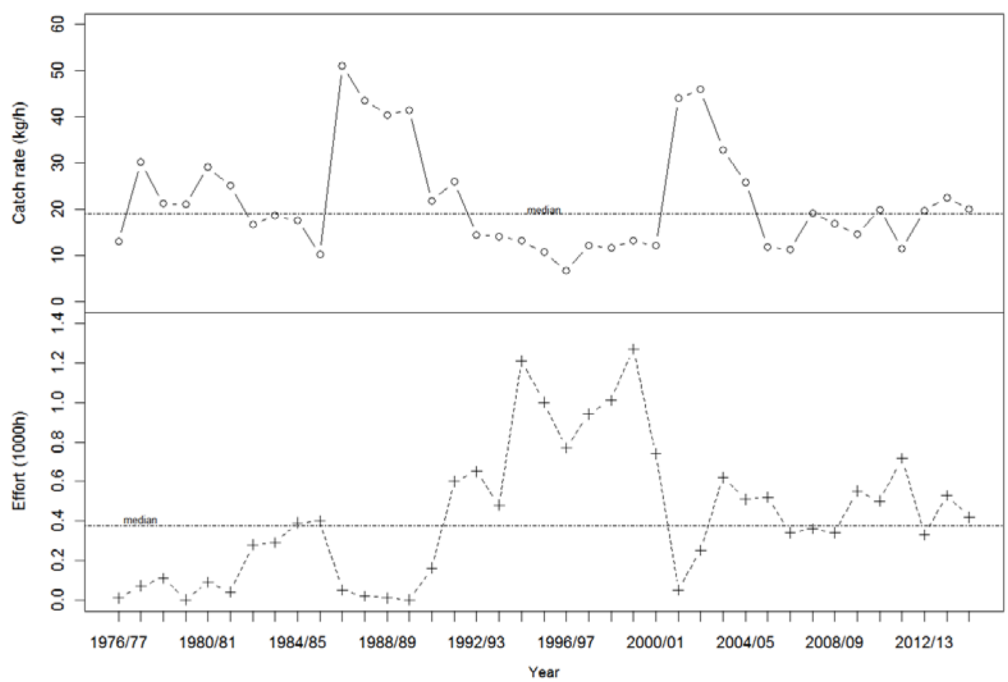

Figure 75. Catch per unit effort (CPUE, kg/h; top panel) and effort (1000 h; bottom panel) in the Scallop Production Area (SPA) 5 portion of the SPA 4 and 5 fishery from 1976/1977 to 2014/2015. Median rates from 1976/1977 to 2013/2014 indicated by dashed line.

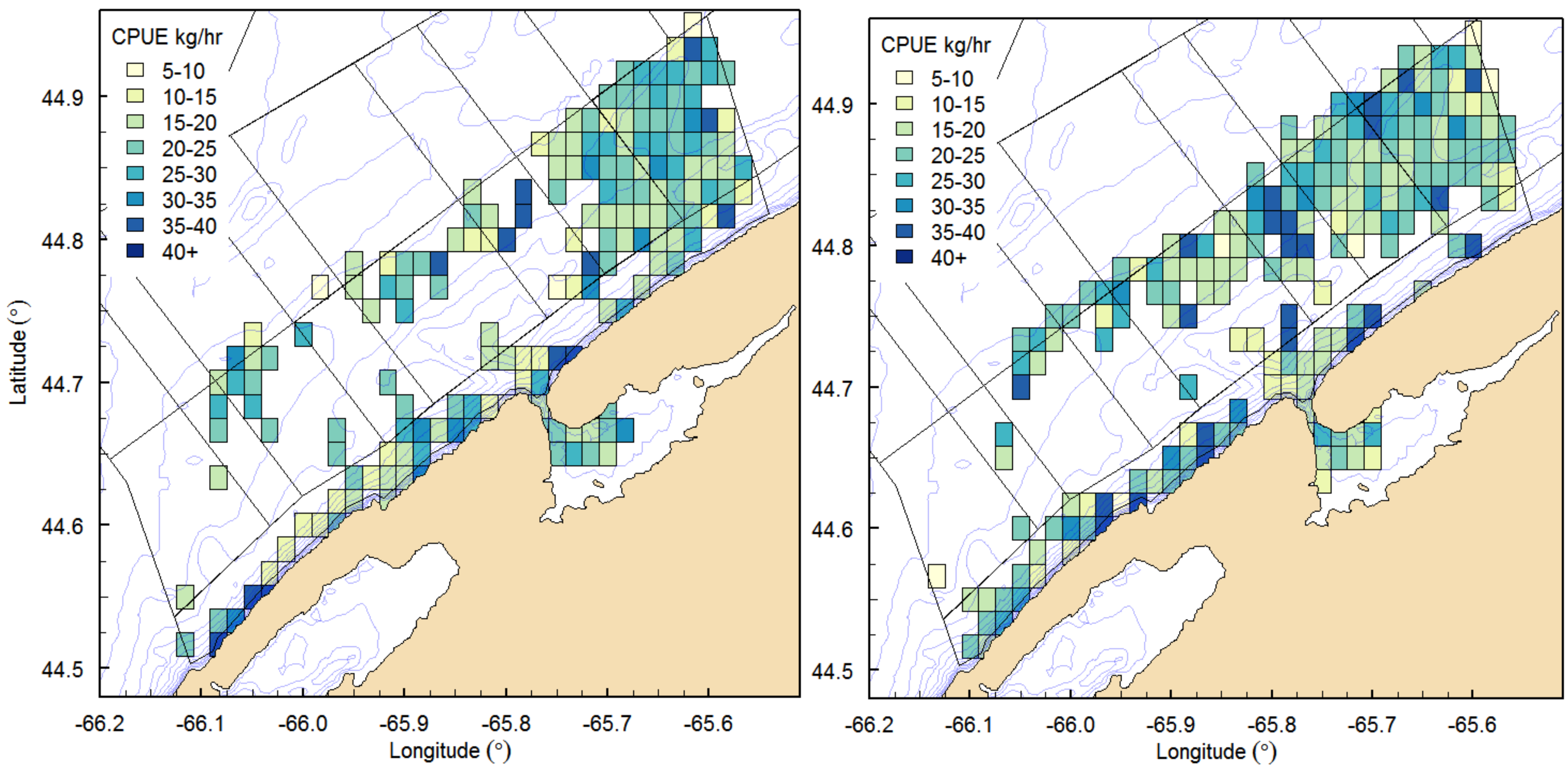

Figure 76. Spatial distribution of catch per unit effort (CPUE, kg/h) in the Scallop Production Area 4 and 5 for the 2014 (left panel) and 2015 (right panel) fishing years. Black lines represent survey strata.

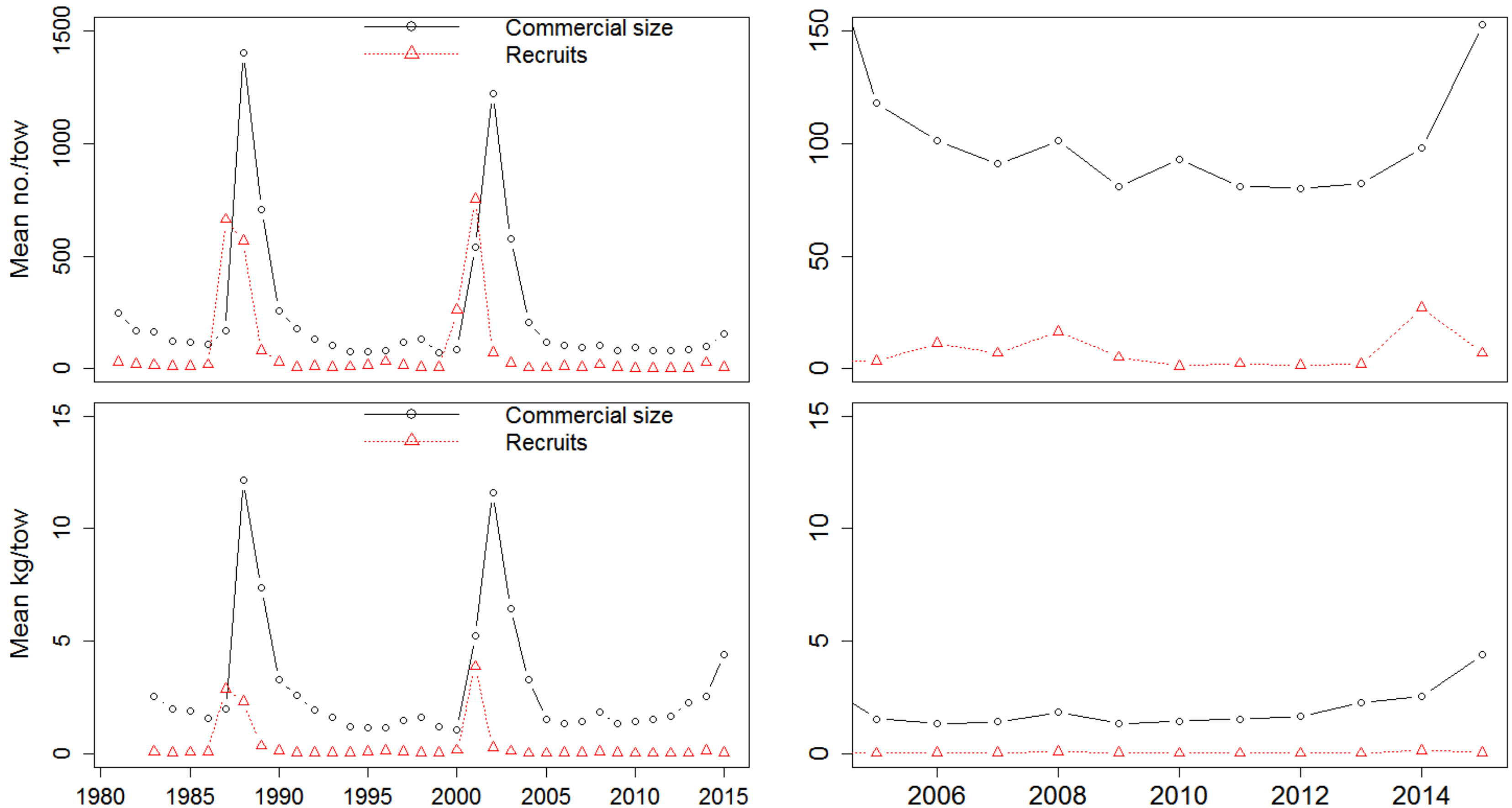

Figure 77. Mean number per tow (top panels) and mean weight (kg) per tow (bottom panels) of commercial (black circles) and recruit (red triangle) sized scallops in the Scallop Production Area (SPA) 4 portion of SPA 4 and 5 from 1983 to 2015 (left panels) and from 2005 to 2015 (right panels). Note different axes.

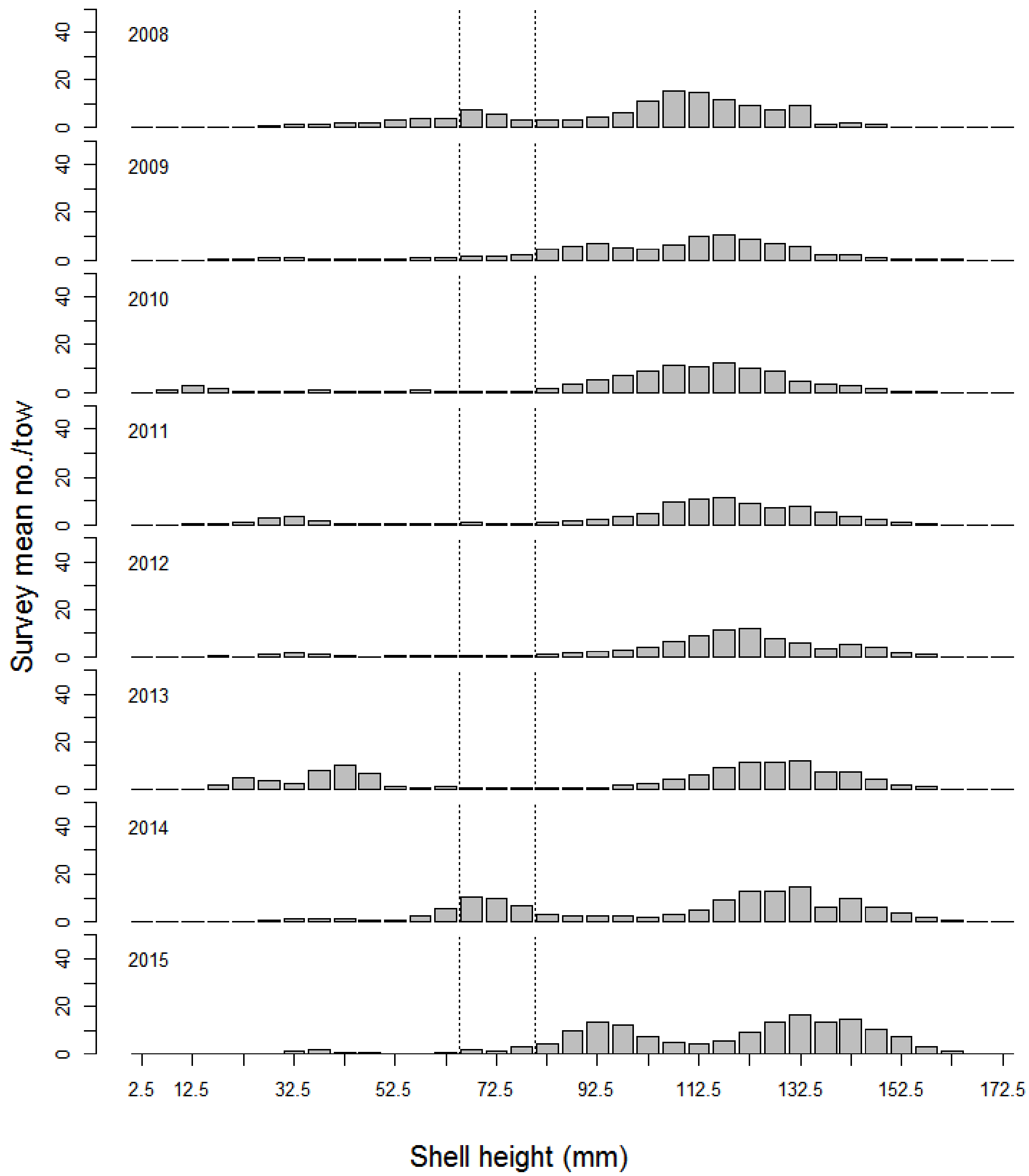

Figure 78. Shell height (mm) frequency (mean number/tow) for the Scallop Production Area (SPA) 4 portion of SPA 4 and 5, from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

Figure 79. Mean shell height (mm) of commercial size scallops in the Scallop Production Area (SPA) 4 portion of SPA 4 and 5, from 1983 to 2015.

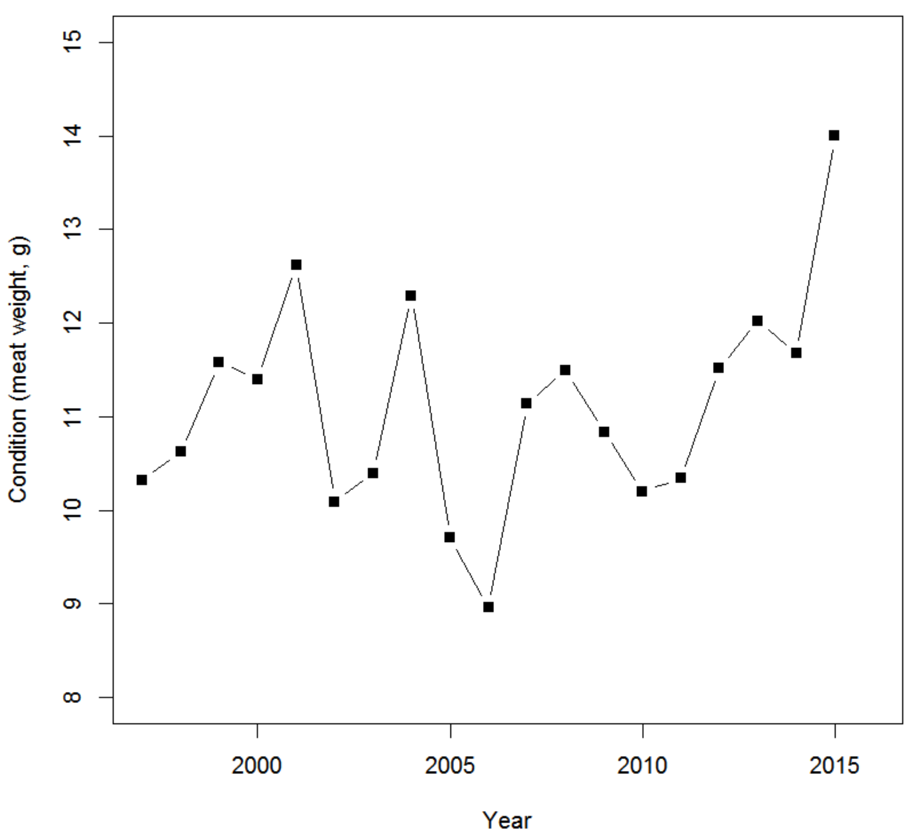

Figure 80. Condition (meat weight, g) for a shell of 100 mm in the Scallop Production Area (SPA) 4 portion of SPA 4 and 5, from 1997 to 2015.

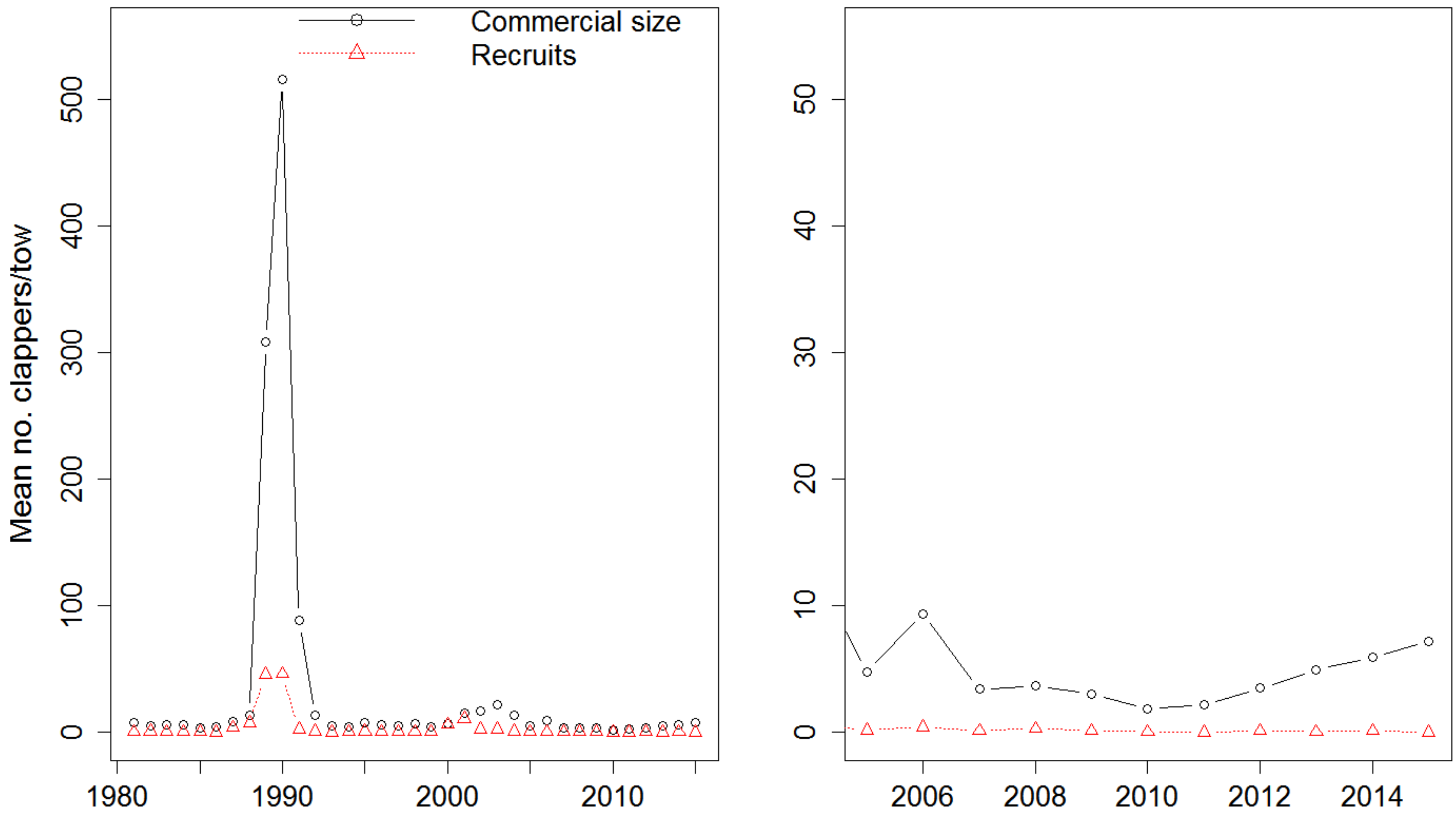

Figure 81. Mean number per tow of clappers (paired, dead shells) of commercial (black circles) and recruit (red triangle) sized scallops in the Scallop Production Area (SPA) 4 portion of SPA 4 and 5 from 1983 to 2015 (left panel) and from 2005 to 2015 (right panel). Note different axes.

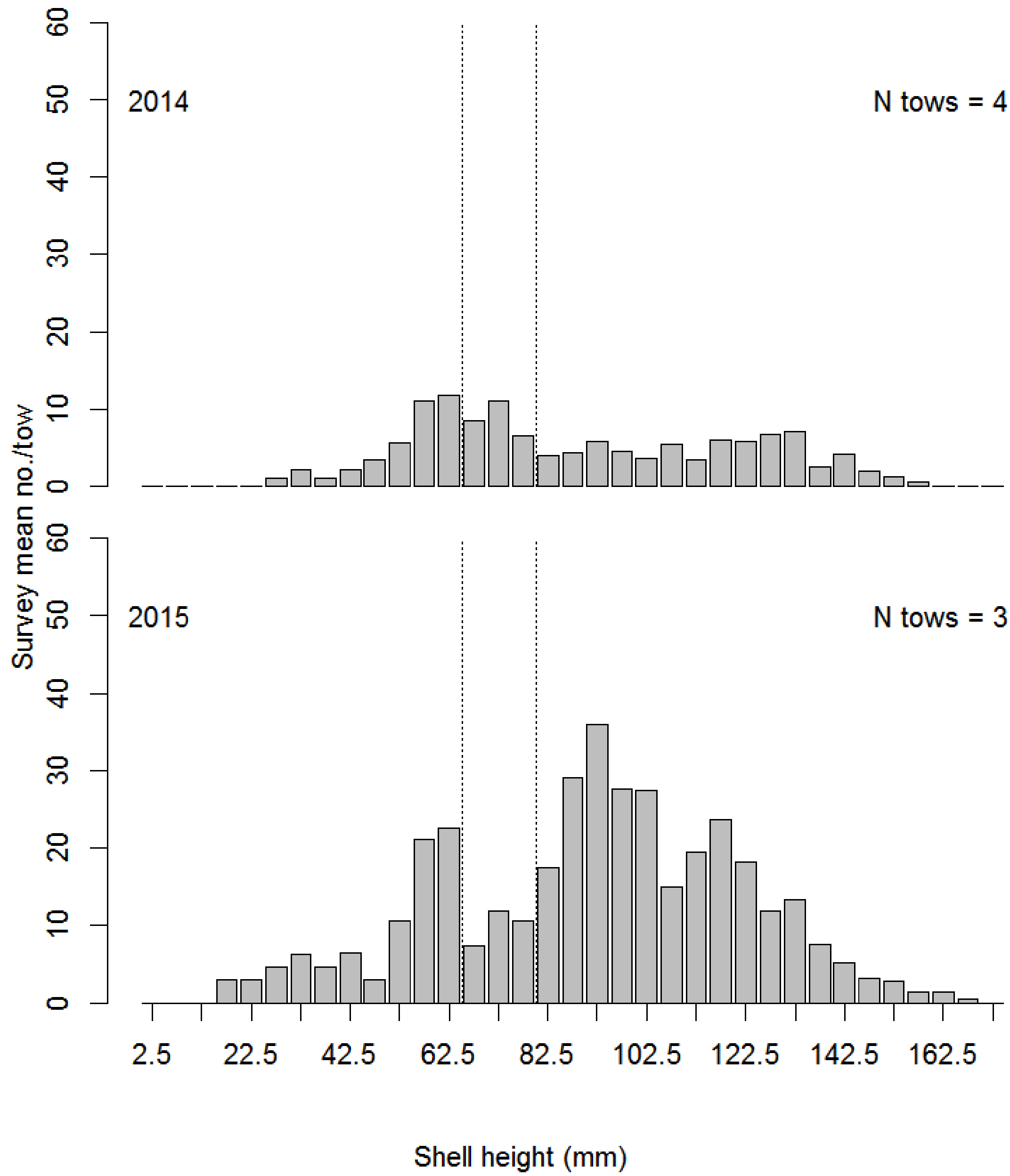

Figure 82. Shell height (mm) frequency (mean number/tow) for 0 to 2 mile inshore area of the Scallop Production Area (SPA) 4 portion of SPA 4 and 5, for 2014 and 2015, number of exploratory tows indicated. Vertical dashed lines represent the recruit size class (65 to 80 mm).

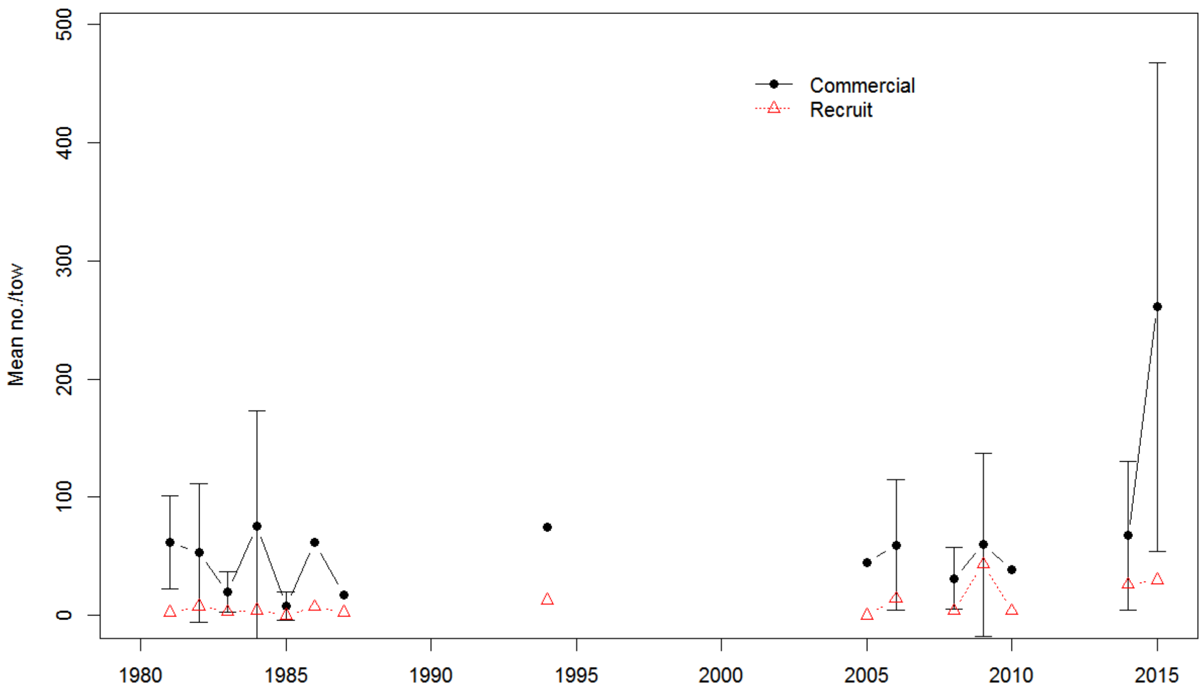

Figure 83. Mean number per tow of commercial (black circles) and recruit (red triangle) sized scallops in the exploratory tows conducted in the 0 to 2 mile inshore area of the Scallop Production Area (SPA) 4 portion of SPA 4 and 5 from 1981 to 2015. Error bars represent ±1 standard deviation.

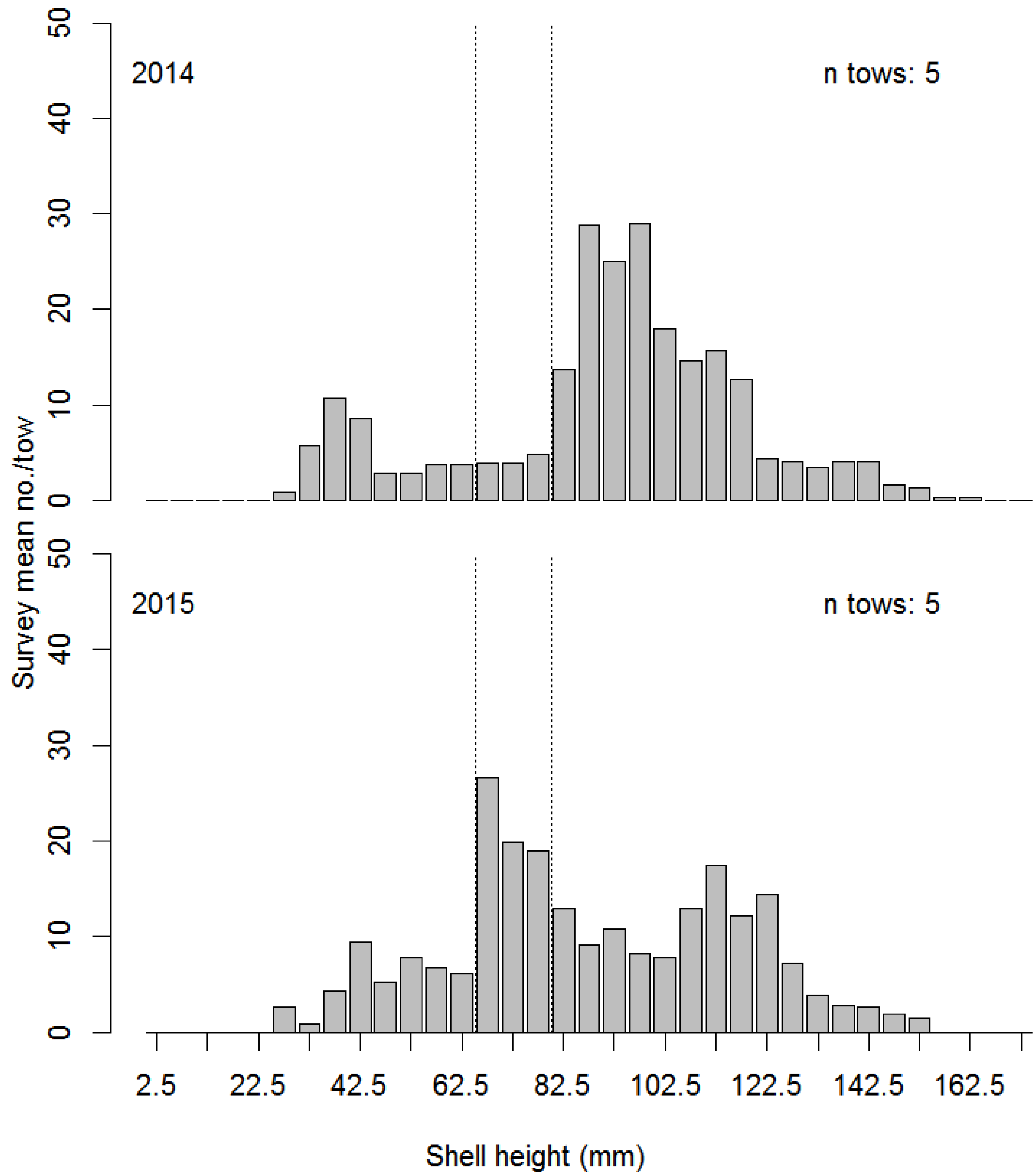

Figure 84. Shell height (mm) frequency (mean number/tow) the Scallop Production Area (SPA) 5 portion of SPA 4 and 5, for 2014 and 2015, number of exploratory tows indicated. Vertical dashed lines represent the recruit size class (65 to 80 mm).

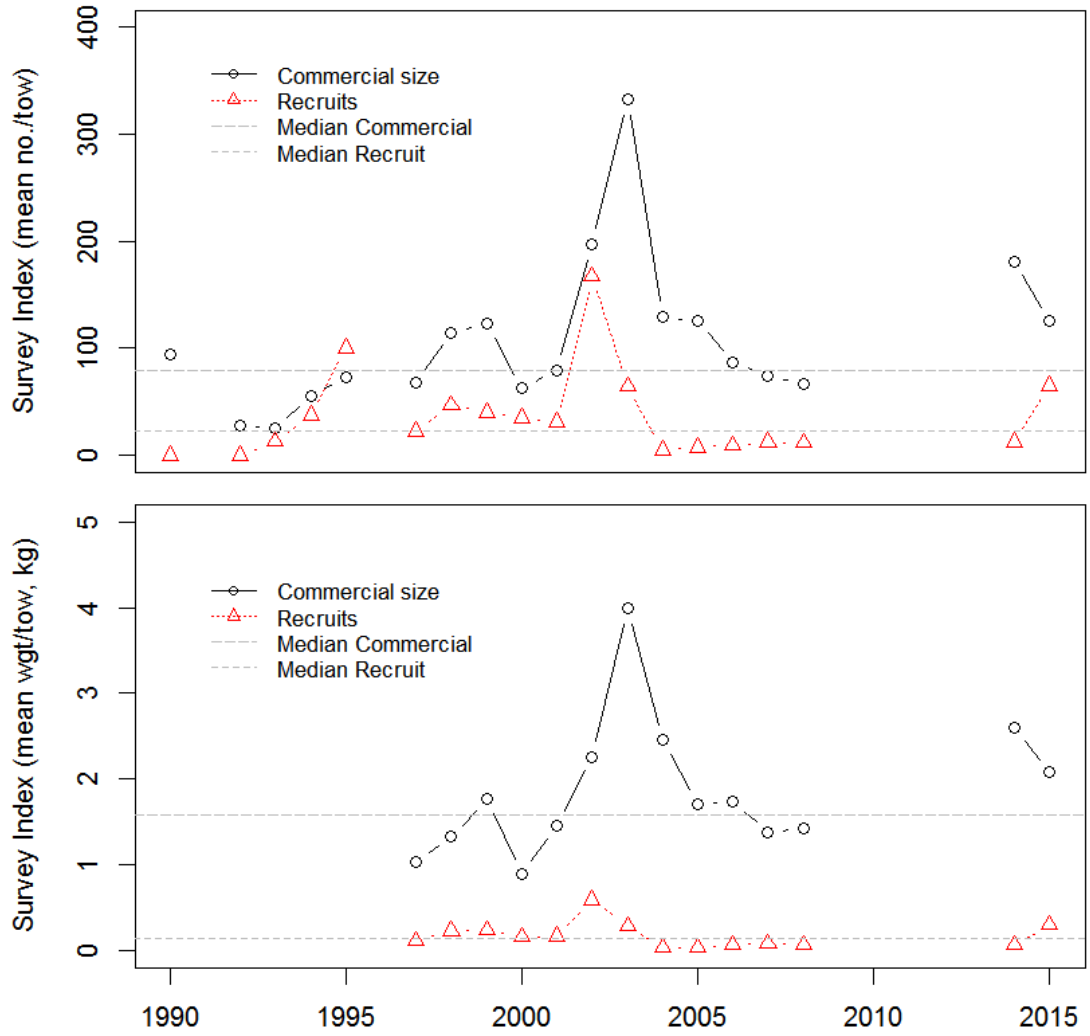

Figure 85. Mean number per tow (top panel) and mean weight (kg) per tow (bottom panel) of commercial (black circles) and recruit (red triangle) sized scallops in the Scallop Production Area (SPA) 5 portion of SPA 4 and 5. Series from 1990 to 2008 from regular survey tows in those years, values from 2014 to 2015 from exploratory tows in those years. Dashes lines represent median values for the commercial and recruit series based only on the 1990 to 2008 data (for mean numbers) or 1996 to 2008 (for mean weight).

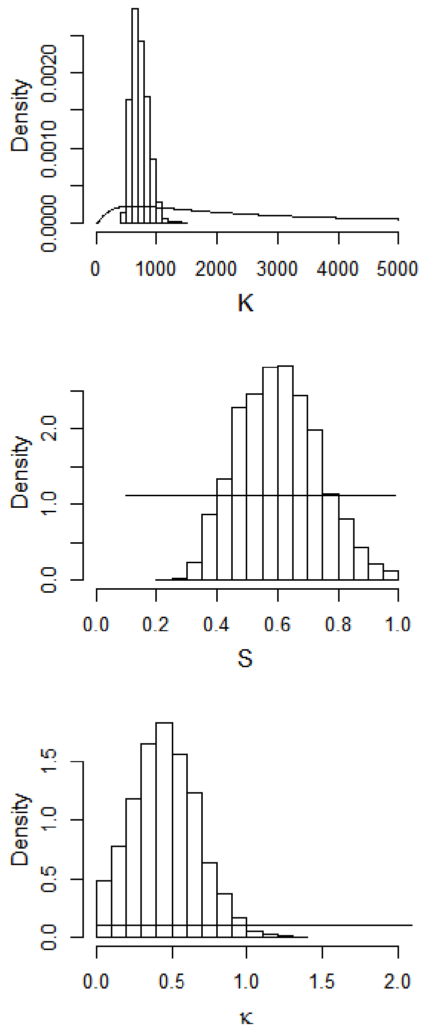

Figure 86. Comparison of prior (lines) and posterior densities (histogram) from the Bayesian state-space assessment model in Scallop Production Area 4.

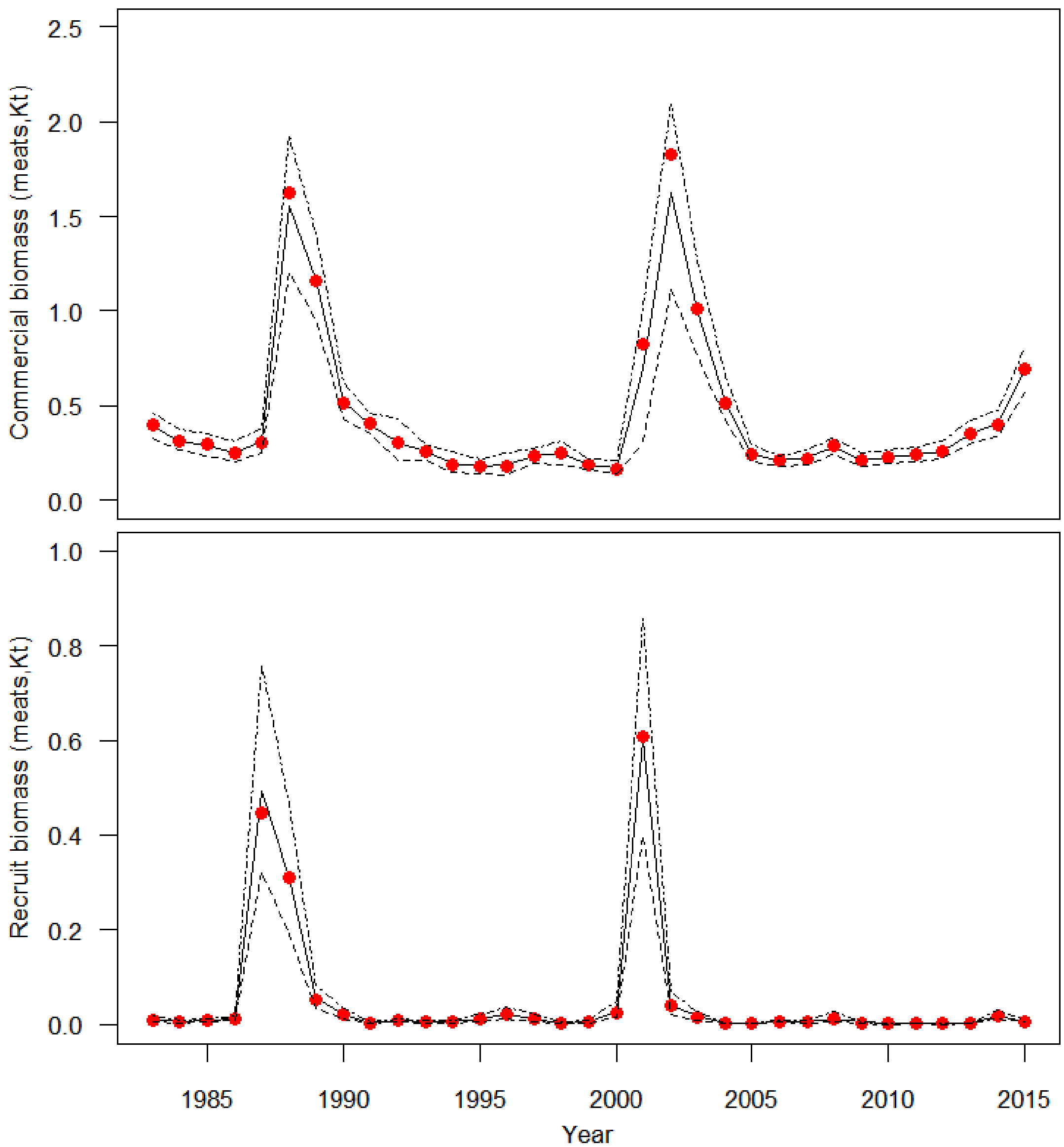

Figure 87. Posterior mean fit to the survey biomass series of commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 4 from 1983 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

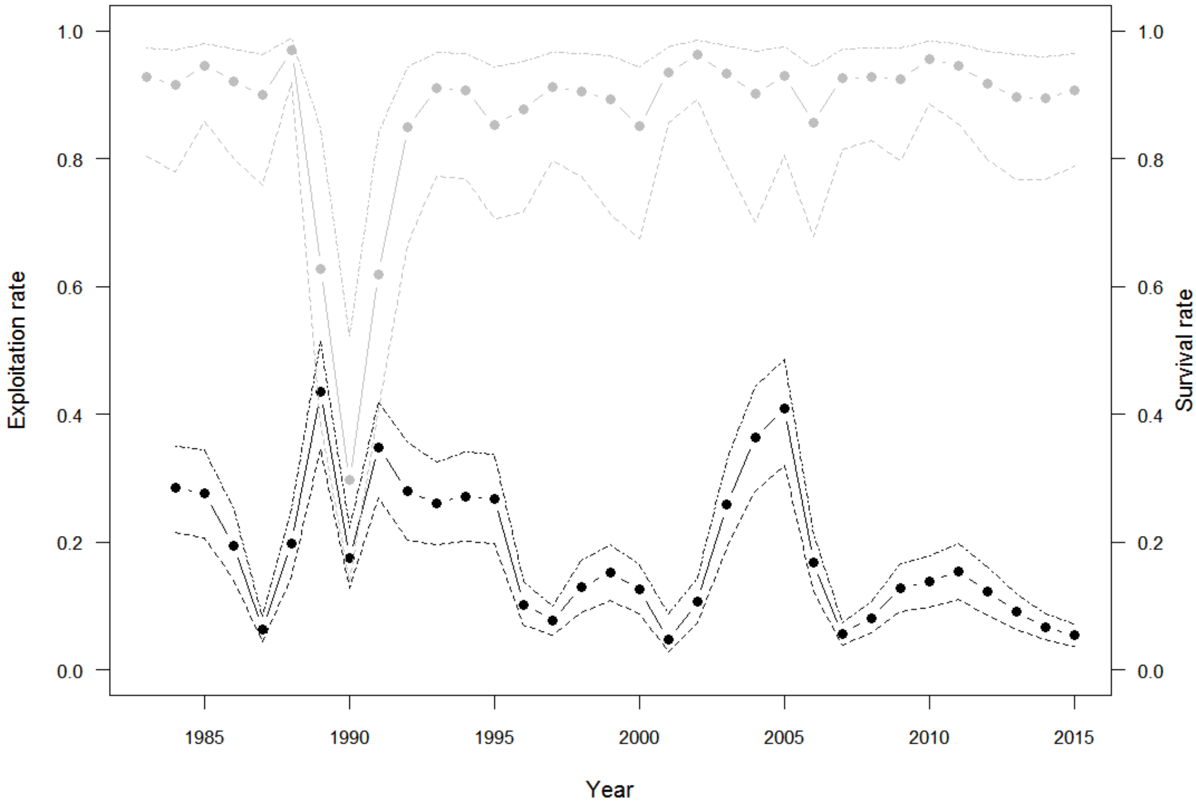

Figure 88. Annual trends (1983 to 2015) in exploitation (black circles) and survival estimates (exp(-m), where m is natural mortality; grey circles) from the Bayesian state-space assessment model in Scallop Production Area 4. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

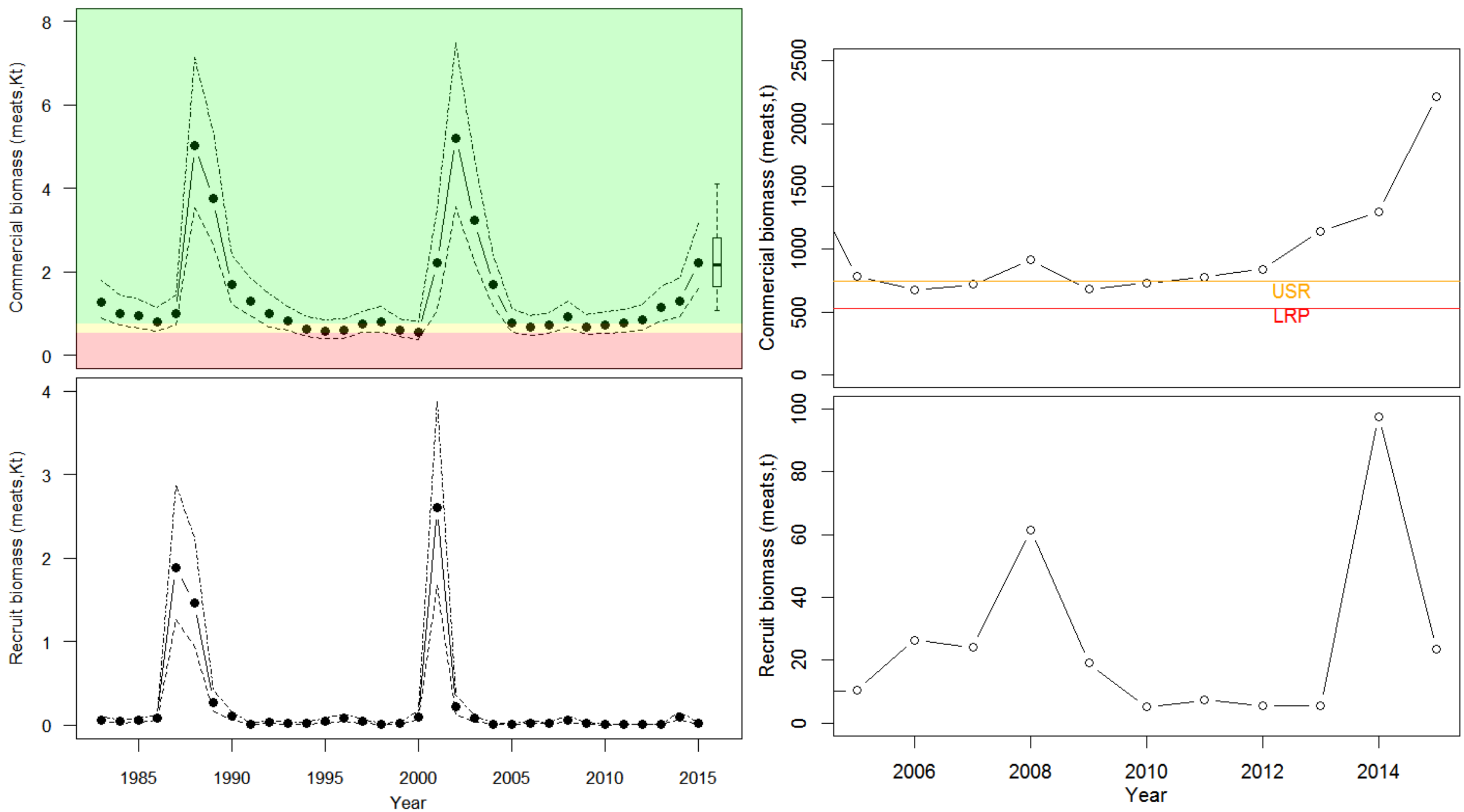

Figure 89. Biomass estimates for commercial (kt; top panels) and recruit (kt; lower panels) scallops from the Bayesian state-space assessment model in Scallop Production Area 4, fit to survey and commercial data from 1997 to 2015 (left panels) and 2005 to 2015 (right panels). Lines in left panels are the upper (dotted) and lower (dashed) 95% credible limits on the estimates. The predicted commercial biomass for 2016 is displayed as a box plot (upper right panel) with median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). This prediction assumes the initial total allowable catch of 80 t for this area is caught. The green-shaded area represents the healthy zone (based on an upper stock reference of 750 t), yellow area represents the cautious zone (based on a lower reference point (LRP) of 530 t) and the red is the critical zone (<LRP). These lines are also indicated in the right panels. Note different axes.

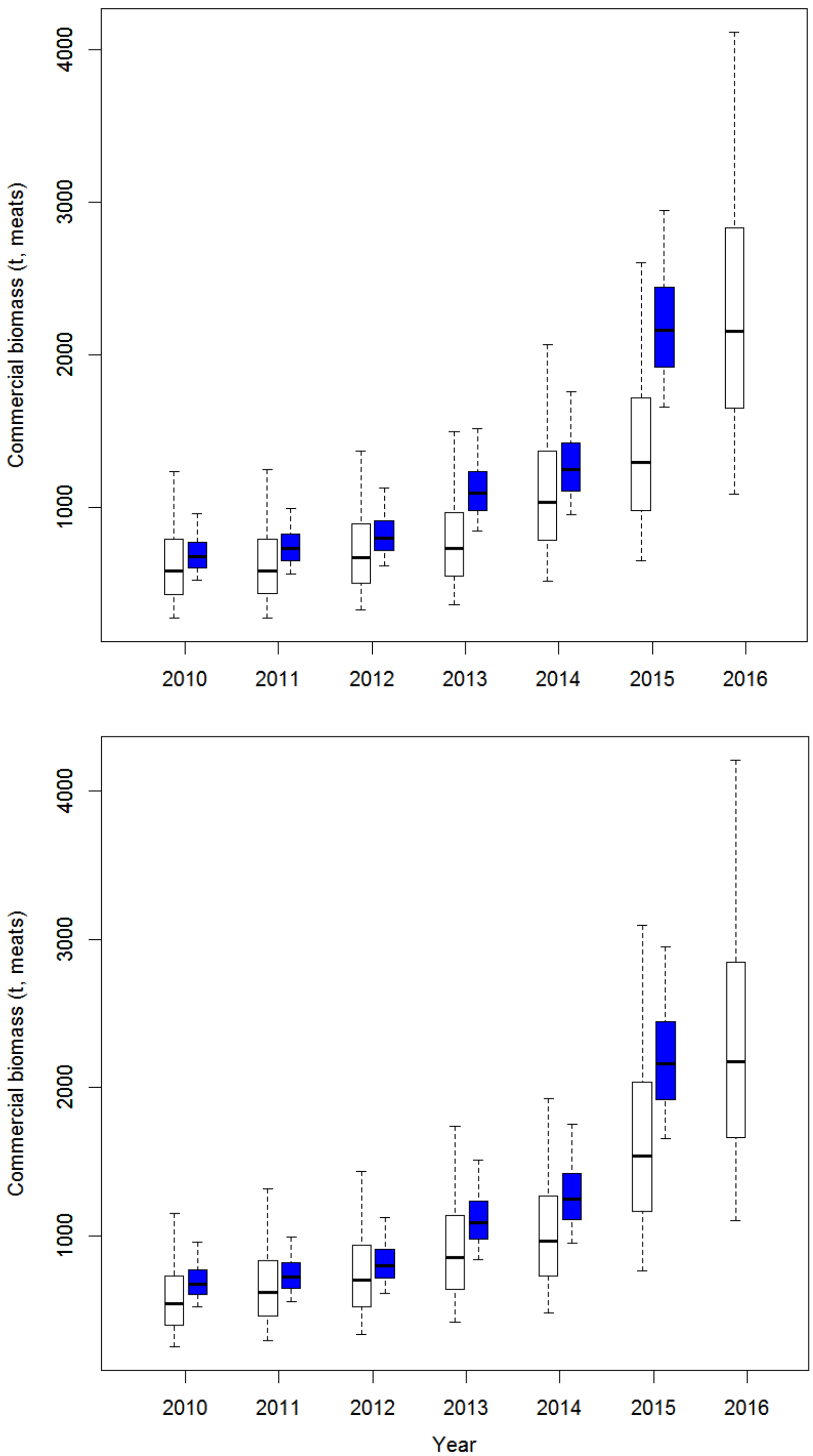

Figure 90. Evaluation of the model projection performance from 2010 to 2015 in Scallop Production Area 4. White box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2010 predictions based on data up to and including 2009). Blue box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t. Upper panel projections use estimated weight from year t to t+1, and lower panel projections use actual growth rate from year t to t+1 to evaluate projections if growth had been known. Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projection for 2016 assumes the initial total allowable catch of 80 t for this area is caught.

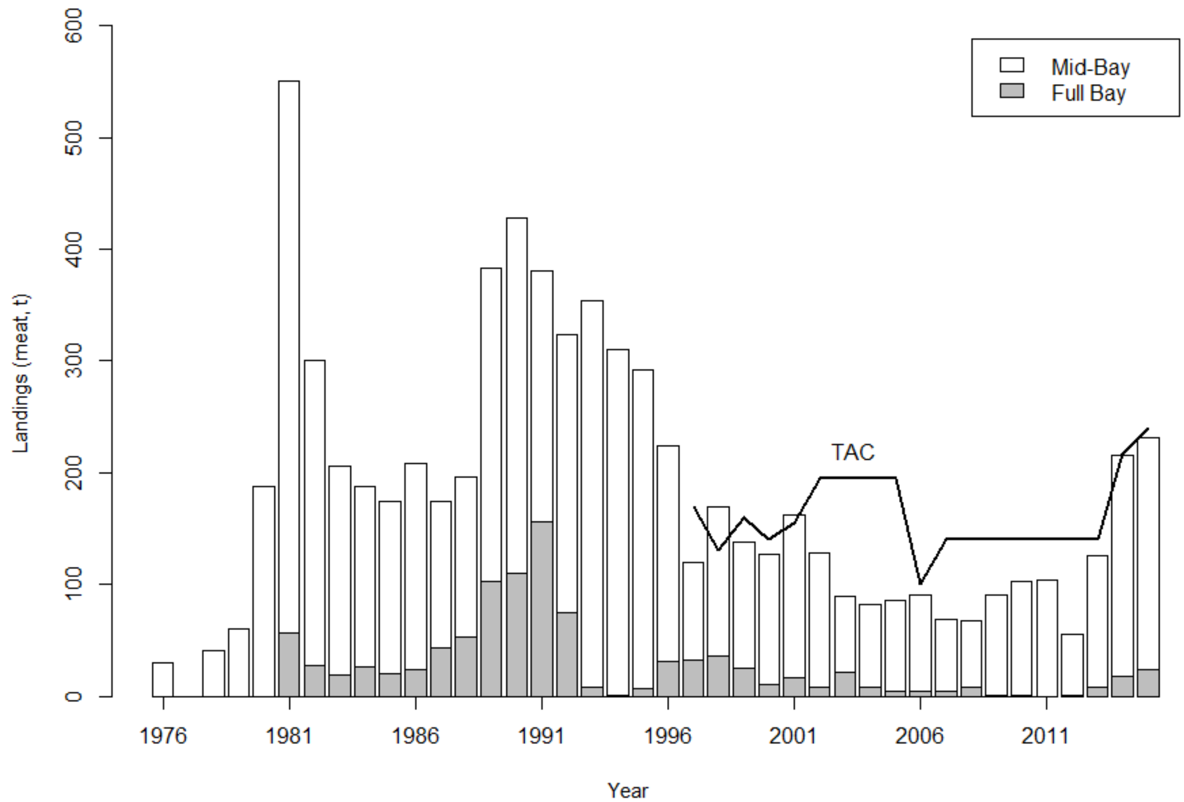

Figure 91. Scallop Production Area 6 landings (t, bars) by the Full Bay fleet (grey) from 1981-2015, and the Mid Bay fleet (white) from 1976, 1978-2015. Combined Total Allowable Catch (TAC, t) is indicated by the black line.

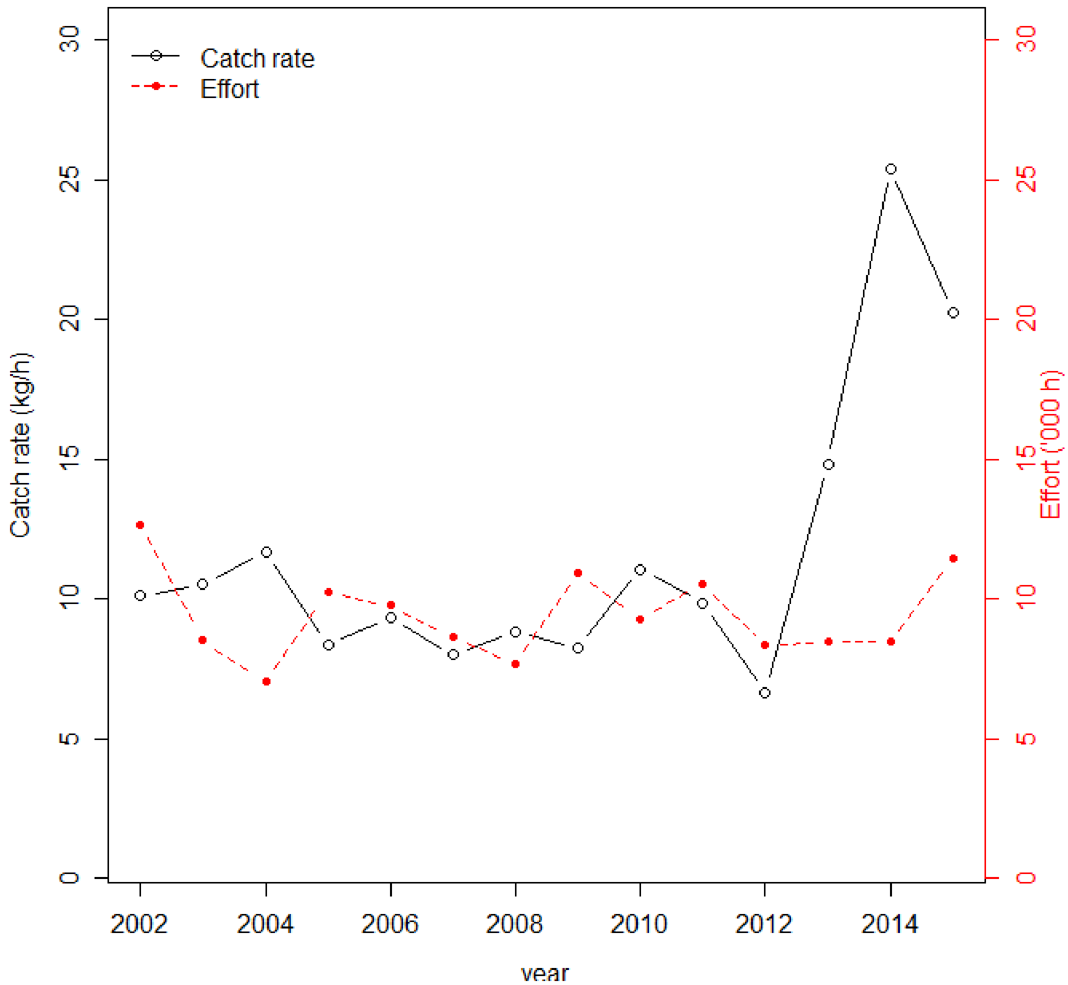

Figure 92. Annual commercial catch rate (kg/h, black closed circles) and total fleet effort (h, red open circles) for SPA 6 for all subareas and both fleets combined.

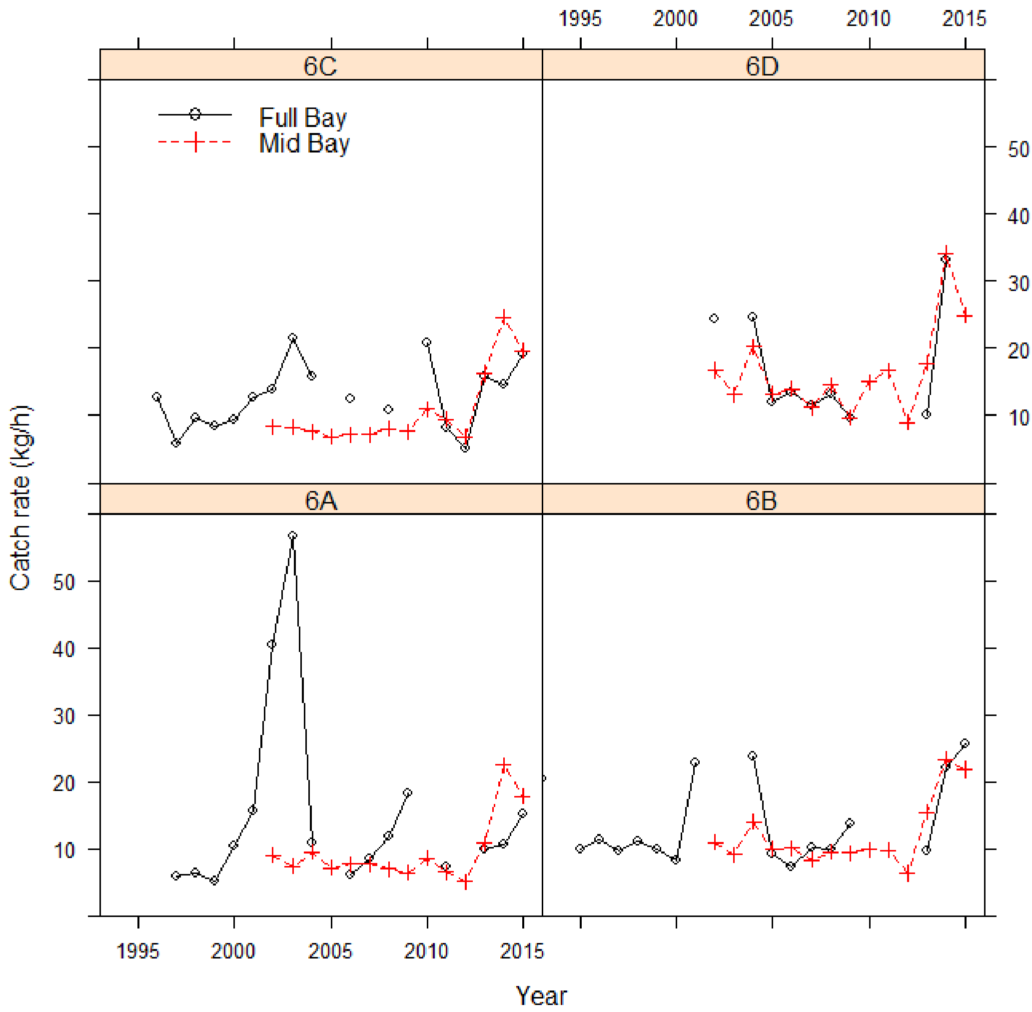

Figure 93. Annual commercial catch rate (kg/h) for SPA 6 by subarea for Mid Bay (black circles) and Full Bay (red crosses). Note catch rate for Full Bay were not presented for 6A in 2005, 2010, 2012, for 6B in 2002, 2003, 2010, 2011, 2012, for 6C in 2005, 2007, 2009, or 6D in 2012, 2015 due to the being too few records to display.

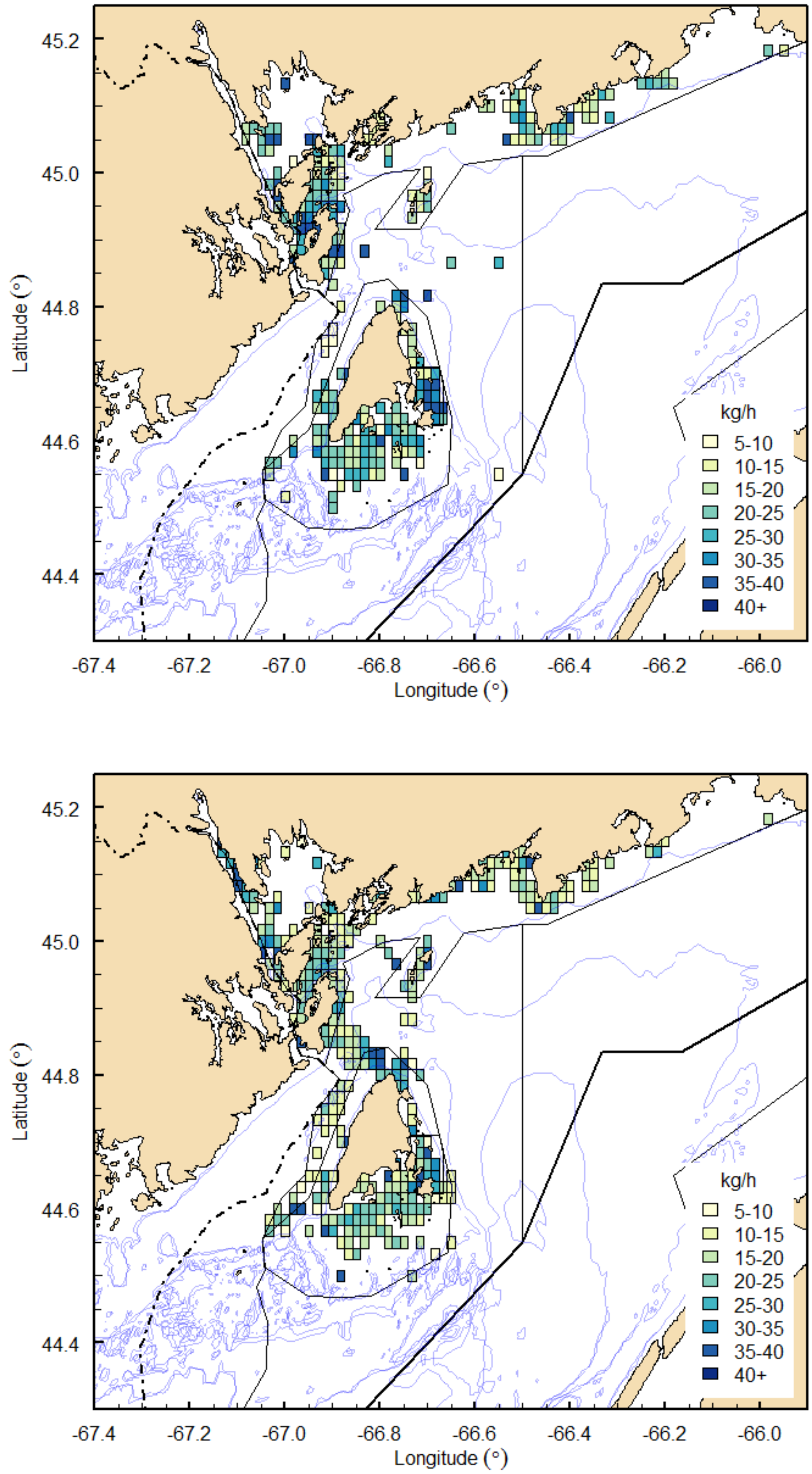

Figure 94. Scallop Production Area 6 mean catch rates (kg/h) by 1-minute square from commercial fishing logs for the 2013/2014 (upper) and 2014/2015 (lower) fishing seasons. Black lines represent management area boundaries.

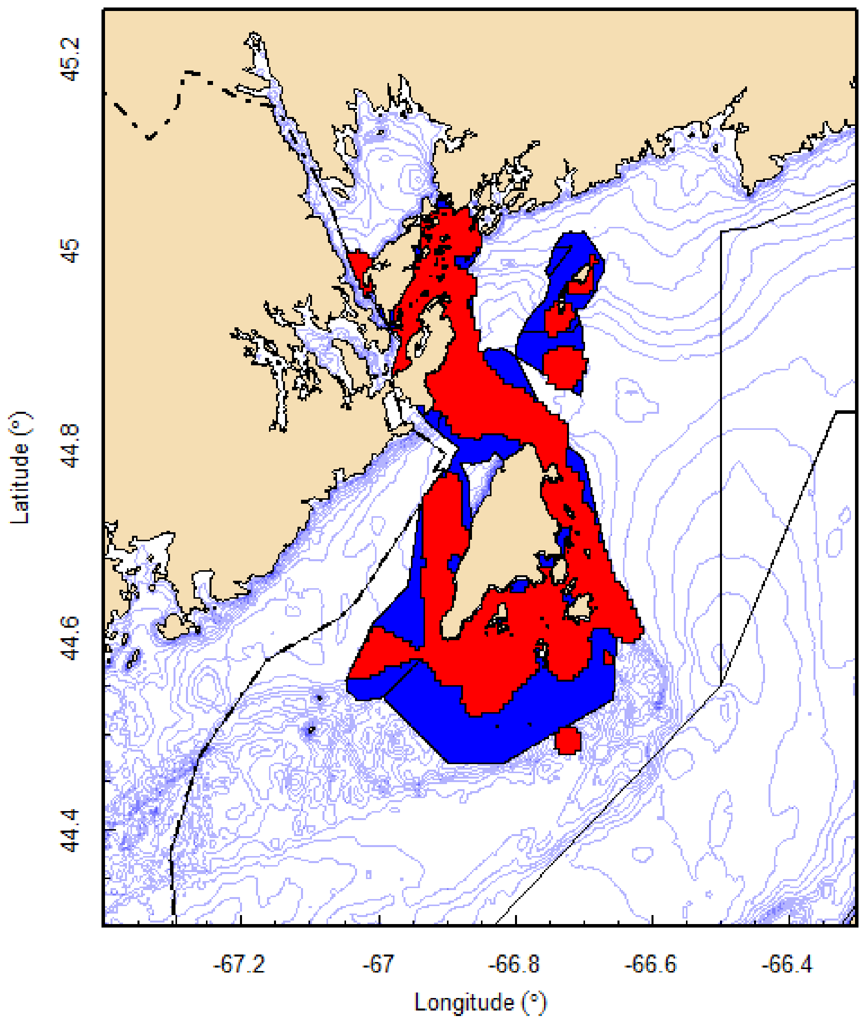

Figure 95. New survey strata for Scallop Production Area 6 as defined by VMS “fishing” intensity from 2002 to 2014 with the Inside VMS stratum defined by a threshold of greater than or equal to 21 hours of fishing per km^2, and the Outside VMS stratum defined by a combination of the historical survey extent and historical survey index. Red represents the Inside VMS stratum whereas blue represents the Outside VMS stratum. Black lines represent management area boundaries.

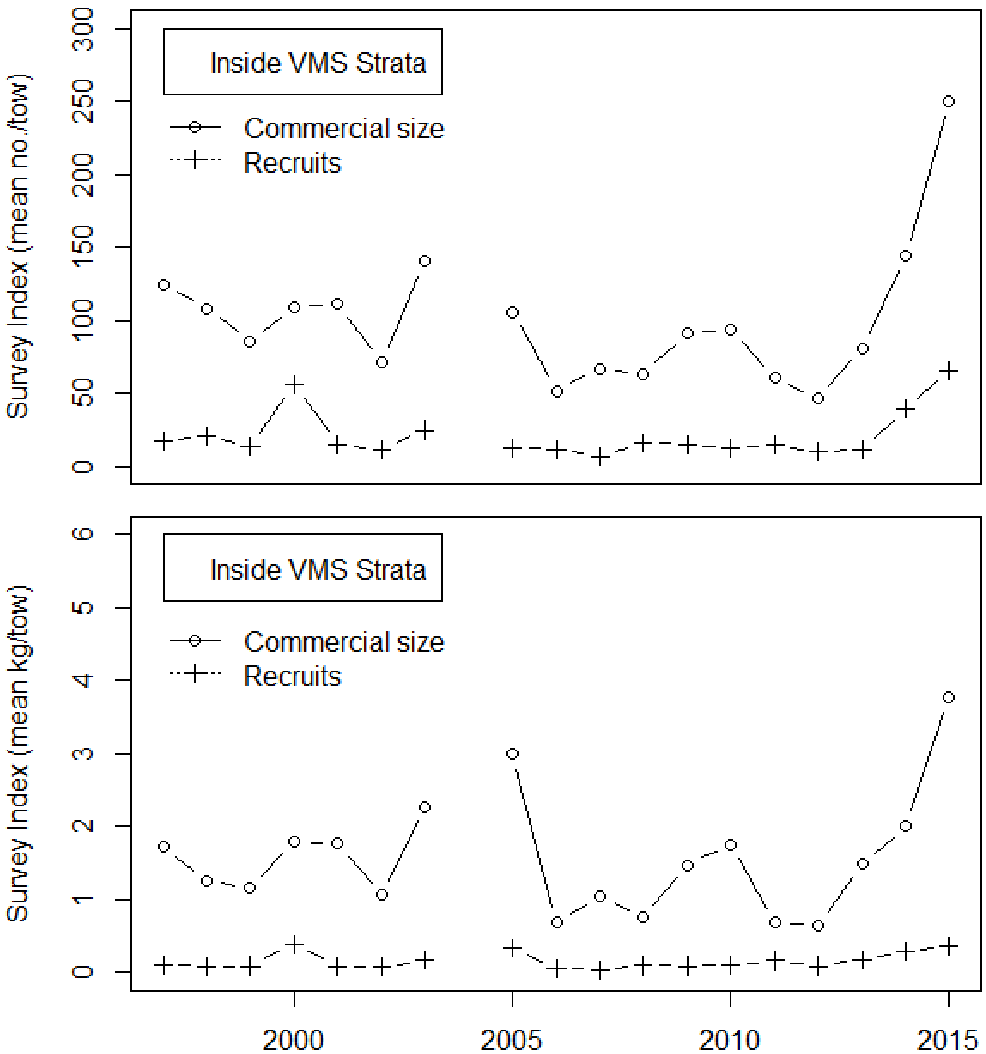

Figure 96. Mean number per tow (top panel) and mean weight (kg) per tow (bottom panel) of commercial (circles) and recruit (crosses) sized scallops in the Inside VMS stratum of Scallop Production Area (SPA) 6 from 1997 to 2015.

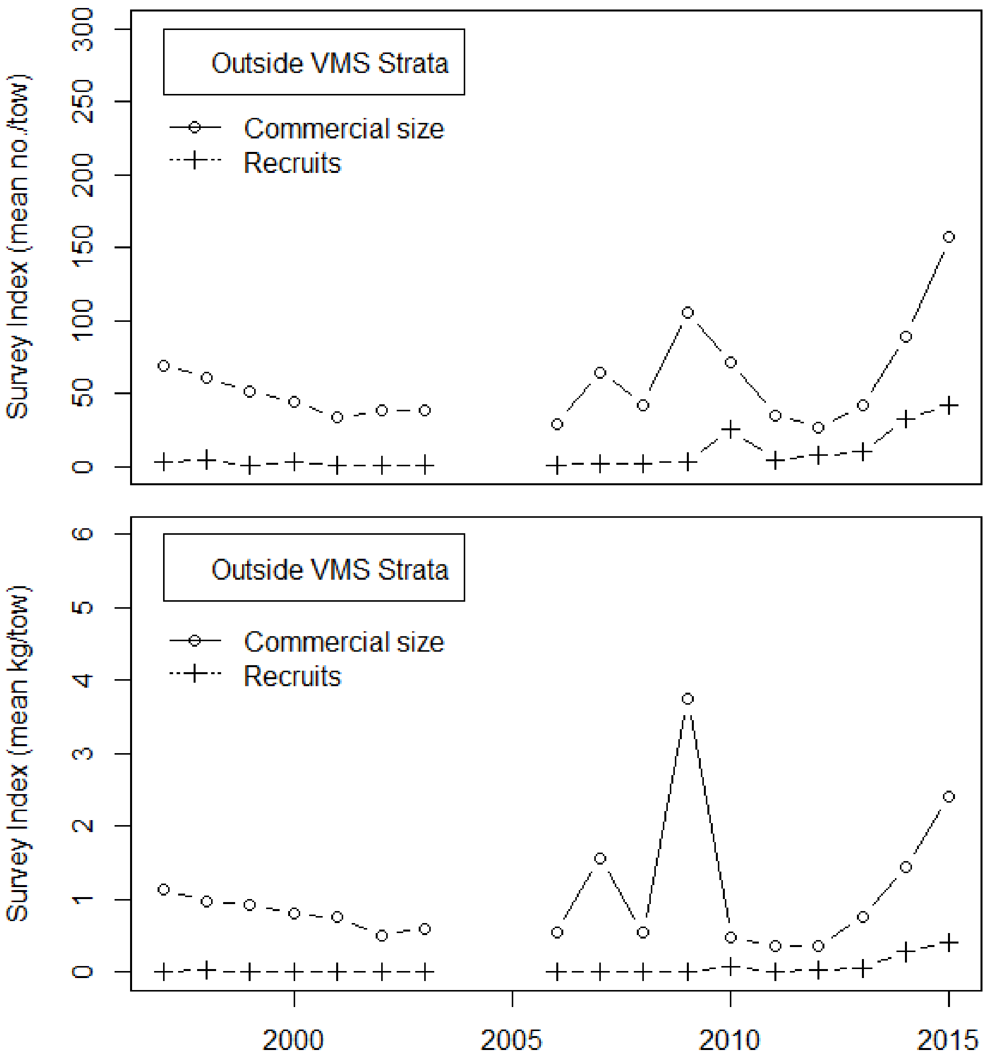

Figure 97. Mean number per tow (top panel) and mean weight (kg) per tow (bottom panel) of commercial (circles) and recruit (crosses) sized scallops in the Outside VMS stratum of Scallop Production Area (SPA) 6 from 1997 to 2015.

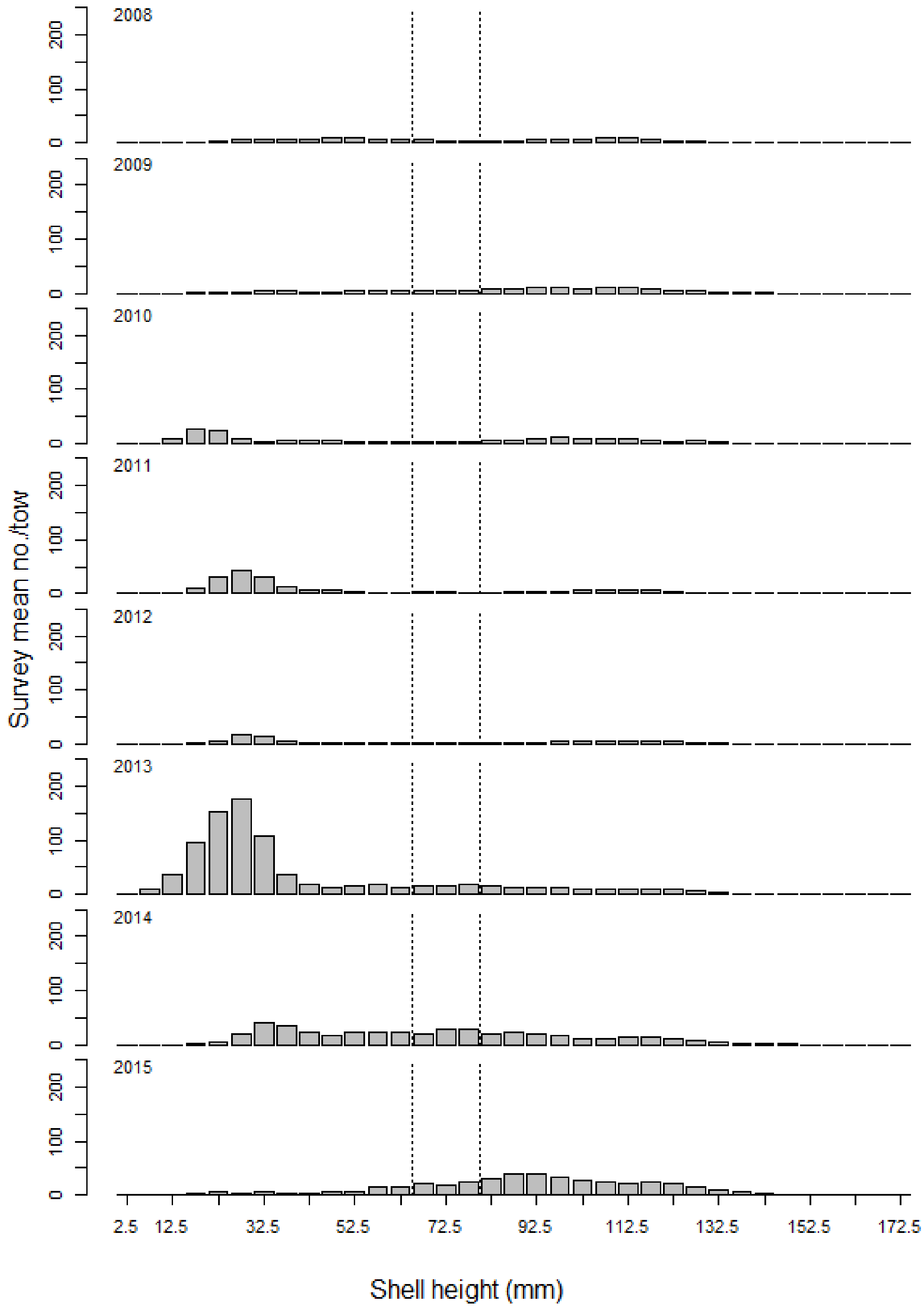

Figure 98. Shell height (mm) frequency (mean number/tow) for the Inside VMS stratum of Scallop Production Area (SPA) 6 from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

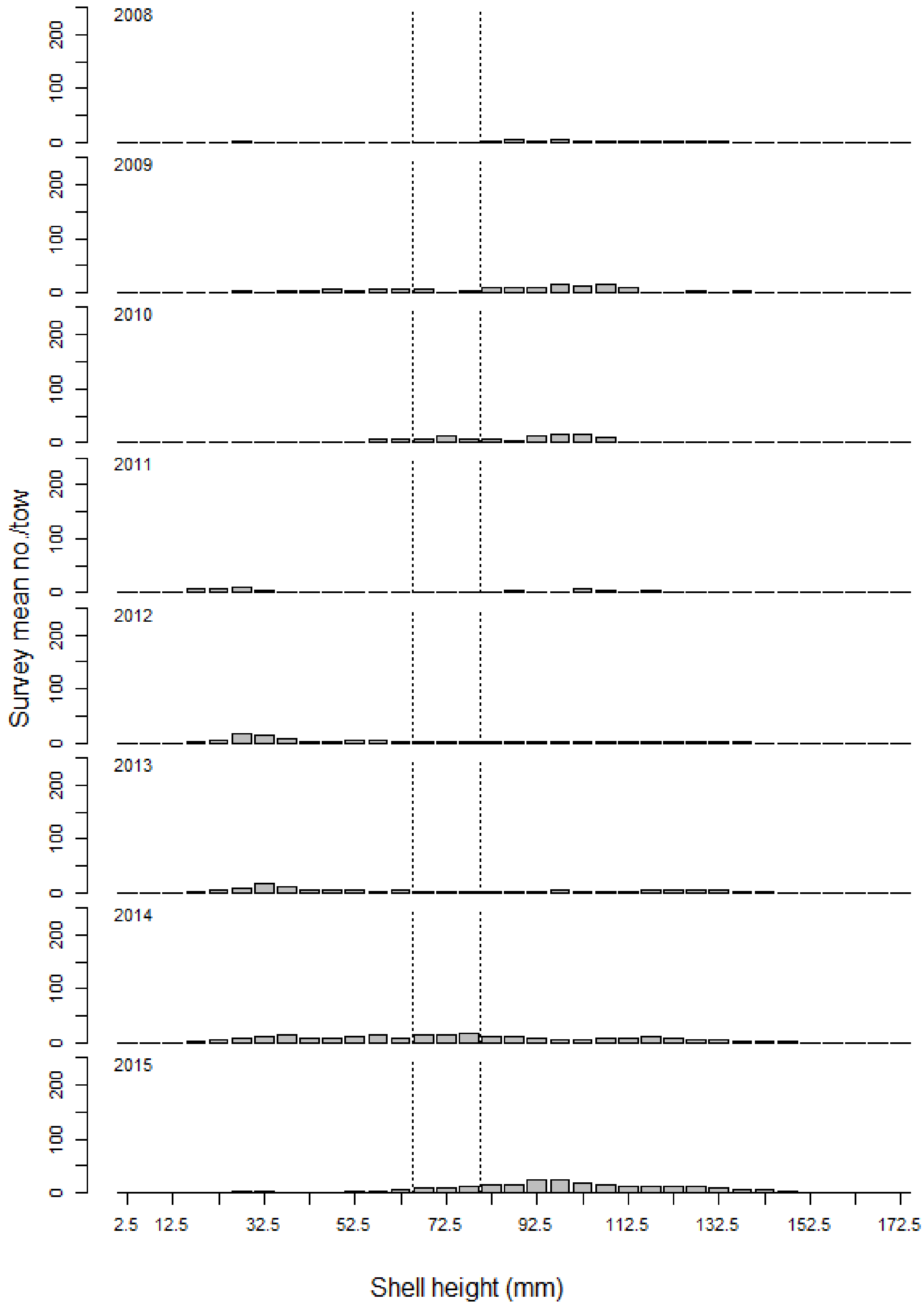

Figure 99. Shell height (mm) frequency (mean number/tow) for the Outside VMS stratum of Scallop Production Area (SPA) 6 from 2008 to 2015. Vertical dashed lines represent the recruit size class (65 to 80 mm).

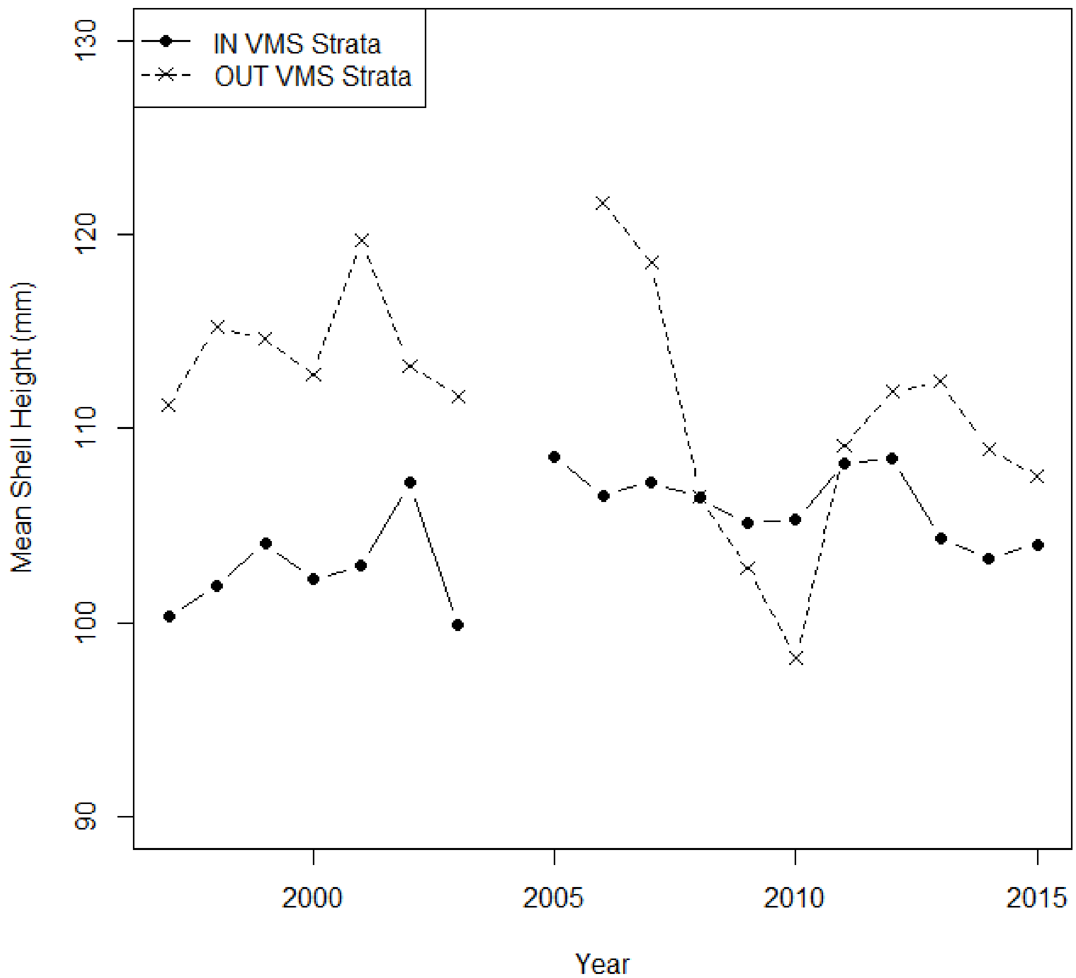

Figure 100. Mean shell height (mm) of commercial size scallops in the Inside (black circles) and Outside (crosses) VMS strata of Scallop Production Area 6 from 1997 to 2015. Note there was no survey in SPA 6 in 2004 and only limited survey coverage in 2005, which resulted in tows falling only in the Inside VMS stratum for that year.

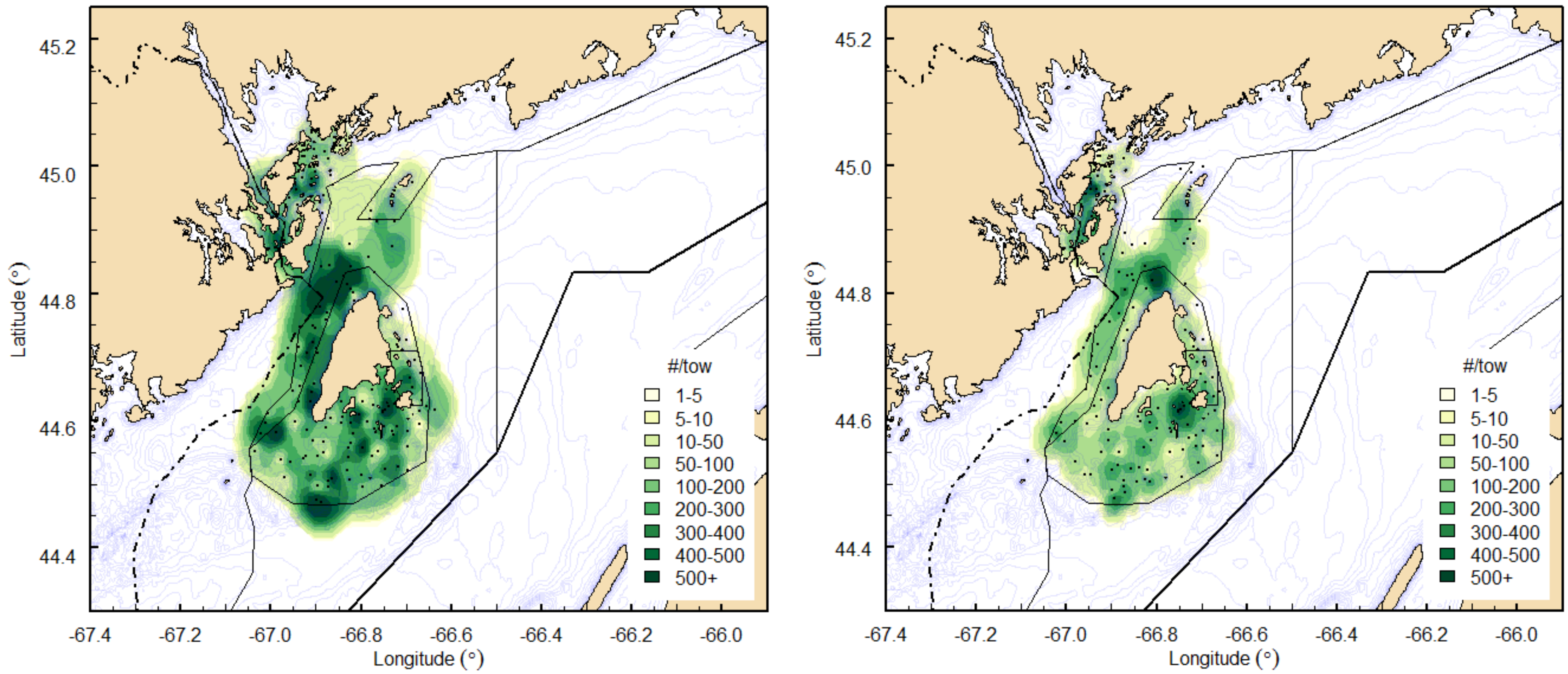

Figure 101. Spatial distribution of abundance (number/tow) of commercial size scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

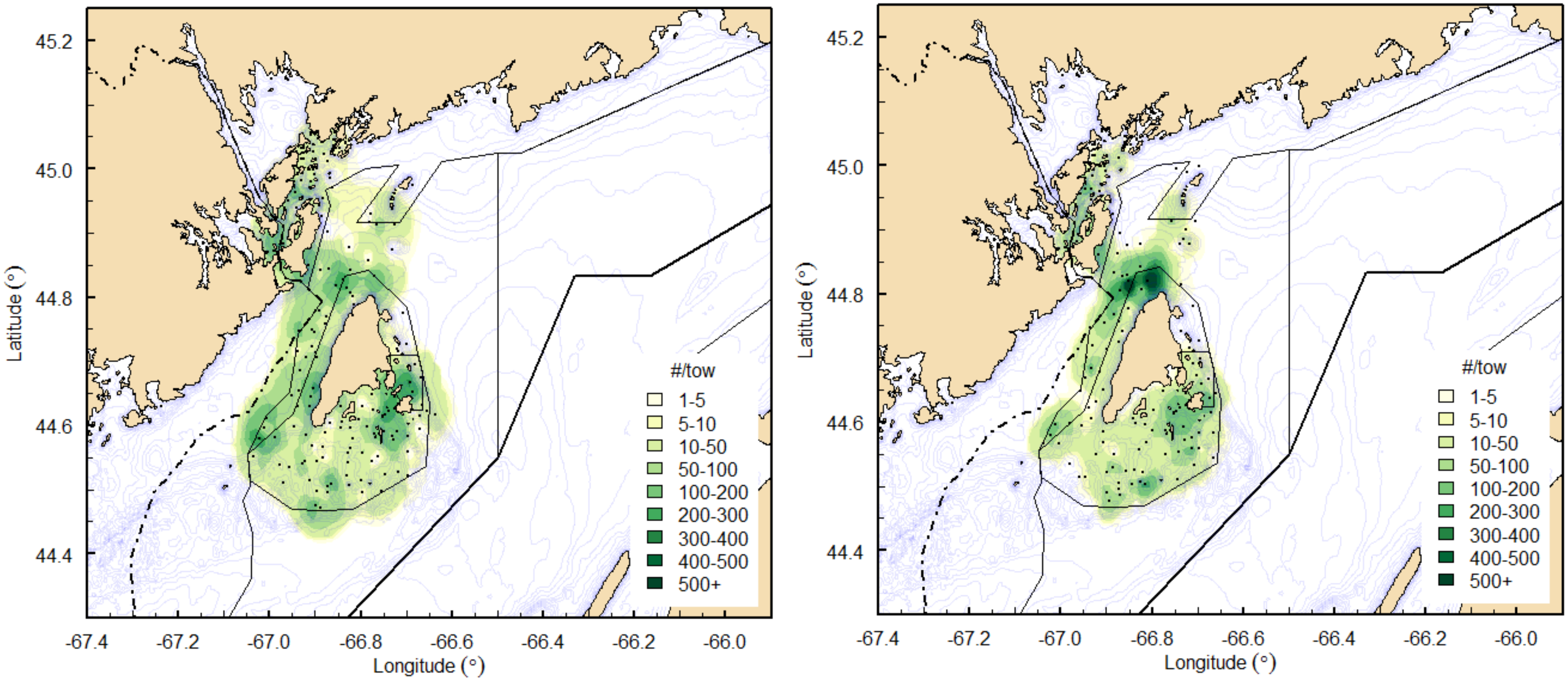

Figure 102. Spatial distribution of abundance (number/tow) of recruit size scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

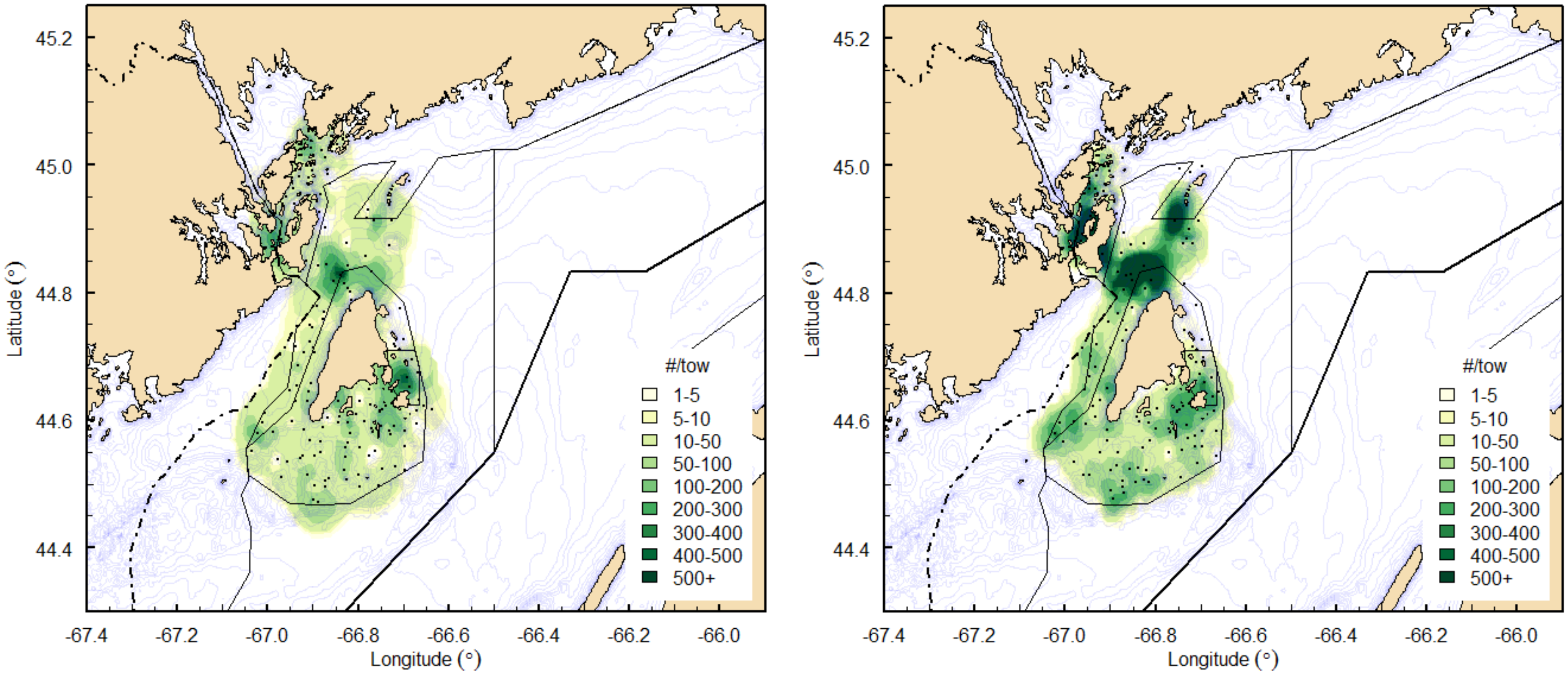

Figure 103. Spatial distribution of abundance (number/tow) of prerecruit size scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

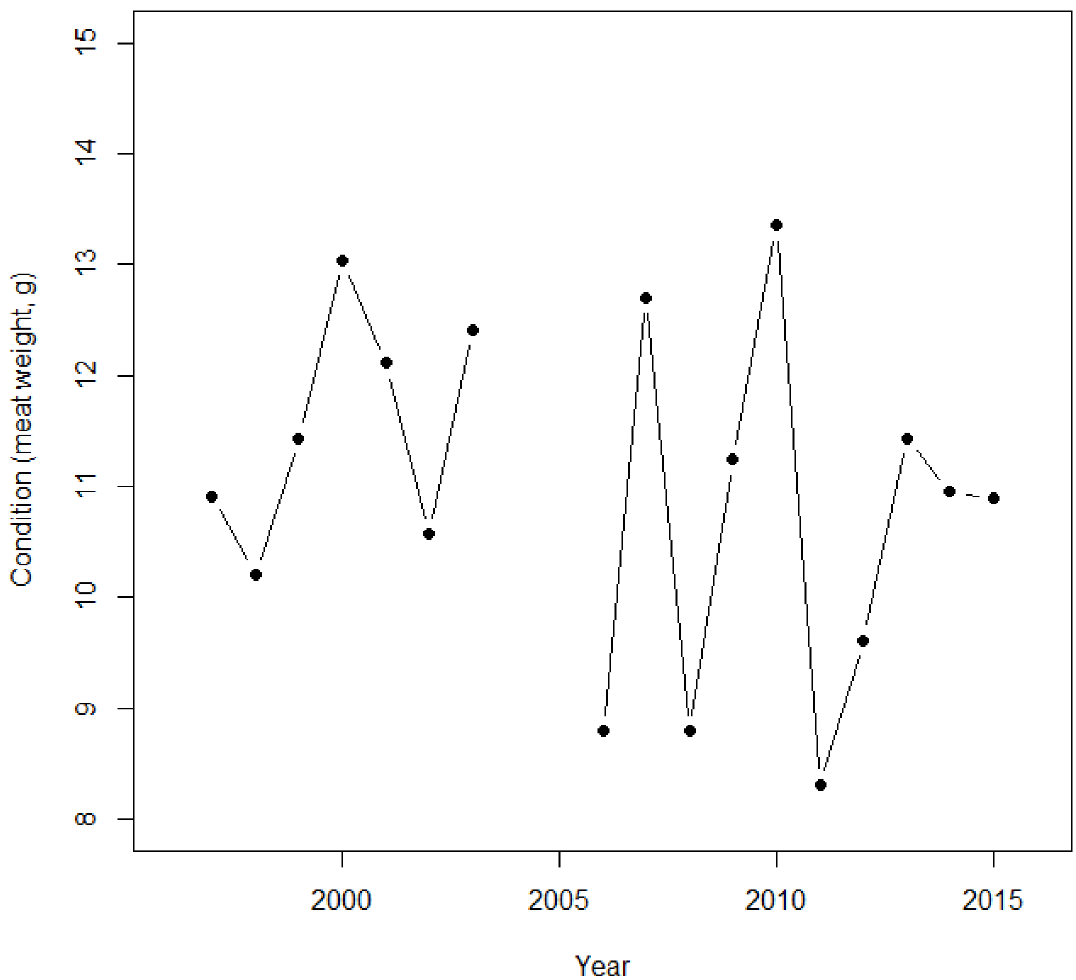

Figure 104. Condition (meat weight, g) for a shell of 100 mm in the Inside VMS stratum of Scallop Production Area 6 from 1997 to 2015.

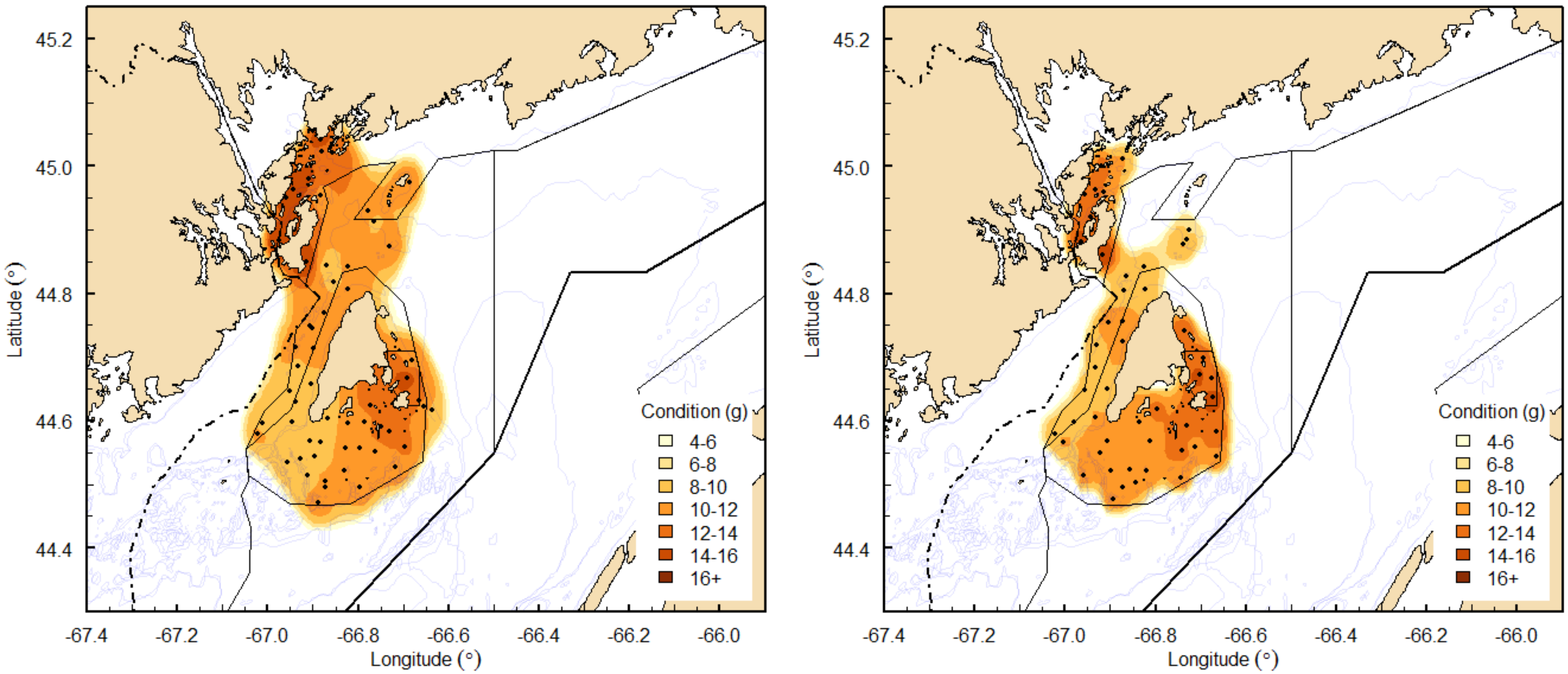

Figure 105. Spatial distribution of condition, weight in grams of a 100 mm scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

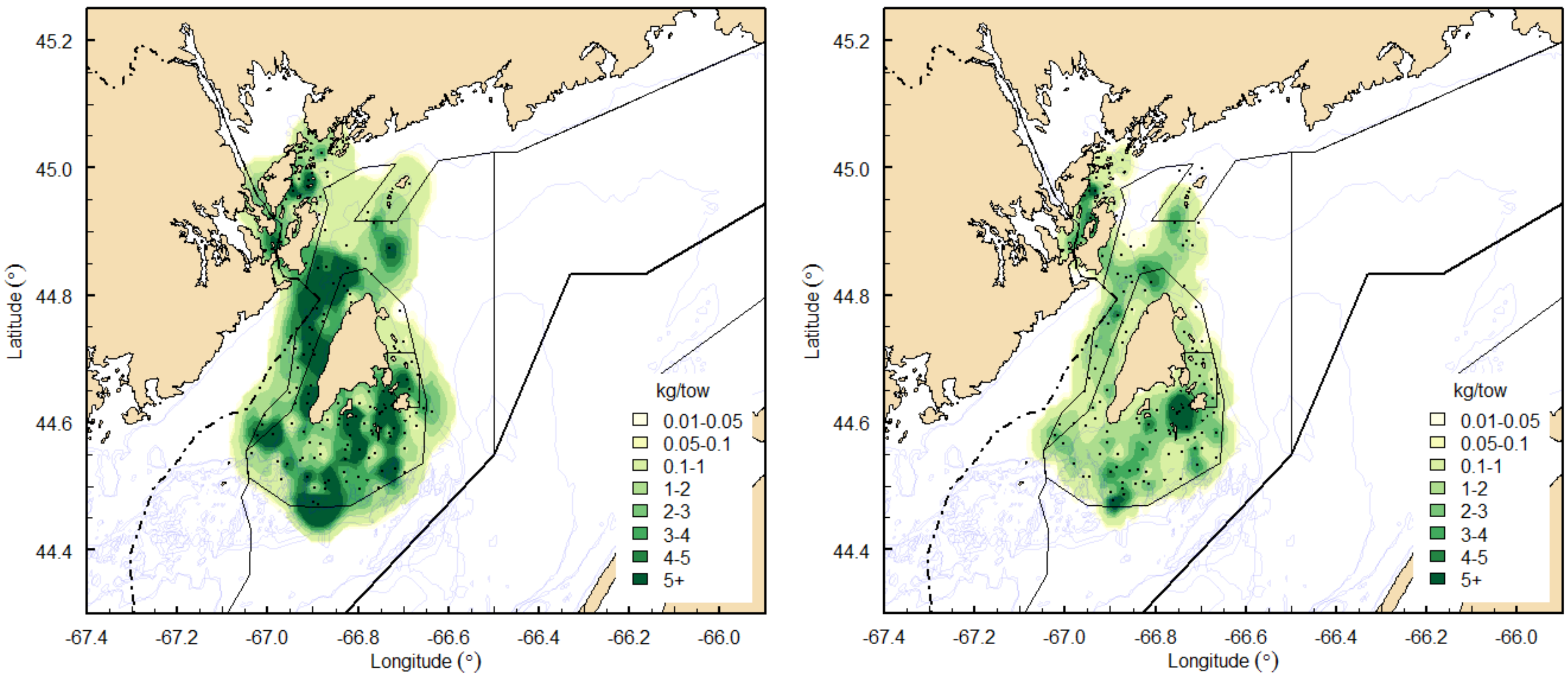

Figure 106. Spatial distribution of biomass (kg/tow) of commercial scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

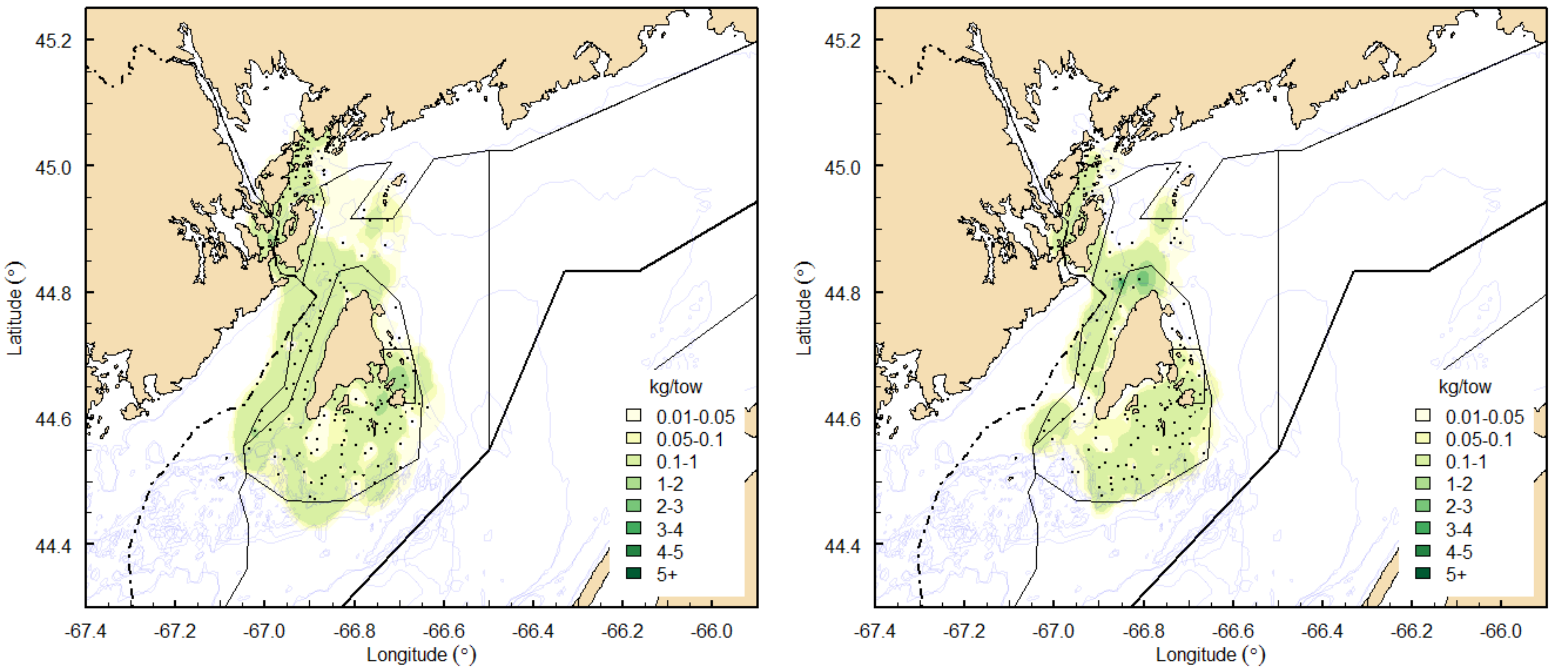

Figure 107. Spatial distribution of biomass (kg/tow) of recruit scallop in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries.

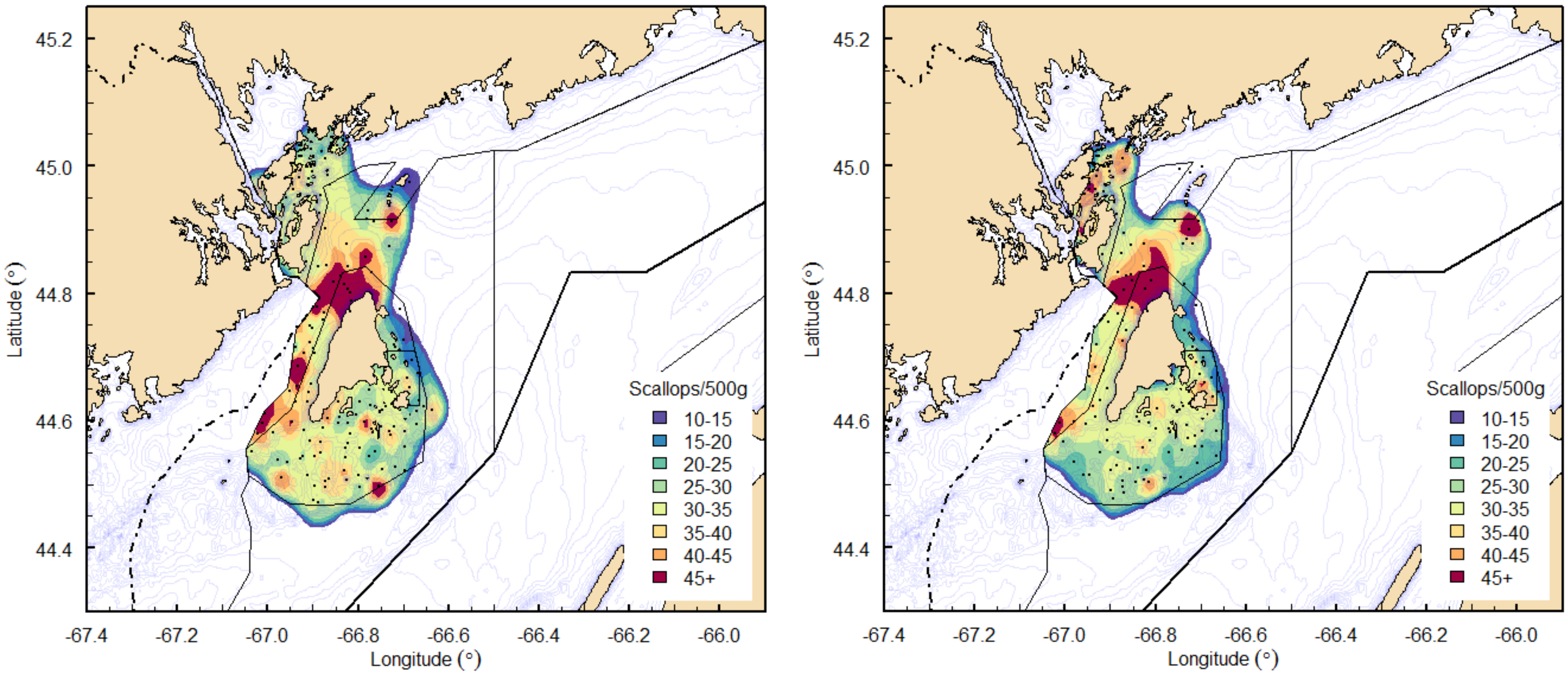

Figure 108. Spatial distribution of meat count (scallops/500 g) in Scallop Production Area 6 in 2014 (left panel) and 2015 (right panel). Black lines represent management area boundaries. These meat counts are based on survey data and are used for illustrative, not regulatory, purposes.

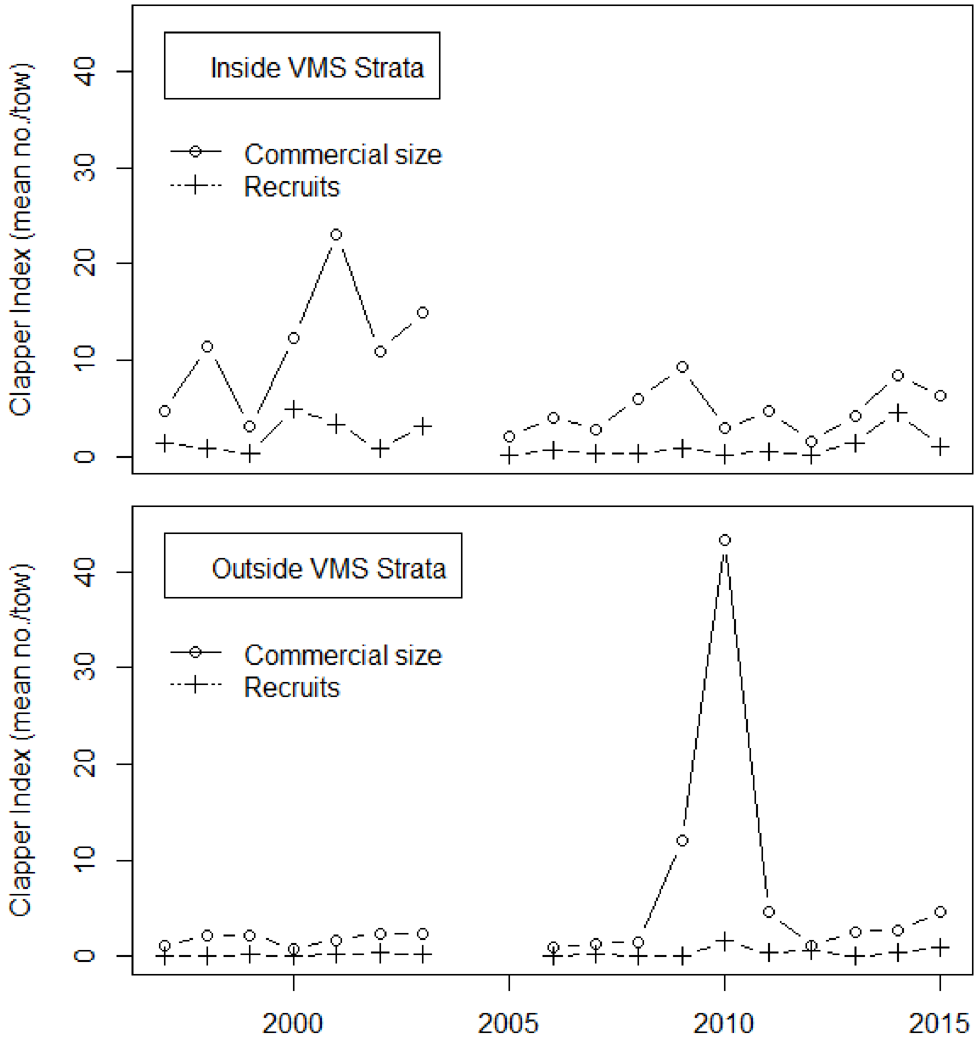

Figure 109. Mean number per tow of clappers (paired, dead shells) of commercial (circles) and recruit (crosses) sized scallops in Scallop Production Area 6 in the Inside (upper panel) and Outside (lower panel) VMS strata.

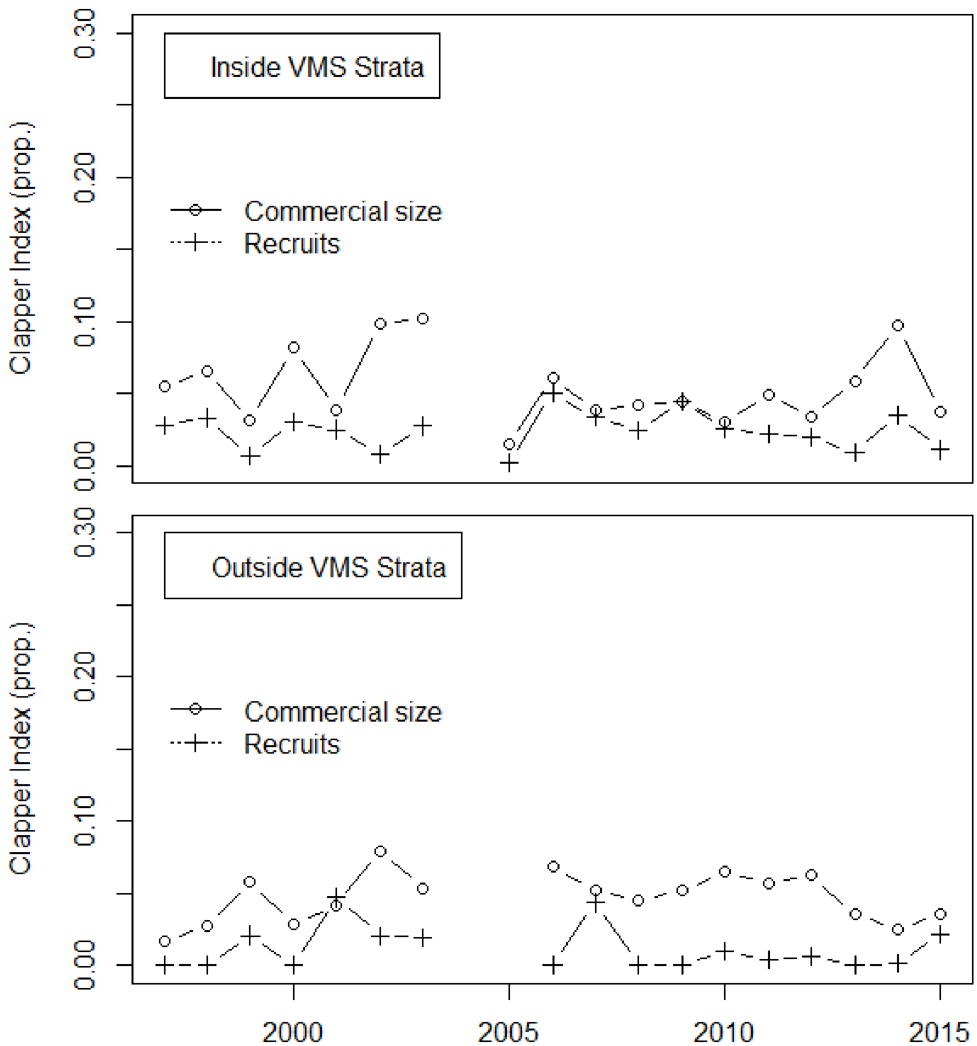

Figure 110. Proportion of clappers (paired, dead shells) of commercial (circles) and recruit (crosses) sized scallops in Scallop Production Area 6 in the Inside (upper panel) and Outside (lower panel) VMS strata.

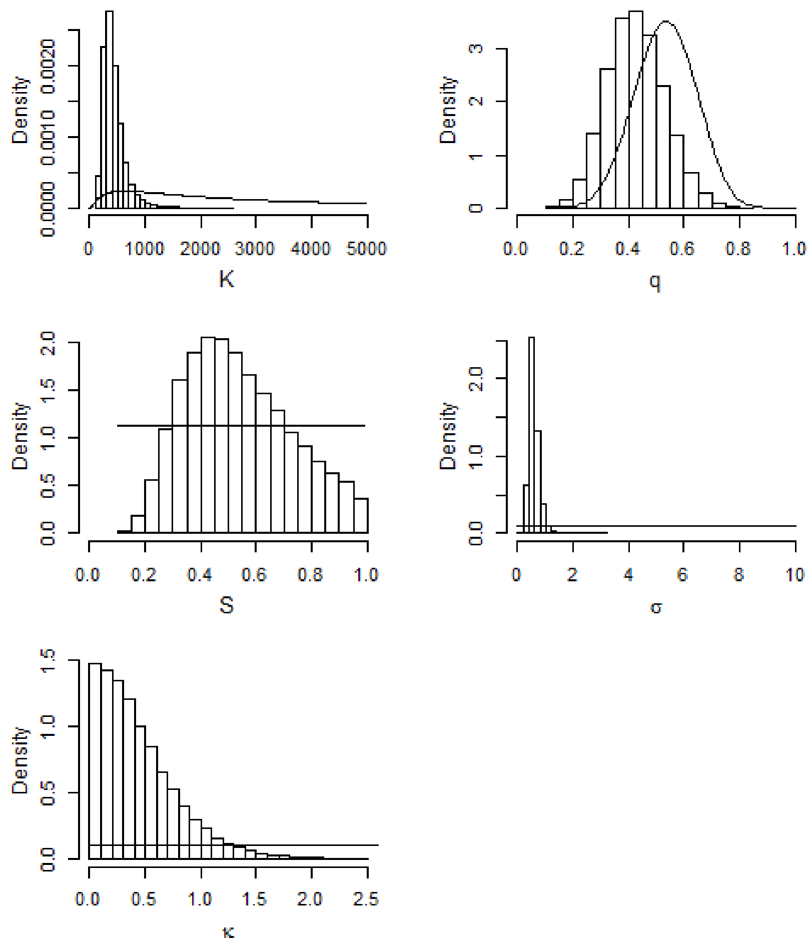

Figure 111. Comparison of prior (lines) and posterior densities (histogram) from the Bayesian state-space assessment model in Scallop Production Area 6.

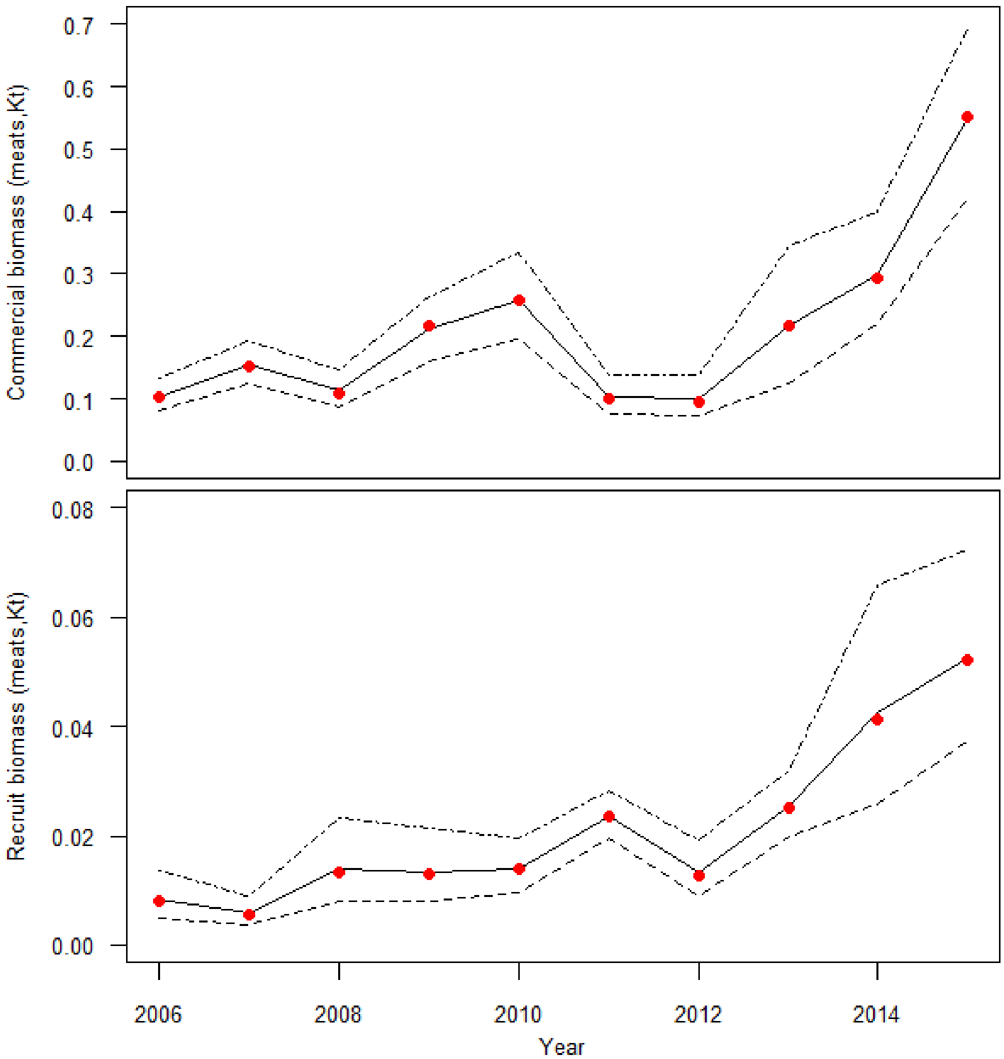

Figure 112. Posterior mean fit to the survey biomass series of commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 6 from 2006 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

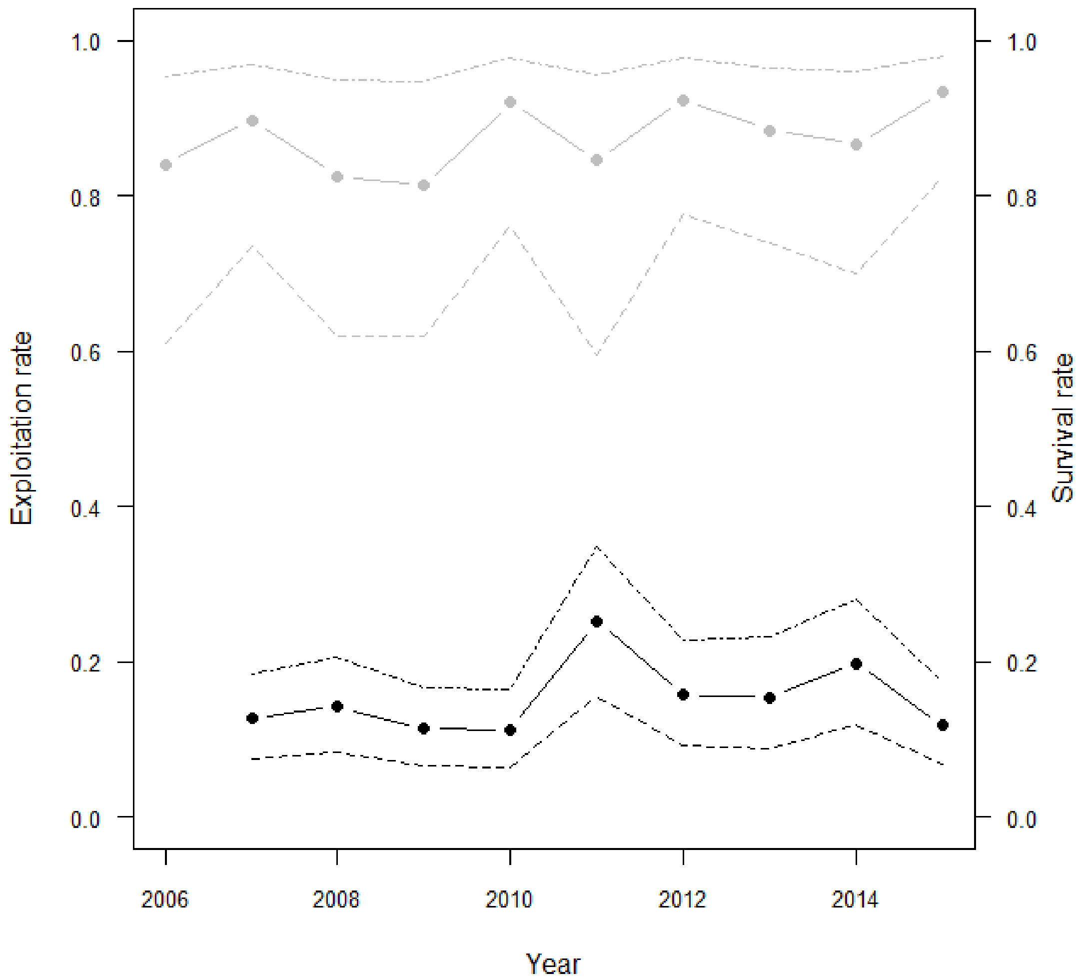

Figure 113. Annual trends (2006 to 2015) in exploitation (black circles) and survival estimates (exp (-m), where m is natural mortality; grey squares) from the Bayesian state-space assessment model in Scallop Production Area 6. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits.

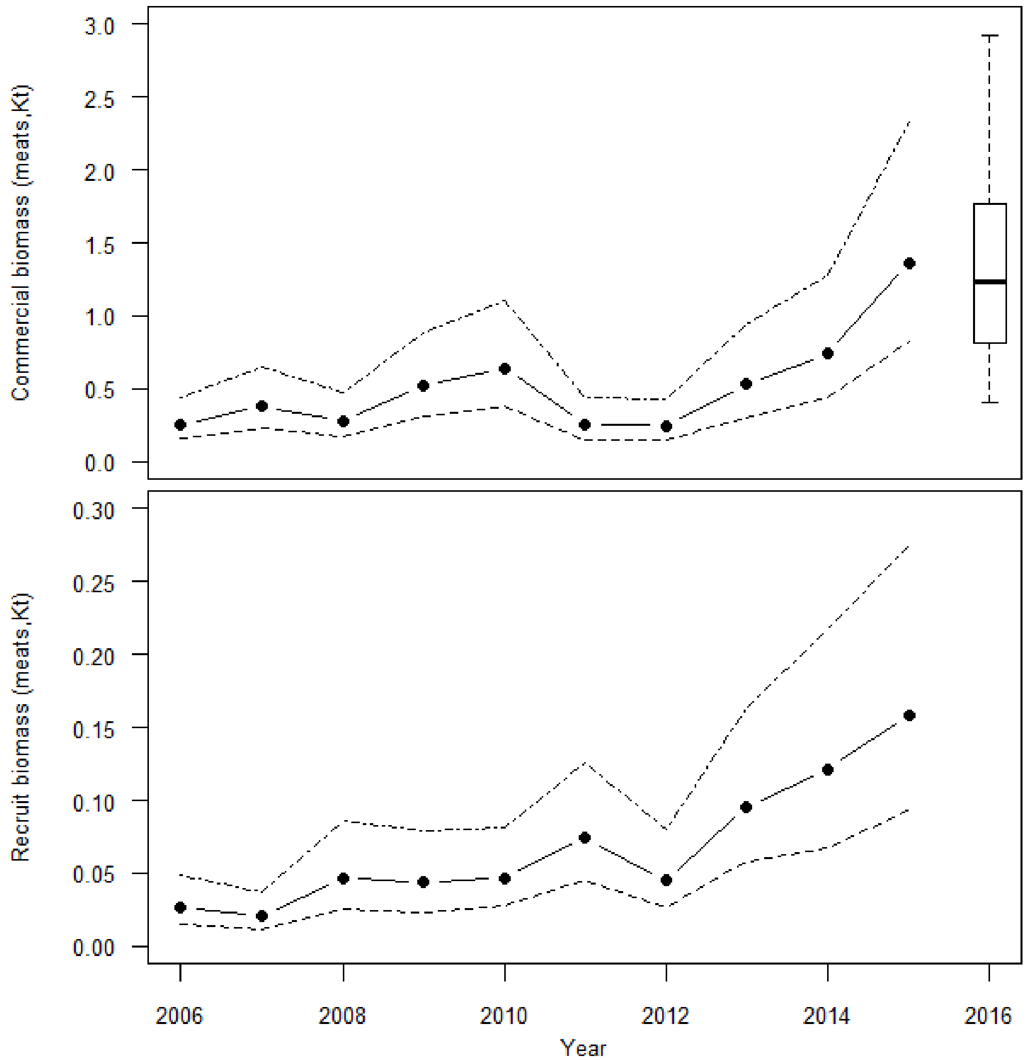

Figure 114. Biomass estimates for commercial (kt; top panel) and recruit (kt; lower panel) scallops from the Bayesian state-space assessment model in Scallop Production Area 6, fit to survey and commercial data from 2006 to 2015. Lines around the points are the upper (dotted) and lower (dashed) 95% credible limits on the estimates. The predicted commercial biomass for 2016 is displayed as a box plot with median, 50% credible limits (box), and 90% credible limits (whiskers), this prediction assumes 200 t is caught in this area.

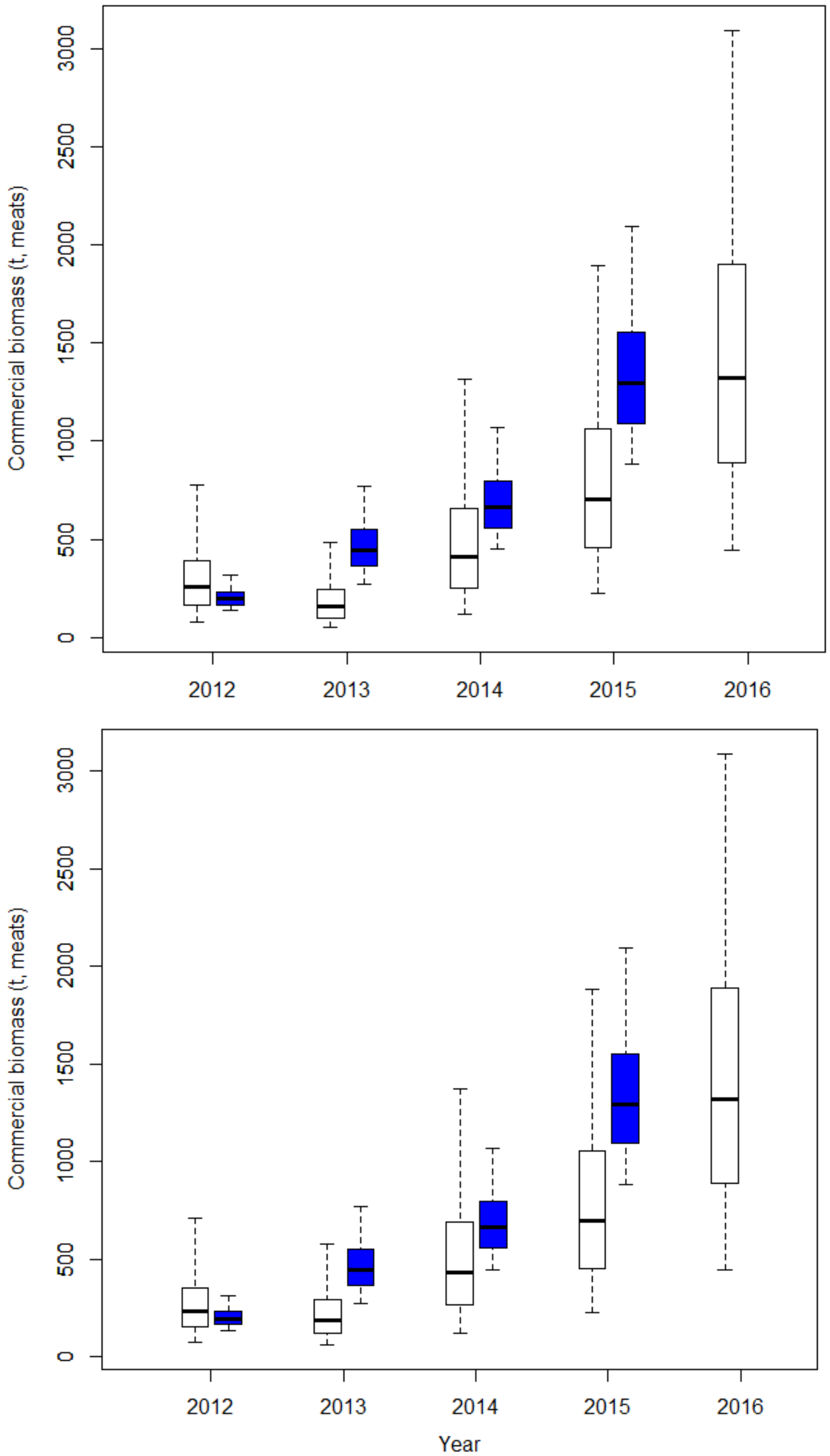

Figure 115. Evaluation of the model projection performance from 2012 to 2015 in Scallop Production Area 6. White box and whisker plots summarize posterior distribution of commercial size biomass in year t based on model fit to year t-1 (e.g., 2012 predictions based on data up to 2011). Blue box and whisker plots summarize the posterior distribution of the commercial biomass in year t using data up to and including year t. Upper panel projections use estimated weight from year t to t+1, and lower panel projections use actual growth rate from year t to t+1 to evaluate projections if growth had been known. Box plots show median (horizontal line), 50% credible limits (box), and 90% credible limits (whiskers). The projection for 2016 assumes 200 t is caught in this area.

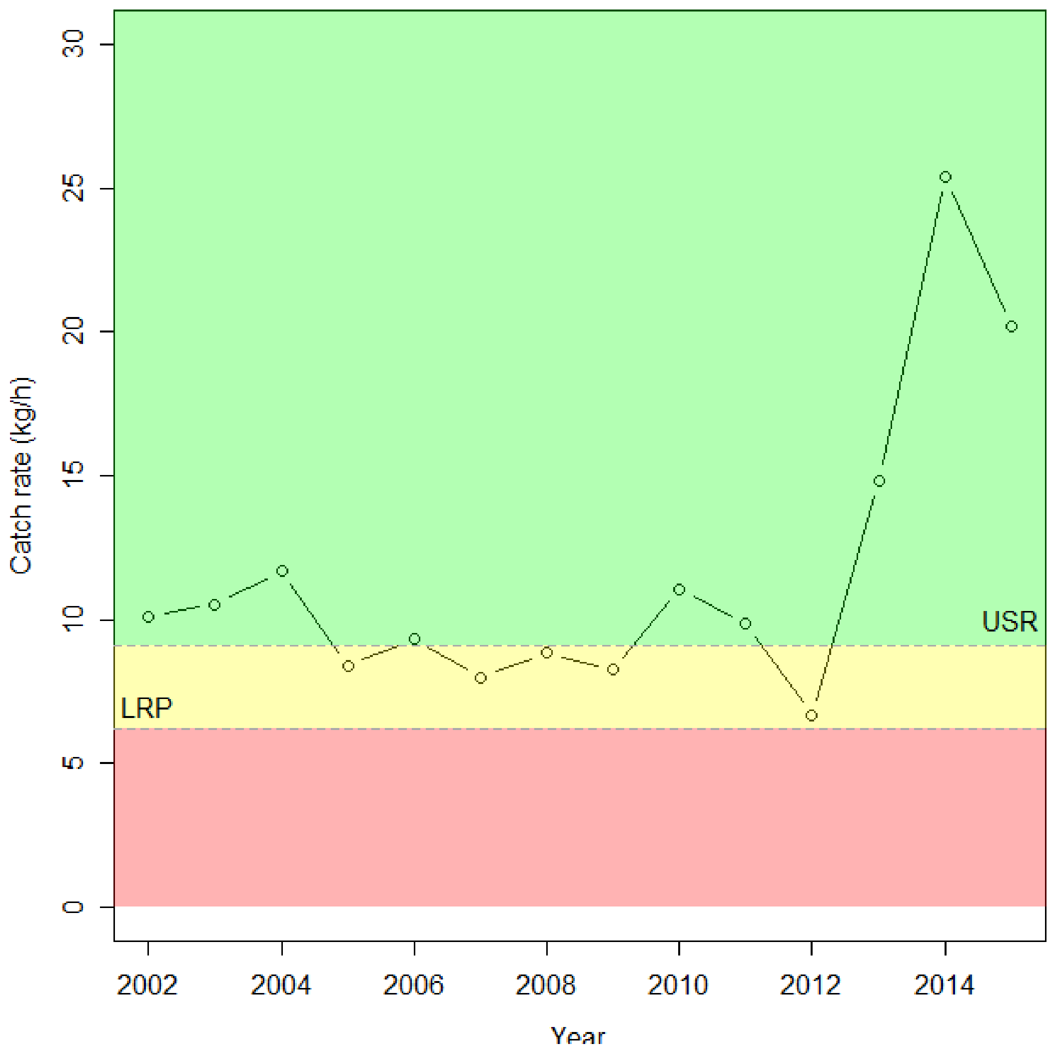

Figure 116. Annual commercial catch rate (kg/h) for SPA 6 for all subareas and both fleets combined. The red area represents the critical zone below the LRP of 6.2 kg/h, the yellow area represents the cautious zone between the LRP and USR of 9.1 kg/h, and the green area represents the healthy zone above the USR.