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Scallop Fishing Area 29: Stock status and update for 2010

Zone de pêche 29 du pétoncle : état du stock et mise à jour pour 2010

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ABSTRACT

This scallop fishery has taken place in the portion of Scallop Fishing Area (SFA) 29 west of longitude 65°30' W since 2001 and is currently conducted by two fleets: the Full Bay fleet and a limited number of inshore East of Baccaro licence holders (i.e., East of Baccaro fleet). During 2009, a total of 242 t (158 t Full Bay; 84 t East of Baccaro) was landed against a total allowable catch (TAC) of 250 t. Fishing activity in subareas A and E has been sporadic during the last three years, and commercial catch rates in these areas appear to have generally increased since 2007. In subarea B, 2009 commercial catch rates for the Full Bay and East of Baccaro fleets increased from 2008 by 13 and 16%, respectively. The Full Bay and East of Baccaro fleet catch rates in 2009 for subarea C both decreased by 8% from 2008. In 2009, the catch rate for Full Bay remained the same as in 2008, while it continued to decline for East of Baccaro (by 10%). All survey abundance indices show a general declining trend since the fishery began in 2001 (2004 for subarea D). Recruitment is presently low in all subareas.

Two methods were used to estimate exploitation rates in SFA 29 West: one from commercial catch rates, representing more localized conditions, and one from the research survey, which represents broader conditions. Results from both methods were generally consistent. Overall, the exploitation rates estimated for subareas A to D have increased from 2008 to 2009, except in subarea B. In subarea A, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be <0.01 and 0.03, respectively. Growth in biomass is expected to be 8% from 2009 to 2010, and there is expected to be little recruitment based on the survey. Landings of 5 t did not result in an appreciable decline in biomass in 2009 and would not be expected to result in an appreciable decline in biomass in 2010. Exploitation rates for subarea B in 2009 from the research survey and commercial catch rates were estimated to be 0.07 and 0.15, respectively. Growth in biomass is expected to be 14% from 2009 to 2010. Recruitment levels are currently low. Landings of 60 t did not result in an appreciable decline in biomass in 2009 and would not be expected to result in an appreciable decline in biomass in 2010. The 2009 exploitation rates for subarea C from the research survey and commercial catch rates were estimated to be 0.26 and 0.32, respectively, both of which exceeded the growth rate (20%) and recruitment from 2008 to 2009. Growth in biomass is only expected to be around 14% from 2009 to 2010 based on the average meat weight of the commercial and recruit size scallops in 2009. Using the survey estimates, catch levels that correspond to a 0.2 exploitation rate (target used in the Bay of Fundy) would be 42 t. In subarea D, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be 0.27 and 0.39, respectively. Growth in biomass is only expected to be 15% in 2009/2010 compared to 17% in the previous year. Using the survey estimates, catch levels that correspond to a 0.2 exploitation rate (target used in the Bay of Fundy) would be 64 t.

Bycatch of lobster by the SFA 29 West scallop fishery in 2009 was estimated at less than 0.1% of the weight of lobsters landed by the Lobster Fishing Area (LFA) 34 lobster fishery corresponding to the SFA 29 West area in 2008/2009. All lobsters caught in the scallop fishery were released back into the water, the majority of which were alive and uninjured.

RÉSUMÉ

Cette pêche au pétoncle s'est déroulée dans une partie de la zone de pêche du pétoncle (ZPP) 29 située à l'ouest de la longitude 65° 30' O depuis 2001 et est effectuée à l'heure actuelle par deux flottilles : la flottille de la totalité de la baie et un petit nombre de titulaires de permis de pêche côtière à l'est de Baccaro (c.-à-d. la flottille de l'est de Baccaro). En 2009, les débarquements totaux se sont chiffrés à 242 t (158 t pour la flottille de la totalité de la baie; 84 t pour la flottille de l'est de Baccaro) par rapport au total autorisé des captures (TAC) de 250 t. L'activité de pêche dans les sous-zones A et E a été sporadique au cours des trois dernières années, et les taux de captures commerciales dans ces secteurs semblent avoir augmenté depuis 2007, en règle générale. Dans la sous-zone B, les taux de captures commerciales en 2009 pour les flottilles de la totalité de la baie et de l'est de Baccaro ont augmenté de 13 et 16 % respectivement en 2008. Les taux de captures des flottilles de la totalité de la baie et de l'est de Baccaro en 2009 dans la sous-zone C ont tous les deux diminués de 8 % par rapport à 2008. En 2009, le taux de captures dans la totalité de la baie est demeuré le même qu'en 2008, tandis qu'il a continué de diminuer pour l'est de Baccaro (de 10 %). Tous les indices d'abondance du relevé montrent une tendance générale à la baisse depuis le début de la pêche en 2001 (2004 pour la sous-zone D). Le recrutement est présentement faible dans toutes les sous-zones.

Deux méthodes ont été utilisées pour évaluer les taux d'exploitation dans la partie ouest de la ZPP 29 : une méthode à partir des taux de captures commerciales, représentant des conditions plus localisées, et l'autre à partir du relevé scientifique, qui représente des conditions plus vastes. Les résultats obtenus grâce aux deux méthodes étaient généralement cohérents. Dans l'ensemble, les taux d'exploitation estimés pour les sous-zones A à D ont augmenté en 2009 par rapport à 2008, sauf dans la sous-zone B. Dans la sous-zone A, les taux d'exploitation de 2009 du relevé scientifique et les taux de captures commerciales ont été estimés à moins de 0,01 et à 0,03, respectivement. Selon le relevé, on s'attend à une augmentation de la biomasse de 8 % en 2010 par rapport à 2009 et à peu de recrutement. Les débarquements de 5 t n'ont pas entraîné une diminution importante de la biomasse en 2009 et on ne s'attend pas à ce qu'ils entraînent une diminution importante de la biomasse en 2010. Les taux d'exploitation dans la sous-zone B en 2009 du relevé scientifique et les taux de captures commerciales ont été estimés à 0,07 et à 0,15, respectivement. On s'attend à une augmentation de la biomasse de 14 % en 2010 par rapport à 2009. Les niveaux de recrutement actuels sont faibles. Les débarquements de 60 t n'ont pas entraîné une diminution importante de la biomasse en 2009 et on ne s'attend pas à ce qu'ils entraînent une diminution importante de la biomasse en 2010. Les taux d'exploitation en 2009 pour la sous-zone C du relevé scientifique et les taux de captures commerciales ont été estimés à 0,26 et à 0,32, respectivement; les deux ont dépassé le taux de croissance (20 %) et le recrutement de 2008 à 2009. L'augmentation de la biomasse devrait atteindre environ 14 % en 2010 par rapport à 2009, selon le poids moyen des chairs des pétoncles de taille commerciale et de la taille des recrues en 2009. À l'aide des estimations du relevé, les niveaux de prises correspondant à un taux d'exploitation de 0,2 (objectif utilisé dans la baie de Fundy) seraient de 42 t. Dans la sous-zone D, les taux d'exploitation de 2009 du relevé scientifique et les taux de captures commerciales ont été estimés à 0,27 et 0,39, respectivement. L'augmentation de la biomasse devrait atteindre seulement 15 % en 2009-2010, comparativement à 17 % au cours de l'année précédente. À l'aide des estimations du relevé, les niveaux de prises correspondant à un taux d'exploitation de 0,2 (objectif utilisé dans la baie de Fundy) seraient de 64 t.

Les prises accessoires de homard par la pêche au pétoncle dans la partie ouest de la ZPP 29 en 2009 étaient estimées à moins de 0,1 % du poids des homards débarqués par la pêche du homard dans la zone de pêche du homard 34 correspondant à la partie ouest de la ZPP 29 en 2008-2009. Tous les homards pêchés lors de la pêche du pétoncle ont été remis à l'eau. La majorité des homards étaient vivants et non blessés.

INTRODUCTION

Scallop Fishing Area (SFA) 29 encompasses a very large inshore area inside the 12-mile territorial sea, from the south of Yarmouth (latitude 43°40'N) to Cape North in Cape Breton (Fig. 1). This report refers to only that portion of SFA 29 west of longitude 65°30'W continuing north to Scallop Production Area 3 at latitude 43°40'N (hereafter referred to as SFA 29 West). This area is fished by the Full Bay (FB) fleet and inshore East of Baccaro (EoB) licence holders who are authorized to fish in SFA 29 West.

The history of fishing in this area up to 2001 can be found in Smith and Lundy (2002). A review of the three-year joint project agreement signed in 2002 with the two fishing fleets, Natural Resources Canada, and Department of Fisheries and Oceans with all parties providing funds to conduct multi-beam acoustic mapping of the seafloor and other scientific work is reported in Smith (2006).

This report summarizes commercial fishery, research survey and observer data for the 2009 fishery and provides advice for the 2010 fishery. As in previous documents, details on lobster bycatch were provided; however, issues with estimating bycatch of other species prevented the analysis of these data being included this year. The scallop fishery in this area was last assessed in 2009 (Smith et al. 2009b).

COMMERCIAL FISHERY

The fishery management plan sets a 100 mm minimum shell height for retained scallops. In this report, scallops with shell height 100 mm and greater will be referred to as commercial size and 90–99 mm scallops will be referred to as recruits for the following year.

All subareas opened for the 2009 fishing season on June 22. As usual, subarea D closed first (July 4 - FB, July 14 - EoB) with overruns of the TAC of 22% and 9% by Full Bay and East of Baccaro fleets, respectively (Table 1). Subarea C closed on August 1 for both fleets with very small quota overruns (FB - 3%, EoB - 4%). Two closed areas within subarea B were instituted for both fleets in response to lobster bycatch on July 16 and August 20. Neither of these closed areas coincided with the area proposed by DFO Science prior to the 2009 season (see lobster bycatch section of this report). Subareas A, B and E closed at the end of the season, August 31, 2009.

COMMERCIAL CATCH RATE

Annual Trends

The fishery in subareas A and E has been sporadic in the last three years and commercial catch rates in these areas appear to have generally increased since 2007 (Fig. 2). In subarea B, commercial catch rates in 2009 for the Full Bay fleet and the East of Baccaro fleet have increased over 2008 by 13 and 16%, respectively. The Full Bay fleet commercial catch rates and the East of Baccaro fleet catch rates in 2009 in subarea C both decreased by 8% from 2008. Catch rates have declined (31 to 34%) for both fleets in subarea D from 2005 to 2008. In 2009, the catch rate for Full Bay remained the same as in 2008 while it continued to decline for East of Baccaro (10%).

Depletion Estimates of Exploitation

In previous assessments (Smith et al. 2008, 2009b), exploitation rates in the 2007 and 2008 fishery were estimated in subareas A to D using the depletion model described by Leslie and Davis (1939). Assuming a closed population, that is, no recruitment, natural mortality and minimal growth during the period of the fishery, then the population biomass at the beginning of the fishery (B_0) should decrease simply as a function of the catches (C_i) up to time t. That is,

$$B_t = B_0 - \sum_{i=0}^{t-1} C_i. \tag{1}$$

where, $C_0 = 0$. Assuming that commercial catch rate K_t was observed at time t and that the catch rate was proportional to the biomass over time then,

$$K_t = qB_t$$
$$= q(B_0 - \sum_{i=0}^{t-1} C_i)$$
$$= qB_0 - q\sum_{i=0}^{t-1} C_i. \tag{2}$$

There are three main quantities that can be obtained from the model in equation 2. The slope is the catchability coefficient for the fishery, while dividing the intercept by the slope gives the population biomass B_0 at the beginning of the fishery. The exploitation rate of the fishery on the population at the end of the fishery (time l) can be estimated as,

$$\hat{E} = \frac{\sum_{i=1}^{l} C_i}{B_0} \tag{3}$$

In Smith et al. (2008) and Smith et al. (2009b), the depletion model was cast as a Bayesian model to independently estimate exploitation rates in each year and subarea of the fishery. The problems with this approach were that there was not always sufficient data to calculate depletion estimates for all areas in all years and, in some cases catch rates did not show a distinct decline in response to removals. This year, an attempt was made to mitigate these deficiencies by adopting a hierarchical Bayesian model (HBM) to estimate exploitation. A hierarchical Bayesian formulation of the depletion model has been used to share information regarding the catchability coefficient across years while still allowing for annual variation (McAllister et al. 2004).

The previous Bayesian model had the likelihood for K_t in equation 2 set as a normal distribution with mean at time t equal to $B_0 - \sum_{i=0}^{t-1} C_i$ and variance σ^2. A normal non-informative prior was assigned to B_0 (mean=0, variance=10^6), a uniform (0,100) distribution was used as the prior on σ^2, and a positive half normal distribution was used as the prior on q. The HBM was set up similarly but with a hyperprior on q so that a common prior was applied to all years within each subarea. This allowed information to be shared on the catchability coefficient (q), improving estimates of exploitation, particularly in years where there were fewer data.

The hyperpriors were placed on the mean and variance of a normally distributed logit

transformed q. The hyperprior on mean of logit q was a uniform (-4, 4) distribution, while the hyperprior on the standard deviation of logit q was a lognormal distribution (mean = -2, sd = 0.25). For the purposes of modelling, catch rate (K) was expressed in kg/h while biomass (B) was expressed in tons so that q is actually 1000 times the true catchability coefficient.

Catch rates within each of subareas A to D were calculated as the ratio of catch to effort by fleet and by day. Commercial log data were used only where catch, effort, date and location were provided. The number of records available by day and fleet were highly variable in addition to there being differing levels of variability of catch and effort for any one day and fleet. This variability was incorporated into the analysis by weighting the variance σ^2 in the model by the standard error associated with each daily catch rate estimate. That is, the variance associated with the model was expressed as $\mathbf{V}\sigma^2$, where $\mathbf{V}$ is a diagonal matrix with element v_{ii} equal to the standard error for the catch rate for day i. The standard error was estimated using the jackknife estimate recommended by Smith (1980) for catch rate estimates. As in Smith et al. (2009b), the model was fit with both fleets combined.

Monte-Carlo markov chain simulations using the Gibbs sampler in WinBugs (Lunn et al. 2000) were used to find the estimates for this model. Two chains with separate starting values were used for each run with the first 10,000 replicates discarded as a burn-in and the second 10,000 replicates per chain kept to describe the posterior distributions of the parameters. The degree of convergence to the posterior distribution was evaluated using the Brooks-Gelman-Rubin method (Brooks and Gelman 1998).

There was no fishery in subarea A in 2003, so the model was fit only to data from 2002 and 2004 to 2009. The prior on q in the HBM served to dampen the variability in q between years (Fig. 3). When fitting the depletion model from Smith et al. (2009b), estimates of q ranged by orders of magnitude (0.11 to 2.4). More realistic estimates of the initial population size were obtained by restricting the variability in q (Fig. 4). Total biomass at the beginning of the fishery was lower in 2002 than in 2004 but these differences may reflect the difference in area fished, which was much smaller in 2002 than in 2004. The estimates of pre-fishery biomass were similar from 2005 to 2008, with medians from 60 t to 73 t. The estimate in 2009 was somewhat higher with a median of 140 t (95% credible bounds of 70 and 396). The exploitation rates were relatively consistent with the catches: high in 2004 (median 0.45) when the catch was large (81 t), moderate in 2006 (median 0.30) and lower in 2007 (median 0.14) when the catch was lower (11 t, Fig. 5). In years where catches were less than 5 t, the estimated exploitation rate was less than 0.07.

Subarea B is a large area that has presented difficulties when attempting to estimate exploitation for past years due to the fishing pattern (Smith et al. 2009b). In most cases, a gradual decline in catch rate was observed over the course of the fishery except for 2002, where no decline was observed, and in 2005, where a steep decline was observed. The HBM also had difficulty with the data from these two years as the hyerpriors for q tended to have a low mean and high variance. Data from 2002 was dropped and an informative hyperprior was used for the mean of q based on the posteriors of the same hyperprior in the two adjacent subareas (A and C). By having an informative hyperprior, q was not so small as to make the estimates of pre-fishery biomass unrealistically high but was still higher in 2005 (Fig. 6). With the exception of 2005, the pre-fishery biomass showed a slight declining trend from a median biomass of 648 t (95% credible bounds of 306 t and 2548 t) in 2003 to 394 t (95% credible bounds of 205 t and 1,530 t) in 2009 (Fig. 7). Estimates of exploitation rate were relatively low (0.13–0.22) in all years except 2005 (0.52) (Fig. 8). The estimates from 2005 stand out from the other years in this subarea and may be the result of a localized fishery in the 2005 season.

As with last year's depletion model, the HBM was most effective at achieving reasonable estimates of initial biomass and exploitation rate for subarea C (Figs. 9, 10 and 11). The very high rate of depletion that occurred in 2002 produced similar results to Smith et al. (2009b) with estimates of pre-fishery biomass (560 t) and exploitation (0.78). The pre-fishery biomass declined sharply at first to 291 t prior to the 2003 fishery and then gradually to 214 t in 2008. In 2009, pre-fishery biomass was estimated to be 240 t (95% credible bounds of 176 t and 426 t). The exploitation rate was relatively low in 2003 (0.24), higher from 2004 to 2006 (range: 0.42 to 0. 53) and declined slightly from 2007 to 2009 (range: 0.25 to 0.32).

Subarea D only partially opened in 2004 and initially very high catch rates were observed in a small concentrated area. These rates declined sharply in the first year, which led to an estimate of q that was 0.46 in 2004, while the mean of the prior was only 0.15 (Fig. 12). As a result, the biomass pre-fishery in 2004 was estimated at only 246 t and the exploitation was 0.77. Pre-fishery biomass was estimated to be greater (569 t) in 2005 when the entire area was opened, but has since declined to 249 t (95% credible bounds of 176 t and 548 t) in 2009 (Fig. 13). The exploitation rate was much lower in 2005 (0.12), increased in 2006 (0.34), dropped again in 2007 (0.17), and has increased since to 0.4 in 2009 (Fig. 14).

Scallops are a nearly sessile organism and, therefore, depletion estimates only apply to the area targeted by the fishery. Fishing patterns are often concentrated in certain high density areas so that depletion estimates may be indicative of local conditions rather than the entire subarea (Smith et al. 2008). There appeared to be a correlation between estimated initial biomass and the area fished as determined from vessel monitoring by satellite (VMS) records (Smith et al. 2009b). The lower estimated biomass for subarea D in 2004 appear to reflect the smaller areas being fished.

RESEARCH SURVEY

Annual surveys in SFA 29 West have been conducted since 2001 when the current fishery started. The survey design for 2001 was a simple random design over the whole area. From 2002 to 2004, a stratified random design was used with strata defined by the management subareas A to E. Starting in 2005, strata have been defined by the bottom types as identified by geologists as part of the joint industry/government multibeam mapping project conducted in this area (DFO 2006). A new interpretation of the bottom types was made available in 2008 (Todd et al. 2009) and was used to design the surveys for 2008 and 2009 (Smith et al. 2009b).

In 2009, LaRocque funds were obtained to fund both the Fishing Vessel (F/V) *Julie Ann Joan* and the F/V *Faith Alone* for the survey. A total of 117 stations were completed within subareas A to D. F/V *Faith Alone* fished stations in subareas C and D only while F/V *Julie Ann Joan* fished in all four subareas.

Abundance Indices

Stratified mean number and meat weights per tow were calculated using strata based on the geophysical bottom types given in Todd et al. (2009). The efficiency of this survey design was evaluated in Smith et al. (2009a). Post-stratification and domain estimates used to convert from surveys using previous designs were presented in Smith et al. (2009b).

Growth curves for shell height-at-age by subarea were calculated based on data from detail sampling conducted during the 2008 survey (Fig. 15). Details on the growth models used are given in Smith et al. (2009b).

With the exception of 2006–2008, there is little evidence of scallops with shell heights less than 60 mm in subarea A (Fig. 16). Scallops in the range 60 to 80 mm are rarely seen in this survey. As in previous years, there were mainly commercial size scallops observed in the survey with no evidence of recruitment for 2010.

There is more evidence for year-class progression in subarea B but, judging by the rate of increase in the modal shell height from 2006 to 2009, growth appears to be much less than expected (Figs. 15 and 17). That is, the shell height frequency indicates that it took four years to grow from a modal shell height of 15 mm to 60 mm while the growth model predicts that the scallops should be at 60 mm at two years of age.

In subarea C, both the F/V *Julie Ann Joan* and F/V *Faith Alone* survey indicate that the commercial size scallops have been fished down with weak indications of recruitment for 2010, especially in the *Julie Ann Joan* survey (Figs. 18 and 19). A larger than average year-class was picked up by both vessels in subarea D in the 2007 survey, and this year-class appears to comprise the expected recruitment for 2010 (Figs. 20 and 21).

Shell height frequencies for clappers (paired empty shells used as indicators of natural mortality) from the survey are presented in Figures 22–27. Overall, the clappers appear to have been more abundant in the earlier years of the survey relative to the abundance of scallops at that time. Currently, the mean numbers of clappers are quite low.

Annual trends for mean number per tow by subarea and survey vessel are presented in Figure 28. Subareas A–C show overall declines since 2001, while subarea D has declined since 2005. Mean weights per tow show similar trends (Fig. 29). The trends for clappers mirror those in the shell height figures with much lower mean number per tow in the last three to four years (Fig. 30).

Survey biomass estimates were obtained by multiplying the mean weight per tow by the bottom area of each subarea (Fig. 31). In addition, the tows from *the Julie Ann Joan* and *Faith Alone* (F/V *Overton Bay* in 2005) were used to provide a combined estimate from 2005 to 2009 for subareas C and D. The trends by each vessel alone have been very similar.

Exploitation Estimates

Methods

Scallop population dynamics in the Bay of Fundy (e.g., Smith et al. 2009c) are modelled using a delay-difference biomass dynamic model (Hilborn and Walters 1992). The most basic version of this model can be written as,

$$B_t = g_{t-1}\left(B_{t-1} + R_{t-1}\right) \tag{4}$$

where B_t is the biomass of the commercial size animals in the current year, and B_{t-1} and R_{t-1} are the commercial and recruitment biomass from the previous year, respectively. The term g_{t-1} is simply the proportional change from one year to the next and is a function of natural mortality (M_{t-1}), fishing mortality (F_{t-1}) and growth (G_{t-1}). The commercial biomass and recruitment biomass are related to survey estimates of the same as follows,

$$I_t = q_I B_t \tag{5}$$

$$r_t = q_R R_t. \tag{6}$$

For the Bay of Fundy models, the natural mortality was estimated using the survey estimates of clappers, fishing mortality was estimated by including catch in the model and growth estimates were obtained from detailed sampling of shell height, meat weight and aged shells also from the survey. The q_I and q_R terms in the above equations scale the survey estimates to the population level and are partly informed by the impact of the catch on changes in the biomass. However, the model generally works best when there is a long time series (> 12–15 years) of data with adequate contrast between high and low population levels. Earlier attempts to use this model for the scallop fishery in SFA 29 were unsuccessful because the time series was short and, for the most part, the survey series generally indicates only declines over the time period. As a result, it was difficult to find an adequate scaling of survey biomass to population biomass.

An alternative approach examined by Trenkel (2008) and Mesnil et al. (2009) (see also Hoenig and Gedamke 2007) simply models the dynamics of the survey data and focusses on estimates of g_{t-1} to determine stock status — increasing, decreasing or stable. In this approach, $q_I = q_R = 1$ and the resulting estimates of B_t and R_t provide a smoothing estimate for the survey trend over time. This model can be cast into a Bayesian framework as follows.

$$\log(I_t) \sim \text{Normal}\left(\log(B_t), \sigma_I^2\right) \tag{7}$$

$$\log(r_t) \sim \text{Normal}\left(\log(R_t), \sigma_r^2\right) \tag{8}$$

Further, recruitment is assumed to follow a lognormal distribution without a stock-recruitment relationship,

$$\log(R_t) \sim \text{Normal}\left(\mu_R, \sigma_R^2\right). \tag{9}$$

Finally, g_t are constrained from varying wildly by applying a random walk process on the log scale (Trenkel 2008).

$$\log(g_t) = \log(g_{t-1}) + \varepsilon_t \tag{10}$$

where

$$\varepsilon_t \sim \text{Normal}\left(-0.5\sigma_g^2, \sigma_g^2\right)$$

Noninformative priors (uniform(0,100)) were used for σ_I, σ_r, σ_R, and σ_g. The prior for the recruitment process was set to Normal(0,10^6). The posterior distribution was simulated using WinBugs (Lunn et al. 2000) with two chains of 10,000 iterations each and a burn-in of 5,000 iterations. Every tenth iteration was kept after burn-in. Convergence to the posterior was checked using the Brooks-Gelman-Rubin method (Brooks and Gelman 1998).

Results

The model successfully provided smoothed fits to the survey data for all subareas (Fig. 32) tending to discount large changes in the survey biomass trend. Goodness of fit of the models was evaluated using the posterior predictive distribution of the probability the original survey

index being greater than replicates from the posterior once the model had been fit (Gelman et al. 2004). These probabilities lay within the (0.025, 0.975) bounds suggesting that there was no substantial lack of fit in the models (Fig. 33).

As the g_{t-1} estimates annual growth rate in the population from time t -1 to time t, values below 1.0 would imply that removals from a combination of fishing (when present) and natural mortality exceeded increases in biomass due to growth over that time period. The probability of g_{t-1} being less than 1.0 can be evaluated from the posterior distribution for this parameter. In subarea A, g_{t-1} estimates were close to 1.0 with probabilities of being less than one in the 0.55 to 0.70 range (Fig. 34). With the exception of 2001 to 2002, g_{t-1} estimates were below 1.0 for subarea B, ranging from 0.79 to 0.92, and the probabilities of being less than 1.0 were greater than 0.83. The estimates for subarea C were below 1.0 with high probability of being below 1.0. There was no fishery in subarea D until 2004, and g_{t-1} estimates prior to 2004 were all above 1.0 with low probability of being below 1.0 as would be expected. The fishery was restricted to the western portion of D in 2004 (by regulation) and 2005 (by choice), and overall the change in biomass appears to be low for those two years. Thereafter, g_{t-1} ranged from 0.84 to 0.88 with the probability of being less than 1.0 being between 0.81 and 0.86.

These results suggest that, while biomass does not appear to have changed by much in subarea A, continual declines have been occurring in subareas B and C since at least 2002 and since 2005 in subarea D despite generally declining catches over the same time period. However, it is difficult to determine from these results what level of catch would reduce or stop the decline in biomass. Growth has been explicitly incorporated into the Bay of Fundy models as ($\rho + \alpha/w_t$) where ρ and α are obtained from the growth model for meat weight and age (see Smith et al. 2009b) and w_t is the average meat weight of the commercial size scallops in year t. Using this relationship, g_{t-1} can be decomposed into a total mortality term and a growth term,

$$B_t = g_{t-1}(\rho + \alpha/w_t)\left(B_{t-1} + R_{t-1}\right) \tag{11}$$

with g_{t-1} now representing survival from fishing and natural mortality (1 - g_{t-1} would give the removals from total mortality).

Application of this form of the model to the data provides almost the same fits (Figs. 32 and 35) and diagnostics (Fig. 36) as the original model. However, the estimates and interpretation of g_{t-1} changes (Fig. 37). While survival estimates are expected to be less than 1.0, some estimates and some upper ranges of estimates did exceed 1.0. In these cases, it could be assumed that the growth estimates used were underestimates; however there isn't a way of recognizing overestimates.

Further refinement of the model to also include natural mortality estimates using the clapper data similar to applications in the Bay of Fundy was not successful here. The clapper numbers tended to be in similar proportion to live numbers over the time period and contributed very little information to the model. Currently, in the Bay of Fundy, natural mortality is estimated to be in the 0.07 to 0.15 range and is assumed to be 0.1 for Georges Bank. Using an estimate of 0.1 for SFA 29 West, exploitation rates can be obtained from the estimates of g_{t-1} as 1 - g_{t-1}/exp(-0.1). Focussing on the most recent period of 2006 to 2009, the following estimates were obtained:

	2006		2007		2008		2009	
Subarea	Exploit	Landings	Exploit	Landings	Exploit	Landings	Exploit	Landings
A	0.06	21.5	0.00	11.5	-0.05	3.1	-0.01	4.5
B	0.31	115.6	0.16	79.9	0.15	65.4	0.07	59.9
C	0.41	111.3	0.19	58.9	0.09	54.4	0.26	77.5
D	0.31	155.9	0.24	95.3	0.21	125.4	0.27	98.7

FISHERY BYCATCH

Lobster

Data sources for lobster bycatch come from both the scallop survey and observer data from the SFA 29 West scallop fishery. The regular monitoring of the SFA 29 fishery by onboard observers is unique relative to other scallop fisheries and has been required since this fishery began in 2001.

The mean numbers of lobsters per tow in the 2009 scallop survey was highest in subarea C with 0.6 or 4.4 lobsters per tow depending on survey. Next highest was subarea A at 1.8 lobsters per tow on average (Figs. 38–39) and subarea B at 1.6 lobster per tow. Subarea B had the highest catch rate of lobsters for most of the period from 2001–2008. Subarea D had 0.0 to 0.7 lobsters per tow depending on survey.

The size of lobsters in the survey ranged from 35 mm carapace length (CL) to 137 mm CL, but most lobsters were between 60 and 100 mm CL. The size distribution lacks the strong mode at 75 mm and the larger sizes seen in 2008 (see Fig. 31 in Smith et al. 2009b) and is more evenly distributed over the 60–95 mm CL size ranges (Fig. 40).

The level of observer coverage has been variable over the history of this fishery. The level of observer coverage can be characterized in terms of the observed number of tows, observed number of days, and observed number of trips (Table 2). The number of observed tows in 2009 was much lower than 2008 and below the observer coverage from 2001–2006.

Most lobsters caught during observed fishing trips were in subarea B (Fig. 41a), similar to previous years. The number of lobsters per ton of scallop meats was higher for the East of Baccaro fleet overall (Table 3). In terms of the open and closed portions of subarea B, the rate of lobster capture per ton of scallop meats was higher inside the closed area for both the Full Bay fleet, and the East of Baccaro fleet. Note that the actual closed areas did not match the area recommended by DFO Science for the 2009 fishery (Fig. 41b).

Observer data on the number and condition of lobsters by subarea are shown in Table 4 for the Full Bay fleet. Of the 295 lobsters caught as a bycatch, 204 were uninjured, 69 were injured, 18 were dead or dying and the condition was not recorded for 4. The same data are shown for the East of Baccaro fleet in Table 5. Of the 329 lobsters caught as a bycatch for this fleet, 97 were uninjured, 17 were injured, and 17 were dead or dying. The condition of 198 lobsters was not recorded.

As in previous years' assessments, it was possible to estimate the total number of lobsters caught during scallop fishing by assuming the numbers of lobsters caught on the observed trips are representative. The number of lobster caught in each observed trip was converted to a number per ton of observed scallop catch and then multiplied by the total scallop catch in the subarea of SFA 29 where the trips occurred. In 2009, the estimated total number of lobsters caught by the Full Bay fleet was 1,389; the estimated number injured or dead was

370 (Table 6). These estimates are near the middle of the range of estimates for 2002–2008. For the East of Baccaro fleet, there were an estimated 1,194 lobsters caught in 2009, of which 124 were dead or dying (Table 7). Summing the numbers from Tables 6 and 7, the estimated total number of lobsters caught as a bycatch during scallop fishing in SFA 29 West in 2009 was 2,583. Of these, an estimated 494 were injured or dead. The total weight of the captured lobster was approximately 1.3 t (2583 lobsters, with an assumed average size of 85 mm CL and average weight of 0.5 kg). This weight is a small fraction (< 0.1%) of the lobsters landed by the LFA 34 lobster fleet in the area corresponding to SFA 29 West.

As far as the direct effects of the scallop fishery on the lobster stock, the only information available was the catch during the scallop fishery and the scallop survey. There were no available data on how any bottom impacts might affect the lobster population. Some progress has been made on an analysis of underwater images to evaluate associations between lobster and habitat. This analysis indicates that there are significant associations between lobster and habitat, with lobsters more evident on coarse bottoms than on gravel pavements typically associated with scallops (Tremblay et al. 2009).

Indirect information on the effect of the scallop fishery comes from trends in the lobster landings by the directed lobster fishery in LFA 34 (Table 8). Trends in lobster catches by the lobster fishery in the SFA 29 West area as a whole are not indicative of an area that has been adversely affected by the scallop fishery since 2001. Lobster landings in SFA 29 West in 2008/09 were higher relative to the previous year and relative to five years earlier. The area adjacent to SFA 29 West showed a larger increase in landings in 2008–09 but a smaller increase compared to five years earlier. LFA 34 landings as a whole showed a smaller increase in 2008–09 and are lower than five years earlier

The lobster landing trends are consistent with the idea that the scallop fishery has not had a negative effect on the lobster fishery, but it is recognized that trends in landings by themselves cannot confirm there has been no effect.

Direct injury and mortality of lobsters due to the scallop fishery is likely greater in localized areas of high lobster density, such as portions of subarea B. Injury is also likely greater when lobsters are less mobile and less robust because they are soft-shelled. Lobster moulting occurs from summer to fall, but there are considerable differences between years and between areas (Smith et al. 2009b). Moult timing is strongly controlled by temperature, with the moult occurring earlier in the warmer, shallower areas of Lobster Bay than in the deeper water areas of SFA 29 West. As temperatures are not constant year to year, the timing of the moult also varies. Between 2004 and 2008, moulting began in Lobster Bay between mid-June and mid-July and on Jacquard's Ridge between late July and early September (unpublished data). Peak moulting (as indicated by 50% of lobster blood samples with a blood protein < 7 g/dL) occurred in Lobster Bay between mid-July and early August and on Jacquard's Ridge between mid-August and late September. Shell hardness information from Jacquard's Ridge and the SFA 29 West survey indicate that recently moulted lobsters are present in October and that these may be more susceptible to capture by the scallop gear than the harder shelled animals that moulted earlier.

STOCK STATUS AND ADVICE FOR 2010

The depletion estimates of exploitation rate by subarea are almost all higher than their respective estimates from the survey model, as would be expected given that the former should reflect conditions within the area being fished rather than the subarea as a whole in any one year (Fig. 42). Scaling the survey estimates by $M = 0.1$ is very approximate and, given the low clapper index in the survey in recent years, natural mortality may actually be lower. However, the trends in the two estimates are very similar by subarea, even though the survey estimate does not contain any information on catch.

In subarea A, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be <0.01 and 0.03, respectively. Growth in biomass is expected to be 8% from 2009 to 2010, and there is expected to be little recruitment based on the survey. Landings of 5 t did not result in an appreciable decline in biomass in 2009 and would not be expected to result in an appreciable decline in biomass in 2010.

In subarea B, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be 0.07 and 0.15, respectively. Growth in biomass is expected to be 14% from 2009 to 2010. Recruitment levels are currently low. Landings of 60 t did not result in an appreciable decline in biomass in 2009 and would not be expected to result in an appreciable decline in biomass in 2010.

In subarea C, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be 0.26 and 0.32, respectively, both of which exceeded the growth rate (20%) and recruitment from 2008 to 2009. Growth in biomass is only expected to be around 14% from 2009 to 2010 based on the average meat weight of the commercial and recruit size scallops in 2009. Using the survey estimates, catch levels that correspond to a 0.2 exploitation rate (target used in the Bay of Fundy) would be 42 t.

In subarea D, 2009 exploitation rates from the research survey and commercial catch rates were estimated to be 0.27 and 0.39, respectively. Growth in biomass is only expected to be 15% in 2009/2010 compared to 17% in the previous year. Using the survey estimates, catch levels that correspond to a 0.2 exploitation rate (target used in the Bay of Fundy) would be 64 t.

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TABLES

Table 1. Scallop landings and total allowable catches (TACs) (meats, t) for Scallop Fishing Area (SFA) 29 West. TAC for subareas A and E combined in 2006.

Year	Subarea	Full Bay		East of Baccaro		Total	
		TAC (t)	Landings (t)	TAC (t)	Landings (t)	TAC (t)	Landings (t)
2005	A	45.0	2.5	15.0	2.2	60	4.7
	B	30.0	22.7	10.0	26.3	40	48.9
	C	75.0	91.9	25.0	23.4	100	115.3
	D	41.25	63.2	13.75	10.7	55	73.9
	E		8.8		1.7		10.5
	Total	191.25	189.1	63.1	64.3	255	253.3
2006	A	18.75	20.4	6.25	1.1	25	21.5
	E		0.8		1.0		1.8
	B	93.75	87.8	31.25	27.8	125	115.6
	C	75.00	85.7	25.00	25.6	100	111.3
	D	112.50	113.0	37.50	42.9	150	155.9
	Total	300	307.7	100	98.4	400	406.1
2007	A	18.75	10.49	6.25	0.99	25.00	11.48
	E		0.24				0.24
	B	75.00	55.56	25.0	24.32	100.00	79.88
	C	37.50	47.86	12.5	11.03	50.00	58.89
	D	56.25	69.00	18.75	26.35	75.00	95.35
	Total	187.50	183.15	62.50	62.69	250.00	245.94
2008	A	7.50	3.05	2.50		10.00	3.05
	E		0.65		0.44		1.09
	B	82.50	44.65	27.50	20.75	110.00	65.40
	C	33.75	42.05	11.25	12.35	45.00	54.40
	D	63.75	99.37	21.25	26.02	85.00	125.39
	Total	187.50	189.77	62.50	59.56	250.00	249.33
2009	A	9.75	4.47	5.25	0.05	15	4.52
	E		0.01		1.96		1.97
	B	48.75	36.46	26.25	23.43	75	59.89
	C	48.75	50.19	26.25	27.35	75	77.54
	D	55.25	67.20	29.75	31.46	85	98.66
	Total	162.50	158.33	87.50	84.23	250	242.56

Table 2. Number of tows, days and trips observed during the SFA 29 West fishery, 2001–2009 (EoB: East of Baccaro. FB: Full Bay).

YEAR	Tows observed		Days observed		Trips observed	
	EOB	FB	EOB	FB	EOB	FB
2001		2,014		97		45
2002	1,933	2,521	78	98	33	36
2003	820	1,524	33	56	10	18
2004	1,305	3,135	42	103	13	31
2005	502	1,414	15	50	5	14
2006	895	2,157	30	67	7	17
2007	3	947	1	28	1	7
2008	548	1,969	17	67	4	19
2009	579	1,212	17	38	4	10

Table 3. Lobsters and scallops observed in the open portion of SFA 29 subarea B versus the closed portion (August Closure) of B.

Observed 2009	Full Bay (FB)		East of Baccaro (EOB)	
	B Open	B Closed	B Open	B Closed
# of lobsters	203	67	300	46
Scallops meat (mt)	6.8	1.4	5.5	0.6
# Lobsters / meat (mt)	30	48	55	77

Note– there was an additional 0.3 mt of scallop meats for each EOB and and FB in subarea B without locations so these cannot be allocated to B Open or B Closed.

Table 4. Numbers of lobsters and condition notes recorded by observers during 1,212 tows aboard vessels of the Full Bay Scallop fleet during the 2009 scallop fishery in SFA 29 West. Note that condition was not recorded for all lobsters caught. N/A refers to condition being recorded as unknown.

Subarea	N/A	Alive		Dead or Dying	Grand Total
		No injury	Injured		
A	0	4	7	0	11
B	2	188	62	18	270
C	2	10	0	0	12
D	0	1	0	0	1
E	0	1	0	0	1
Total	**4**	**204**	**69**	**18**	**295**

Table 5. Numbers of lobsters and condition notes recorded by observers during 579 tows aboard vessels of the East of Bacaro Scallop fleet during the 2009 scallop fishery in SFA 29 West. Note that condition was not recorded for all lobsters caught. N/A refers to condition being recorded as unknown.

Subarea	N/A	Alive		Dead or Dying	Grand Total
		No injury	Injured		
A	0	0	0	0	0
B	197	97	17	17	328
C	0	0	0	0	0
D	0	0	0	0	0
E	1	0	0	0	1
Total	**198**	**97**	**17**	**17**	**329**

Note: there were 198 lobsters that were not assessed for condition. A percentage of these were likely dead or injured but cannot be included in the calculations in this table.

Table 6. Estimated total numbers of lobsters caught in the scallop fisheryin SFA 29 West by Full Bay Scallop fleet for 2001–2009 based upon observer data. DI (%) refers to the percentage of dead or injured lobsters.

Year	Area	Observer data			Fishery	Estimated	
		No. lobsters	DI (%)	Meats (t)	Meats (t)	No. lobsters	DI
2001	A	35		0.4	2	183	
	B	706		23.2	71	2158	
	C	102		72.2	309	436	
	Unknown				18		
	Total	**843**		**95.8**	**400**	**2777**	
2002	A	0	0	0.0	1	0	
	B	815	38	33.0	193	4773	1814
	C	90	39	43.6	334	690	269
	E	0	0	0.0		0	
	Total	**905**		**76.6**	**528**	**5463**	**2083**
2003	A	0	0	0.0	0	0	
	B	1297	37	31.4	114	4713	1743
	C	38	39	9.1	33	138	54
	E	78	33	NA	2	NA	
	Total	**1413**		**80.5**	**149**	**4851**	**1797**
2004	A	12	30	11.4	70.2	74	22
	B	200	15	12.6	33.1	527	79
	C	87	14	22.3	123.8	483	68
	D	3	33	9.6	148.6	46	15
	E	20	20	0.2	0.2	26	5
	Total	**322**		**56.1**	**375.9**	**1156**	**189**
2005	A	0	0	0	2.5	0	
	B	151	24	3.3	22.7	1047	251
	C	50	17	12.3	91.9	375	64
	D	0	0	5.4	63.2	0	
	E	107	19	3.1	8.8	308	59
	Total	**308**		**24.1**	**189.1**	**1730**	**374**
2006	A	17	18	1.1	20.4	309	56
	B	640	37	14.7	88.5	3861	1429
	C	30	43	6.6	86	393	169
	D	9	11	13.1	113.1	78	9
	E	0	0	0	0.01	0	
	Total	**696**		**35.4**	**308.0**	**4641**	**1662**
2007	A	7	0	1.28	10.49	57	0
	B	155	24	2.68	55.56	3213	771
	C	24	20	2.3	47.86	499	100
	D	8	38	7.71	69.00	72	27
	E	0	0	0	0.24	0	0
	Total	**194**		**14.0**	**183.15**	**3842**	**898**
2008	A	6	17	0.8	3.0	24	4
	B	1,353	8	17.4	44.6	3,478	278
	C	1	0	0.2	42.5	266	0
	D	2	0	8.8	102.5	23	0
	E	37	5	0.2	0.6	97	5
	Total	**1,399**		**27.3**	**193.3**	**3,888**	**287**
2009	A	11	64	1.9	4.5	26	17
	B	270	30	8.5	36.5	1190	353
	C	12	0	2.8	50.2	107	0
	D	1	0	1.0	67.2	66	0
	E	1	0	0.4	0	0	0
	Total	**295**		**14.6**	**158.4**	**1,389**	**370**

Table 7. Estimated total numbers of lobsters caught in the scallop fisheryin SFA29 West by East of Baccaro fleet for 2001–2009 based upon observer data. DI (%) refers to the percentage of dead or injured lobsters.

Year	Area	Observer data			Fishery	Estimated	
		No. lobsters	DI (%)	Meats (t)	Meats (t)	No. lobsters	DI
2002	A	8	25	0.1	4	460	115
	B	110	15	6.5	75	1268	190
	C	39	26	27.9	106	148	38
	E	0	0	0		0	
	Total	**157**		**34.5**	**185**	**1876**	**343**
2003	A	0	0	0	0	0	
	B	72	29	4.7	38	579	168
	C	184	13	6.2	32	953	124
	E	61	0	NA	2	NA	
	Total	**317**		**10.9**	**72**	**1532**	**292**
2004	A	3	0	1	9.9	29	0
	B	421	16	13.8	46.8	1426	228
	C	3	0	3	35.2	35	35
	D	0	0	1.4	40	0	
	E	0	0	0	3.4	0	
	Total	**427**		**19.2**	**135.3**	**1490**	**263**
2005	A	0	0	0	0	0	
	B	480	23	5.2	26.3	2426	558
	C	4	50	0.6	23.4	163	82
	D	0	0	0	0	0	
	E	25	12	0.5	1.7	81	10
	Total	**509**		**6.3**	**51.4**	**2670**	**650**
2006	A	0	0	0	8.8	0	
	B	794	17	11.1	27.9	2002	340
	C	46	37	2.5	25.3	464	172
	D	0	0	0.8	43.9	0	
	E	0	0	0	3.5	0	
	Total	**840**		**14.3**	**109.4**	**2466**	**512**
2008	A	0	0	0	0.0	0	0
	B	70	7	2.4	20.4	606	43
	C	4	0	1.2	12.3	42	0
	D	0	0	1.2	26.0	0	0
	E	0	0	0	0.4	0	0
	Total	**74**	**7**	**4.8**	**59.1**	**647**	**43**
2009	A	0	0	0	0	0	0
	B	328	10	6.4	23.4	1,192	124
	C	0	0	0	27.3	0	0
	D	0	0	0	31.5	0	0
	E	1	0	1.0	2.0	2	0
	Total	**329**		**7.4**	**84.2**	**1,194**	**124**

Note: there were 198 lobsters that were not assessed for condition in 2009. A percentage of these are likely dead or injured but cannot be included in the calculations in this table.

Table 8. Recent lobster landings (t) by the LFA 34 lobster fishing fleet. Shown are the landings by SFA subarea, for SFA 29 West as a whole, for the area adjacent to SFA 29, and LFA 34 as a whole.

Area	SFA 29 West						Adjacent to SFA 29 West	LFA 34
	A	B	C	D	E	Total		
2000–01	352	1343	432	348	538	3013	4584	16503
2001–02	448	1566	565	294	631	3504	5284	19055
2002–03	323	1239	632	432	499	3125	4805	17607
2003–04	367	1131	649	387	484	3018	4906	17801
2004–05	314	971	714	493	363	2855	4224	17237
2005–06	335	1120	937	596	479	3468	4545	16997
2006–07	362	1020	796	609	547	3335	4468	16577
2007–08	605	1265	840	581	658	3949	4754	17137
2008–09*	602	1376	887	494	729	4087	5376	17245
				% Change				
1 year	-0.5%	8.8%	5.6%	-15.0%	10.8%	3.5%	13.1%	0.6%
5 year	64.0%	21.7%	36.7%	27.6%	50.6%	35.4%	9.6%	-3.1%

* 2008–09 landings are preliminary.

FIGURES
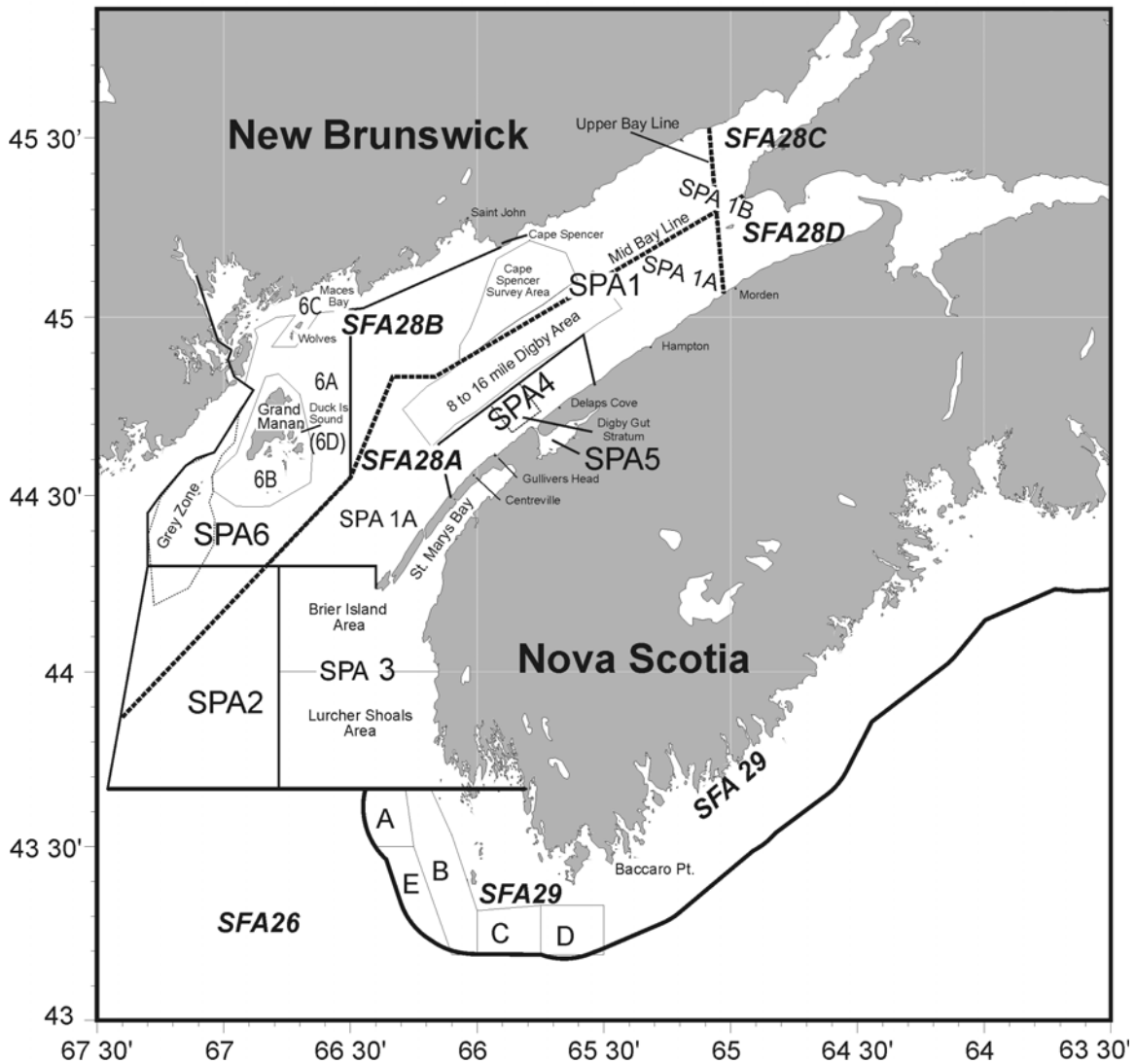
Figure 1. Map of Scallop Fishing Areas (SFA) and Scallop Production Areas (SPA).
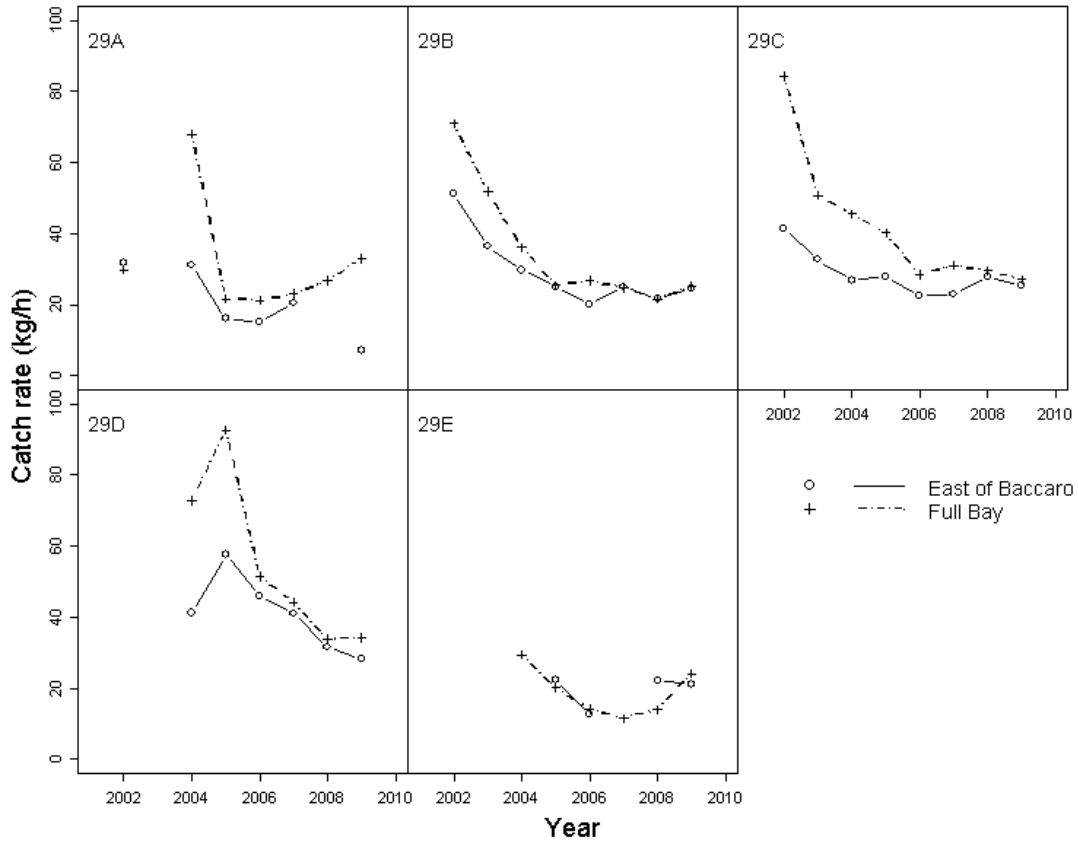
Figure 2. Annual trends for average commercial catch rate (kg/h) for SFA 29 West scallop fishery for each subarea by fleet.
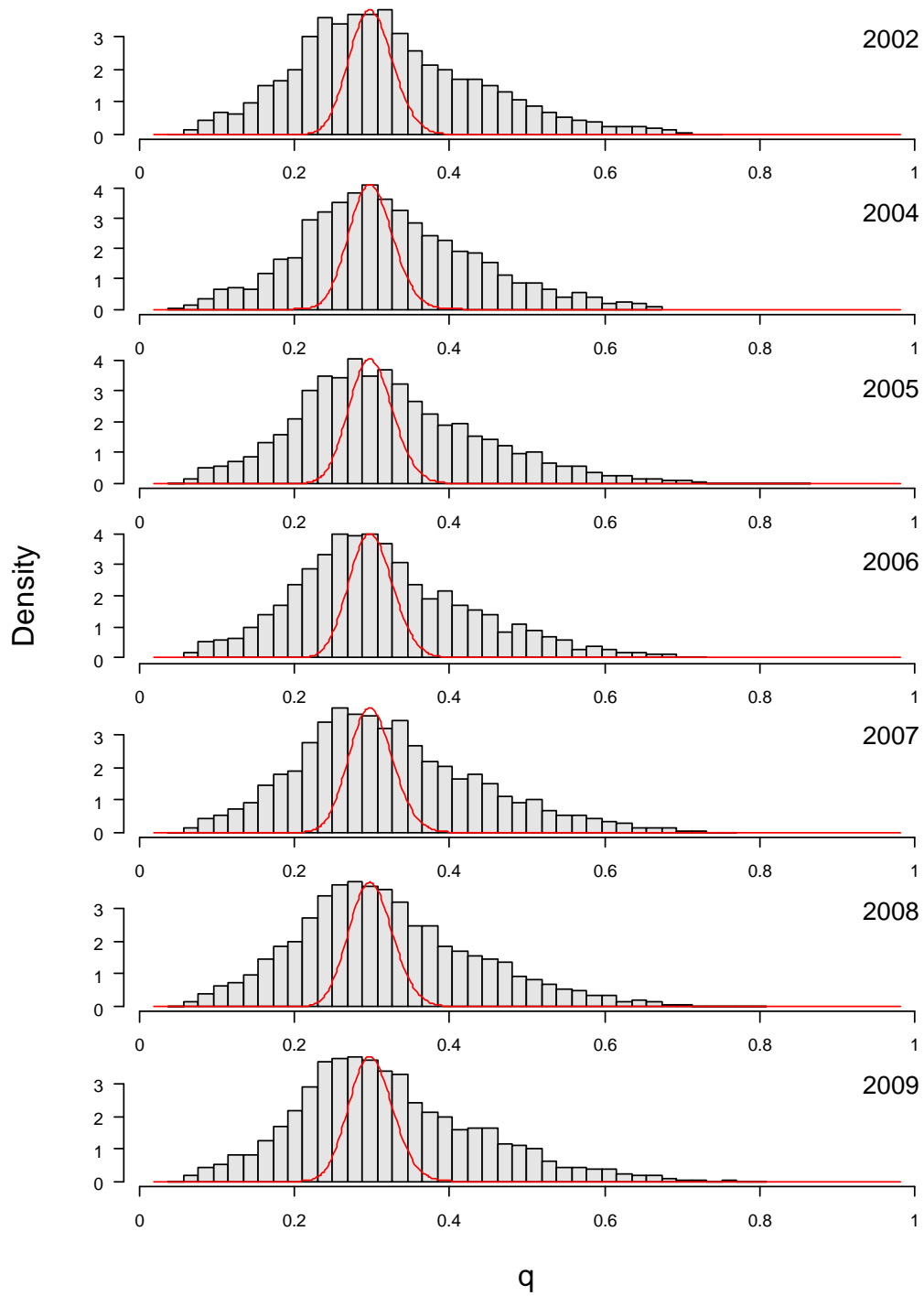
Figure 3. Posterior distributions of the catchability coefficient (q) for SFA 29 subarea A. The red line is the prior for q shared among years.
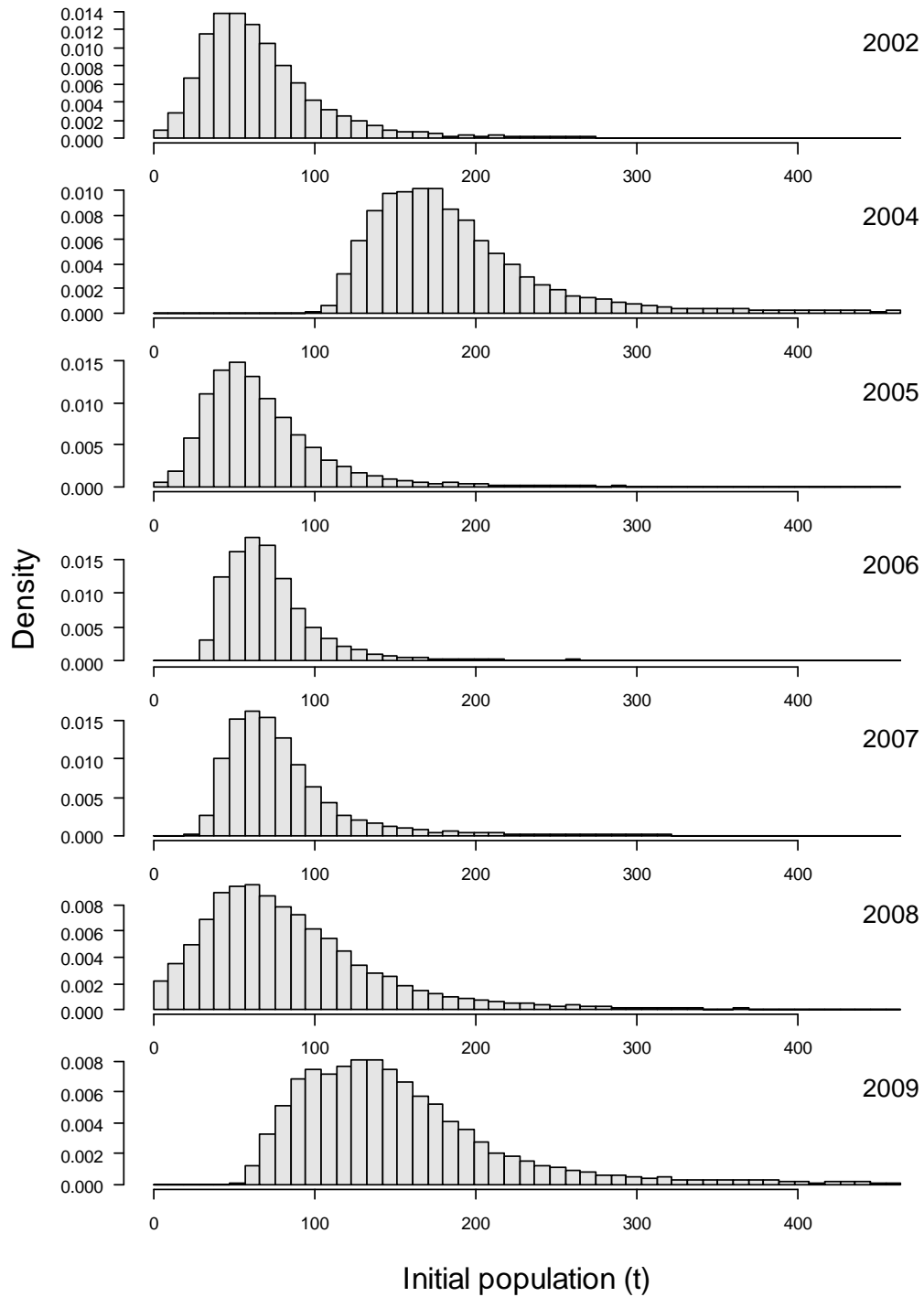
Figure 4. Posterior distributions of initial population biomass for SFA 29 subarea A. The initial population represents only the area fished in a given year.
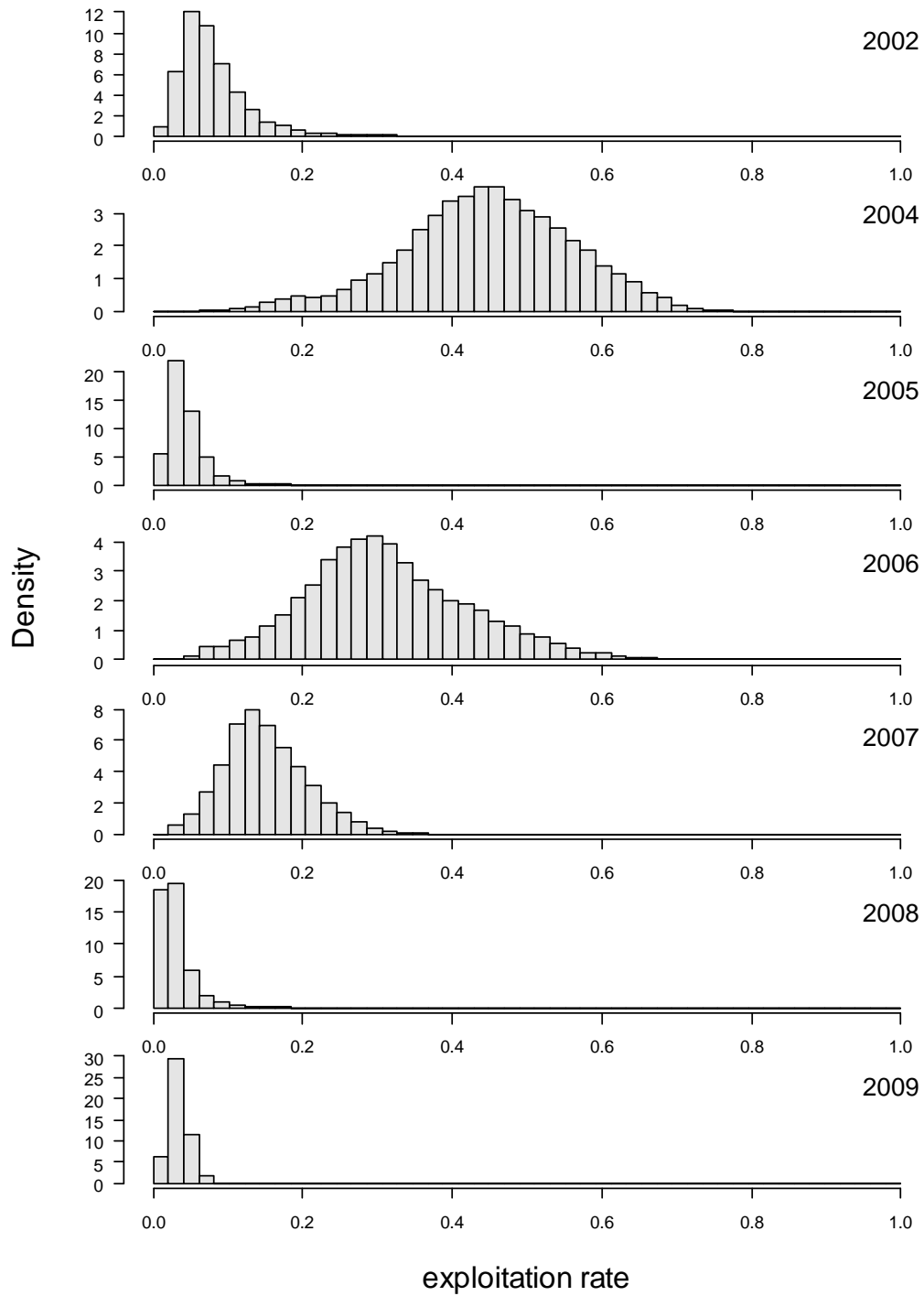
Figure 5. Posterior distributions of exploitation rate for SFA 29 subarea A. There were no landings for subarea A in 2003, so exploitation was 0.
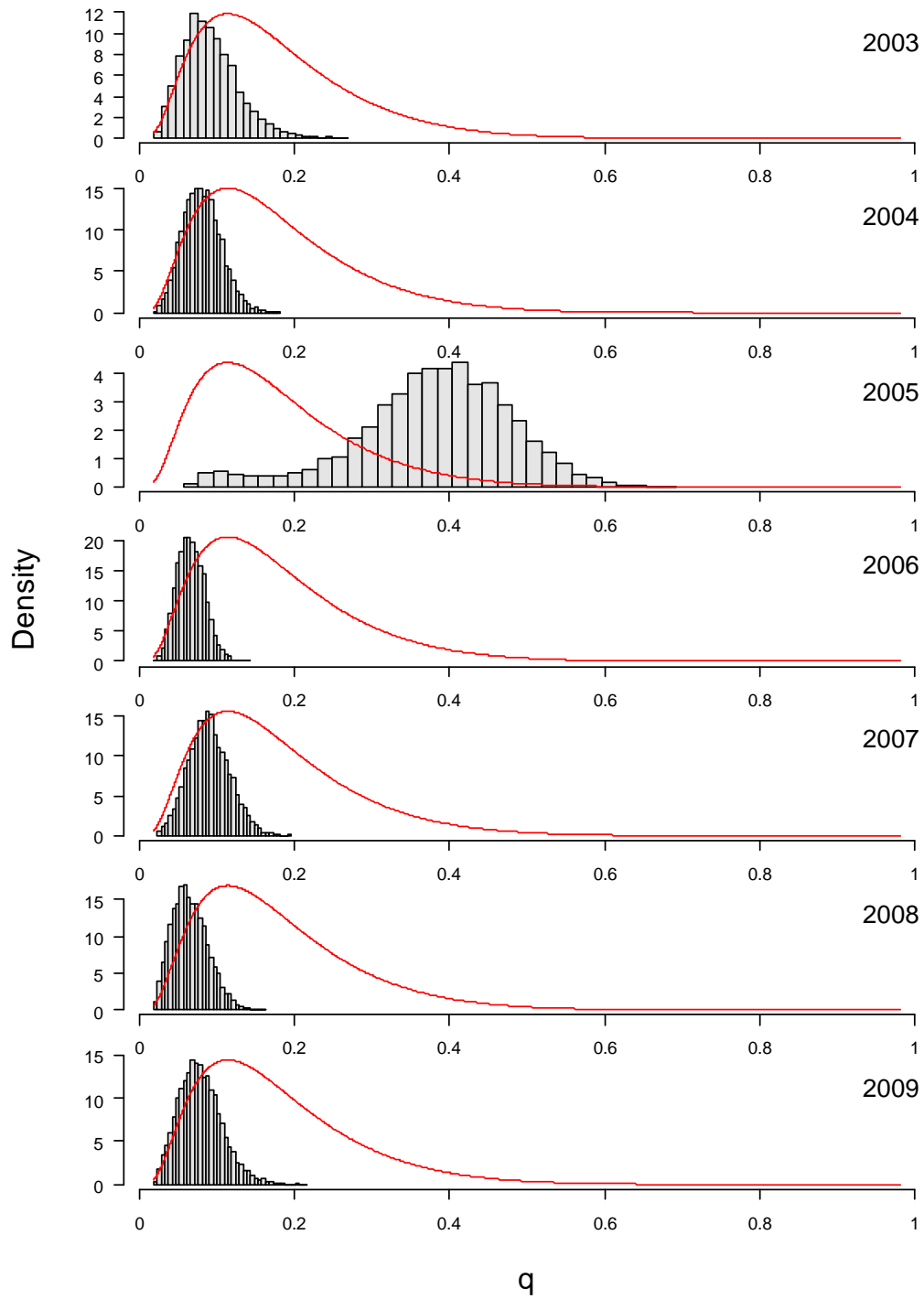
Figure 6. Posterior distributions of the catchability coefficient (q) for SFA 29 subarea B. The red line is the prior for q shared among years.
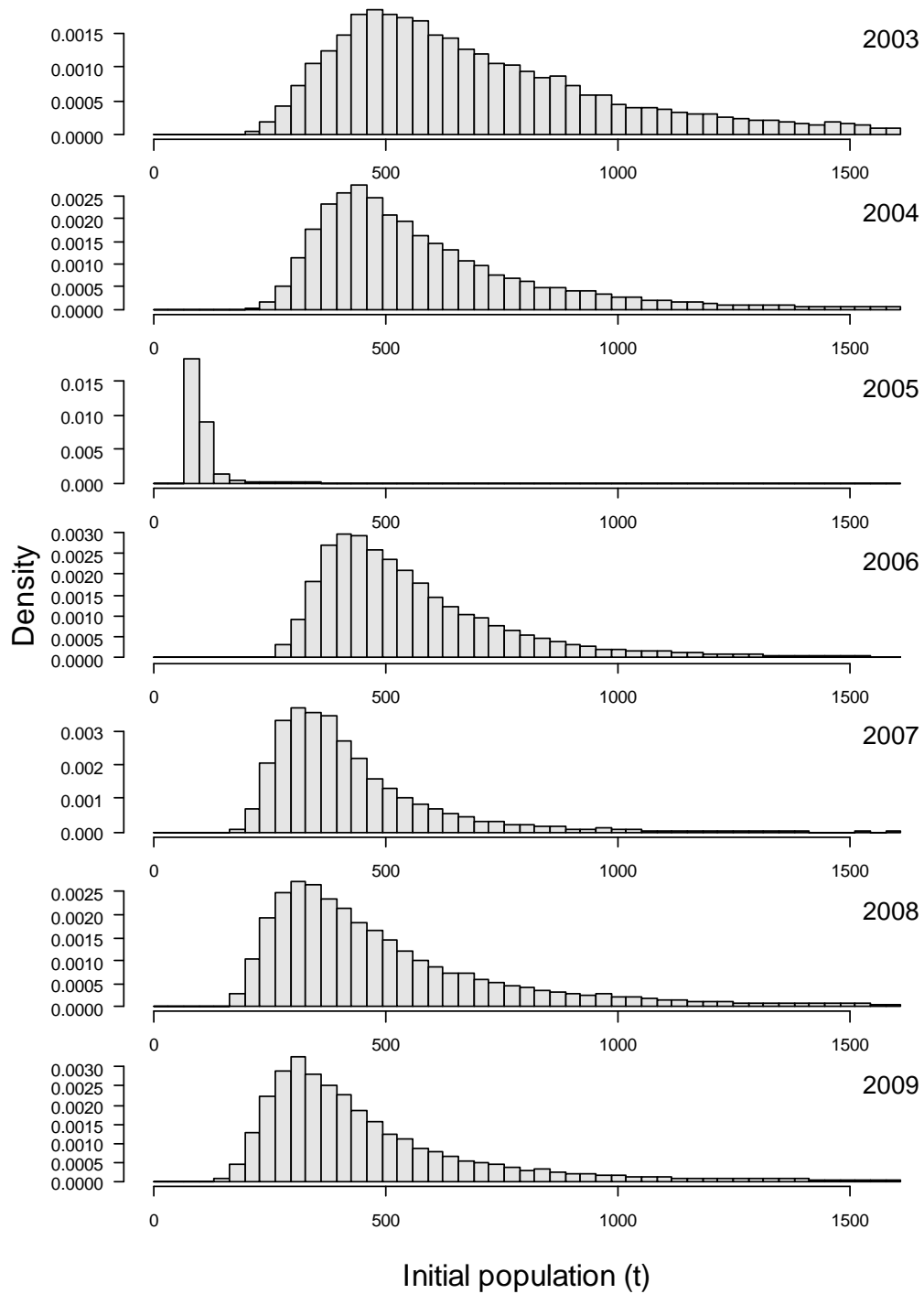
Figure 7. Posterior distributions of initial population biomass for SFA 29 subarea B. The initial population represents only the area fished in a given year.
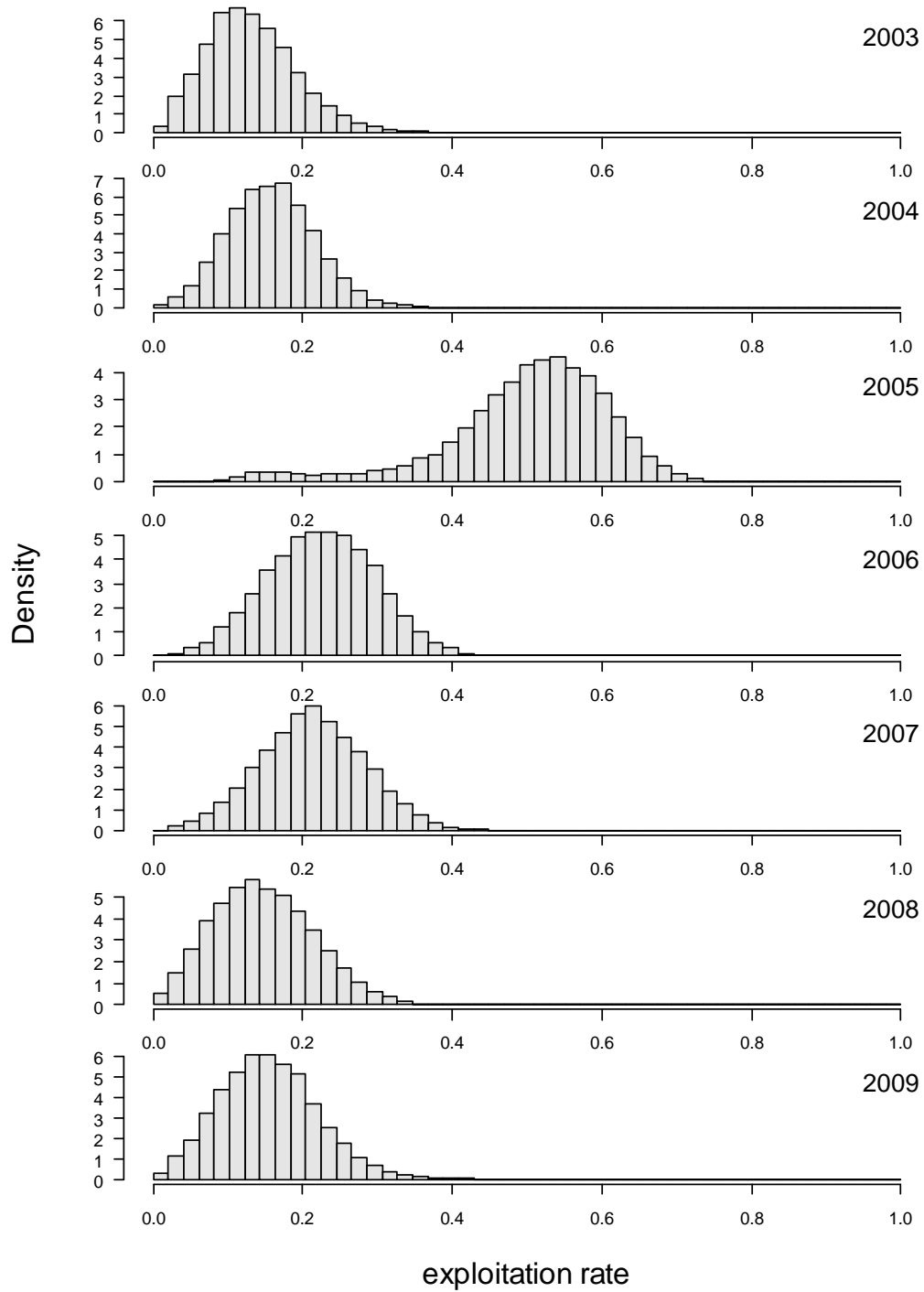
Figure 8. Posterior distributions of exploitation rate for SFA 29 subarea B.
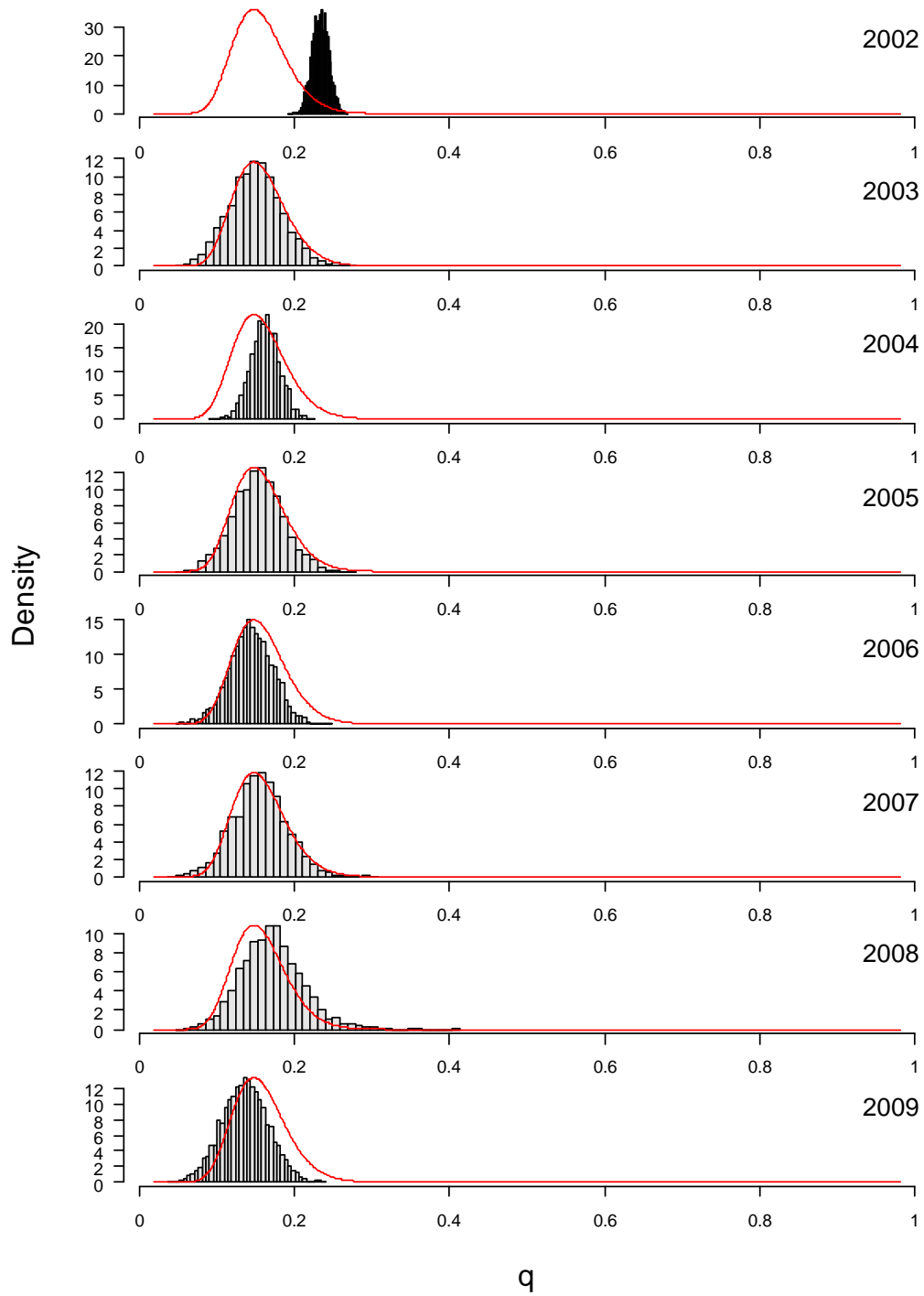
Figure 9. Posterior distributions of the catchability coefficient (q) for SFA 29 subarea C. The red line is the prior for q shared among years.
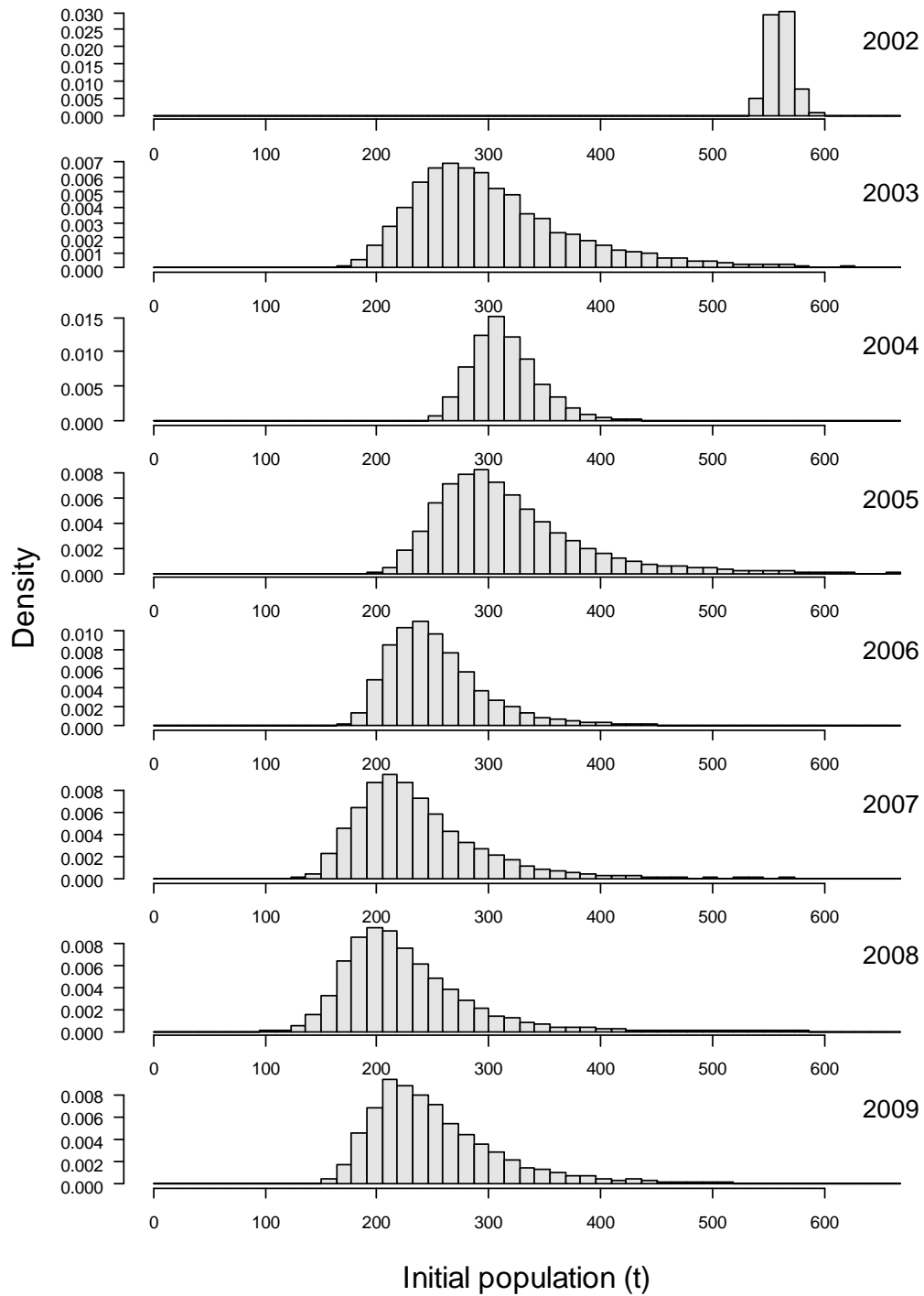
Figure 10. Posterior distributions of initial population biomass for SFA 29 subarea C. The initial population represents only the area fished in a given year.
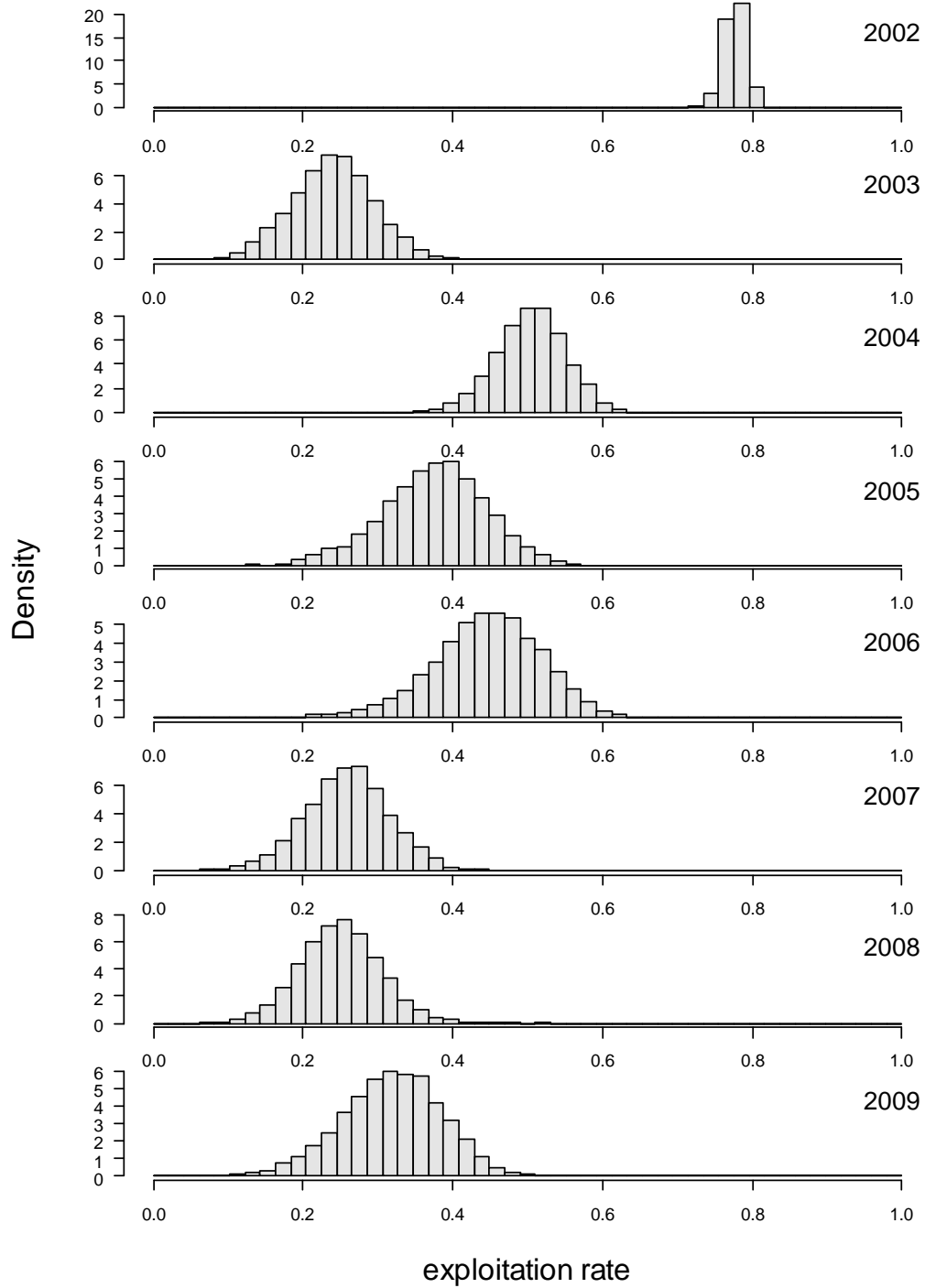
Figure 11. Posterior distributions of exploitation rate for SFA 29 subarea C.
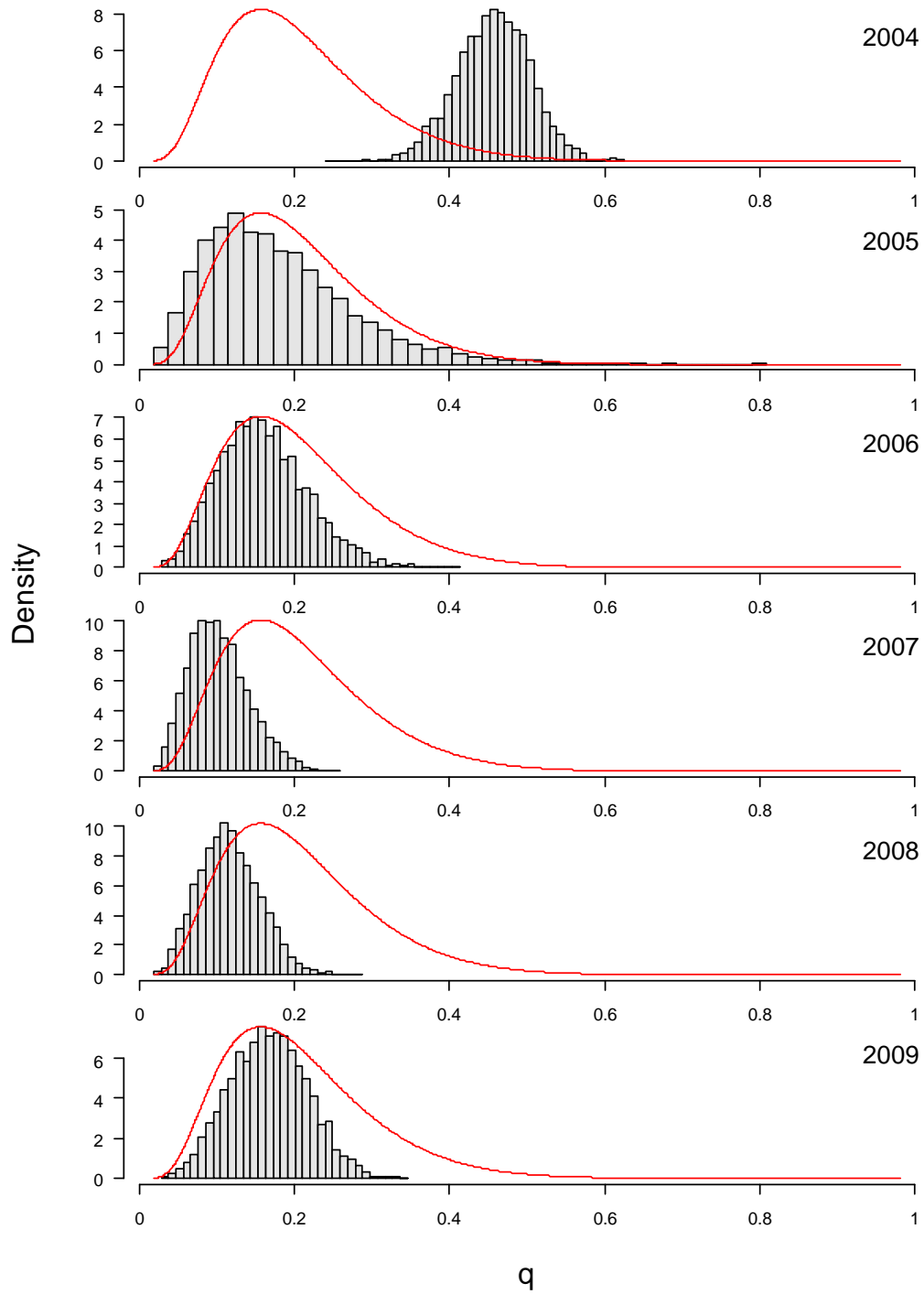
Figure 12. Posterior distributions of the catchability coefficient (q) for SFA 29 subarea D. The red line is the prior for q shared among years.
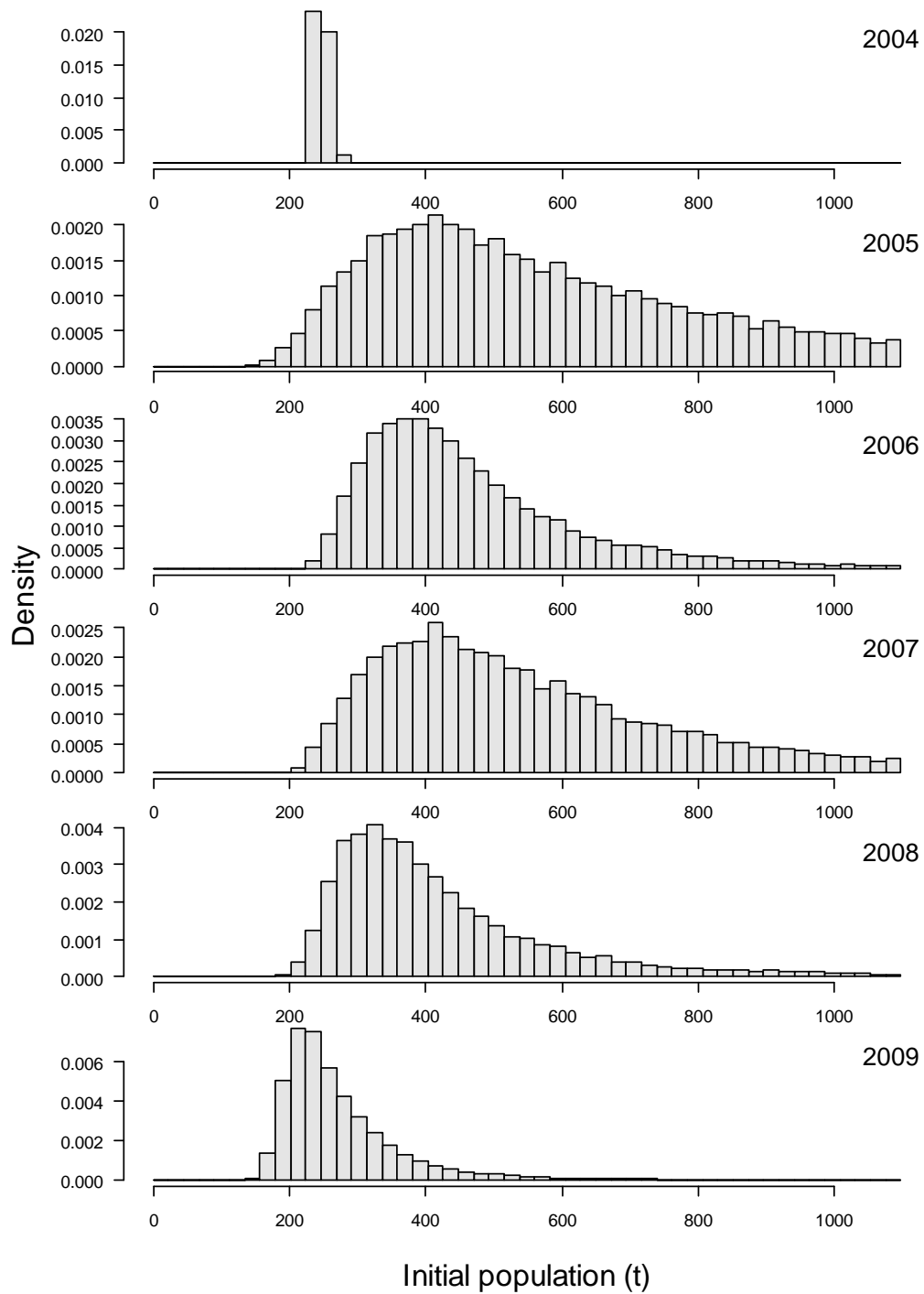
Figure 13. Posterior distributions of initial population biomass for SFA 29 subarea D. The initial population represents only the area fished in a given year.
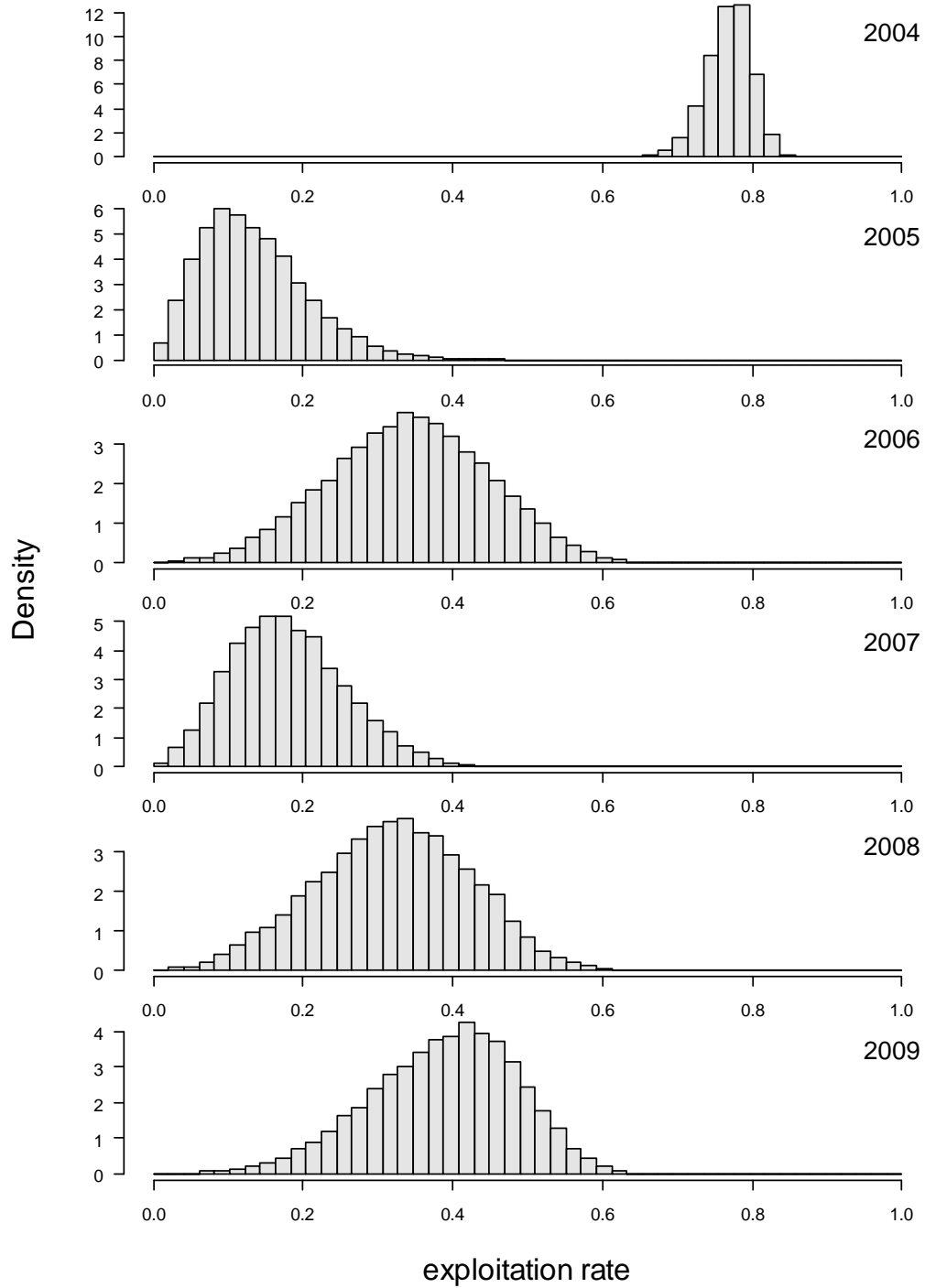
Figure 14. Posterior distributions of exploitation rate for SFA 29 subarea D.
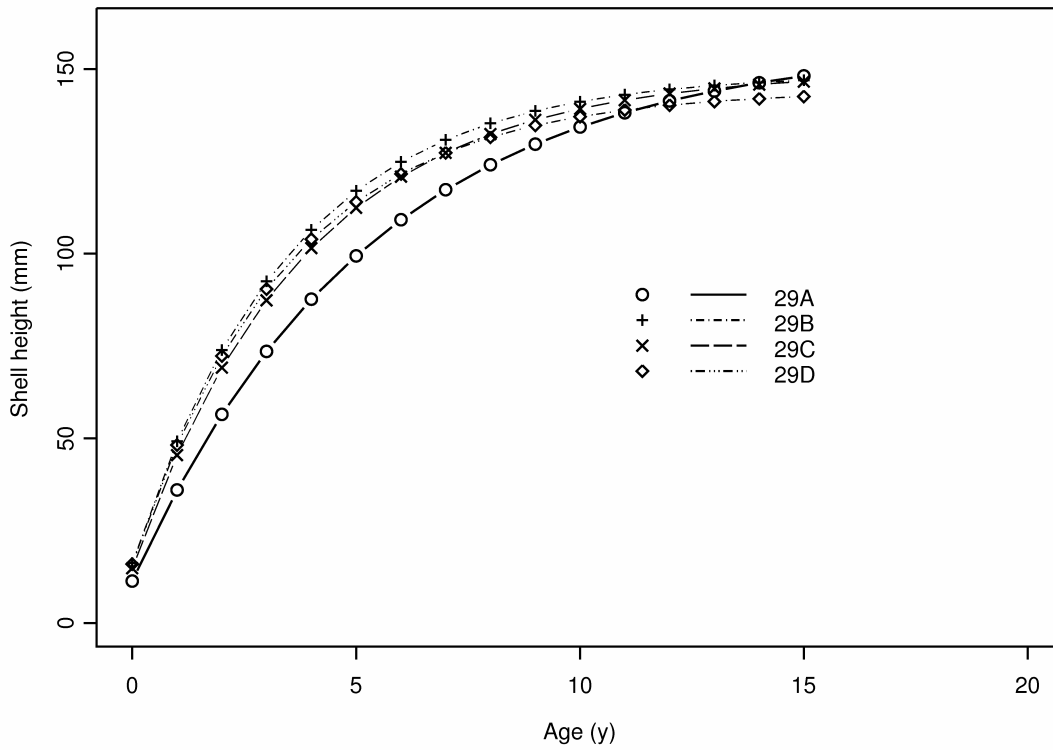
Figure 15. Scallop shell height modelled as a function of age for each subarea based on survey data collected in 2008. A mixed effects von Bertalanffy curve was used to model growth.
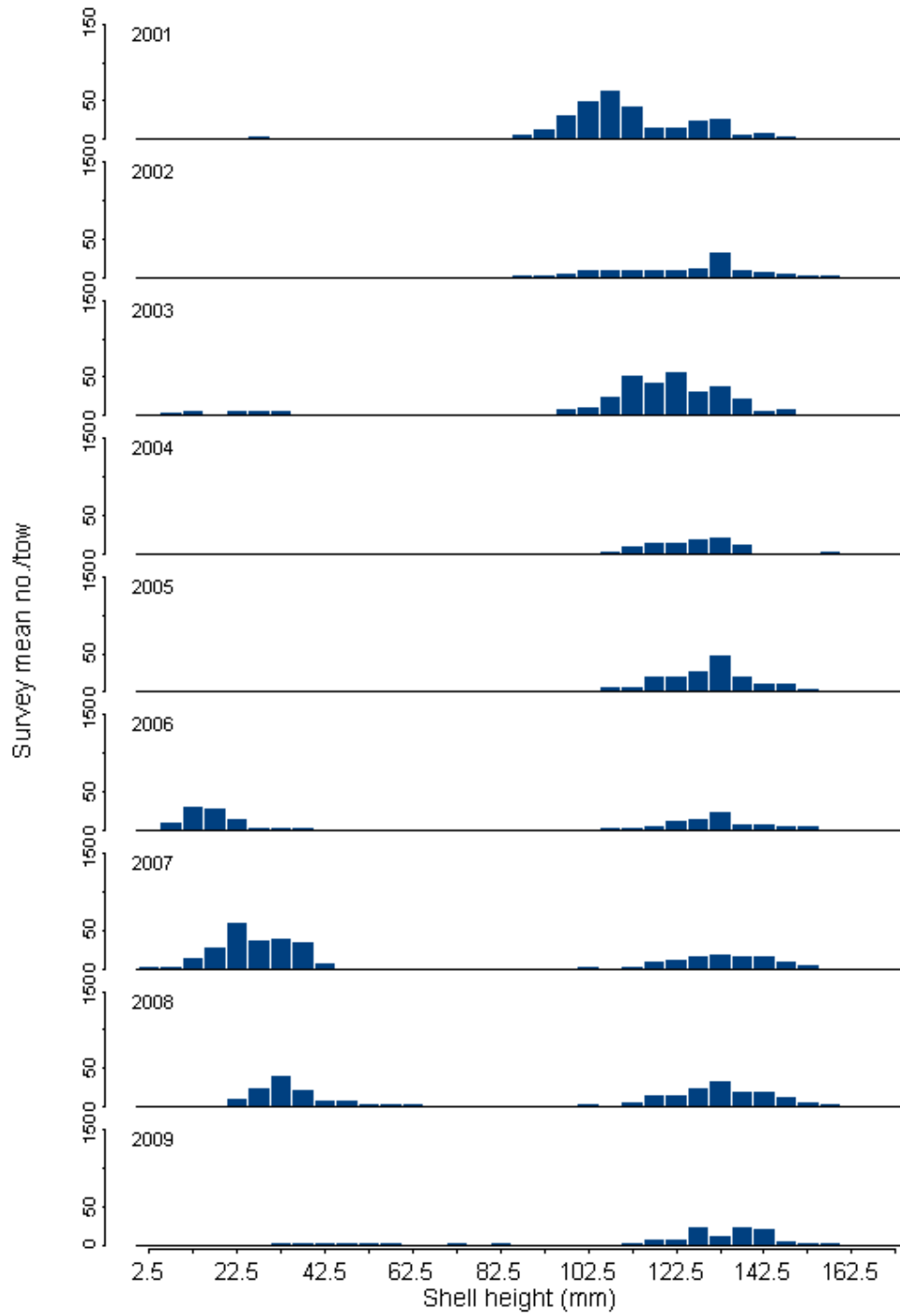
Figure 16. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea A conducted by vessels from the Full Bay fleet.
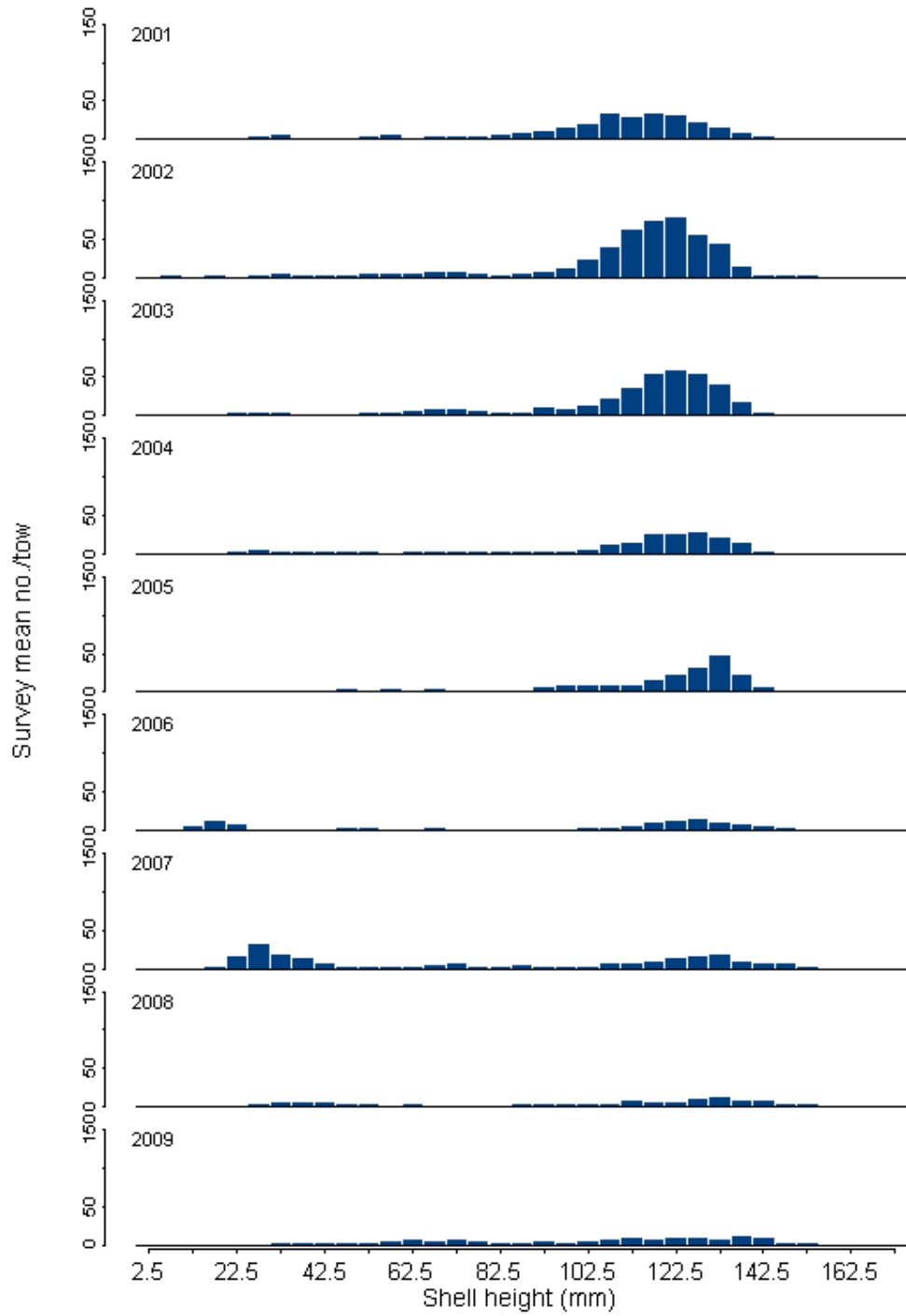
Figure 17. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea B conducted by vessels from the Full Bay fleet.
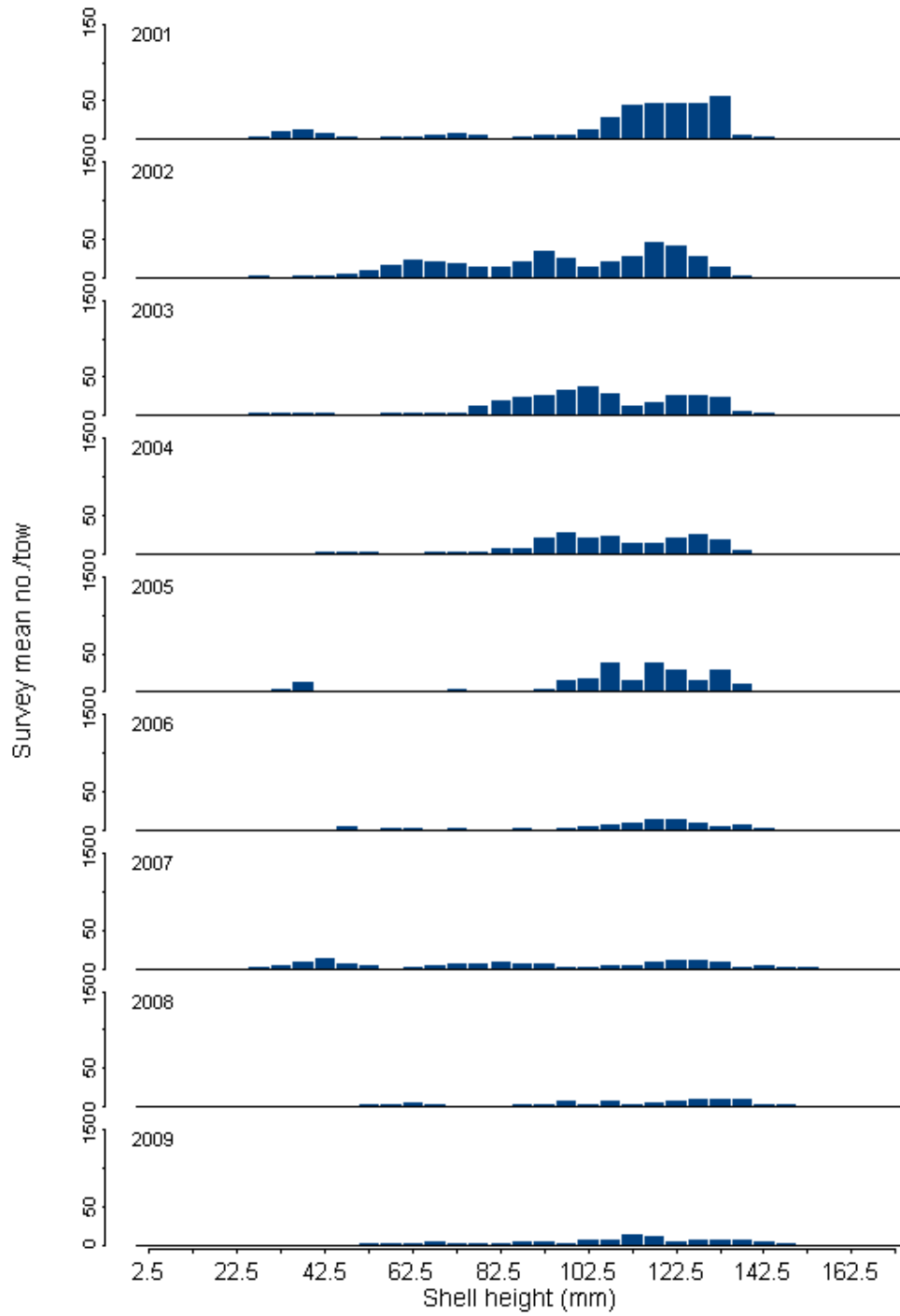
Figure 18. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea C conducted by vessels from the Full Bay fleet.
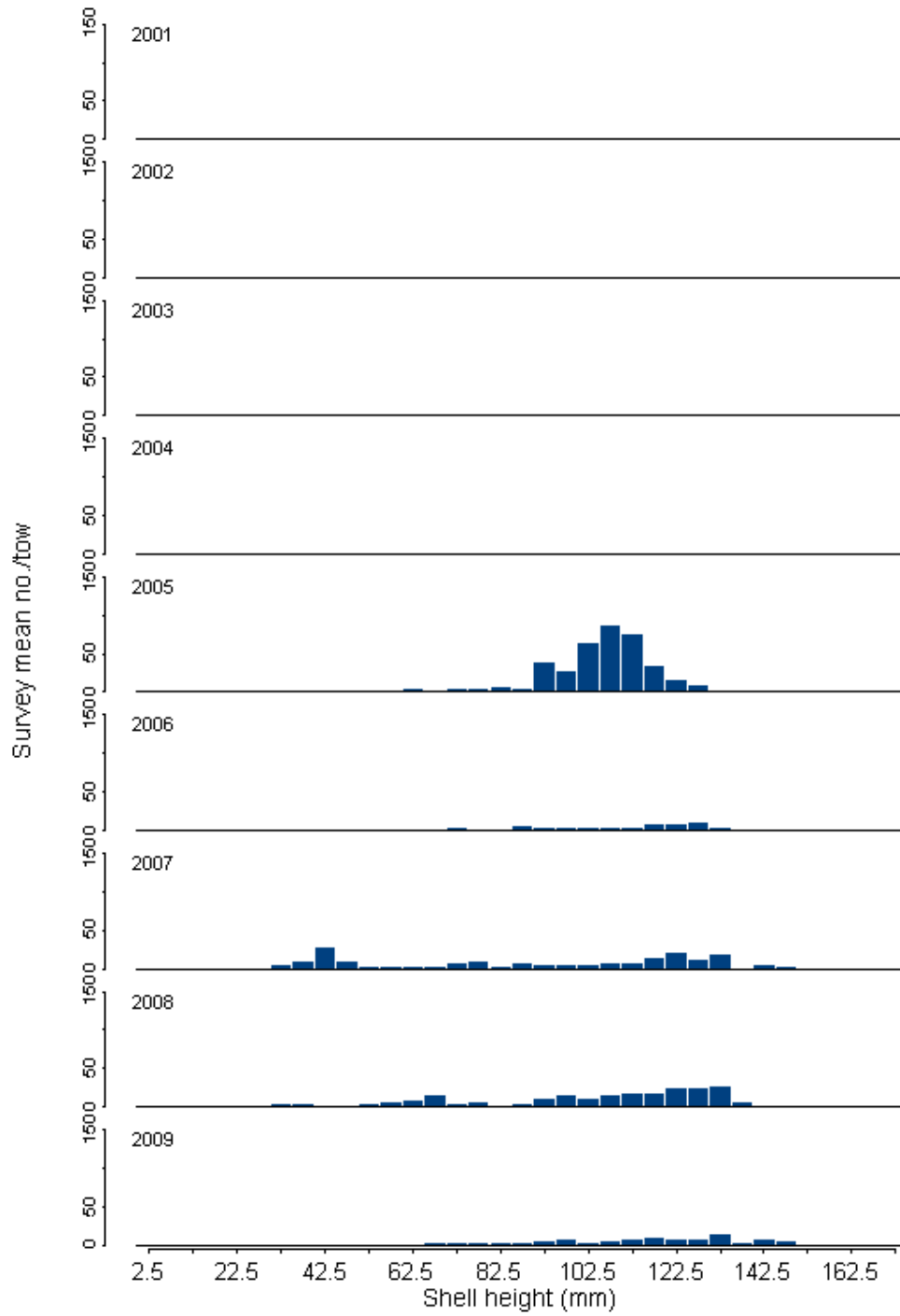
Figure 19. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea C conducted by vessels from the East of Baccaro fleet.
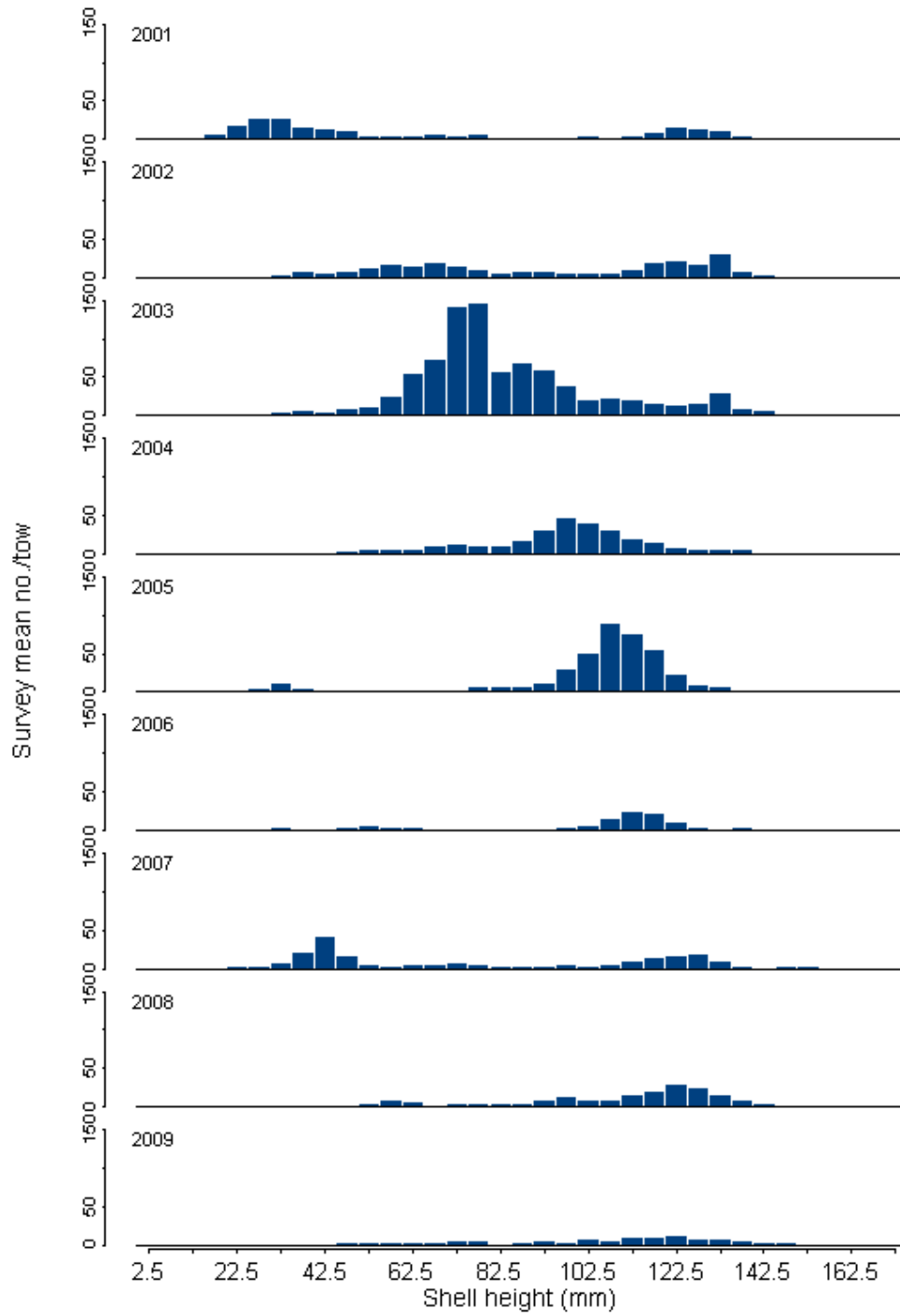
Figure 20. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea D conducted by vessels from the Full Bay fleet.
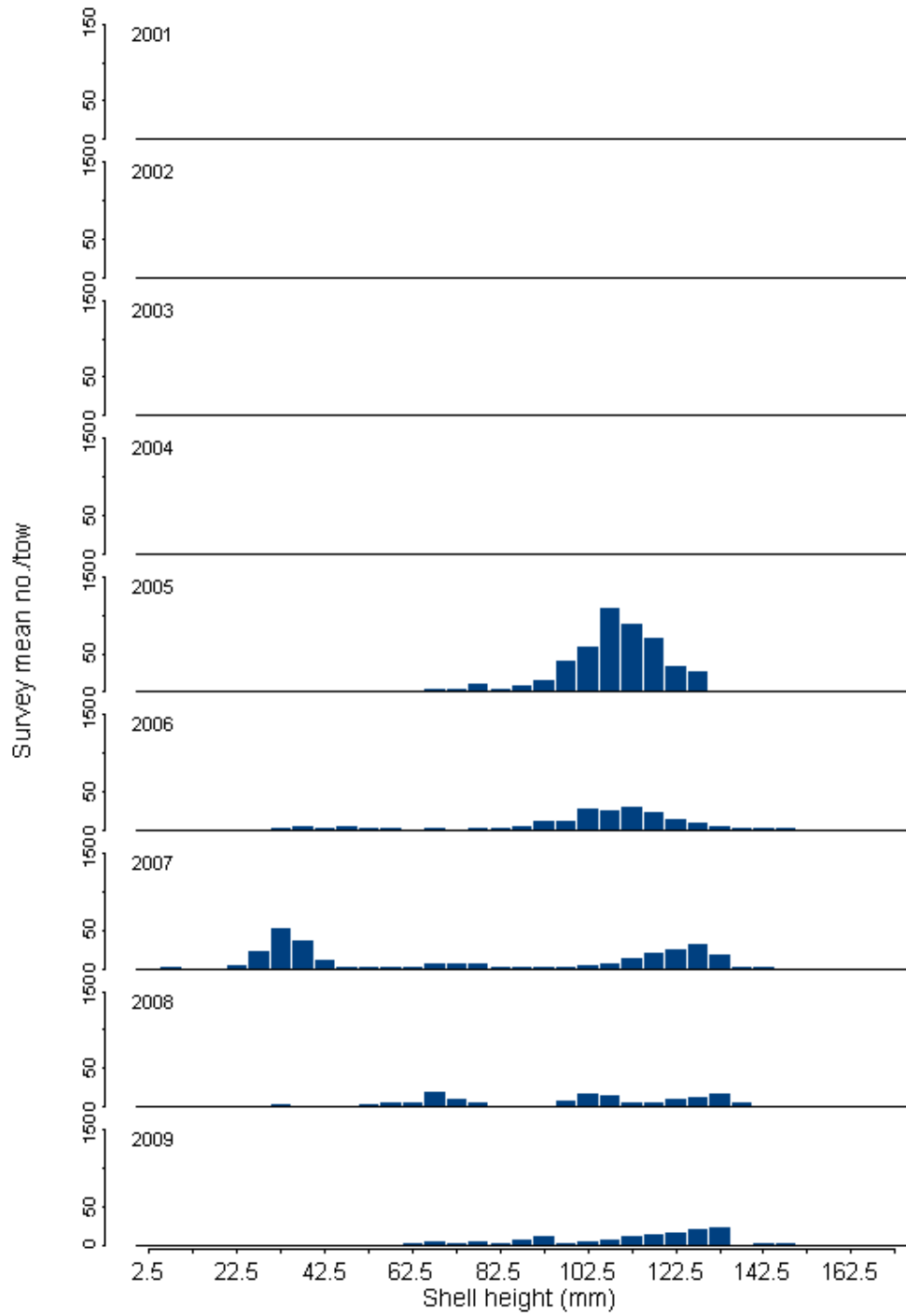
Figure 21. Scallop shell height frequencies (mean number/tow) from the surveys in SFA 29 subarea D conducted by vessels from the East of Baccaro fleet.
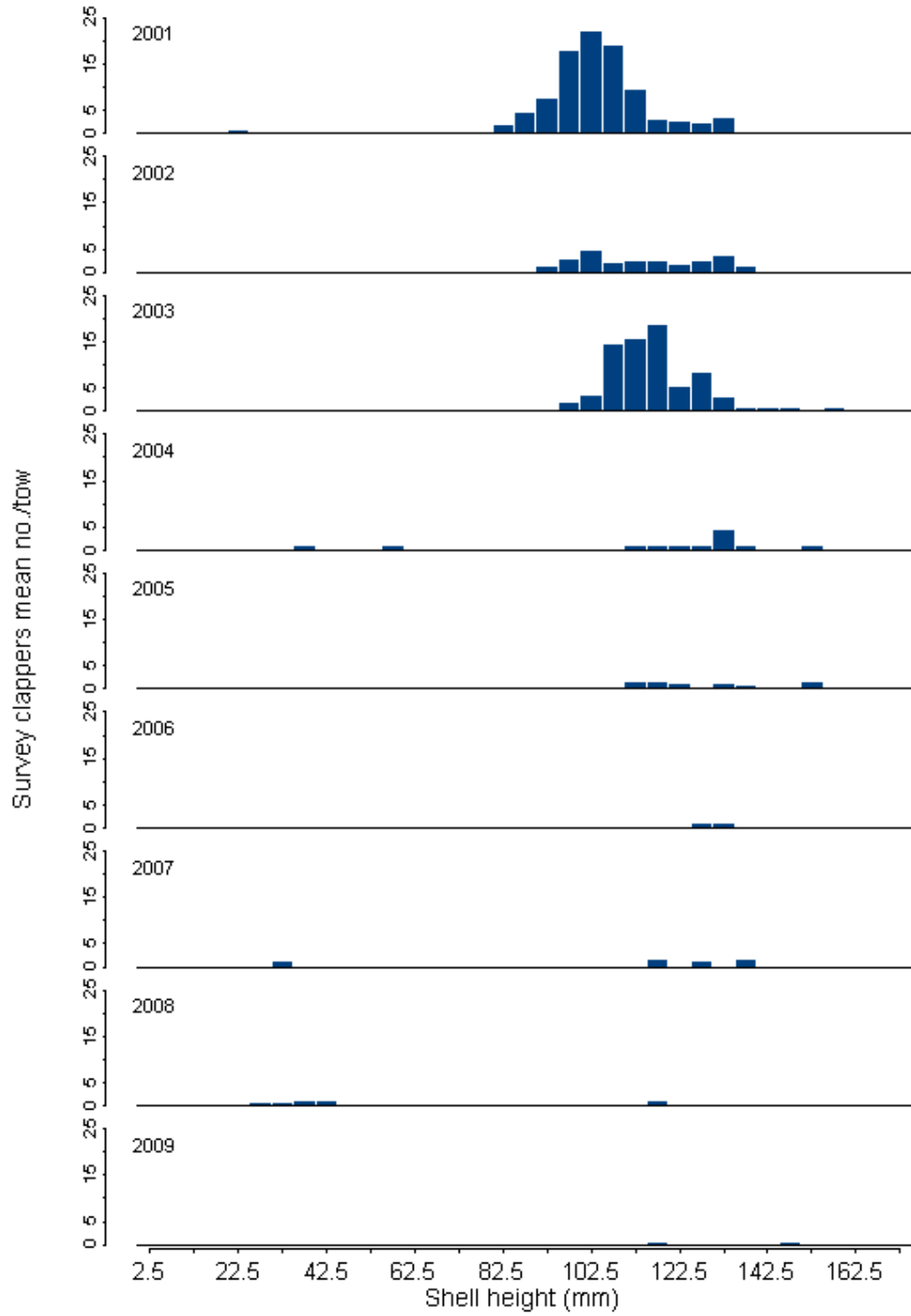
Figure 22. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea A conducted by vessels from the Full Bay fleet.
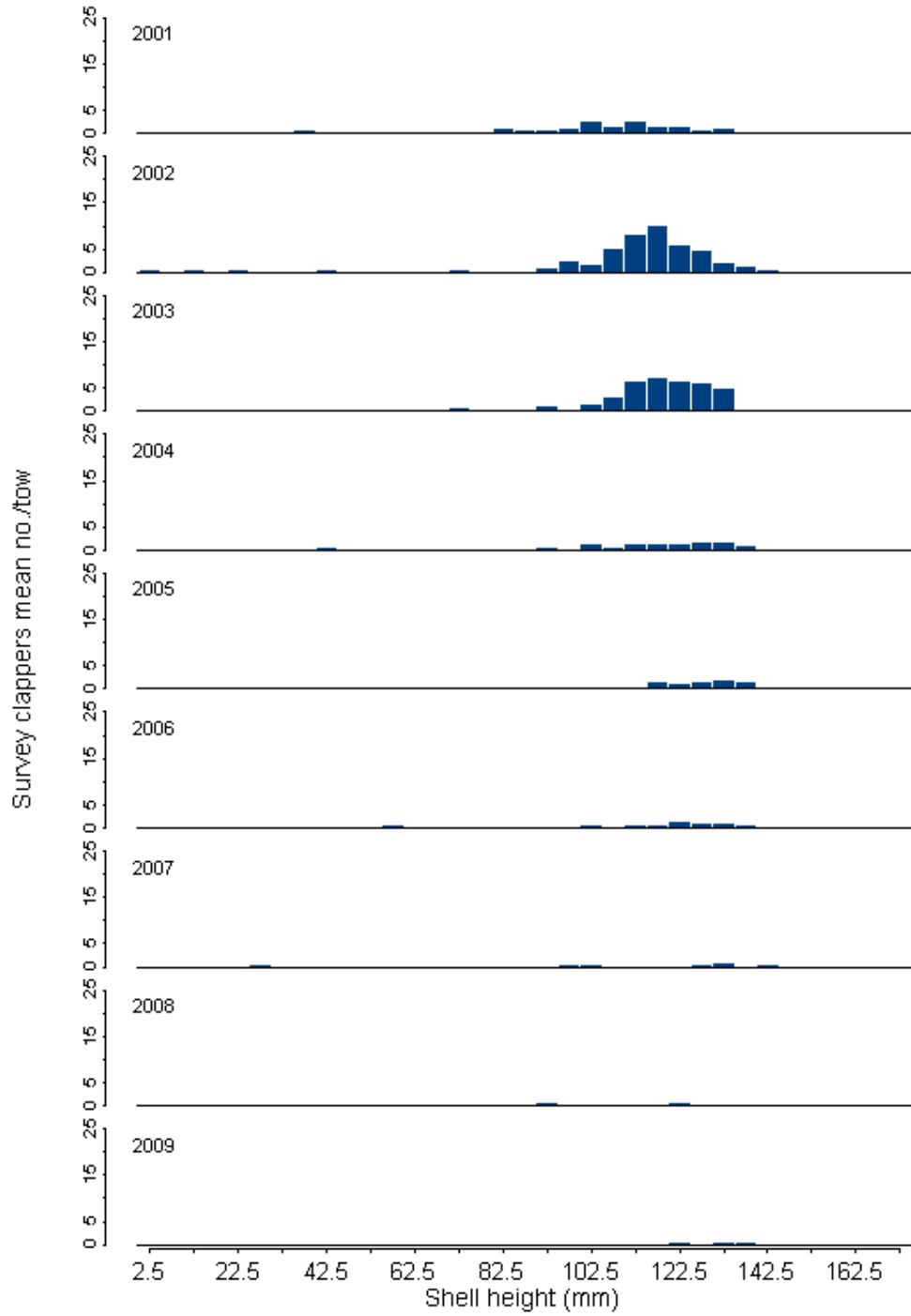
Figure 23. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea B conducted by vessels from the Full Bay fleet.
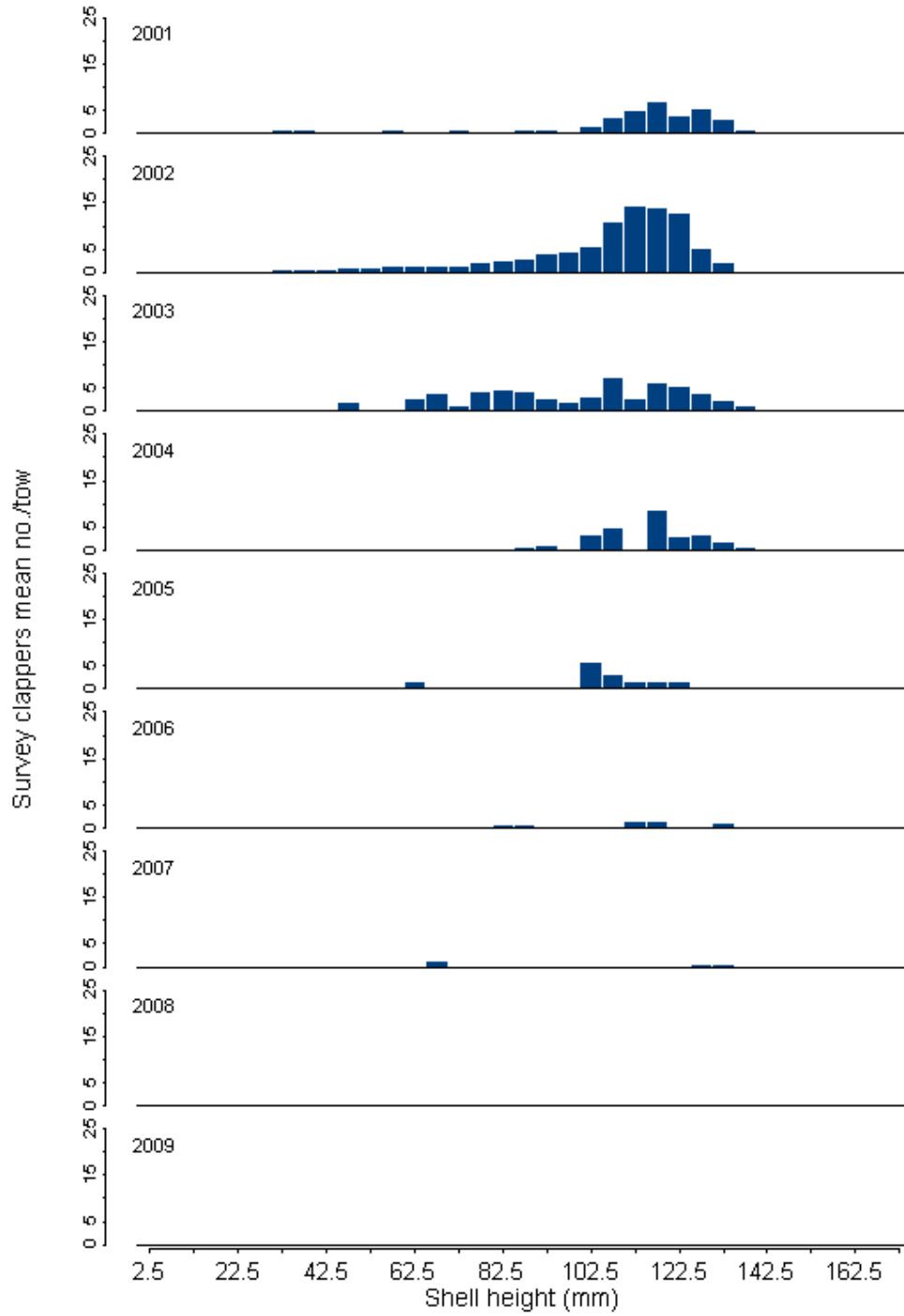
Figure 24. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea C conducted by vessels from the Full Bay fleet.
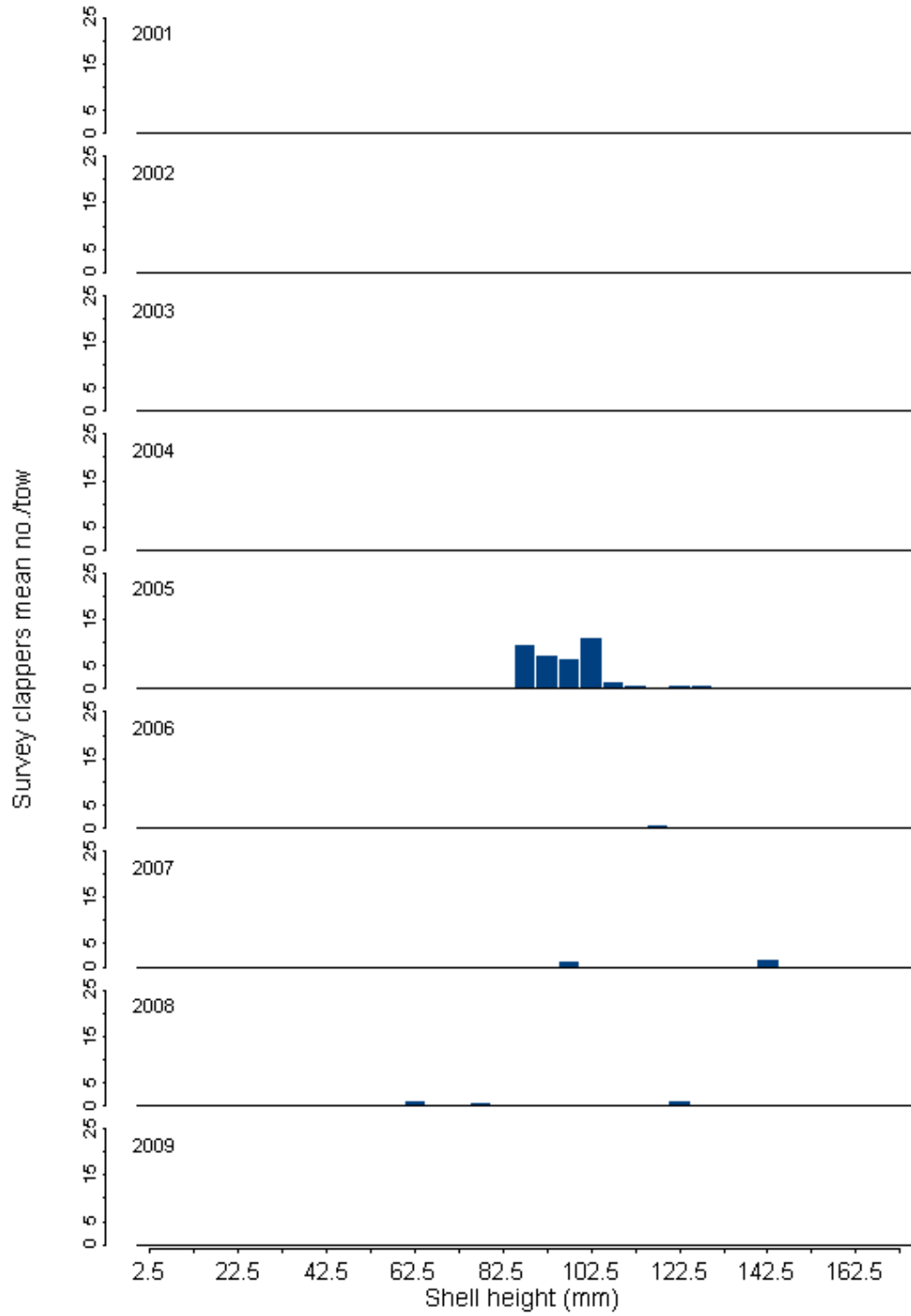
Figure 25. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea C conducted by vessels from the East of Baccaro fleet.
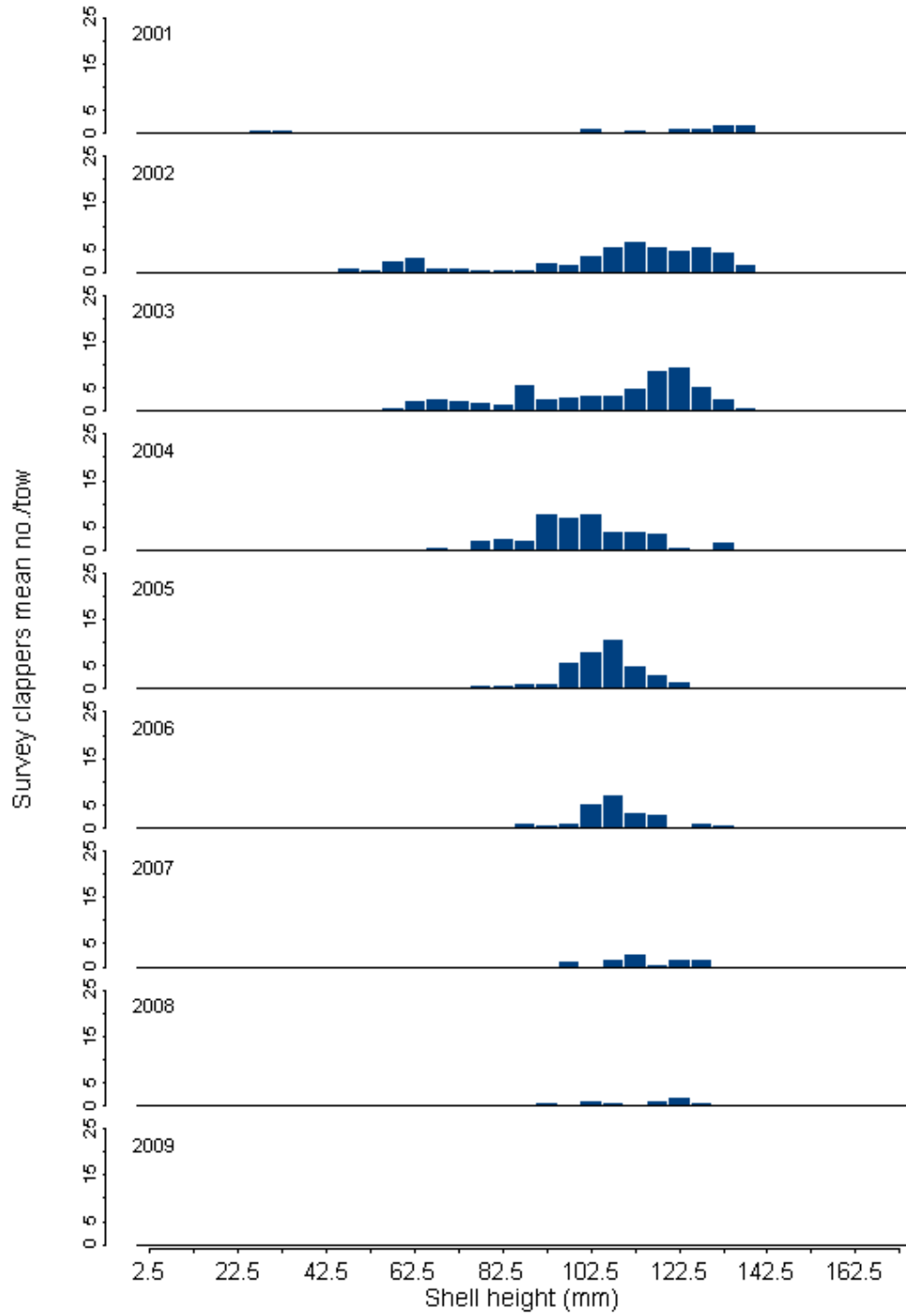
Figure 26. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea D conducted by vessels from the Full Bay fleet.
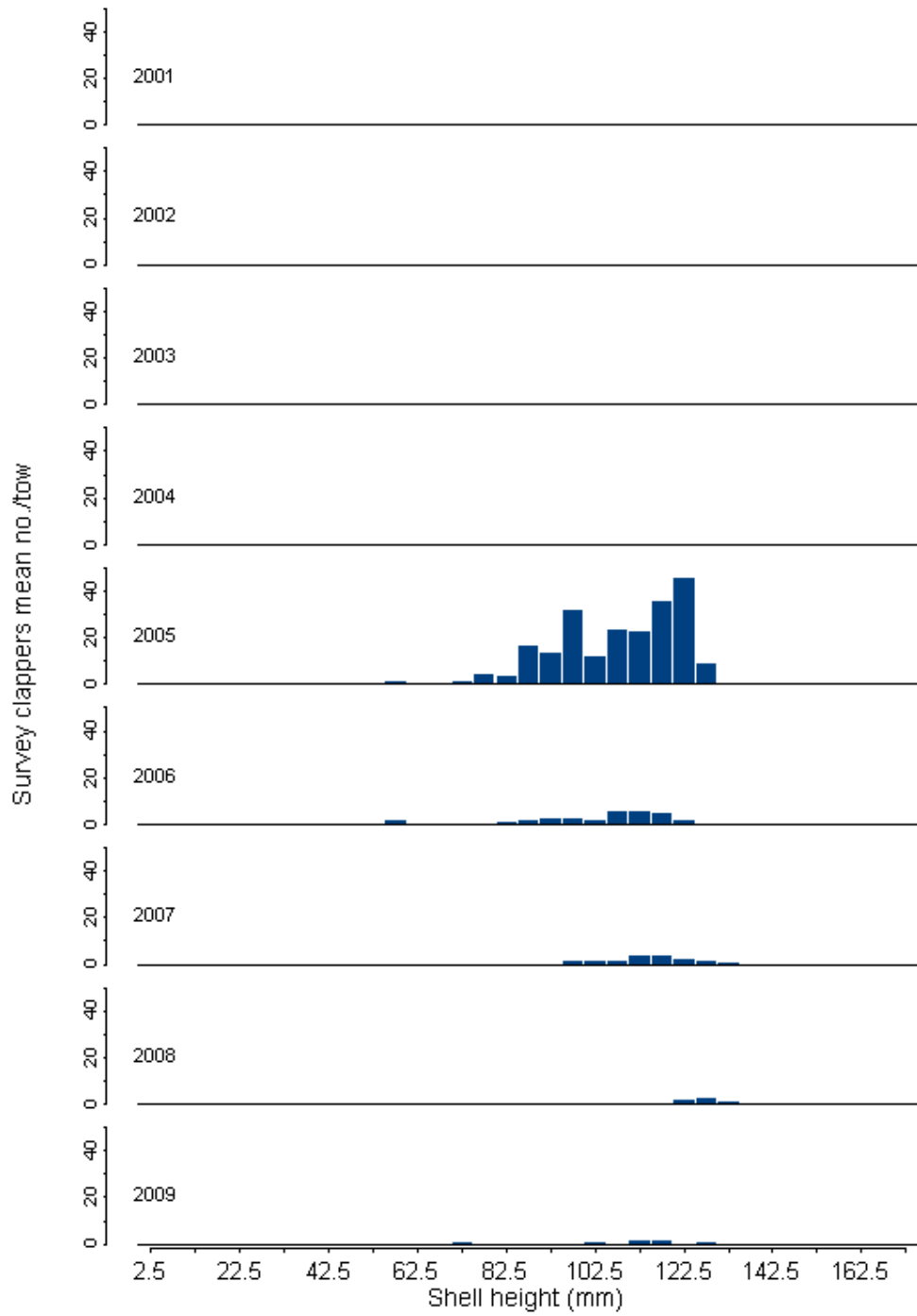
Figure 27. Scallop shell height frequencies for clappers (mean number/tow) from the surveys in SFA 29 subarea D conducted by vessels from the East of Baccaro fleet.
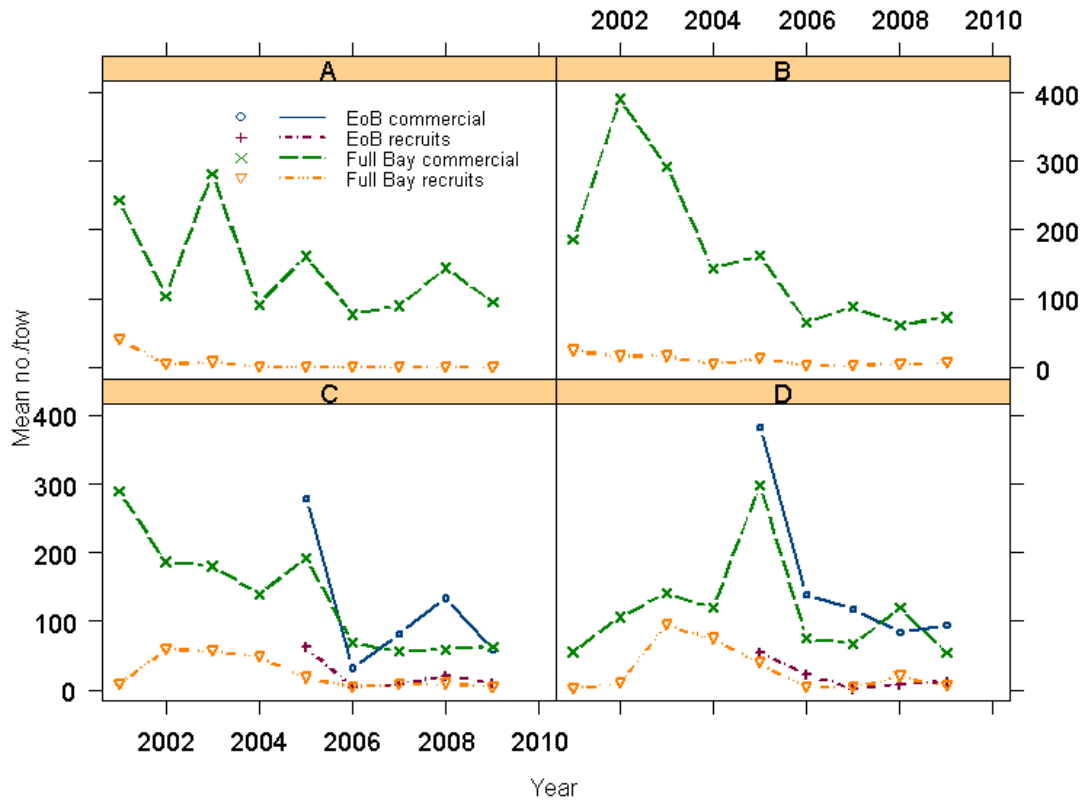
Figure 28. Annual trends of fully recruited (≥100 mm) and recruit (90–99 mm) size classes of estimates of mean number per tow from research surveys by subarea in SFA 29 West. Full Bay commercial and recruits series estimated from F/V Julie Ann Joan (2001–2003, 2005–2009) and F/V Branntelle (2004) tows. East of Baccaro (EoB) commercial and recruits estimated from F/V Overton Bay (2005) and F/V Faith Alone (2006–2009). Geophysical strata used for design.
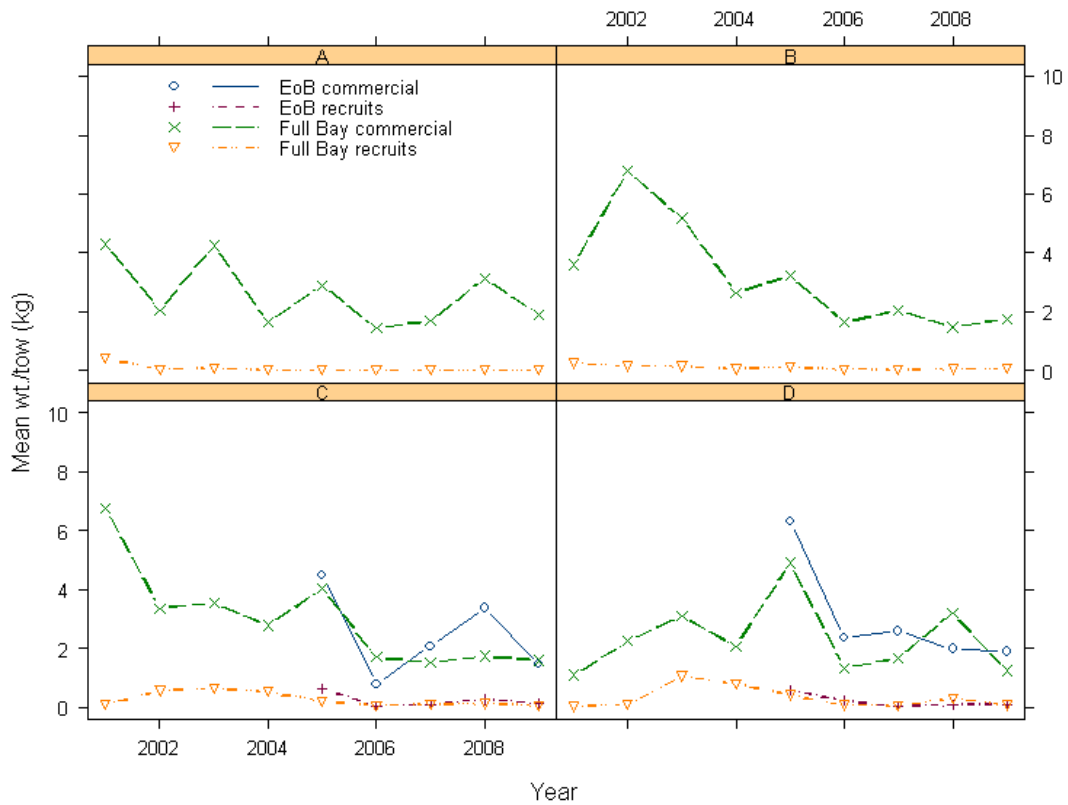
Figure 29. Annual trends of fully recruited (≥100 mm) and recruit (90–99 mm) size classes of estimates of mean weight per tow (meats, kg) from research surveys by subarea in SFA 29 West. Full Bay commercial and recruits series estimated from F/V Julie Ann Joan (2001–2003, 2005–2009) and F/V Branntelle (2004) tows. East of Baccaro (EoB) commercial and recruits estimated from F/V Overton Bay (2005) and F/V Faith Alone (2006–2009). Geophysical strata used for design.
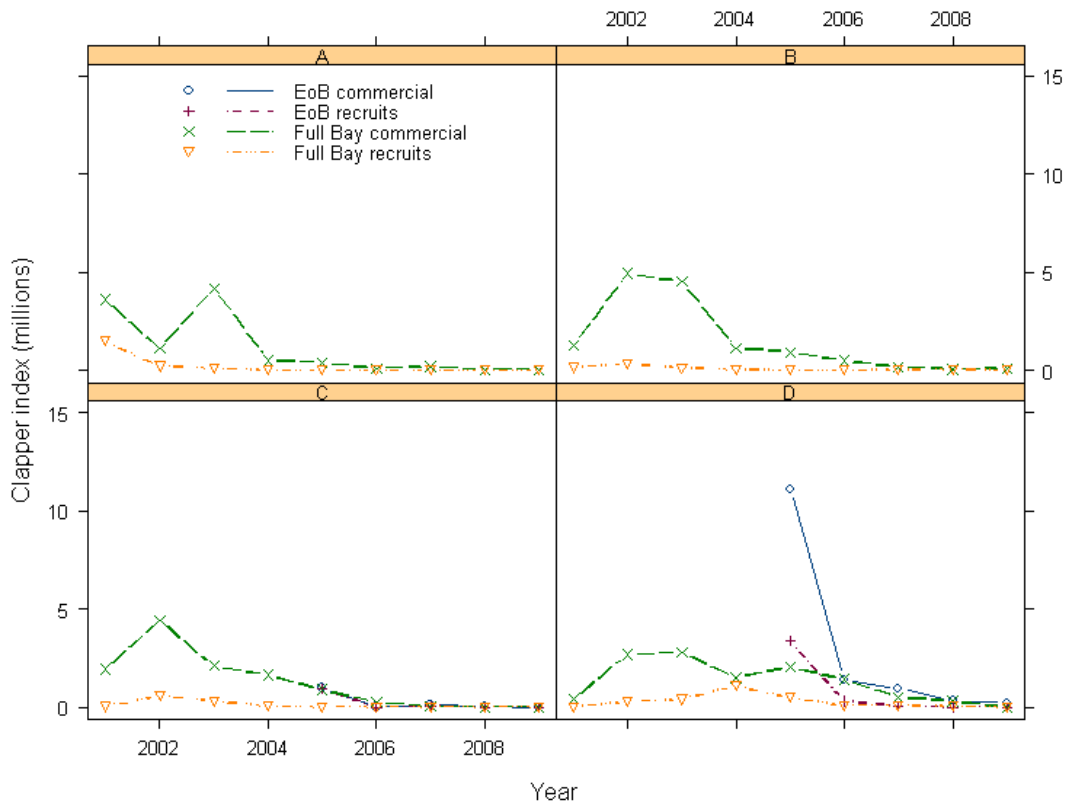
Figure 30. Annual trends of fully recruited (≥100 mm) and recruit (90–99 mm) size classes of estimates of mean number per tow of clappers from research surveys by subarea in SFA 29 West. Full Bay commercial and recruits series estimated from F/V Julie Ann Joan (2001–2003, 2005–2009) and F/V Branntelle (2004) tows. East of Baccaro (EoB) commercial and recruits estimated from F/V Overton Bay (2005) and F/V Faith Alone (2006–2009). Geophysical strata used for design.
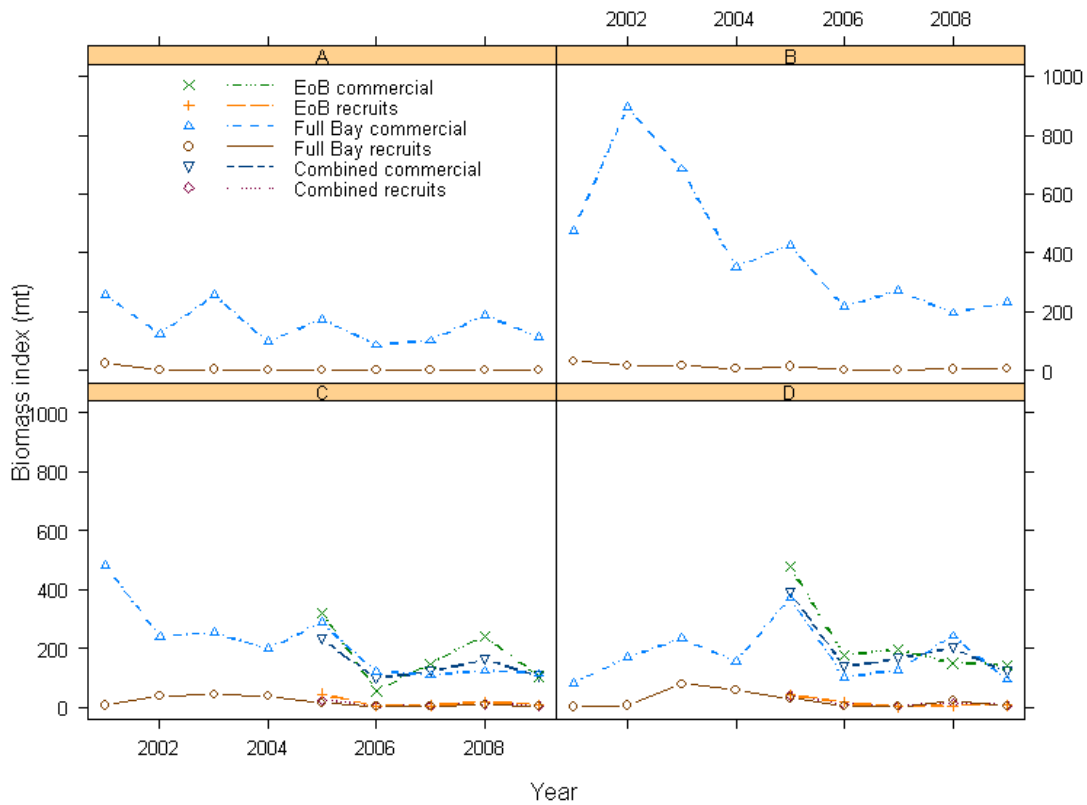
Figure 31. Annual trends of fully recruited (≥100 mm) and recruit (90–99 mm) size classes of estimates of survey biomass indices (meats, mt) from research surveys by subarea in SFA 29 West. Full Bay commercial and recruits series estimated from F/V Julie Ann Joan (2001–2003, 2005–2009) and F/V Branntelle (2004) tows. East of Baccaro (EoB) commercial and recruits estimated from F/V Overton Bay (2005) and F/V Faith Alone (2006–2009). Geophysical strata used for design.
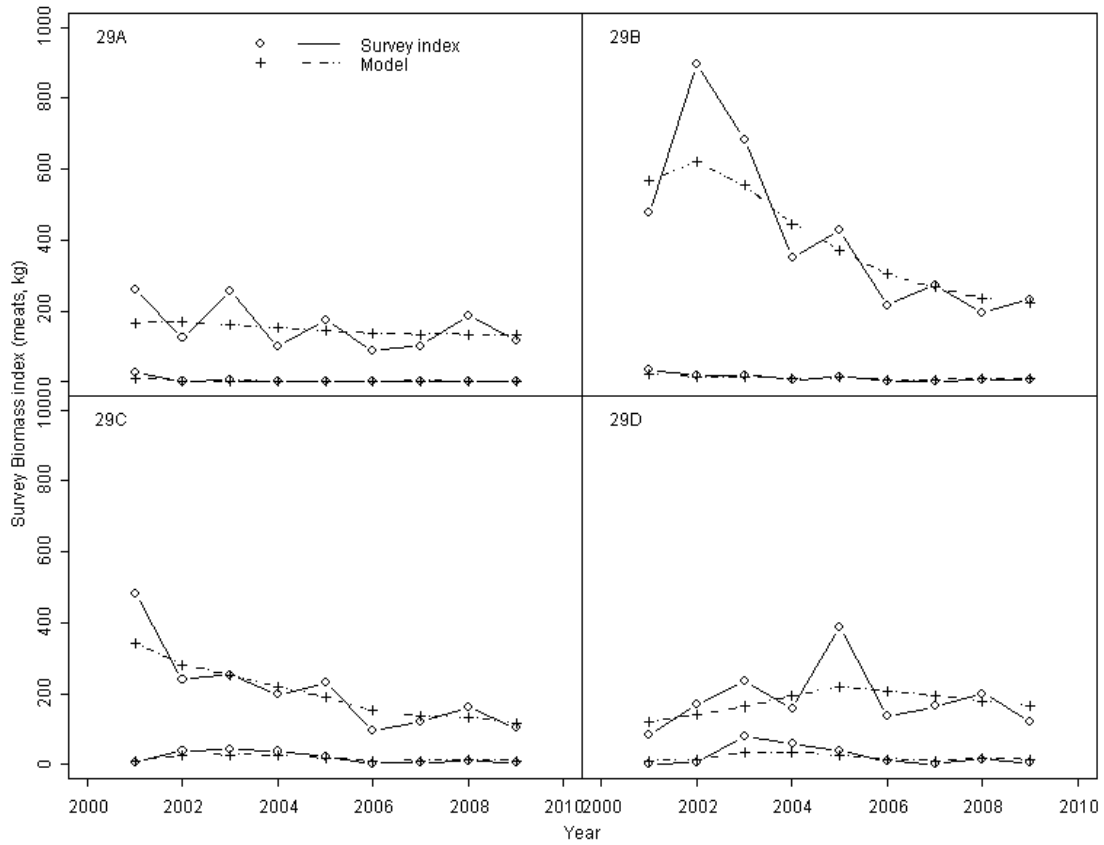
Figure 32. Biomass model fits to survey estimates for commercial and recruitment size scallops by subarea. Model included one term to account for removals due to natural and fishing mortality and increases due to growth.
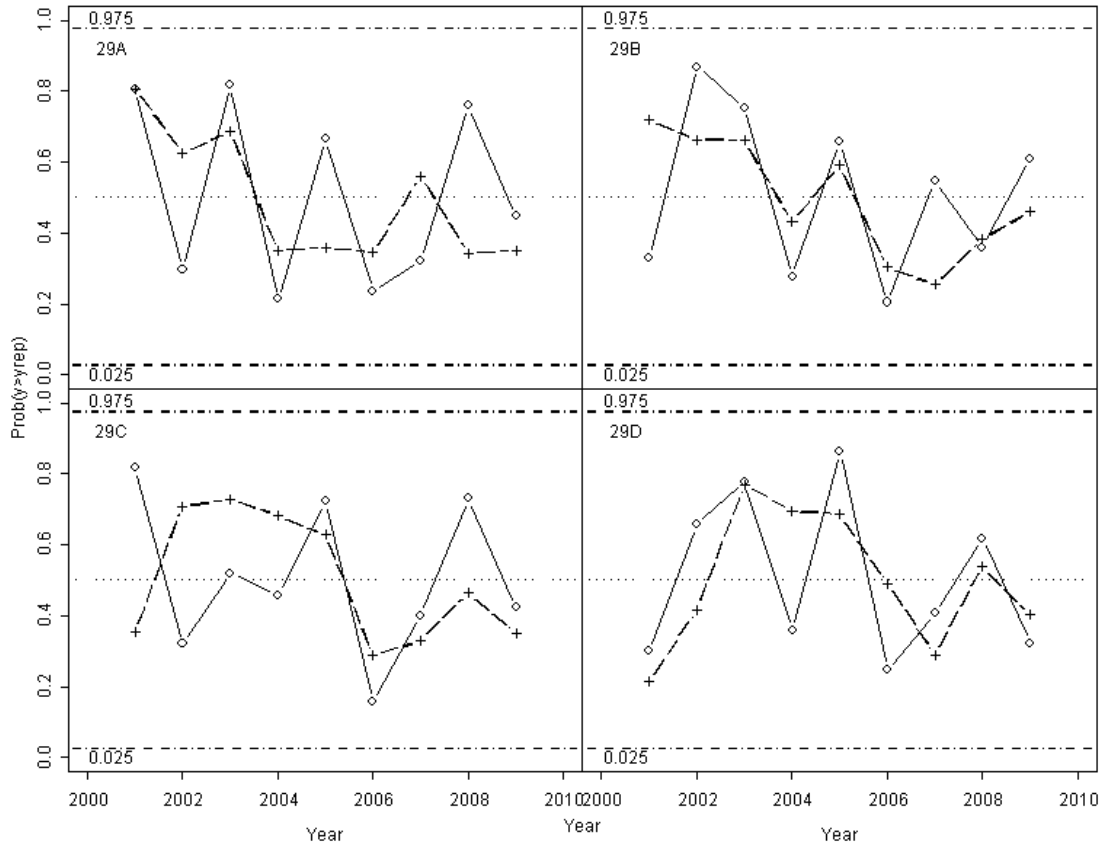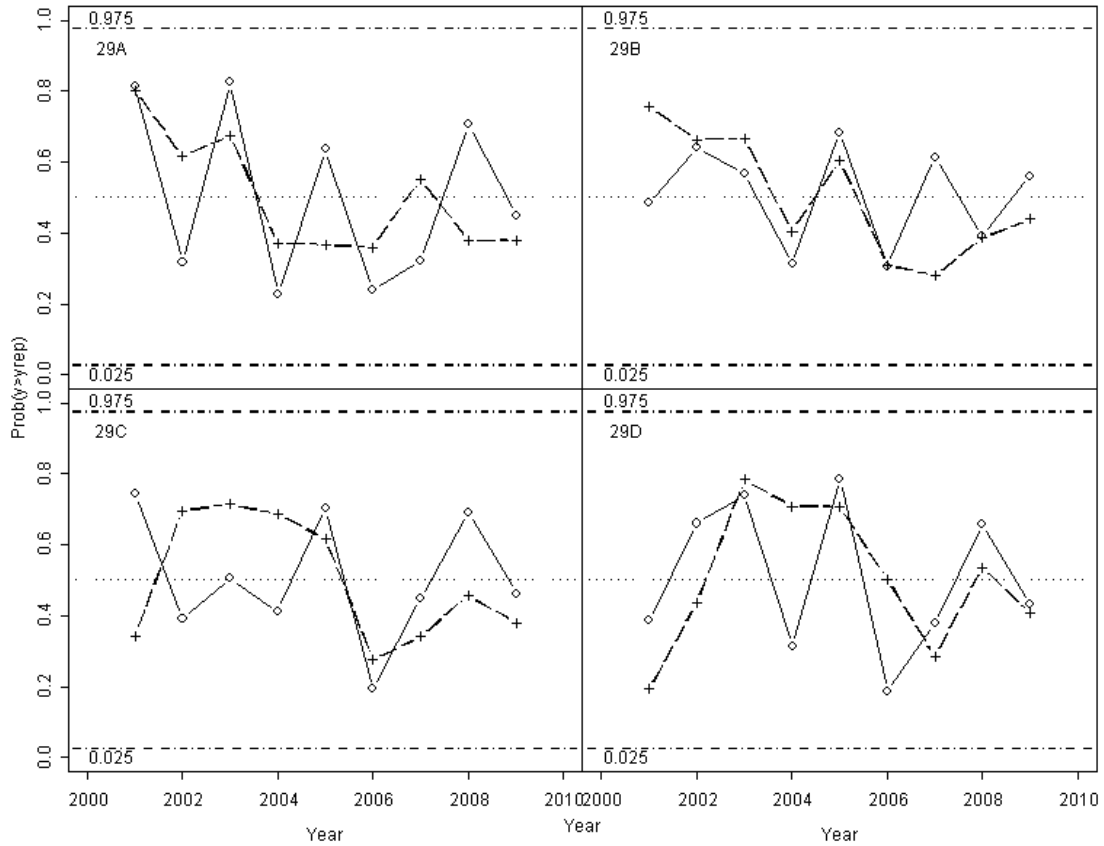
Figure 33. Probability of survey estimate being greater than replicates generated from the posterior predictive distribution from biomass survey model with one term for natural, fishing mortality and growth. Commercial size biomass represented by solid line and recruits by dashed line. Upper (0.975) and lower (0.025) bounds indicated.
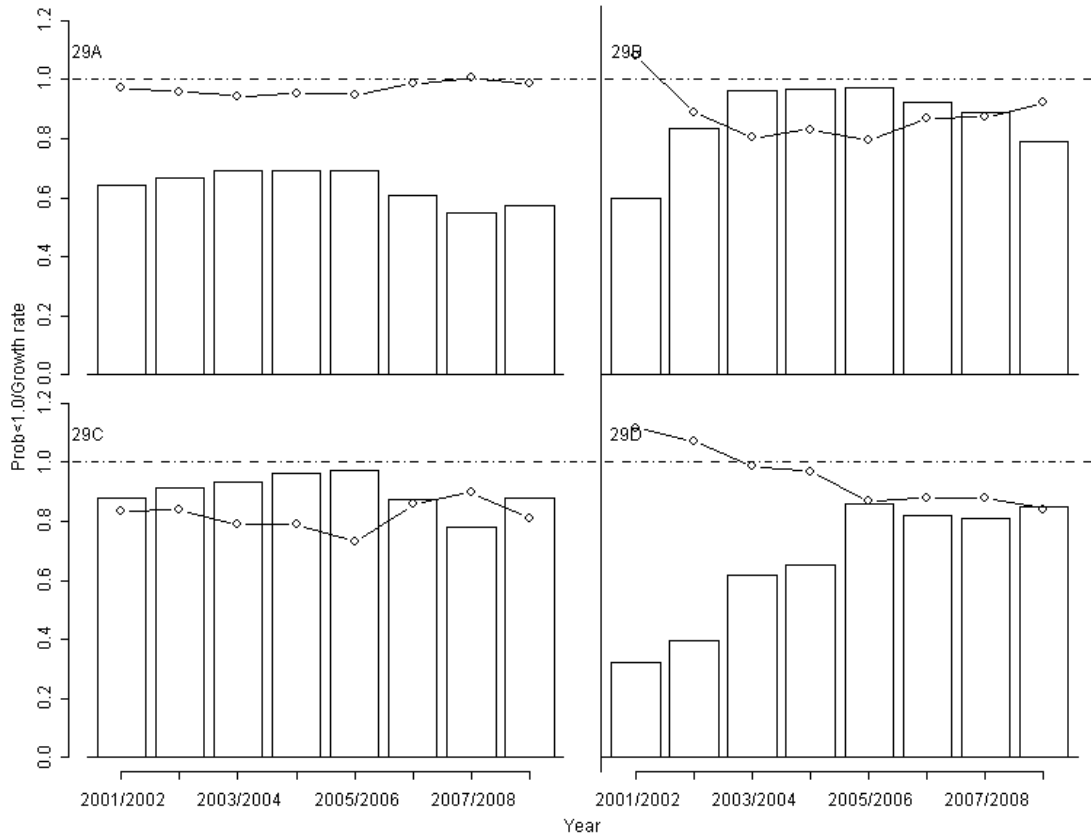
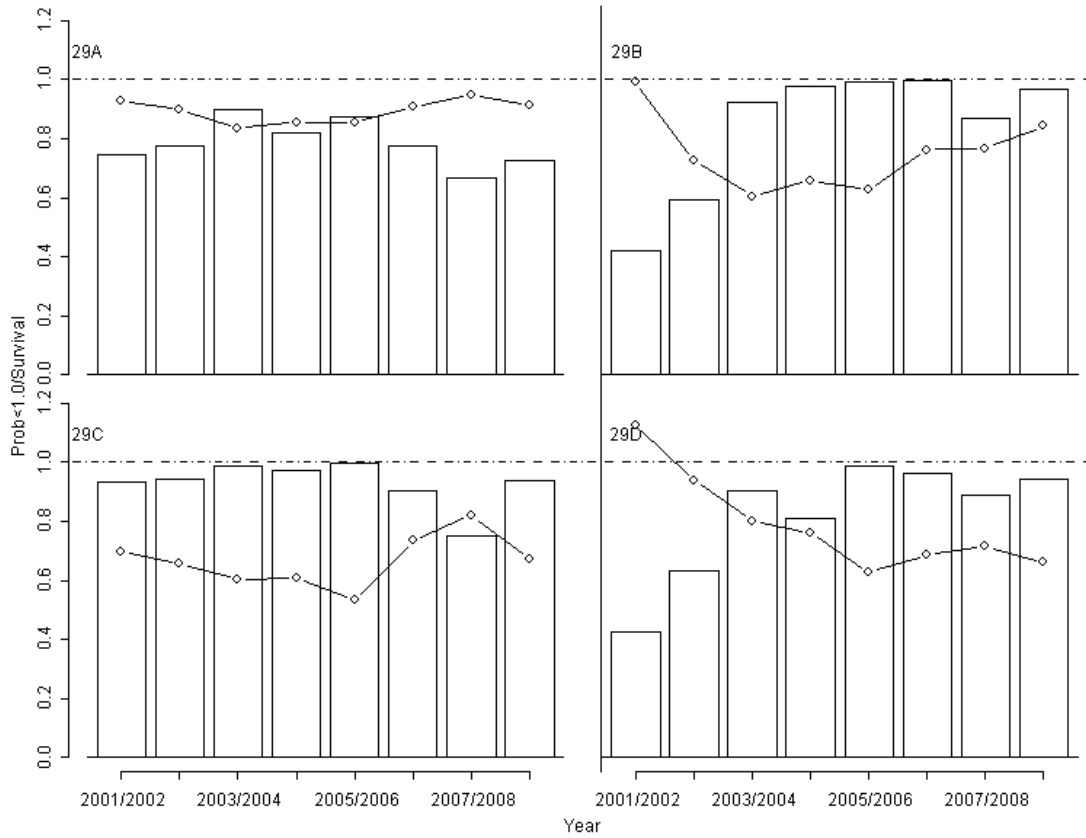*Figure 34. Trend in estimated population growth rate (g_t in text) is represented by solid line. Probability of the population growth rate being less than 1.0 is indicated by the bars.*
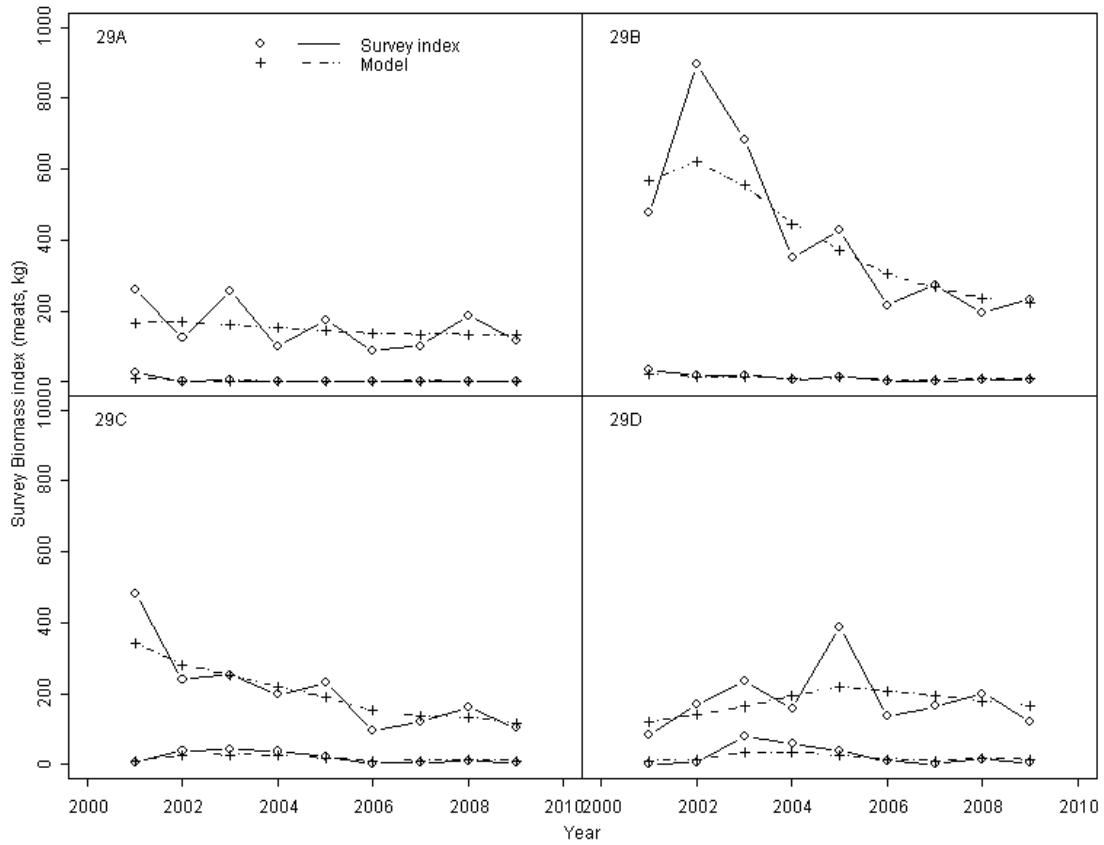
Figure 35. Biomass model fits to survey estimates for commercial and recruitment size scallops by subarea. Model included one term to account for removals due to natural and fishing mortality and a separate term for increases due to growth.

Figure 36. Probability of survey estimate being greater than replicates generated from the posterior predictive distribution from biomass survey model with one term for natural and fishing mortality and a separate term for growth. Commercial size biomass represented by solid line and recruits by dashed line. Upper (0.975) and lower (0.025) bounds indicated.

Figure 37. Trend in estimated population survival rate (g_t in text for separate growth model) is represented by solid line. Probability of the survival rate being less than 1.0 is indicated by the bars.
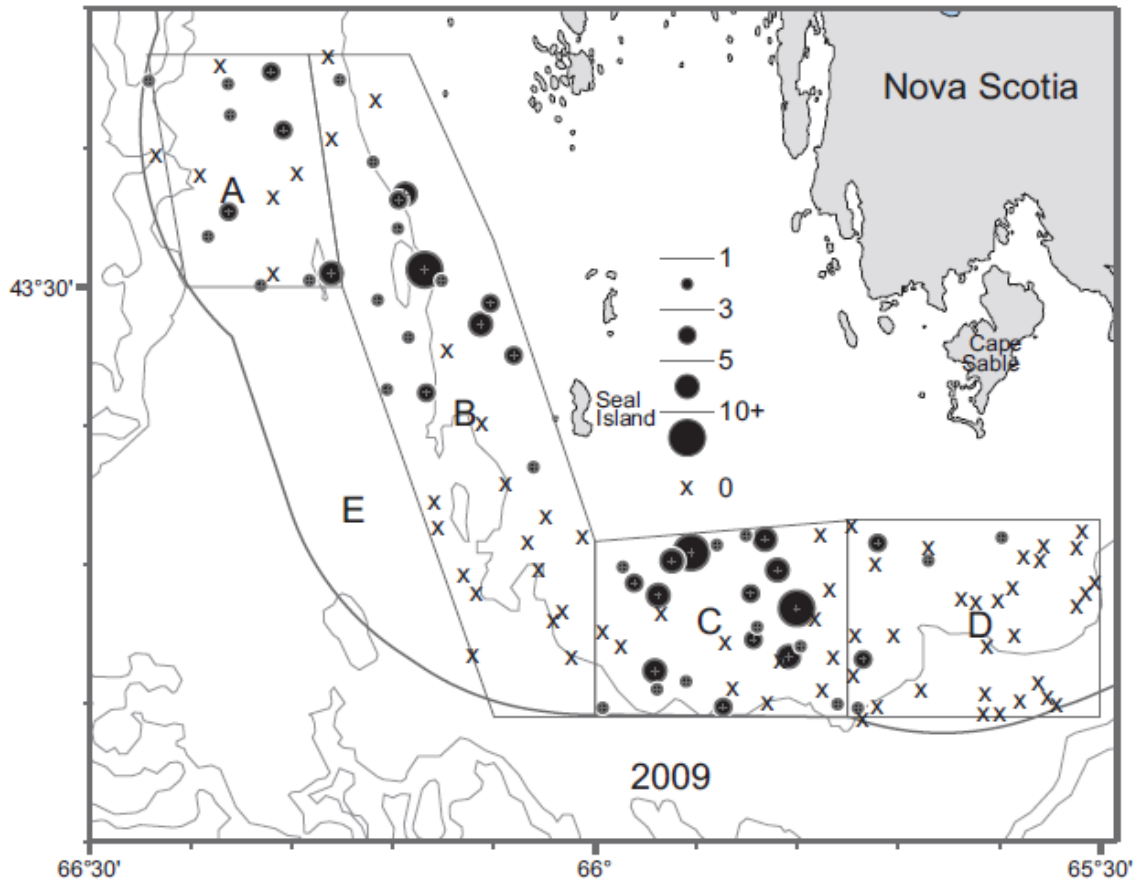
Figure 38. Location and number of lobsters caught in SFA 29 during the 2009 survey. Crosses indicate locations where no lobsters were caught.
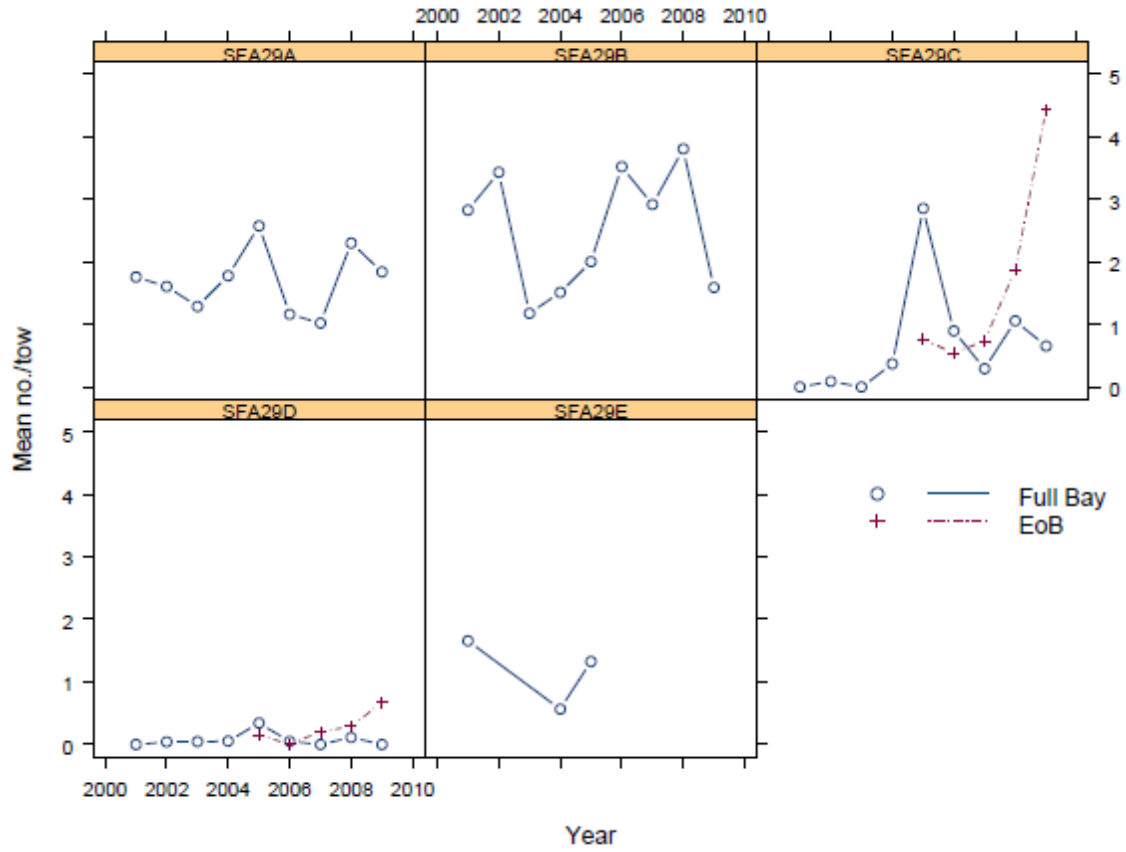
Figure 39. Lobster number per tow from scallop survey. The two series for subareas C and D from 2005–2009 are for the different survey vessels (FB: Full Bay, EoB: East of Baccaro).
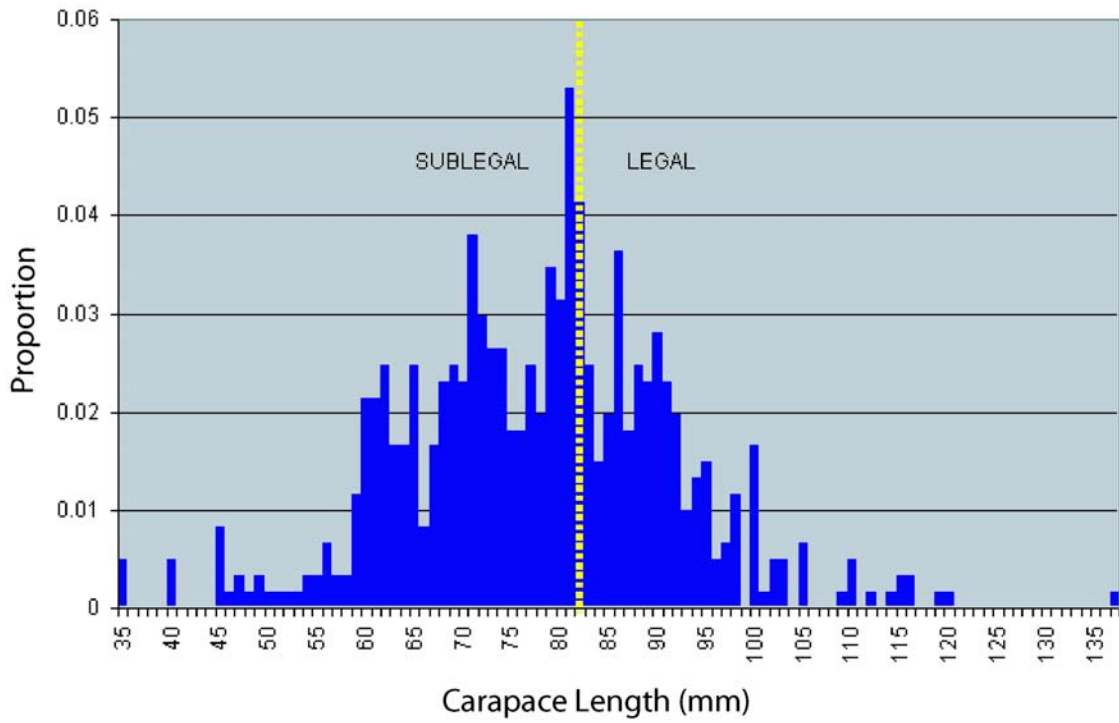
Figure 40. Carapace length frequency for all lobsters recorded by observers in the 2009 SFA 29 scallop fishery of subarea B
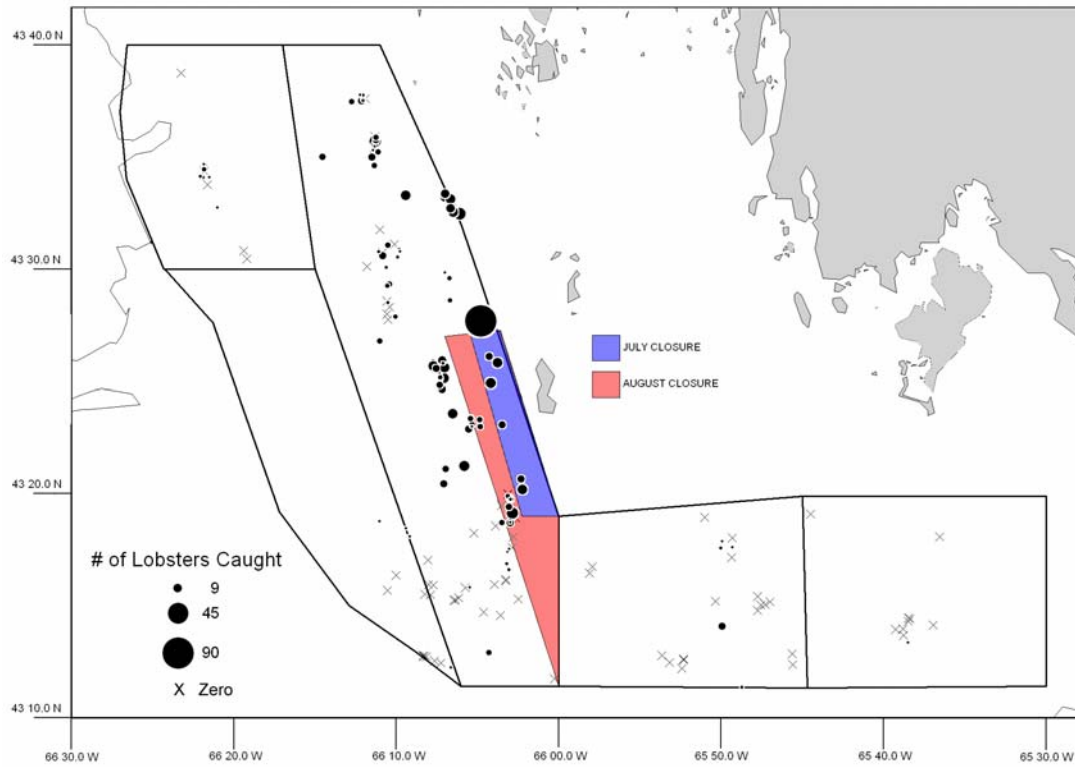
Figure 41a. Location and number of lobsters caught in SFA 29 West during 2008 from observed scallop fishing trips. Crosses indicate locations where no lobsters were captured. Areas closed in subarea B during the fishery due to lobster bycatch are indicated by the two polygons.
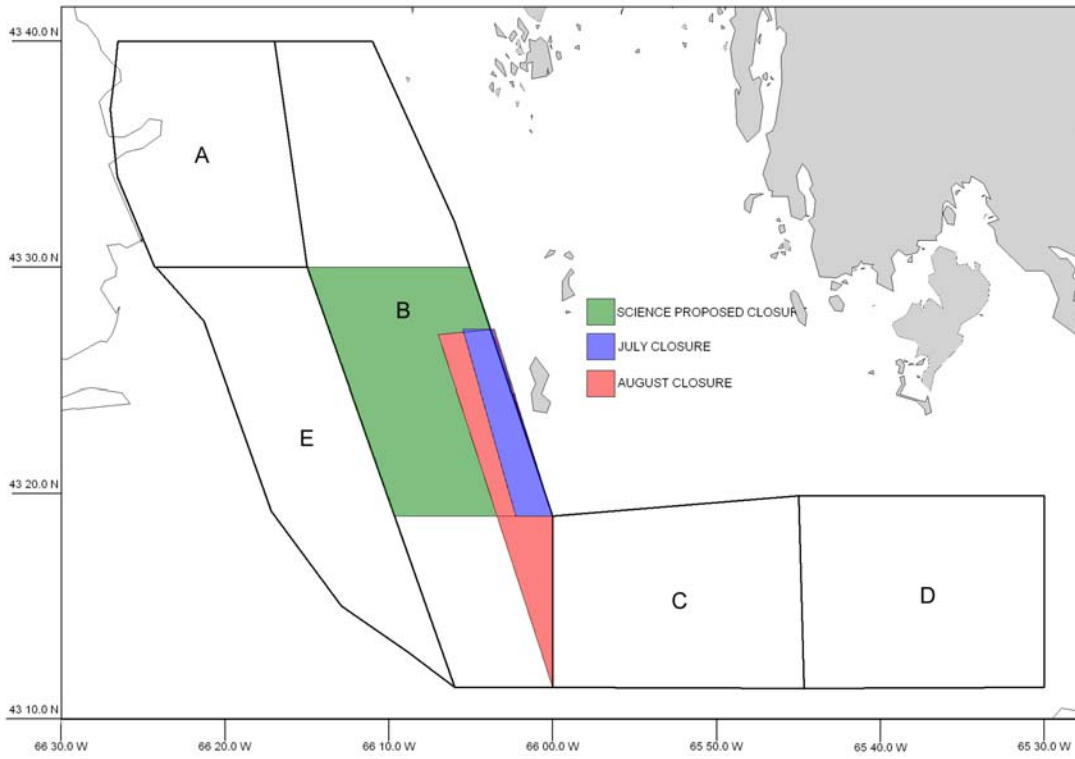
Figure 41b. Proposed and actual areas closed in SFA 29 subarea B during the fishery due to lobster bycatch are indicated by the two polygons.
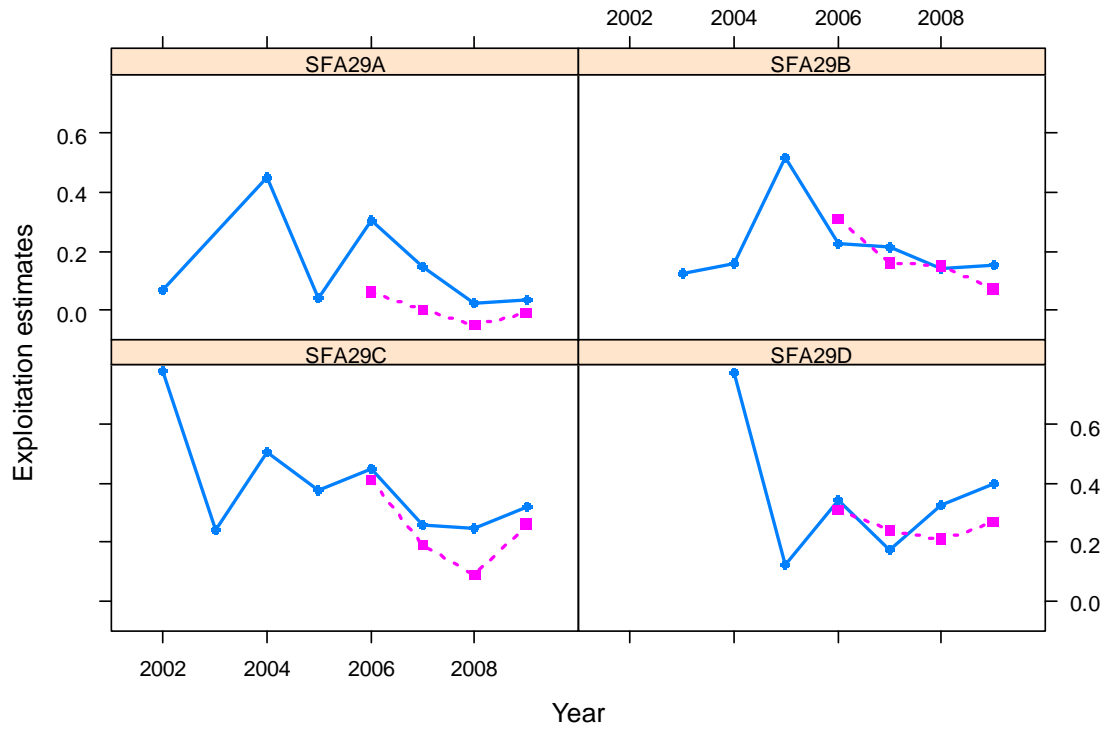
Figure 42. Comparison of exploitation estimates from the depletion method (●) and survey model (■) assuming M = 0.1.