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Scallop Production Areas 4 and 5 in the Bay of Fundy: Stock status update for 1999

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Abstract

This document reports on the stock status of scallops in two scallop production areas (SPA) on the eastern side of the Bay of Fundy that were evaluated in the fall of 1999. In 1998, the fishing season in scallop production area 4 (SPA 4) ran from 22 September to 22 December with total landings of 103 t against a TAC of 120 t. Preliminary reports from the 1999 fishery which opened on 1 October, are that only 32.5 t have been landed as of 13 November compared to 90.7 t landed by this date in 1998. The fishing industry has reported that bad weather has reduced opportunity to fish. A large part of the effort in 1998 was targeted on the deeper waters off of Centreville to Digby Gut which previous research surveys had shown to be areas of high density but low yield. The survey continues to show that the greatest concentration of scallops in SPA 4 were in the deeper water off of Centreville to Digby Gut. However, densities were much reduced compared to previous years. There were no strong signs of recruitment in the survey. Estimates of exploitation rate either from commercial catch rate data or the survey data indicate that fishing mortality has increased by over 50 percent from 1996 to 1998. Forecasts for the year 2000 from the population model using the survey data, suggest that in the absence of fishing, recruitment will not balance the losses due to natural mortality and as a consequence there is no surplus production and the population is in decline. This decline will continue unless recruitment increases in the near future. Estimates of population biomass are uncertain and it is difficult to determine what proportion of the population is being taken by the fishery. In 1996 the area inside of 1 mile from shore in SPA 4 was closed to scallop fishing due to concerns of the lobster fishermen and has remained closed to date. In 1999 commercial fishermen on the Inshore Scallop Advisory Committee proposed that this area be reopened for a limited time during January/February when lobster gear are not in the water. Three exploratory surveys of the different parts of the area have been conducted each year since 1997. None of the surveys detected substantial recruitment. While the survey catch rates were judged to be adequate for fishery operations, the resource may be quite patchy. An exploratory winter fishery for a limited time period with meat weight sampling and real time monitoring of catch-rates may provide needed data on the size composition and extent of scallops in the inshore zone. The 1999 SPA 5 (Annapolis Basin) fishery opened on 2 January and closed 13 January when the quota had been caught. Landings in 1998 and 1999 were double those reported in the previous two years. The mean number per tow from the 1999 survey was higher than that observed for 1998. Meat weights-at-shell height have significantly increased in June 1999 (20 to 30 percent) over those observed in June and December 1998. The combined increase in number per tow and meat weight suggests an increase in survey biomass of 68 percent from 1998 to 1999. An increase in TAC from 10 t to 17 t could be indicated here.

Résumé

Le présent document traite de l'état des stocks de pétoncle dans deux zones de production du pétoncle (ZPP) de l'est de la baie de Fundy qui ont fait l'objet d'une évaluation à l'automne de 1999. En 1998, la saison de pêche dans la zone de production 4 (ZPP 4) a duré du 22 septembre au 22 décembre et les débarquements totaux ont atteint 103 t, le TAC étant fixé à 120 t. Les rapports préliminaires obtenus pour la pêche de 1999, qui a été ouverte le 1er octobre, font état de débarquements n'ayant atteint que 32,5 t, en date du 13 novembre, comparativement à 90,7 t à la même date en 1998. L'industrie de la pêche a signalé que le mauvais temps avait nui aux activités de pêche. Une grande partie de l'effort de 1998 a porté sur les eaux plus profondes allant, au large, de Centreville au chenal de Digby que des relevés de recherche avaient montré être des zones de fortes densités mais de rendements faibles. Les relevés continuent de montrer que les plus importantes concentrations de pétoncles de la ZPP 4 se situent dans ces eaux profondes. Les densités sont cependant de beaucoup inférieures à celles des années antérieures et qu'il n'y a pas d'indice d'un fort recrutement dans ce relevé. Les estimations des taux d'exploitation, obtenues des données des prises commerciales ou des données de relevés, indiquent que la mortalité due à la pêche s'est accrue de plus de 50 % de 1996 à 1998. Les prévisions faites pour l'an 2000 à l'aide du modèle de population et des données des relevés portent à croire qu'en l'absence de pêche, le recrutement n'équilibrera pas les pertes dues à la mortalité naturelle et que, par conséquent, il n'y a pas d'excédent de production et que la population est en déclin. Le déclin se poursuivra à moins d'une hausse prochaine du recrutement. Les estimations de la biomasse de la population sont incertaines et il est difficile de déterminer la proportion de la population prélevée par la pêche. En 1996, la zone située à moins d'un mille de la côte de la ZPP 4 a été fermée à la pêche du pétoncle à cause des préoccupations des pêcheurs de homard et elle est depuis demeurée fermée. En 1999, les pêcheurs membres du comité consultatif de la pêche côtière du pétoncle ont proposé la réouverture de cette zone pendant une période limitée en janvier-février lorsque les engins de pêche du homard ne sont pas à l'eau. Trois relevés exploratoires ont été effectués dans les diverses parties de cette zone à chaque année depuis 1997. Aucun n'a permis de déceler un recrutement appréciable. Les taux de capture des relevés ont été jugés suffisants pour la pratique d'une pêche, mais les concentrations pourraient être passablement dispersées. Une pêche exploratoire d'hiver d'une durée limitée, o le poids des chairs serait déterminé par échantillonnage et les taux de capture contrôlés, en temps réel pourrait permettre d'obtenir les données nécessaires sur la composition par tailles des pétoncles et leur répartition dans la zone côtière. La pêche du pétoncle de 1999 dans la ZPP 5 (bassin Annapolis) a été ouverte le 2 janvier et fermée le 13 janvier suite à l'atteinte du quota. Les débarquements de 1998 et 1999 étaient le double de ceux signalés au cours des deux années précédentes. Le nombre moyen par trait obtenu au cours du relevé de 1999 était supérieur à celui obtenu en 1998. Le poids des chairs par rapport à la hauteur de coquille était accru de faon appréciable en juin 1999 (de 20 à 30 pour cent) par rapport à juin et décembre 1998. L'augmentation combinée du nombre de pétoncles par trait et du poids des chairs porte à croire à une augmentation de la biomasse déterminée par relevé de 68 pour cent entre 1998 et 1999. Il pourrait donc y avoir lieu d'augmenter le TAC de 10 t à 17 t.

Introduction

Total allowable catches (TAC) for the scallop fishery in the Bay of Fundy and approaches have been allocated within seven scallop production areas (SPA) since 1 January 1997 (Fig. 1). Scallop production area 4 is situated off of Digby, Nova Scotia and extends to approximately 8 miles from shore. Prior to 1996, the Digby scallop beds in this area were fished according to seasonal restrictions. The "Inside Fishing Zone" encompassed an area within the current boundaries of SPA 4 that extended 6 miles from shore between Parker's Cove (northeast boundary) and Centreville (southwest boundary). This zone was closed to fishing by regulation from 1 May to 30 September. The remainder of the Digby beds outside of this zone had no seasonal restrictions and were referred to as being in the "Outside Zone". In 1987, the Inside Fishing zone was extended to 8 nautical miles from shore to protect small scallops. In 1992, the Inside Zone returned to being the area within 6 miles from shore. The Inside Fishing Zone was closed in 1995 for a whole year to protect broodstock and pre-recruit scallops. A limited fishery was conducted in a portion of this zone from Digby Gut to Parker's Cove, under a dockside monitoring condition from 15 November to 15 December in 1996. The meat count (number of adductor muscles per 500 g) was set at 40 for the 1996 fishery. Fishing also occurred in the area from 6 to 8 miles from the shore until the establishment of the 8 mile limit for SPA 4 on 1 January 1997. The quota for the 1997 fishery in SPA 4 was 100 mt (meats) with a meat count of 33/500 g. This area is fished by the Full Bay fleet license holders only under an ITQ program.

Scallop landings off of Digby, Nova Scotia have varied over the last decade. A strong recruitment pulse, first observed in 1986 and 1987 as 2 year old animals, contributed to unprecedented high landings in 1988 through to 1991. Although scallop abundance increased in many parts of the Bay of Fundy during this time, the greatest concentrations of scallops was found in the former Inside Fishing Zone. These beds have been fished down from 1993 to 1996 and closures have been implemented a number of times.

The last evaluation of SPA 4 (Smith and Lundy 1998) reported that much of the recruited biomass and population numbers were found in the low yield deep water areas and that there was little sign of recruitment in the near future. The 1998 TAC of 120 t (meats) was expected to correspond to a fishing mortality of around 0.22 (Smith and Lundy 1998).

Modern scallop fishing began in Annapolis Basin (SPA 5) in 1920 and currently operates as a short-term winter fishery due to restrictions concerning the lobster fishery in the area (Kenchington and Lundy 1994). This area is also fished by the Full Bay fleet license holders only under an ITQ program.

SPA 5 was reviewed by Kenchington et al. (1997) and the expectations given in DFO (1998) were that strong recruitment detected by fishermen in 1997 would enter the fishery in 1998 and 1999.

In this document we evaluate the stock status for scallops in SPA 4 and 5 using information from the commercial fishery up to and including 1999 as well as the data from recent research surveys.

Commercial Fishery

SPA 4

In 1998, the scallop fishery in SPA 4 occurred from 22 September to 22 December with a meat count restriction of 33 meats per 500 g[1]. The TAC was set at 120 t but only 103 t were landed. A total of 65 of the 99 vessels licensed to fish in this area participated in the the 1998 fishery. While not all of the licensed vessels fished in 1998, quota transfers between vessels did occur which resulted in all of the quota being available for fishing. Preliminary reports from the 1999 fishery which opened on 1 October are that only 32.5 t have been landed by 13 November compared to 90.7 t landed by this date last year. The fishing industry has reported that bad weather has reduced the opportunity to fish.

Scallop Production Area 4 Landings (metric tons meats)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999[2]
Total	678.7	318.4	244.2	162.7	94.8	71.2	116.1	103	32.5
Kg/h	28.55	18.75	14.73	11.84	10.60	8.89	12.81	9.41	8.92
TAC							100	120	120

[2] Preliminary to 13 November, 1999.

The catch rate declined in 1998 from the previous year and was the second lowest in the series (Table 1). The 1999 catch rate appears to have declined as well. While this estimate is preliminary, catch rates have tended to be highest at the beginning of the fishing season and decline as the season progresses suggesting that the final 1999 estimate will be end up lower than that observed in 1998.

A large part of the 1998 catch was taken in the deeper water portion of the southwestern area (Fig. 2: Upper Panel) of the SPA (off of Centreville to Gulliver's Head). This area was identified as having the highest densities and biomass in the 1998 research survey (Smith and Lundy 1998). Plotted locations of the commercial catch-per-unit effort (CPUE) indicated very few high densities areas (Fig. 2: Lower Panel). Fishing effort was concentrated in the deeper water areas off of Gulliver's Head to Digby Gut (Fig. 3) in the same area where the 1998 surveys had identified high densities of scallops (Smith and Lundy 1998).

Currently the only information on size composition of the catch comes from fishermen voluntarily allowing departmental contractors to sample their catch. While blending of different size meats does occur, it appears from the samples collected that the regulated meat count of 40/500 g was being respected (Table 2, Fig. 4). However, few vessels participate and sampling intensity is quite low (Table 2).

SPA 5

The 1999 fishery opened on 1 January with the official closing data given as 13 February. The fishery was closed on 13 January because the TAC was caught.

[1]except an area 1 mile from shore which is closed to scallop fishing due to the lobster fishery.

Scallop Production Area 5 Landings (metric tons meats)

Year	1994	1995	1996	1997	1998	1999[3]
Total	4.2	13.8	4.9	5.0	11.4	11.9
Kg/h	14.90	13.98	10.59	6.47	12.61	11.50
TAC				25	10	10

[3] Preliminary.

Size composition estimates from the departmental voluntary port sampling program suggest that meat count was within the regulated level of 40/500 g (Table 3).

Research Surveys

SPA 4

Annual stock surveys are conducted every June in SPA 4 to monitor stock abundance and detect incoming recruitment. Since 1991, the stratified random design has been used with strata defined to correspond to historical patterns of fishing effort and named according to adjacent landmarks.

Surveys are conducted using the research vessel J.L. Hart. The four-gang dredge gear configuration has remained unchanged throughout the survey series (Kenchington et al. 1997). As in previous surveys, two of the four dredges were lined with 38 mm polypropylene stretch mesh. Catches in the lined gear were used to estimate the abundance of scallops with shell height less than 80 mm while the catches from the unlined gear were used to estimate the abundance of scallops with shell heights greater than or equal to 80 mm. Catches of scallops with shell heights less than 40 mm are thought to give qualitative indications of abundance only, due to uncertainties about catchability of the small animals. All catches are prorated to the expected catch of a seven-gang Digby gear rig and numbers are standardized to a standard tow length of 800 m.

Abundance

The estimated mean number for each stratum for pre-recruits (55 to 79 mm shell height) and the recruited animals (80+ mm shell height) are presented in Table 4. The designation of 55 to 79 mm animals as pre-recruit was determined in an analysis of spatial patterns of growth by Smith et al. (1999a). Pre-recruits are at very low densities throughout the management area with the highest concentrations occurring in the deeper areas along the northern edge (Fig. 5). The higher densities of the recruited animals continue to be found in the Centreville to Gulliver's Head strata and generally occur in the deeper water in these strata (Fig. 6).

Trends in shell height composition in the survey since 1991 are presented in Figs. 7 and 8. Apart from a fairly strong recruitment pulse, first detected as 20 to 40 mm in shell height in 1995, recruitment to this fishery in 1990's has been at low levels. The effect of the 1998 fishery is quite pronounced in the 1999 survey with the recruited size classes cropped down to below the average densities for this area (Fig. 8).

Smith et al. (1999a) demonstrated that growth and hence yield characteristics vary spatially with the main determinant being depth. While growth rates decreased with increasing depth, a very distinctive change in growth rates was found at around 90 metres. Assuming that the fishermen will concentrate on the higher yield shallower areas first and then move into the deeper lower yield areas when the shallow areas become depleted, survey indices of abundance were calculated separately for those areas above and below 90 m depth. Both depth ranges exhibit overall declining trends (Fig. 9) over time with some augmentation from the recruitment in 1997. This recruitment was more pronounced in the deeper water as has been reported by Smith and Lundy (1998) and Kenchington et al. (1997) (Fig. 9: Right Panel). The decline from 1998 to 1999 was also more pronounced again coinciding with the larger portion of the catch coming from the Gulliver's Head to Digby Gut area (see Fig. 2).

In past reports (Kenchington et al. 1997, Smith and Lundy 1998), relationships between log(meat weight) and log(shell heights) had been derived for each stratum and depth zones within stratum. This year the analysis was conducted incorporating a depth relationship only as per the findings of Smith et al. (1999a)[4]. The residuals from fitting one linear regression model to all of the observations indicate a very strong trend in depth with a prominent breakpoint in the trend at around 94 metres (Fig. 14: Left panel). The trend in the residuals was detected using a locally weighted regression or loess curve (Cleveland and Devlin 1988). Addition of a natural spline relationship for depth with a knot at 94 metres removes the trend from the residuals (Fig. 14: right panel). The model fitting results and parameter estimates are presented in Table 5a. The natural spline terms are essentially a depth correction to the intercept term. Predictions from model II illustrate the lower yield that can be expected at the deeper depths (table 6). Note that these meat weights are specific to June. Roddick et al. (1994) report that meat weights can increase by 23 percent between June and the fall. A comparison of meat weights-at-shell height between 1998 and 1999 indicates that there has been a small increase in 1999 (Table 6b).

Previously, (e.g., Smith and Lundy 1998) the estimated biomass of meats had been calculated for the survey each year by using the regression model developed in Kenchington et al. (1997). Pending reanalysis of the meat weight/shell height data to deal with issues raised in Smith et al. (1999a), we will only present biomass estimates for those years in which meat weight data was actually collected, that is, 1996 to 1999 inclusive (Fig. 10). Biomass shows similar patterns over time as the numbers do in Fig. 9 with levels being the lowest in 1999.

Fishermen have reported that the branching bryozoan commonly referred to as lemonweed (*Flustra foliacea*) has become more widespread in SPA 4 in recent years. This trend of increasing distribution of the lemonweed was also reported by Fuller et al. (1998) and Magee et al. (1999). Our own observations of the presence of lemonweed in the survey catches confirms all of the these reports and show that the bryozoan has become increasingly widespread in SPA 4 since 1996 (Figs. 11 and 12). Fishermen have reported that the byrozoan fouls commercial dredges but these animals have less of an impact on the survey dredge because of the shorter tow duration for survey tows.

Industry participants at the peer review of this stock assessment suggested that the lemonweed may be behind the declining trends that we reported for the survey data. No specific mechanism was put forward but suggestions raised in discussion ranged from the fact

[4]Note: Smith et al. (1999a) corrected depths for the tidal range. Depths used in the analysis presented here have not been so corrected.

that scallops may be in the lemonweed but inaccessible to survey gear to the actual exclusion of scallops by the lemonweed. The mean number of scallops per tow from survey tows made shallower than 90 m for tows with and without lemonweed present were compared (Fig. 13). The differences between the means for tows with lemonweed present or absent have decreased as the distribution of the lemonweed has increased, however the trends, especially for the recruited scallops are very similar and still indicate declines in the recent years.

In addition to the standard survey in 1999 an experiment in adaptive allocation of tows to strata was conducted. Adaptive allocation is a technique of increasing the precision of survey estimates by using the observations made during the current survey to add additional tows to the more variable strata. This method was developed by Thompson and Seber (1996) and has been successfully used in the Georges Bank scallop survey (Robert et al. 1999). In our application 86 tows were randomly allocated to strata with the tows being allocated in proportion to densities observed in previous surveys (first phase number of tows in Table 7). After the 86 tows were completed an additional 3 tows were added to those strata where the mean number per tow was greater than 40. The mean number and variance estimates given in the Second Phase columns of Table 7 are for the first and second phases combined using the unbiased Rao-Blackwell estimators developed by Thompson and Seber (1996). Overall there was some reduction in the variance of the mean (11.50 versus 13.70). Further work is planned on refining the decision rule for additional sampling and allocating the number of tows between the first and second phase to increase the benefits from this approach.

Inshore surveys in SPA 4

The annual survey of SPA 4 does not include areas within 2 miles of the Nova Scotia shoreline. On the 11 September 1997 the first survey of the 0 to 2 mile area was conducted with the F/V **Nova Delight** (owner: Mitchell Longmire). A total of 20 tows (19 successful) were allocated to the 0 to 2 mile portions of the strata used in the June survey. This survey was conducted according to the procedures outlined earlier for the annual June survey.

A survey of this area (20 tows) was also completed on 7 October 1998 using the same approach with the F/V **Ryan Royale** (owner: Eugene Oliver). There was very little sign of recruitment in this survey similar to the previous year (Tables 8 and 9). However, while the overall estimates of post-recruit animals were similar between the two years catches were much lower in the Digby Gut stratum and each adjacent stratum in 1998 than in 1997.

In 1996 the area inside of 1 mile from shore was closed to scallop fishing due to concerns of the lobster fishermen and has remained closed to date. In 1999 commercial fishermen members of ISAC (Inshore Scallop Advisory Committee) proposed that this area be reopened. A survey of this area (41 tows) was conducted on 9–10 September with the F/V **Julie Ann Joan** (owner: Kevin Ross). The locations of the tows were determined primarily by the owner predominantly in locations of historical fishing throughout the area (Sandy Cove to Parker's Cove) (Fig. 15). The mean number per tow increased dramatically from that observed in 1997 and 1998 surveys but this may be attributed to the sampling design and increased sampling intensity (Table 9). However, the catch rates (Fig. 16) were relatively good when compared with other commercial fishing areas and the catch was predominantly large, older animals with high meat yields (Fig. 17).

SPA 5

The Annapolis Basin has been surveyed in June 1998 and 1999 as part of the annual survey of the Bay of Fundy. Stations were randomly allocated within the historical fishing areas in the Basin and standard survey protocols were followed.

Figures 18 and 19 illustrate the spatial distribution of the pre and post-recruits respectively. While there was little change in the densities of pre-recruits from 1998 to 1999, there was an increase of approximately 21 percent in the numbers per tow of recruited animals (Table 10). A comparison of mean number per tow at shell height between the two years shows some cropping down of animals 85 mm and greater but overall the recruited population exhibits a wide range of shell height sizes (Fig. 20).

Fishery representatives on ISAC requested an increase to the 1999 TAC of 10 mt that had been allocated to SPA 5. An additional survey of this area was conducted on 17 December 1998 on the F/V **Brannetelle** (owner: Vance Hazelton) using the same randomized survey design as the June 1998 survey. Analysis of the population biomass from this survey did not support a possible TAC increase for the 1999 fishery.

A comparison of the relative shell height frequencies from the three surveys suggests that the January 1999 fishery did not have a detrimental effect on the size composition (Fig. 21).

Regressions models were fit to the log(meat weight)/log(shell height) data from all three surveys. Plots of residuals did not show any relationship with depth (Fig. 22). An analysis of covariance indicates that the parameter estimates (Table 11a) from all three surveys are significantly different. While weights at the same shell heights do not differ by a large amount between June and December in 1998, there was an appreciably larger increase in weight in June 1999 over the previous two surveys.

Stock Status

SPA 4

Exploitation rate was estimated from the commercial catch rate data using a Leslie depletion estimator (p. 150, Ricker 1975). This procedure assumes a relationship between fishing success or catch rate (CPUE) and catch already taken. If stock size is proportional to CPUE then stock size can be estimated by the following relationship:

$$\frac{C_t}{E_t} = qN_t \tag{1}$$

where C_t is catch during the time interval t, E_t is the effort during the time interval, q is the catchability coefficient or the proportion of the population caught by one unit of effort, and N_t is the population numbers at time t.

Stock size at any time t is the original population minus the catch up to the time interval

$$N_t = N_0 - K_t \tag{2}$$

where N_0 is the original population and K_t is the cumulative catch prior to the time interval.

Substituting equation 2 into 1 gives the following relationship.

$$\frac{C_t}{E_t} = qN_0 - qK_t \tag{3}$$

This is a linear regression model with the slope equal to q and intercept qN_0. The dependent variable is C_t/E_t, and the independent variable is the cumulative catch K_t.

Dividing the intercept by the slope estimates the population numbers. Exploitation rate can then be estimated by dividing the catch by the population estimate.

Instantaneous fishing mortality is calculated as:

$$F = -\ln(1-h)$$

where h is the exploitation rate calculated as C_{total}/N_0 (p. 352, Hilborn and Walters 1992).

The assumptions of this method for estimating population size are (Ricker 1975, Hilborn and Walters 1992, Miller and Mohn 1993):

1. Fishing effort is uniformly distributed over the area occupied by the stock.

2. The population is closed and has no movement in or out and no natural mortality during the fishery.

3. Landings and effort are reported accurately.

4. Catchability of the fished population is constant over a fishing season.

Catch and effort data used to derive the exploitation rate was derived from logbooks. Location of fishing was provided for the first tow of each day during a fishing trip. The data selected for analysis of SPA 4 consisted of all logbook reports fishing within the designated coordinates during the dates that corresponded to the fishing seasons.

Effort data was estimated using data supplied by fishery logbooks as the number of tows × average time per tow.

The effort data was reported on a daily basis while catch was recorded for each trip. As a result, CPUE and catch data were aggregated on a trip basis. The day associated with catch and CPUE was the last day of each trip. Thus, catch and effort were summed over all boats according to last day of each trip. The day associated with cumulative catch was the last day of each trip and CPUE was estimated as:

$$\sum_{b,d} \text{catch}_{b,d} / \sum_{b,d} \text{effort}_{b,d}, \tag{4}$$

where b refers to all of the boats that finished a trip on a given day, d.

Only catch associated with effort data was used to estimate CPUE but cumulative catch was based on all reported logbook catches.

Numbers in the catch for each trip were estimated by:

$$\text{catch}_{b,d}/\text{mean weight}_w \tag{5}$$

where b and d are defined as above and w is the week in which the catch occurred as determined from the last day of the fishing trip.

The mean weight of scallop meats in the catch for each week was estimated using port sampling data. Port sampling data consisted of two sub-samples of 500 g each from each boat sampled. These samples were tested to determine if there were significant differences ($p < 0.01$) between the sub-samples for each sampling day. There were no significant differences and the sub-samples were combined for each sampling day. The samples were then matched to the boat and trip by comparing the reported sampling date and boat to the last date of the trips for each boat. Occasionally, the reported sampling date was one to a few days later than the last day of the trip for the indicated boat. In these cases, the sample was matched with the trip whose date ended just before the reported sample date. In other cases, the boat providing the sample was not identified. Dates for these samples were left unaltered from the reported date. Weekly mean scallop meat weights were estimated by determining the mean weight of each sample and calculating the weighted weekly mean weight with the trip catch associated with each sample as the weight. In cases where boats were not identified the mean catch for the week was used as the weighting factor (Tables 12–14).

Numbers in the catch and CPUE by numbers for each end of trip day were obtained by dividing these estimates by the mean scallop weight for the week in which these days occurred as described above.

Data for the regression model used to estimate population numbers and exploitation rates were CPUE (numbers/hour) and catch in numbers by date of last trip (Table 15). Influential data points were identified by large residuals. All regression procedures were done using SAS `PROC REG` (SAS 1999).

All regressions were significant ($p < 0.01$) except for 1996. The 1996 regression was significant with the one influential point removed.

Exploitation rates for significant relationships varied from 35% to 50%, corresponding to instantaneous fishing mortalities (F) of 0.40 to 0.70 (Fig. 23,Table 15). These results indicate that exploitation rates and F values are extremely high for this fishery.

Violation of the assumptions identified above will certainly affect the estimates of population size and exploitation rate. Our purpose was to estimate exploitation rate and evaluate management plan effectiveness in changing the exploitation rate from one year to the next. As a result, violation of some of the assumptions will not affect our conclusions to the same extent that they would have if our purpose was primarily to estimate population numbers. We examine each of the assumptions to determine the possible effects on the results.

The assumption (1) that fishing effort is uniformly distributed over the area occupied by the stock was not met by these fisheries in all years. As noted earlier the 1996 fishery was restricted to a smaller portion of the area within 6 miles. In 1997, the fishery was mainly concentrated in the area from Digby to Gulliver's Head (Smith and Lundy 1998). While the 1998 fishery was somewhat more widespread in location, effort was concentrated in the deeper water areas off of Gulliver's Head and Digby Gut (Fig. 3). The immediate impact of violating this assumption is that the population sizes and hence the exploitation rates estimated here apply to the area most heavily fished and not to the whole SPA.

The assumption (2) that the population is closed and has no movement in or out and no natural mortality occurred during the fishery is a reasonable assumption. The fishery is of short duration and this does not allow sufficient time for growth of small animals that were unavailable at the beginning of the season to become available during the fishing season.

Similarly, there is likely to be little or no movement of scallops into or outside of the fishing area over these short time periods.

The assumption (3) that landings and effort are reported accurately has a major effect on our estimate of population numbers but not on exploitation rate. If for example there is appreciable under-reporting of catch then we would be under-estimating population size. If we had evidence that catches should be double what they were and we then add these into the cumulative catches by day then we would obtain a much higher population size. Provided the reported CPUE was equal to the unreported CPUE and that the un-reported and reported catches were equally distributed in time, then these factors would not affect the estimates of exploitation rate.

Violation of assumption (4) that catchability (q) of the fished population is constant over a fishing season is probably the most serious source of concern. Changes in catchability may occur if the most vulnerable animals (those with the highest q) are caught first. This tendency has the effect of producing population estimates that are too low. Alternatively, the presence in the latter part of the fishery of less vulnerable animals or a reservoir of uncatchable animals would lower q and produce higher population estimates (Hilborn and Walters 1992).

Miller and Mohn (1993) examined the effect of a stepped decrease in q from 0.12 to 0.08 and a gradual decrease in q from 0.15 to 0.06 over a simulated 10 week season and found that this resulted in the true population size being underestimated by 21 to 26 percent.

In the SPA 4 scallop fishery, all areas of the fishing area are vulnerable to the gear and there is unlikely to be a large reservoir of unharvestable animals. There is unlikely to be major changes in temperature or activity of animals over the lengths of these fishing seasons that would cause a major violation of the assumption of constant catchability. If we are willing to make the assumption that these factors might be constant from year to year, then we would still be able to make conclusions concerning the relative change in exploitation rates from one year to the next.

The fishing conditions, seasons, and type of animal being harvested make these assumptions more likely to be met in the SPA 4 scallop fishery than in other fisheries that proceed over longer periods and with gear that is more prone to change in catchability such as passive traps. As a result, the exploitation rates and in particular the changes in exploitation rates that we observe among these years can be used to assess management plans to reduce exploitation rates to target levels and to manage this fishery within target $F_{0.1}$ exploitation rates.

In 1996, fishing was restricted to a small geographic section of SPA 4 with the intent of keeping exploitation rate low. Effort during this fishery was just over 7000 hours which was only about 20 percent less than in 1997 when fishing was permitted throughout SPA 4 for a similar time period (Table 15). Nevertheless, exploitation rates were similar between these two years in the areas where the fishing occurred. Thus, the restriction in area implemented in 1996 was only successful in reducing the overall exploitation rate if there was an appreciable portion of the stock outside the fishing area.

In 1998, the fishing season was lengthened to 8 weeks compared to 5 weeks in 1997 and all of SPA 4 was available for fishing. Effort increased by about 20 percent and exploitation rate increased by about 30–40 percent.

These results indicate that increasing opportunities for effort lead to increased exploitation rates in this fishery. They also indicate that current fishing efforts cause a depletion in the CPUE and most likely a decrease in abundance over the fishing period. Effort decreases will be necessary to reduce exploitation rates in this fishery.

Fishing Mortality estimated from Survey data

The Collie and Sissenwine approach (Collie and Sissenwine 1983) as studied by Conser (1995) was used to model the dynamics of the scallop population in SPA 4 based on trends in the survey data. Their approach starts off with expressing the fully recruited stock size (population numbers) at the beginning of year t as,

$$N_t = (N_{t-1} + R_{t-1} - C_{t-1}) \times \exp(-M), \tag{6}$$

where N_{t-1}, R_{t-1} and C_{t-1}, are the population numbers (fully recruited), pre-recruit numbers and catch numbers from the previous year $(t-1)$. Natural mortality is designated as M. From the annual survey we have indices for the fully recruited numbers, n_t and pre-recruits, r_t and we assume that these indices are related to their population values via catchability coefficients as,

$$\begin{aligned} n_t &= q_n N_t \\ r_t &= q_r R_t. \end{aligned} \tag{7}$$

Substitution of equation 7 into equation 6 results in the following relationship with process error ε_t,

$$n_t = \left(n_{t-1} + \frac{r_{t-1}}{s_r} - q_n C_{t-1} \right) \times \exp\left(-M + \varepsilon_t\right), \tag{8}$$

and $s_r = q_r/q_n$.

Further we assume measurement error for the survey quantities such that we really observe the following.

$$n'_t = n_t \exp\left(\eta_t\right), \quad t = 1, \ldots, T. \tag{9}$$

$$r'_t = r_t \exp\left(\delta_t\right), \quad t = 1, \ldots, T-1. \tag{10}$$

All error terms (ε_t, η_t and δ_t) are assumed to be normally distributed with mean 0 and non-zero variances (i.e., σ^2_ε, σ^2_η and σ^2_δ).

Parameter estimates are obtained for the n_t, r_t and q_n by minimizing the following nonlinear least squares objective function.

$$S\left(\Theta\right) = \lambda_\varepsilon \sum_{t=2}^{T} \varepsilon_t^2 + \sum_{t=1}^{T} \eta_t^2 + \lambda_\delta \sum_{t=1}^{T-1} \delta_t^2 \tag{11}$$

The objective function has $3T - 2$ residual terms and $2T$ parameters to be estimated leaving $T-2$ degrees of freedom for the model. Note that given the large number of parameters to estimate it is usually difficult to estimate q_r. In this analysis we assumed that $q_r = q_n$ (i.e., $s_r = 1$) which seems reasonable given the use of lined dredges to estimate pre-recruits.

In our analysis we estimated catch numbers (C_t) by dividing the total weight of the catch by the average meat weight from the port sampling program.

Estimates of N_t and R_t are presented in Fig. 24. The overall trend of the fully recruited numbers is consistent with this fishery. The high population numbers in 1991 reflect the large recruitment pulse in the late 1980's with a subsequent fishing down of the population until the closure of the Inside Fishing Zone in 1995 and the limited fishery in the Inside Zone in 1996. Thereafter, there was a recruitment pulse in 1996 which was fished down in the 1997 and 1998 fishery. At present, recruitment is at the lowest observed in this short time series.

The commercial CPUE has also been plotted on Fig. 24 and shows that the commercial index is in agreement with the general overall trend. The potential further decline in 1999 noted earlier is only additional validation of the model results presented here. Biomass trends of the fully recruited population show the same general trend but also reflect the increase in meat weights in recent years as reflected by the port samples (Fig. 25). This increase may also be indicative of an ageing population with low recruitment.

Fishing mortalities estimated from the Collie and Sissenwine model are presented below. Note that while the fishery in the Inside Zone was closed in 1995, fishing did continue in the 6 to 8 mile portion of the present boundaries of SPA 4.

Year	1991	1992	1993	1994	1995	1996	1997	1998
Fishing Mortality	0.30	0.19	0.23	0.19	0.07	0.07	0.11	0.20
Catch (t)	678.7	318.4	244.2	162.7	94.8	71.2	116.1	103

Forecasts for the year 2000 suggest that in the absence of fishing (Projected, M only in Fig. 24), recruitment will not balance the losses due to natural mortality, hence there is no surplus production as the population is in decline. If the entire 120 t TAC is taken this fall, the overall expected decline in the population from June 1999 to June 2000 based on the model is 10 percent (Projected, $M + F$ in Fig. 24).

The estimated fishing mortality of 0.20 for the catch of 103 t in 1998 is close to the 0.22 forecast for the TAC of 120 t in Smith and Lundy (1998). However, the model estimated a population biomass of about 1500 t in 1998 and it should have been possible to catch a TAC of 120 t. The fact that the 1998 catch was only 103 t suggests either the biomass estimates or the reported catch, or both, are incorrect. Applying the estimated q_n of 0.20 to the biomass estimates from the survey in Fig. 10 results in the following population estimates which are compared with those from the Collie-Sissenwine model.

Year	1996	1997	1998	1999
Biomass (t): Model	1020	1253	1481	1125
Biomass (t): Survey	1241	1397	1549	788

Estimates from the two methods were quite similar until 1999. The difference between the 1999 survey biomass estimate and the model biomass estimate suggest two possible sources of error in the data used in the model. If the average meat weights in the catch (Table 2) were overestimated then the number of scallops in the catch in 1998 would be underestimated along with the fishing mortality. This would lead to an overestimate of the number of survivors in 1999 and as a consequence an overestimate of biomass. On the other hand, the reported catch in weight may be less than what was actually removed from the area and again fishing mortality would be underestimated while the number of survivors in 1999 would have been overestimated.

The first scenario is entirely possible given the very low sampling intensity of the commercial catch for meat weights. The Full Bay fleet has agreed to supply a vessel to collect data on the spatial distribution of meat weights in January of 2000 and our estimates of the average meat weight in the commercial catches will be re-evaluated once these data have been obtained. While these data will not tell us exactly how many scallops were caught in the 1998 fishery, they will help us better evaluate the impact of the 1999 fishery. In addition, the data could help evaluate our estimates of the average meat weights used for the 1998 fishery given the spatial distribution of the catches.

The second scenario implies either non-reporting of catch or misreporting of catch from SPA 4 into another SPA. While misreporting of catch into SPA 2 and 3 was an issue in the 1999 fishery (Smith et al. 1999b) we do not have any evidence that either misreporting or non-reporting was a problem in the SPA 4 fishery in 1998.

SPA 5

We do not have a formal population model for the scallops in Annapolis Basin but indications from the survey estimates are that the fishery in 1999 was not detrimental to the population there. Given the increase in numbers of recruited scallops in 1999 and the increase in meat weight we expect that the overall increase of 68 percent in survey biomass from 1998 to 1999 could be translated to a similar increase in the TAC from last year's 10 t to 17 t for 2000.

Summary

1. SPA 4

    - Landings in 1998 were 103 t against a TAC of 120 t. The TAC for 1999 is also 120 t and as of 13 November preliminary landings are 32.5 t.
    - Commercial CPUE was lower in 1998 than in 1997 and indications are that CPUE in 1999 may be lower still.
    - Survey data indicate that the fully recruited population has been declining since 1997 and that there are no immediate indications of significant recruitment. Information from the fishing logs and the survey indicate that the higher density areas in the deeper water sections of SPA 4 were targeted in the 1999 fishery. The decline in population numbers in these areas was more severe than in the shallower areas.

- Population models indicate that fishing mortality has increased by more than 50 percent since 1996.
- Given the lack of recruitment in this stock it would be prudent to refrain from setting the 2000 TAC until a better estimate of biomass can be obtained. Currently plans are being made to have fishing vessels obtain more data in early 2000 on the spatial distribution of meat weights which could help us evaluate our estimates of the number of scallops caught in the 1998 (and 1999) fishery. The 2000 fishery is not scheduled to open until 1 October and therefore there should be time to consider these data as well as information from the June 2000 survey before the fishery opens.

2. SPA 4 inshore.

    - The surveys show very good catch rates and large scallops. There may be potential for a limited experimental fishery here in the winter when there is no lobster gear in the water.

3. SPA 5

    - The 1999 fishery landed 11.9 t against a TAC of 10 t.
    - The 1999 survey indicated an increase in numbers and meat weight since 1998.
    - An increase in TAC for 2000 from 10 t to 17 t could be indicated here.

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Table 1. Statistics for commercial catch-per-unit effort from Class 1 logs for Scallop production area. Class 1 logs are those with complete information.

	Year	Mean	Std. Dev.	Min.	Max	N
Inside	1990	30.66	11.40	5.62	71.27	266
Zone	1991	28.55	14.85	6.66	125.62	515
	1992	18.75	7.59	5.61	69.44	625
	1993	14.73	5.47	3.53	42.15	361
	1994	11.84	4.54	4.46	64.23	394
	1995	10.60	4.62	4.35	24.91	205
SPA 4	1996	8.89	3.25	2.56	18.80	910
	1997	12.81	4.00	6.10	24.90	728
	1998	9.41	4.32	2.57	66.32	1193

Table 2. Results of the departmental port sampling program in Scallop production area 4, 1996–1998.

			Meat Weight (g)				Count	Number of
Year	Month	N	Mean	SD	Min.	Max.	per 500 g.	Vessels
1996	November	1250	12.41	9.57	4.0	49.7	40.3	10
	December	584	21.06	8.73	5.0	46.8	46.8	8
1997	October	1168	20.78	5.79	7.1	45.4	45.4	11
	November	193	14.39	4.79	6.3	29.7	29.7	3
1998	September	282	25.24	7.83	8.7	45.9	19.8	6
	October	331	22.92	6.73	7.9	49.2	21.8	5
	November	177	24.29	7.26	11.5	61.3	20.6	4
	December	354	24.40	8.99	15.4	99.0	20.5	5

Table 3. Results of the voluntary departmental port sampling program in Scallop production area 5, 1996–1998.

			Meat Weight (g)				Count
Year	Month	N	Mean	SD	Min.	Max.	per 500 g.
1996	January	35	19.03	8.71	7.0	37.8	26.3
1997	January	229	22.73	8.01	7.5	40.1	22.0
1998	January	143	14.80	2.14	9.9	19.3	33.8
1999	January	207	17.03	2.16	11.0	24.2	29.4

Table 4. Estimates from stratified survey for scallops in scallop production area 4, June 1999. Pre-recruits are represented by shell height size range 55 to 79 mm while recruited animals are greater than or equal to 80 mm.

			55 to 79 mm		80+ mm	
Stratum Name	Propn. area in stratum	Number of Tows	Mean number	Standard error	Mean number	Standard error
Centreville	0.133	14	6.54	1.92	81.57	13.52
CV to GH	0.068	10	5.86	1.31	95.08	18.89
Gulliver's Head	0.133	20	10.82	1.80	67.01	8.02
GH to DG	0.100	5	4.00	1.99	58.18	11.44
Digby Gut	0.200	16	10.53	3.41	37.09	5.20
DG to DC	0.100	5	8.60	5.63	48.96	13.91
Delaps Cove	0.133	8	13.62	5.65	53.59	9.40
Parkers Cove	0.133	8	2.95	1.38	30.84	10.16
Total	1.000	86	8.28	1.55	55.54	3.70

Table 5. Analysis of relationship between meat weight and shell height of scallops caught during June 1999 survey in scallop production area 4. Models are: I. log(meat weight) = $\beta_0 + \beta_1 \log(\text{shell height})$ II. log(meat weight) = $\beta_0 + \beta_1 \log(\text{shell height}) + \beta_{2,i}\text{depth}$; where $i = 1$ when depth $\leq$ 90m and $i = 2$, otherwise.

a) Model fitting results.

Model	Residual DF	Residual SS	Model DF	Model SS	F-Statistic	p-value
I.	2230	92.376	1			
II.	2228	59.221	2	33.155	623.68	< 0.0001

b) Parameter estimates.

Model	$\widehat{\beta}_0$	$\widehat{\beta}_1$	$\widehat{\beta}_{2,1}$	$\widehat{\beta}_{2,2}$
I.	−11.388	3.011		
II.	−10.867	2.918	−0.207	−0.476

Table 6. Predicted meat weights (g) from meat weight shell height model with depth included for scallop production area 4.

a) Predicted meat weights from 1999 survey.

Shell	Observed depth m					
height mm	60	70	80	90	100	110
80	6.95	7.09	7.01	6.56	5.70	4.69
85	8.29	8.47	8.36	7.82	6.80	5.60
90	9.80	10.00	9.88	9.24	8.04	6.62
95	11.47	11.71	11.57	10.82	9.41	7.75
100	13.32	13.60	13.44	12.57	10.93	9.00
105	15.36	15.69	15.49	14.49	12.61	10.38
110	17.59	17.97	17.74	16.60	14.44	11.89
115	20.03	20.45	20.20	18.90	16.44	13.53
120	22.67	23.16	22.87	21.40	18.61	15.32
125	25.54	26.09	25.77	24.10	20.97	17.26
130	28.64	29.25	28.89	27.03	23.51	19.35
135	31.97	32.65	32.25	30.17	26.24	21.61
140	35.55	36.31	35.86	33.55	29.18	24.02
145	39.39	40.22	39.73	37.17	32.33	26.61
150	43.48	44.41	43.86	41.03	35.69	29.38
155	47.85	48.87	48.27	45.15	39.27	32.33

b) Comparison of predicted weights-at-length (g) for 1998 and 1999.

		Shell height mm						
Year	Depth (m)	80	85	90	95	100	105	110
1998	60	6.16	7.41	8.83	10.42	12.19	14.15	16.32
1999	60	6.95	8.29	9.80	11.47	13.32	15.36	17.59
1998	110	4.03	4.85	5.77	6.81	7.97	9.25	10.67
1999	110	4.69	5.60	6.62	7.75	9.00	10.38	11.89

Table 7. Estimates from stratified survey for scallops greater than or equal to 80 mm in shell height in scallop production area 4, June 1999. An adaptive allocation scheme was used to allocate tows to strata in the second phase of the survey. The decision rule was to add 3 more tows if the mean in the first phase was greater than 40.

		First Phase			Second Phase		
Stratum Name	Propn. area in stratum	Number of Tows	Mean number	Variance of mean	Number of Tows	Mean number	Variance mean
Centreville	0.133	14	81.57	182.57	17	87.06	150.92
CV to GH	0.068	10	95.08	356.23	13	95.98	255.13
Gulliver's Head	0.133	20	67.01	64.27	23	69.68	66.70
GH to DG	0.100	5	58.18	130.91	8	62.56	91.09
Digby Gut	0.200	16	37.09	26.99	16	37.09	26.99
DG to DC	0.100	5	48.96	193.45	8	48.18	175.48
Delaps Cove	0.133	8	53.59	88.33	11	52.89	51.55
Parkers Cove	0.133	8	30.83	103.27	8	30.83	103.27
Total	1.000	86	55.54	13.70	104	56.95	11.50

Table 8. Estimates from stratified survey for scallops in the 0 to 2 mile inshore zone of scallop production area 4, October 1998. Pre-recruits are represented by shell height size range 55 to 79 mm while recruited animals are greater than or equal to 80 mm.

			55 to 79 mm		80+ mm	
Stratum Name	Propn. area in stratum	Number of Tows	Mean number	Standard error	Mean number	Standard error
Centreville	0.133	2	1.50	2.12	34.25	14.64
CV to GH	0.068	2	0.00	0.00	36.85	9.69
Gulliver's Head	0.133	4	1.28	2.55	31.72	22.86
GH to DG	0.100	2	0.00	0.00	5.55	7.85
Digby Gut	0.200	3	0.00	0.00	0.00	0.00
DG to DC	0.100	2	1.90	2.69	9.75	2.89
Delaps Cove	0.133	3	1.07	1.85	25.90	25.42
Parkers Cove	0.133	2	1.80	2.55	64.95	39.24

Table 9. Estimates of mean number of scallops per tow from fall surveys of the 0 to 2 mile inshore zone of scallop production area 4.

		55 to 79 mm		80+ mm	
Year Name	Number of Tows	Mean number	Standard error	Mean number	Standard error
1997	19	1.95	0.96	27.17	5.20
1998	20	0.94	0.43	24.90	4.72
1999	41	3.35	1.11	37.68	5.13

Table 10. Estimates of mean number of scallops per tow from June surveys of scallop production area 5.

Survey Name	Number of Tows	55 to 79 mm Mean number	55 to 79 mm Standard error	80+ mm Mean number	80+ mm Standard error
June 1998	10	67.34	26.73	101.07	34.33
June 1999	19	66.05	11.77	122.44	24.73

Table 11. Analysis of relationship between meat weight and shell height of scallops caught during surveys in scallop production area 5. The model is: log(meat weight) = $\beta_0 + \beta_1$ log(shell height).

a) Parameter estimates.

Survey	$\widehat{\beta}_0$	$\widehat{\beta}_1$
June 1998	−10.51	2.83
December 1998	−12.23	3.21
June 1999	−10.95	2.98

b) Predicted meat weights.

	Shell height mm						
Survey	80	85	90	95	100	105	110
June 1998	6.68	7.93	9.33	10.87	12.57	14.43	16.47
December 1998	6.30	7.65	9.20	10.94	12.90	15.08	17.51
June 1999	8.00	10.00	12.00	14.00	16.00	18.00	21.00

Table 12. Estimated mean meat weights from port samples by week for the 1996 fishing season in scallop production area 4. In cases where there were no port samples in a week, mean weights were estimated using the mean weight from the nearest week.

Week	Date	Meat Weight (g)	Catch (kg)	No. of Samples	Numbers (1000's)
46	18-Nov	31.55	2982	2	95
47	25-Nov	25.12	23793	6	947
48	02-Dec	21.60	19549	11	905
49	09-Dec	25.55	6368	4	249
50	16-Dec	27.38	6869	2	251
51	23-Dec	27.38	395	0	14
Total			59956	25	2461
Average		24.36			

Table 13. Estimated mean meat weights from port samples by week for the 1997 fishing season in scallop production area 4. In cases where there were no port samples in a week, mean weights were estimated using the mean weight from the nearest week.

Week	Date	Meat Weight (g)	Catch (kg)	No. of Samples	Numbers (1000's)
40	07-Oct	21.00	6036	0	287
41	14-Oct	21.00	25295	3	1204
42	21-Oct	19.96	35199	11	1764
43	28-Oct	22.39	11519	5	515
44	04-Nov	17.44	14895	7	854
45	11-Nov	17.44	2905	0	167
Total			95849	28	4790
Average		20.01			

Table 14. Estimated mean meat weights from port samples by week for the 1998 fishing season in scallop production area 4. In cases where there were no port samples in a week, mean weights were estimated using the mean weight from the nearest week or from the weighted average of adjacent weeks.

Week	Date	Meat Weight (g)	Catch (kg)	No. of Samples	Numbers (1000's)
38	23-Sep	25.56	16362	0	640
39	30-Sep	25.56	29206	6	1143
40	07-Oct	20.47	9533	4	466
41	14-Oct	27.51	12659	2	460
42	21-Oct	28.32	8474	0	299
43	28-Oct	29.26	10963	1	375
44	04-Nov	26.76	2594	0	97
45	11-Nov	24.32	11270	4	463
46	18-Nov	24.32	792	0	33
47	25-Nov	24.05	540	0	22
48	02-Dec	22.80	1344	0	59
49	09-Dec	22.80	2482	3	109
50	16-Dec	27.28	1553	3	57
51	23-Dec	27.28	641	0	23
Total			108413	23	4246
Average		25.53			

Table 15. Estimated exploitation rates and catchability coefficients from Leslie analyses 1996–1998.

Model Quantities	1996 15 Nov–15 Dec	1997 7 Oct–11 Nov	1998 22 Sep–22 Dec
		All Data	
Exploitation Rate (%)	24	35	50
Fishing Mortality (F)	0.27	0.43	0.69
Effort (hours)	7132	8870	10589
CPUE (numbers/hours)	358	654	381
q	0.043	0.062	0.062
Mean Meat Wt (g)	24.36	20.1	25.53
R^2	0.07	0.22	0.55
p-level	0.11	0.0073	0.0001
		Influential points removed	
Exploitation Rate (%)	36	35	46
Fishing Mortality (F)	0.45	0.43	0.62
Effort (hours)	7132	8870	10589
CPUE (numbers/hours)	357	654	380
q	0.066	0.062	0.055
Mean Meat Wt (g)	24.36	20.1	25.53
R^2	0.37	0.22	0.49
$p - level$	0.0016	0.0073	0.0001

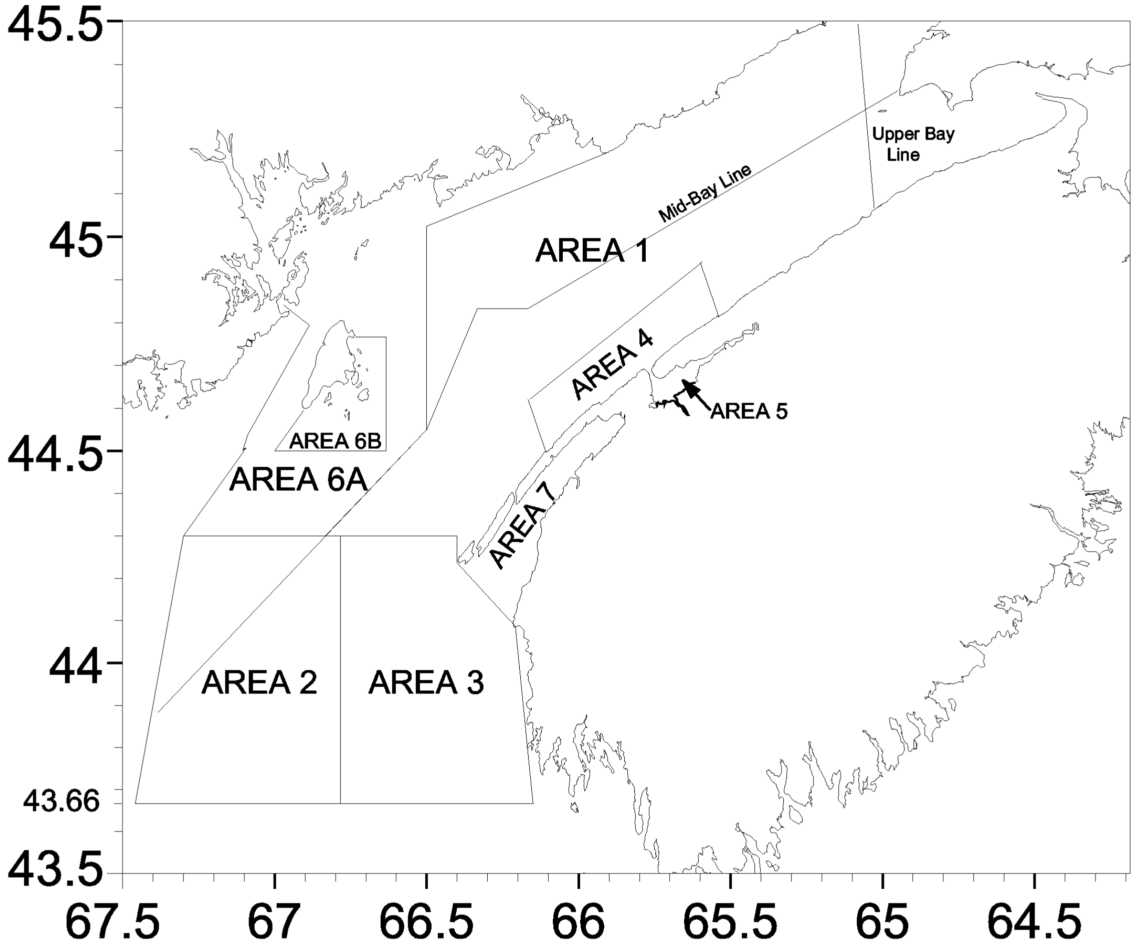

Fig. 1. Scallop production areas in the Bay of Fundy (as of 1 January 1997).

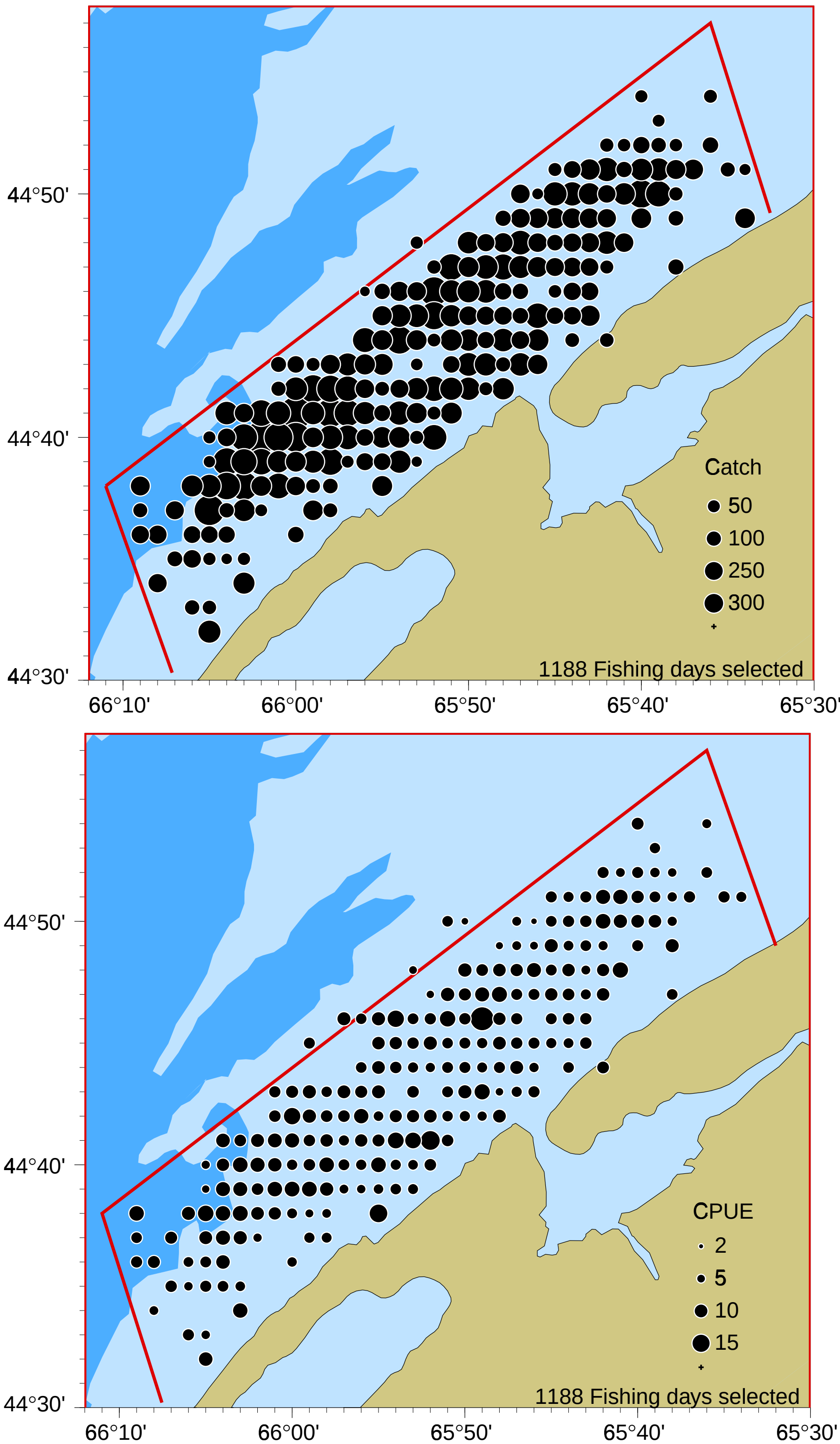

Fig. 2. Fishing locations from class 1 fishing logs in 1998 for SPA 4. Upper panel: Catch (t). Lower panel: Catch-per-unit-effort (kg/h).

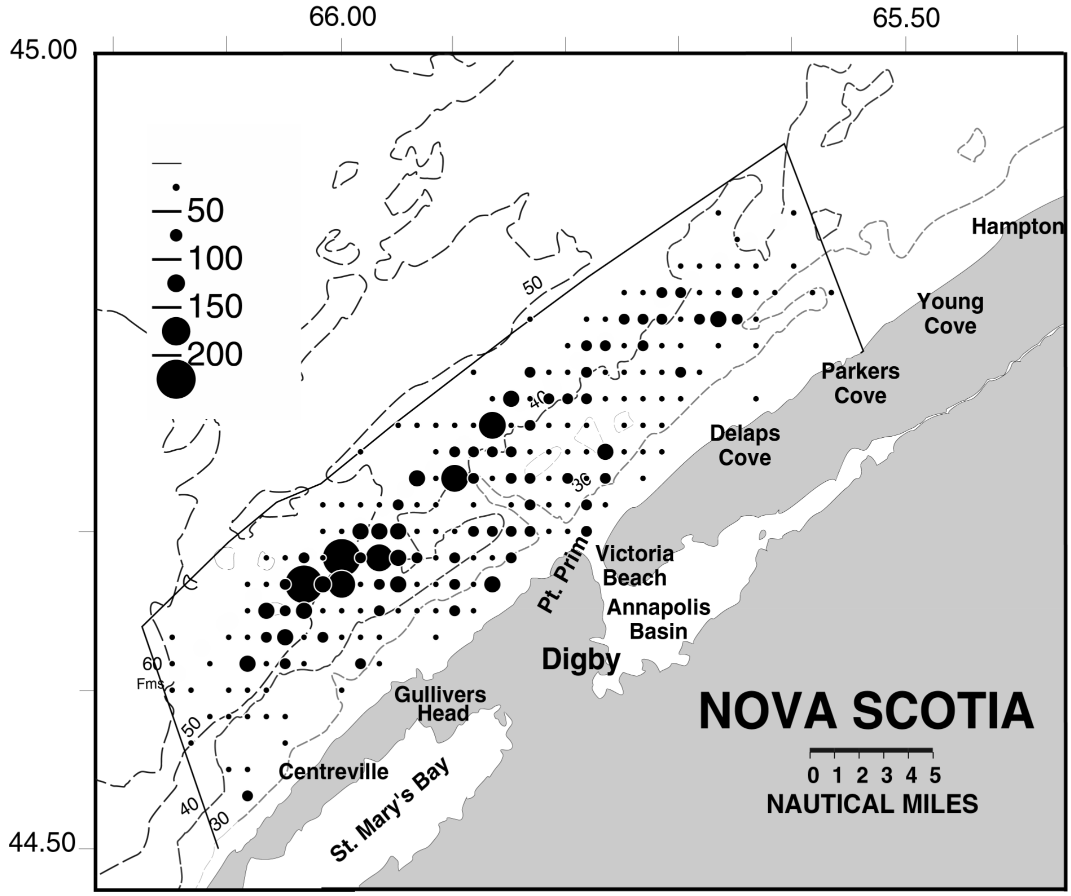

Fig. 3. Fishing locations from class 1 fishing logs in 1998 for SPA 4. Fishing effort in hours.

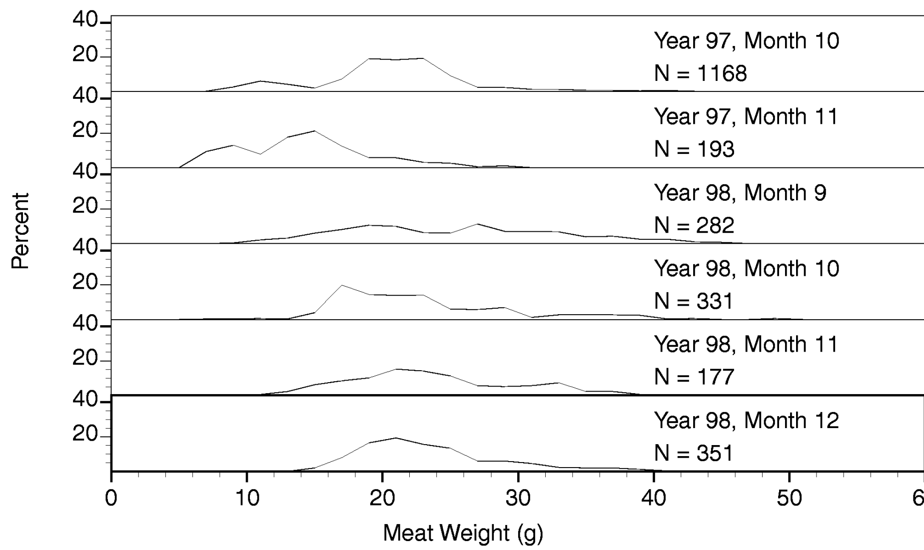

Fig. 4. Frequency distribution of meat weights from samples of the commercial catch in SPA 4. Sample size of meats (N) given for each month.

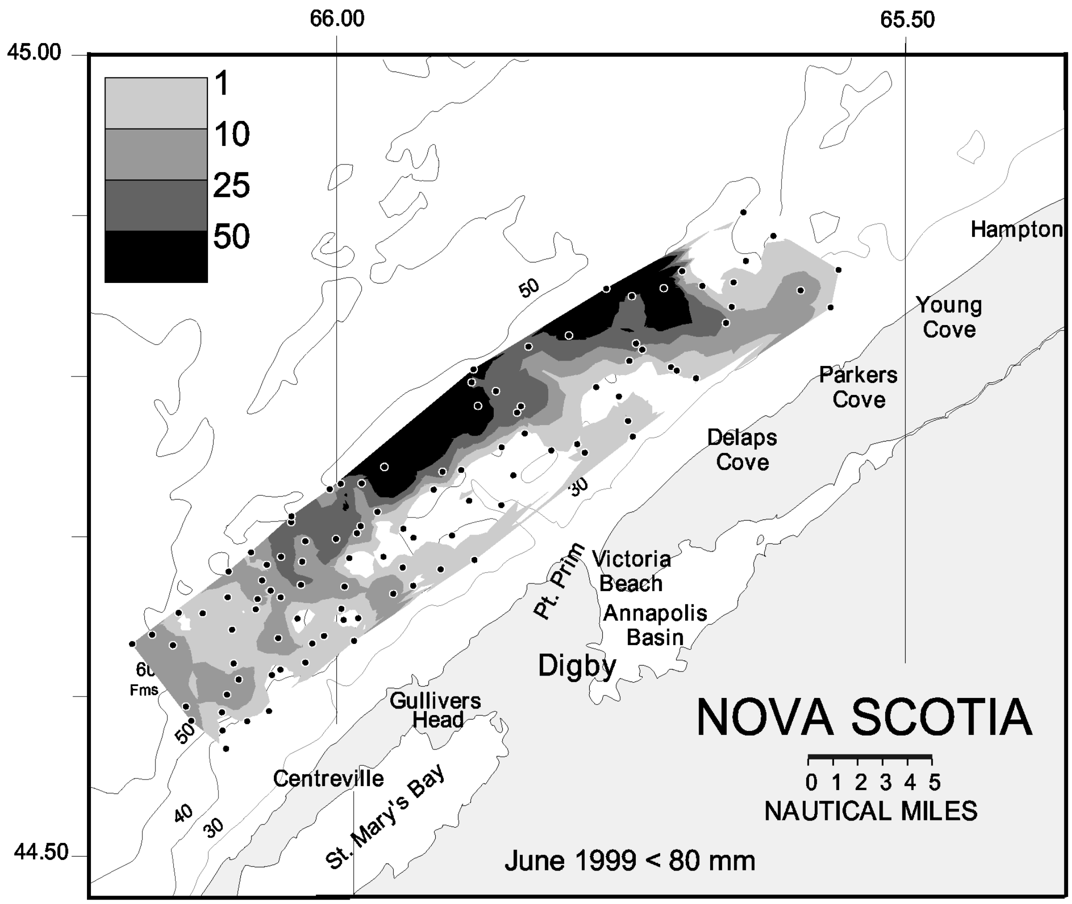

Fig. 5. Spatial distribution of scallop catches from 1999 survey of SPA 4 for scallops with shell heights less than 80 mm. Contouring was derived using Delauney triangles and inverse distance weight interpolation.

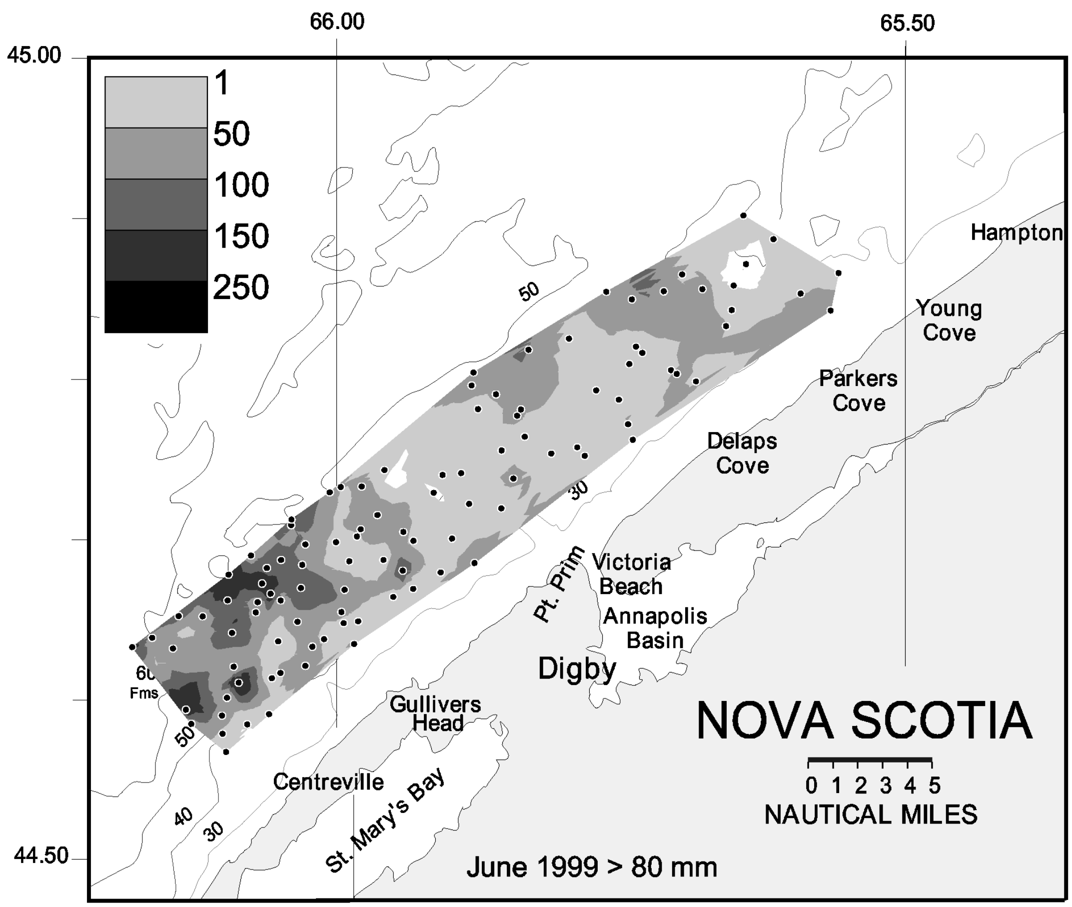

Fig. 6. Spatial distribution of scallop catches from 1999 survey of SPA 4 for scallops with shell heights greater than or equal to 80 mm. Contouring was derived using Delauney triangles and inverse distance weight interpolation.

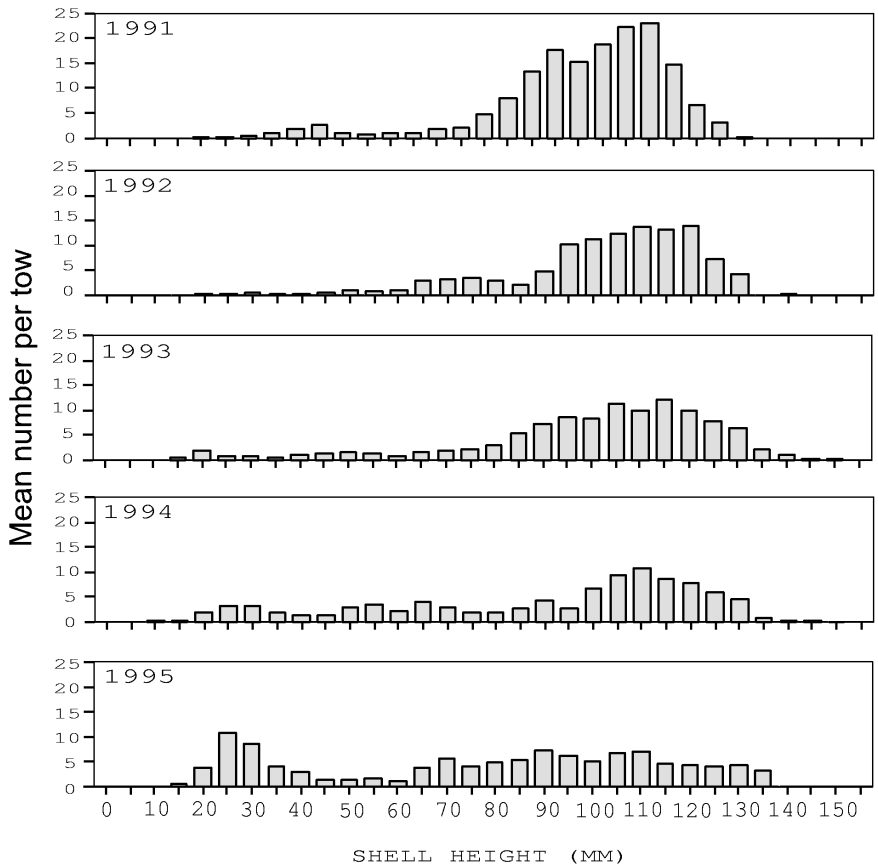

Fig. 7. Shell height frequencies (stratified mean number per tow) from the June 1991 to 1995 survey of Scallop production area 4.

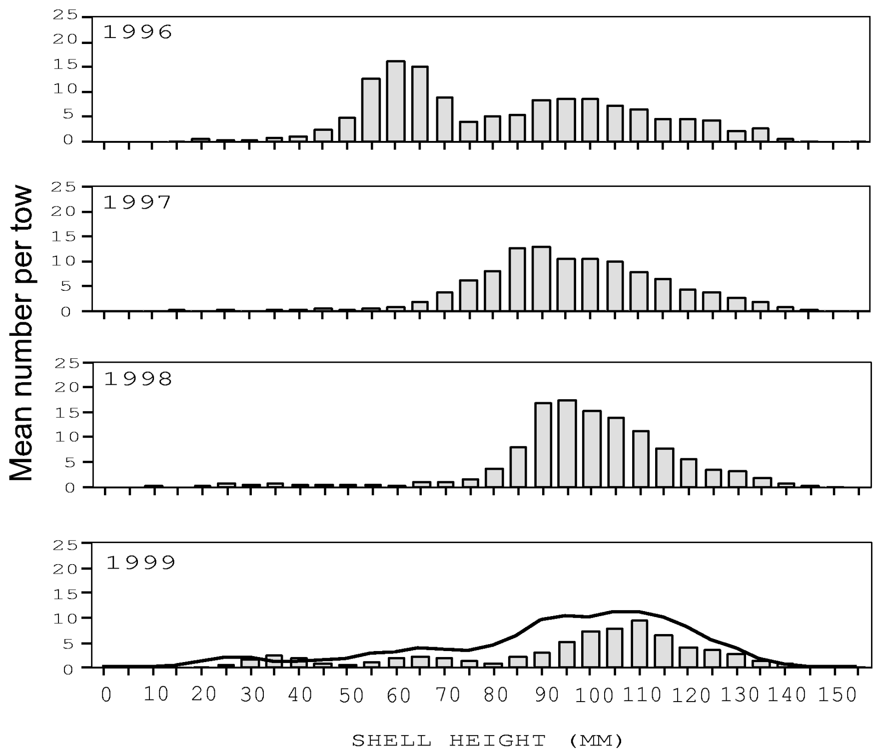

Fig. 8. Shell height frequencies (stratified mean number per tow) from the June 1996 to 1999 survey of Scallop production area 4. The solid line on the 1999 panel represents the mean frequency from 1991 to 1998.

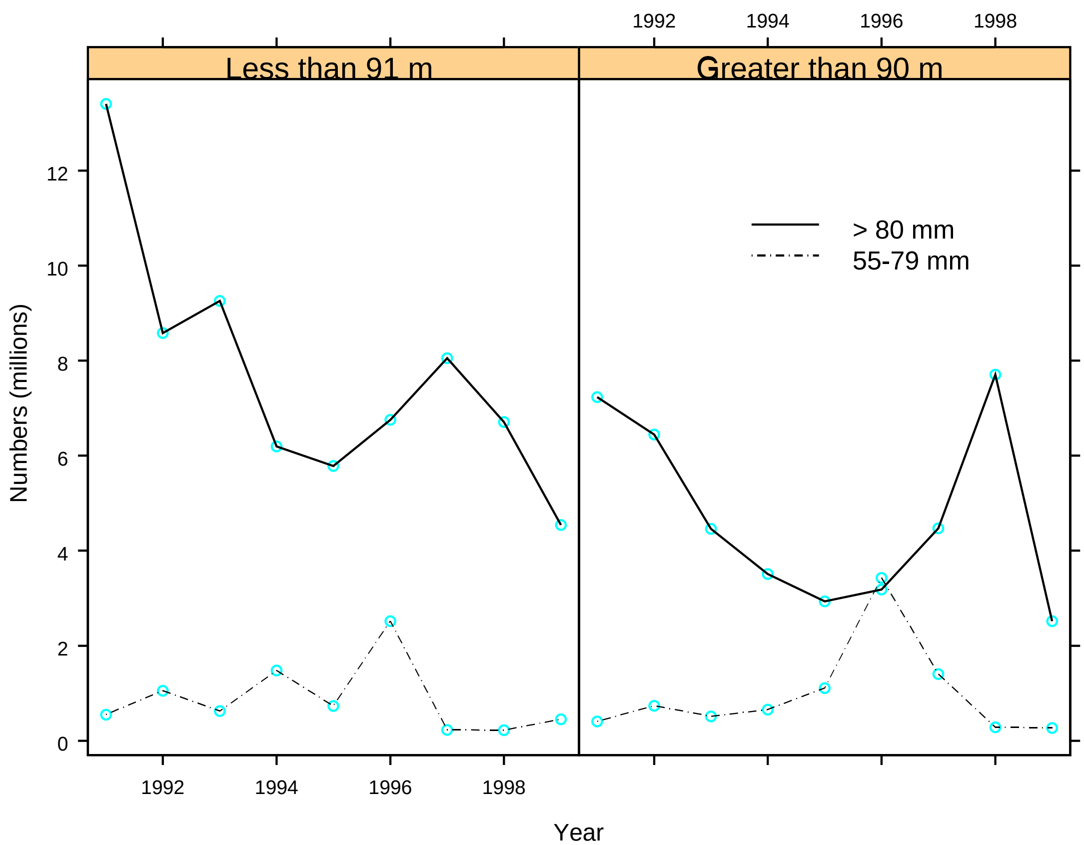

Fig. 9. Estimates of stratified total numbers of scallops by size range and depth range from June surveys of scallop production area 4.

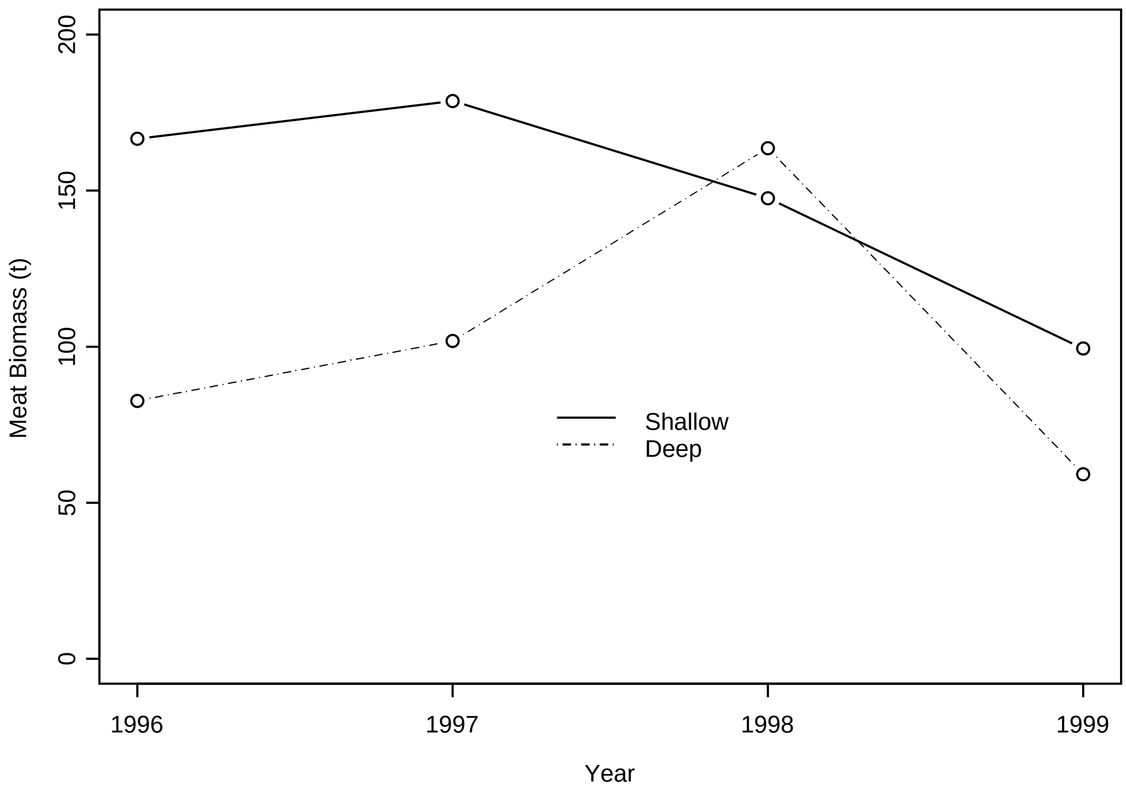

Fig. 10. Estimates of meat biomass (t) from June survey for shallow ($\leq$ 90m) and deep ($>$ 90m) water areas.

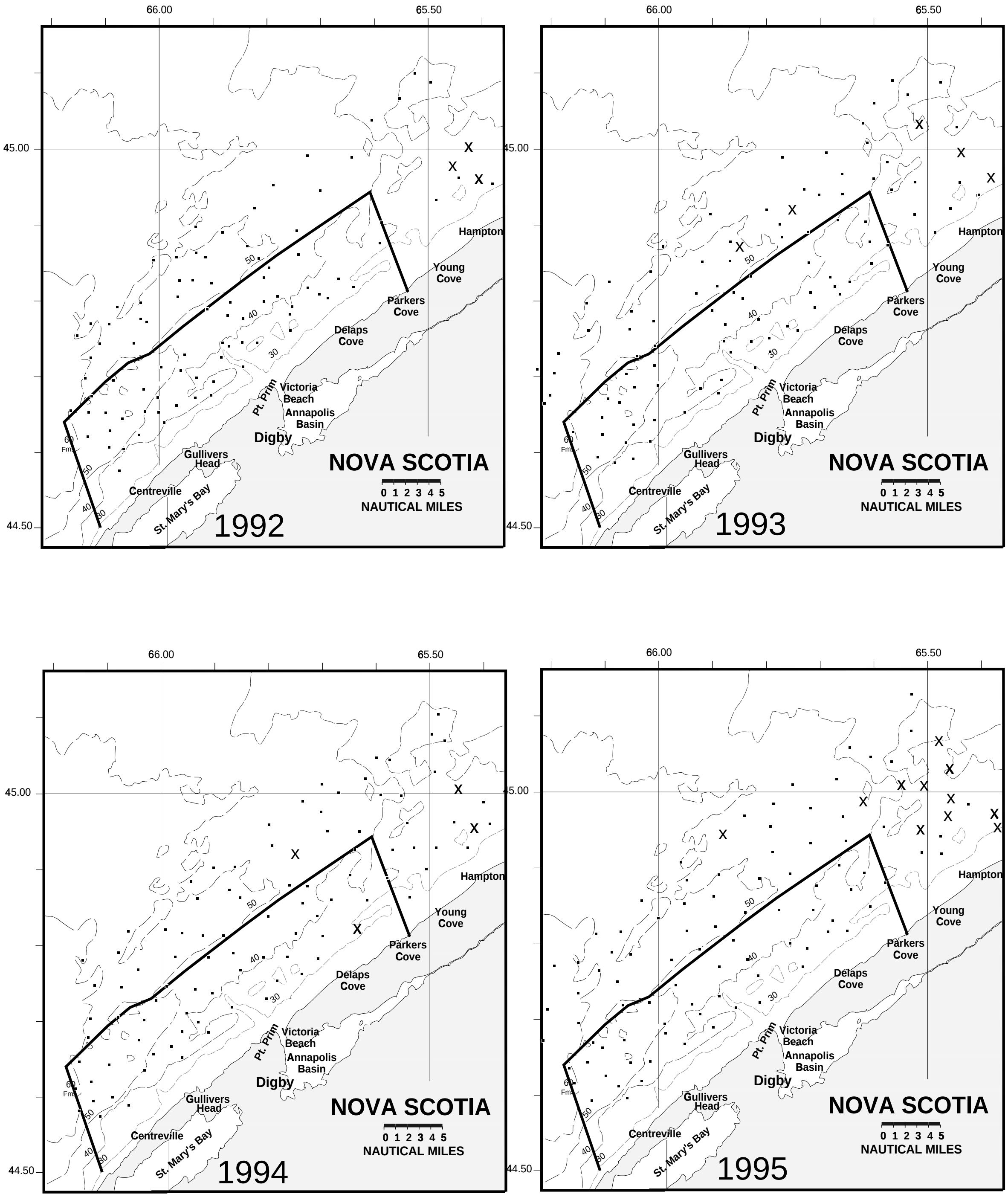

Fig. 11. Positions of tows made during the June survey of Bay of Fundy from 1992 to 1995 inclusive. Tows with lemonweed (*Flustra foliacea*) in the dredge indicated by an (X) and tows with no lemonweed indicated as (.).

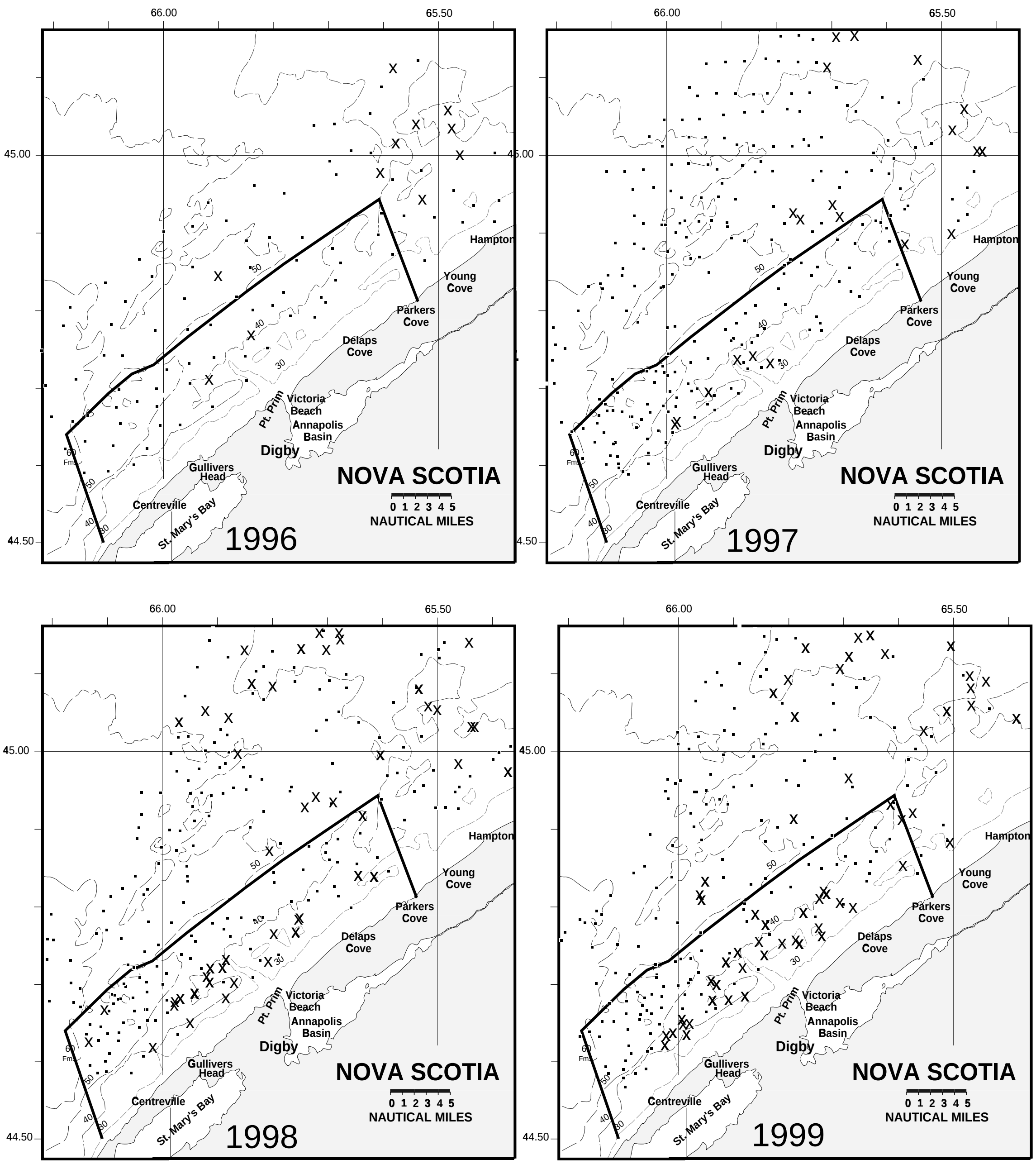

Fig. 12. Positions of tows made during the June survey of Bay of Fundy from 1996 to 1999 inclusive. Tows with lemonweed (*Flustra foliacea*) in the dredge indicated by an (X) and tows with no lemonweed indicated as (.).

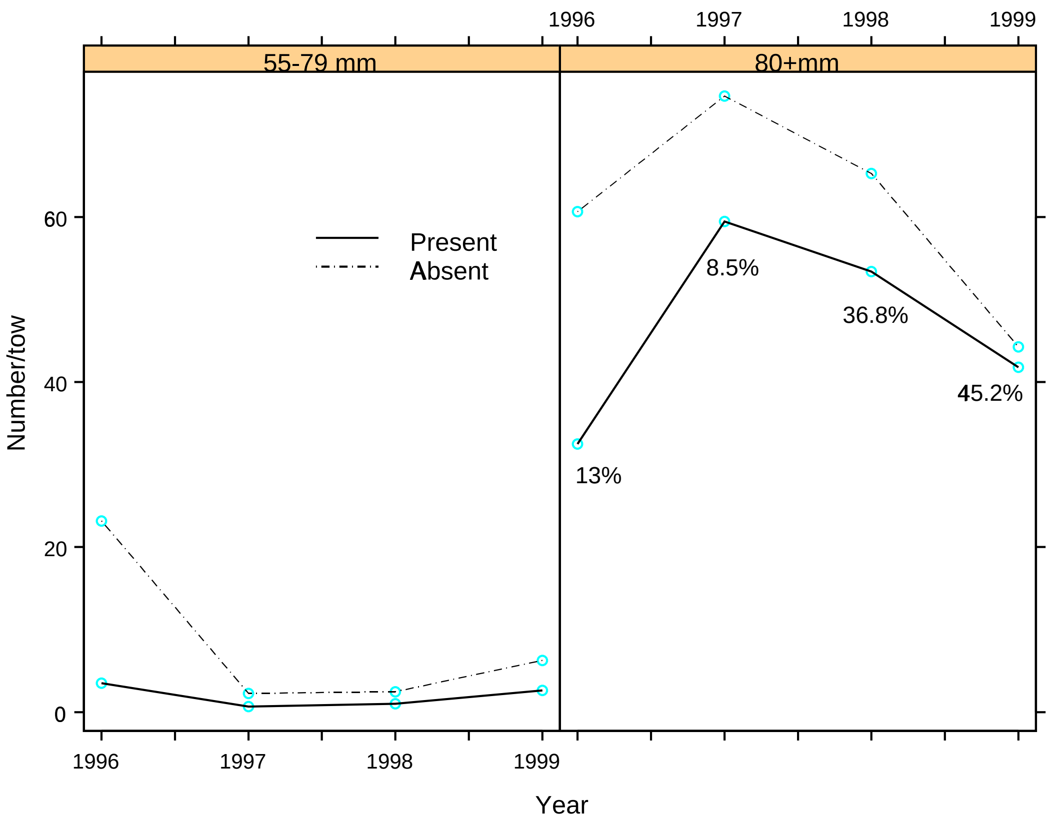

Fig. 13. Mean number of scallops per tow from June surveys of SPA 4 for pre-recruits (left panel) and recruited (right panel) animals from tows where lemonweed (*Flustra foliacea*) was present or absent. The percent of tows with lemonweed present for each year are given in the right panel.

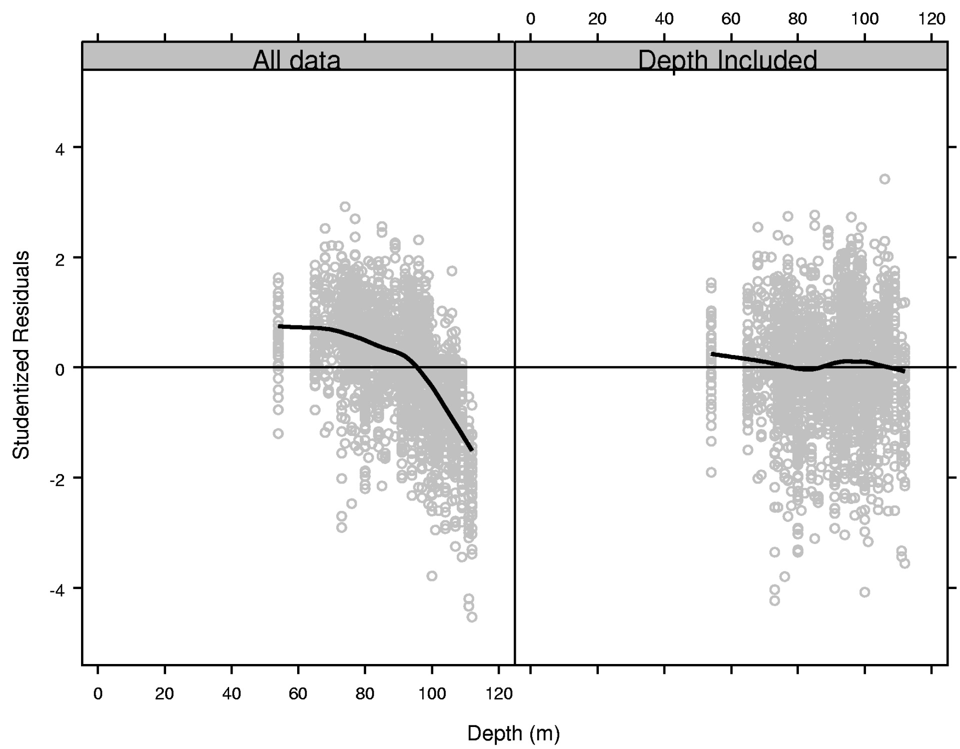

Fig. 14. Studentized residuals from fit of linear model of log(meat weight) as a function of log(shell height) for scallops from June 1999 survey of Scallop production area 4. Left panel: one linear model fit to all data. Right panel: Linear model with depth term included. Loess curve used to detect trend in residuals.

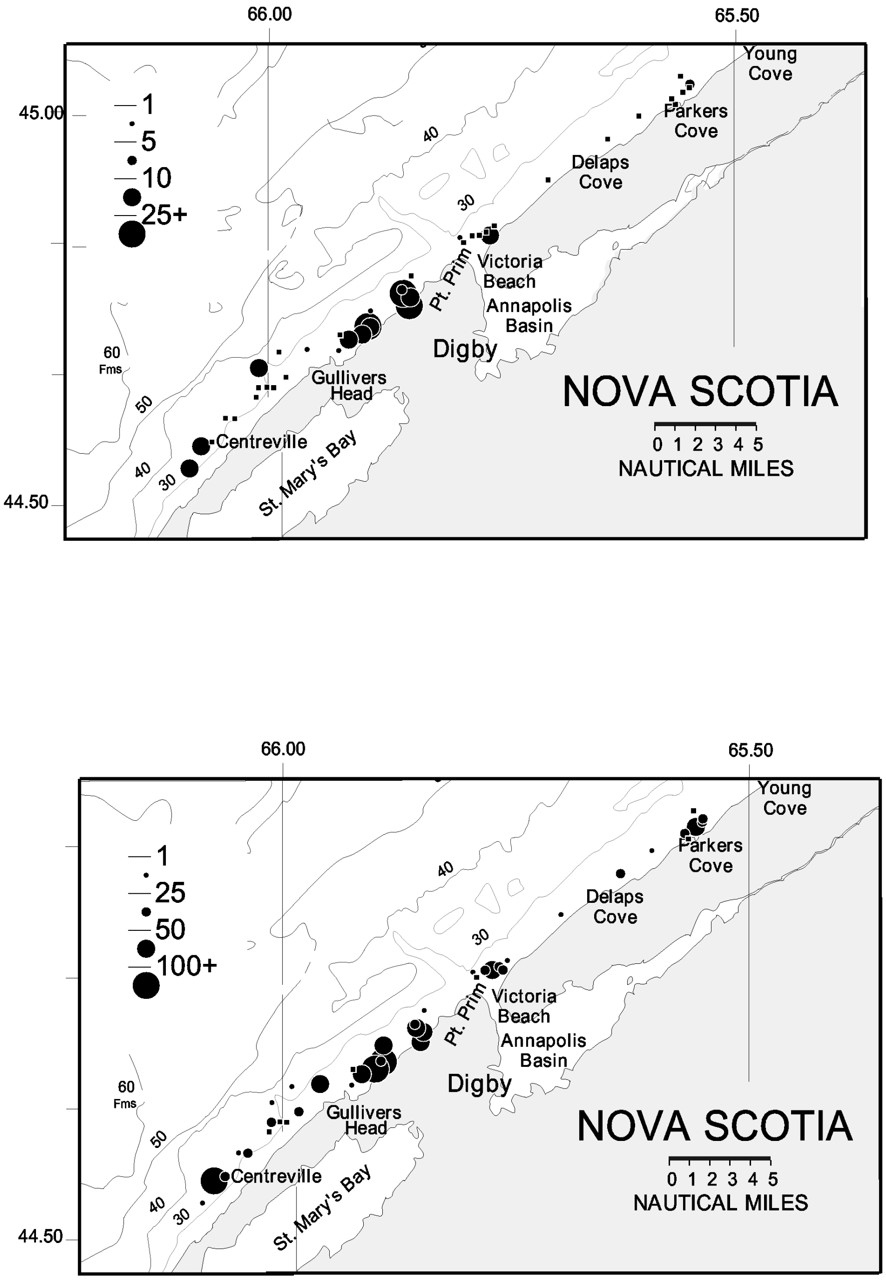

Fig. 15. Expanding symbol plot of scallop catches (numbers) from 1999 survey of SPA 4 less than 2 miles from shore. Top panel represents catches for scallops with shell heights less than or equal to 80 mm. Bottom panel represents catches for scallops with shell heights greater than 80 mm.

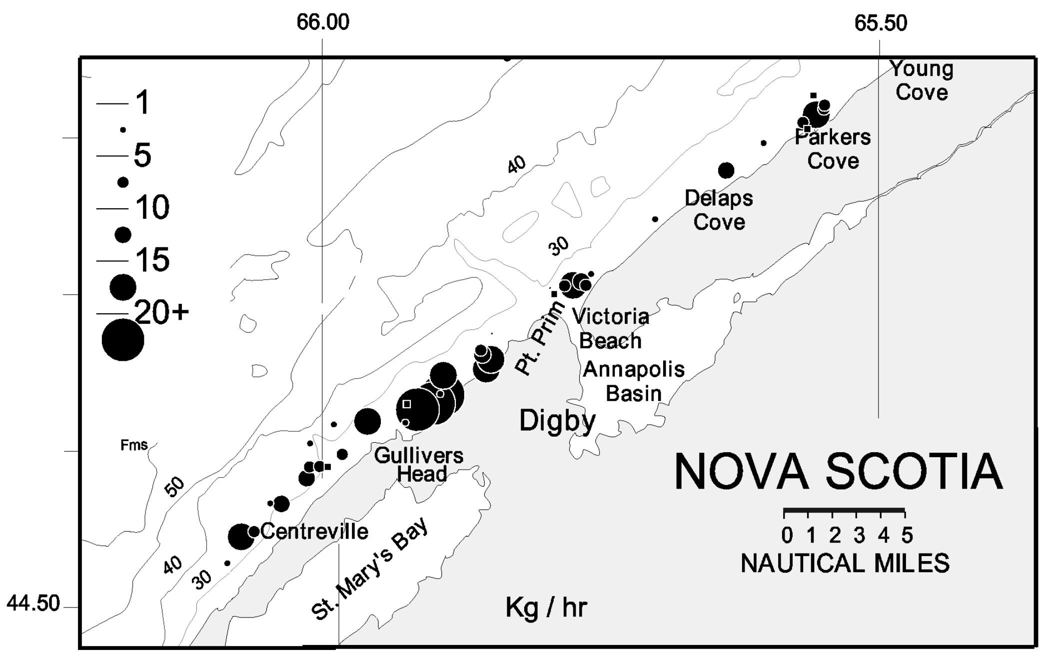

Fig. 16. Expanding symbol plot of scallop catches from 1999 survey of SPA 4 less than 2 miles from shore. Catches are given in weight (kg) per tow per hour.

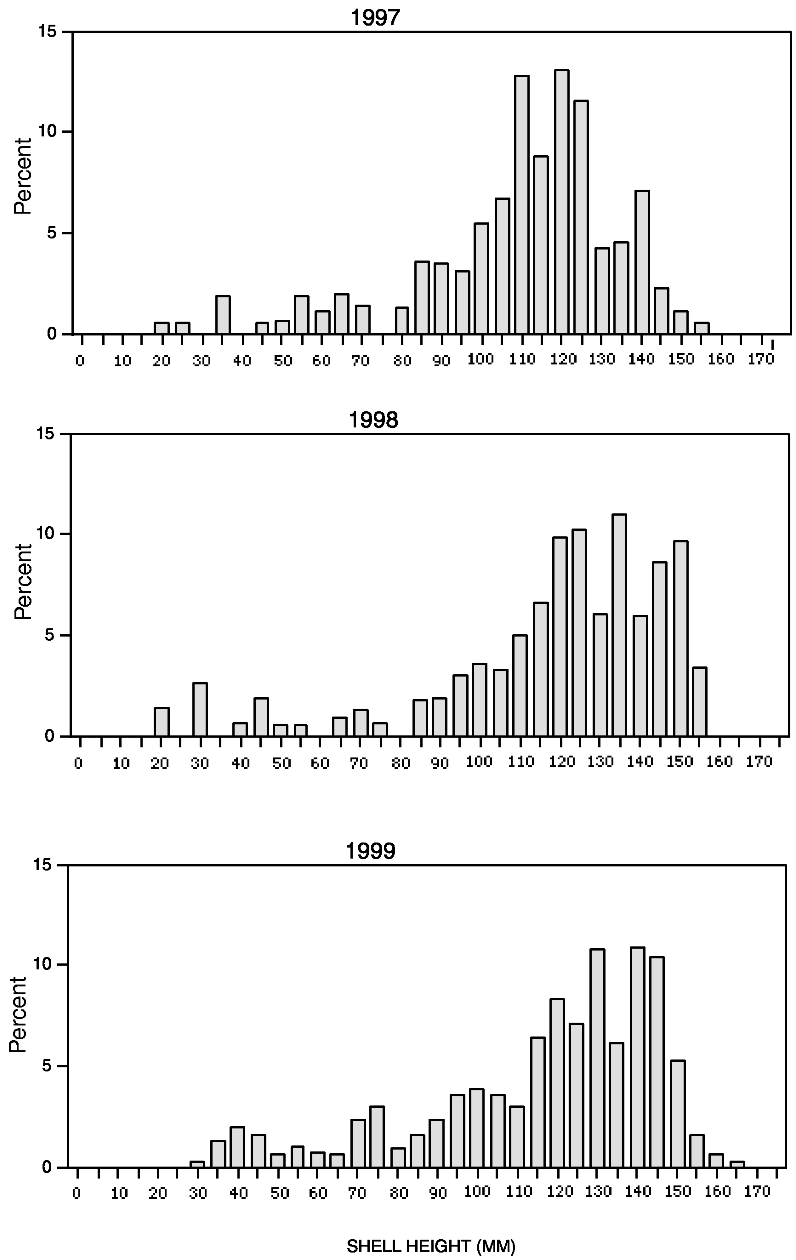

Fig. 17. Shell height relative frequencies from the inshore surveys of Scallop production area 4, 1997 to 1999.

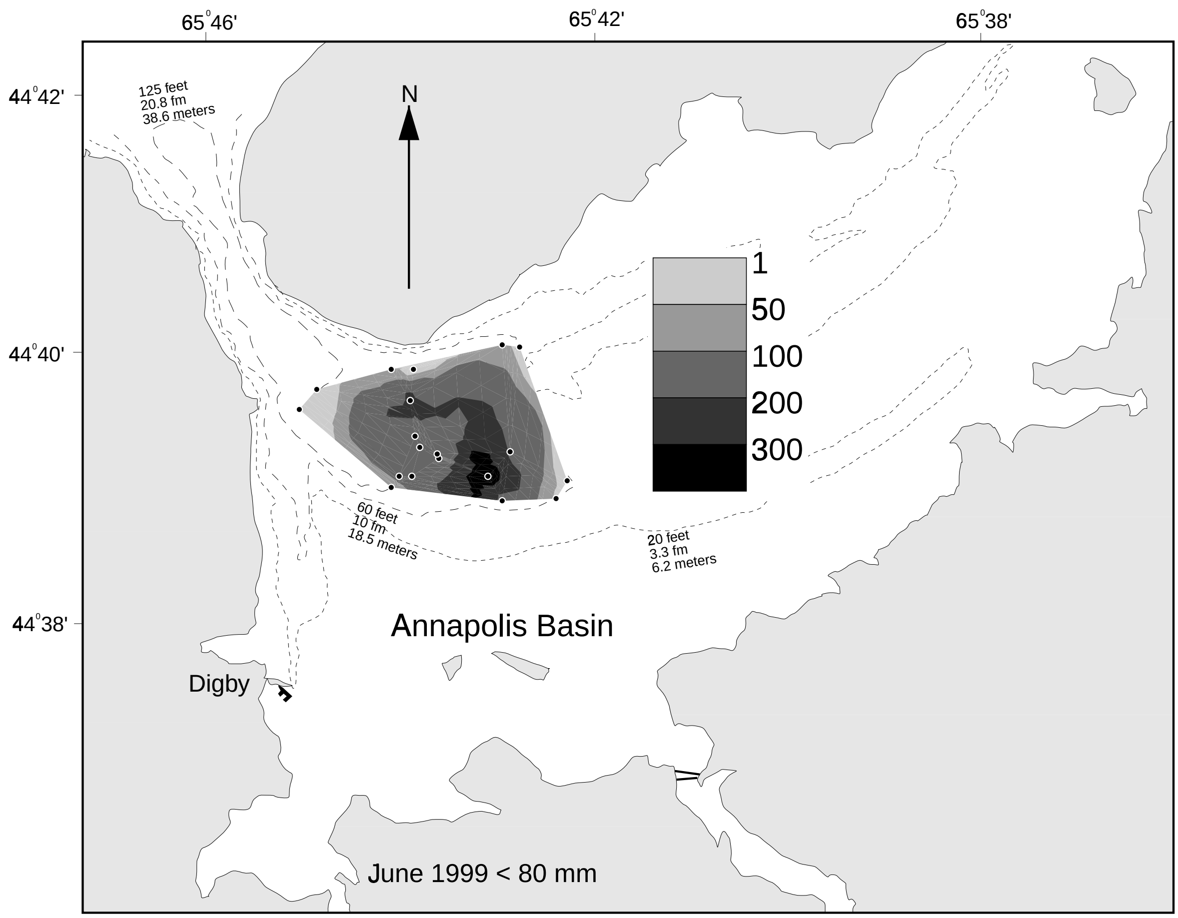

Fig. 18. Spatial distribution of scallop catches from 1999 survey of SPA 5 for scallops with shell heights less than or equal to 80 mm. Contouring was derived using Delauney triangles and inverse distance weight interpolation.

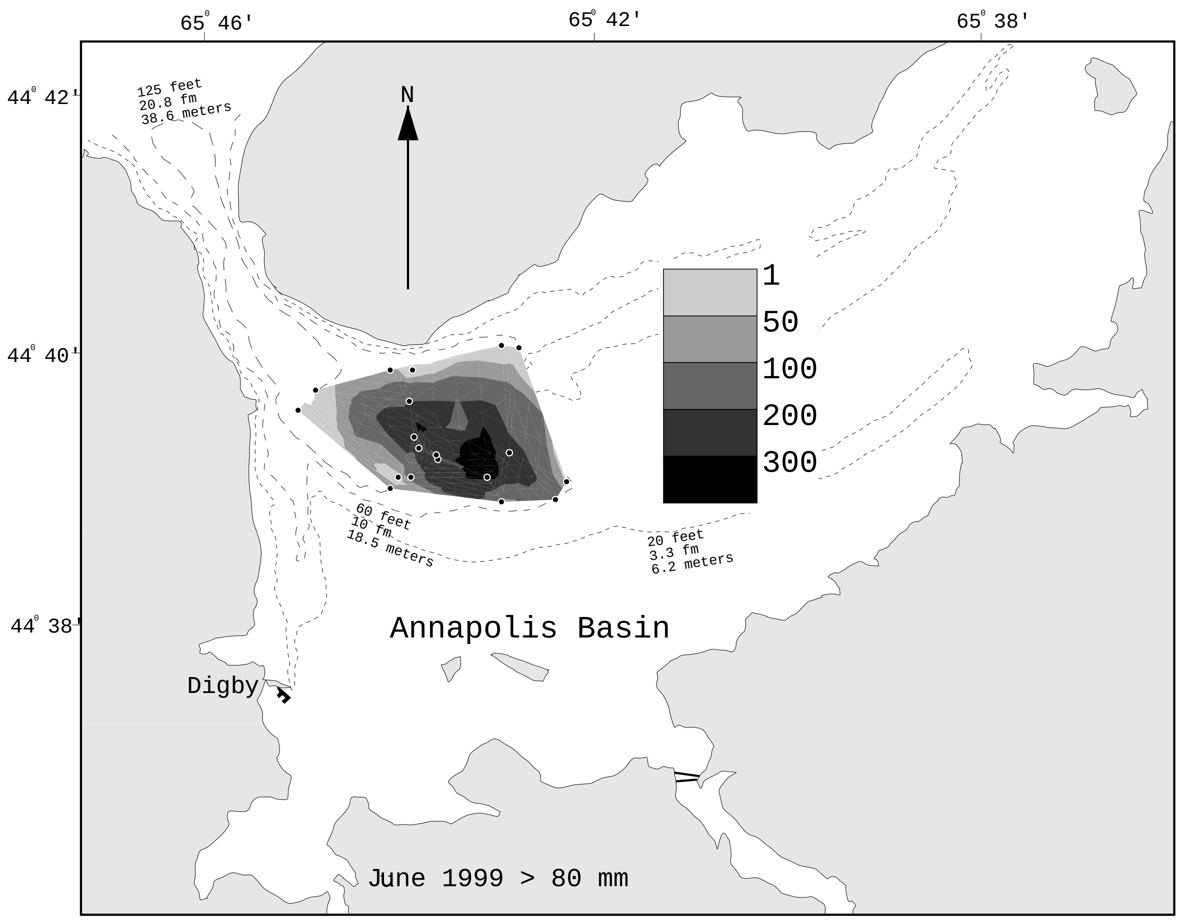

Fig. 19. Spatial distribution of scallop catches from 1999 survey of SPA 5 for scallops with shell heights greater than 80 mm. Contouring was derived using Delauney triangles and inverse distance weight interpolation.

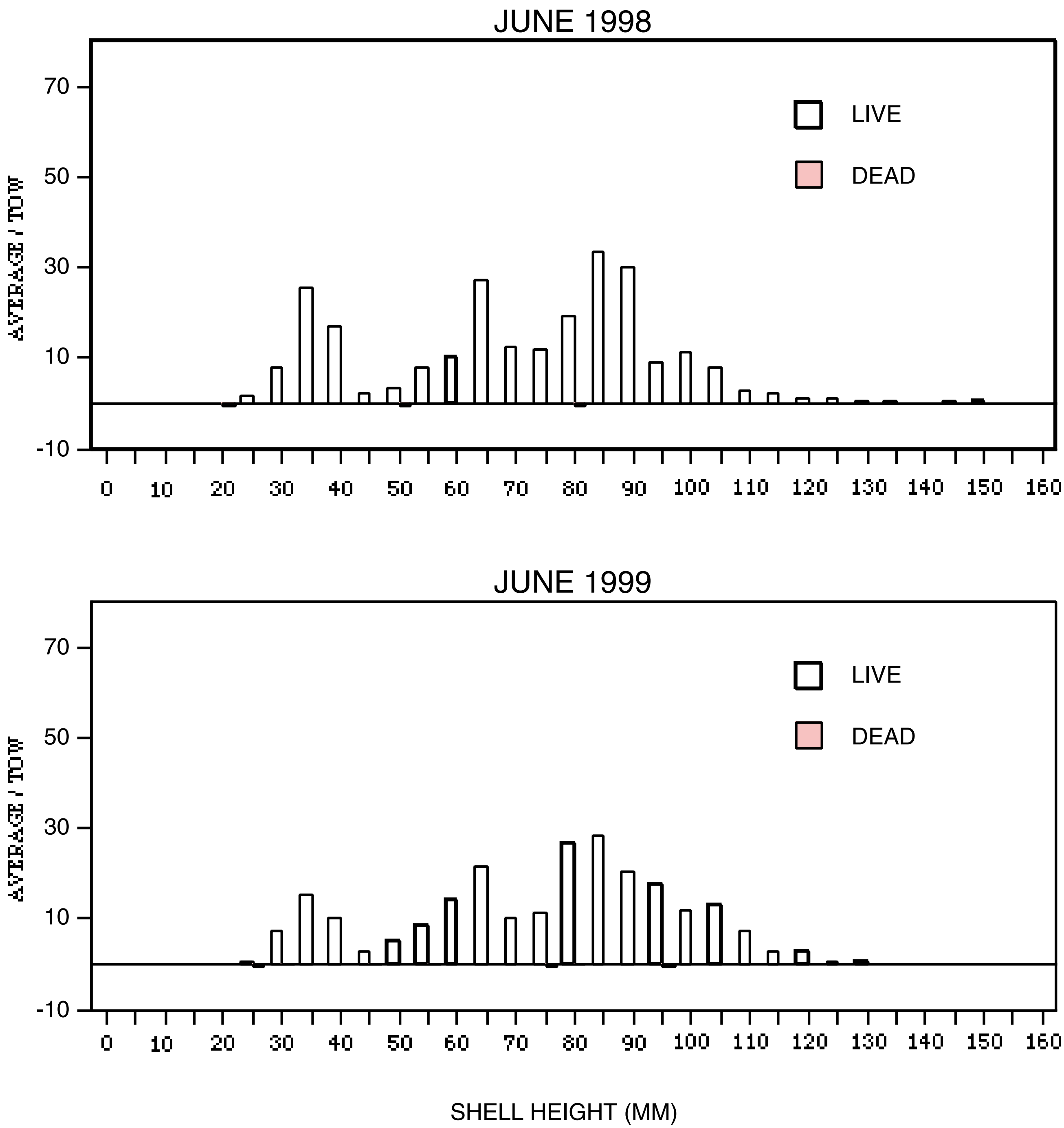

Fig. 20. Shell height frequencies (mean number per tow) from the June 1998 and 1999 surveys of Scallop production area 5.

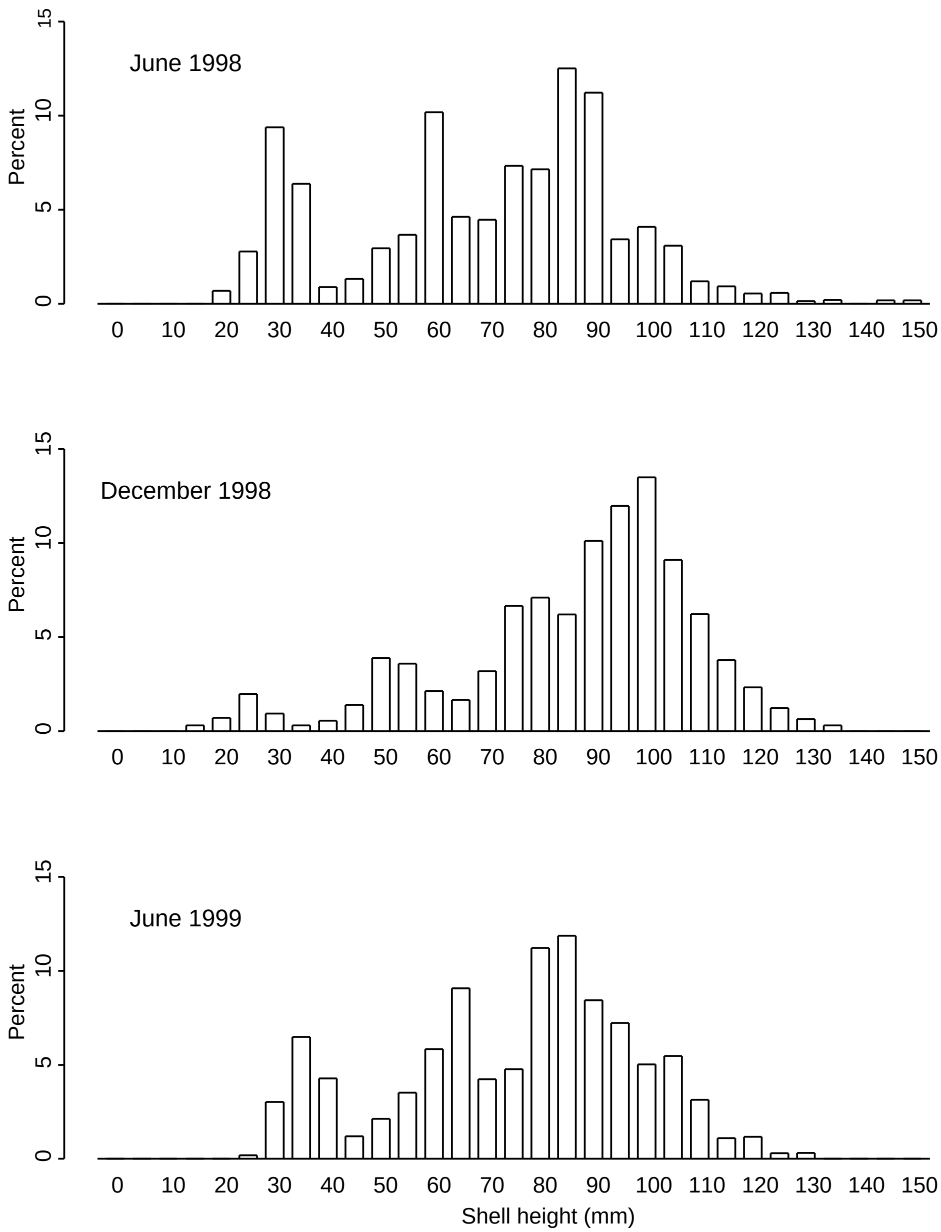

Fig. 21. Shell height relative frequencies (mean number per tow) from the June 1998, December 1998 and June 1999 surveys of Scallop production area 5.

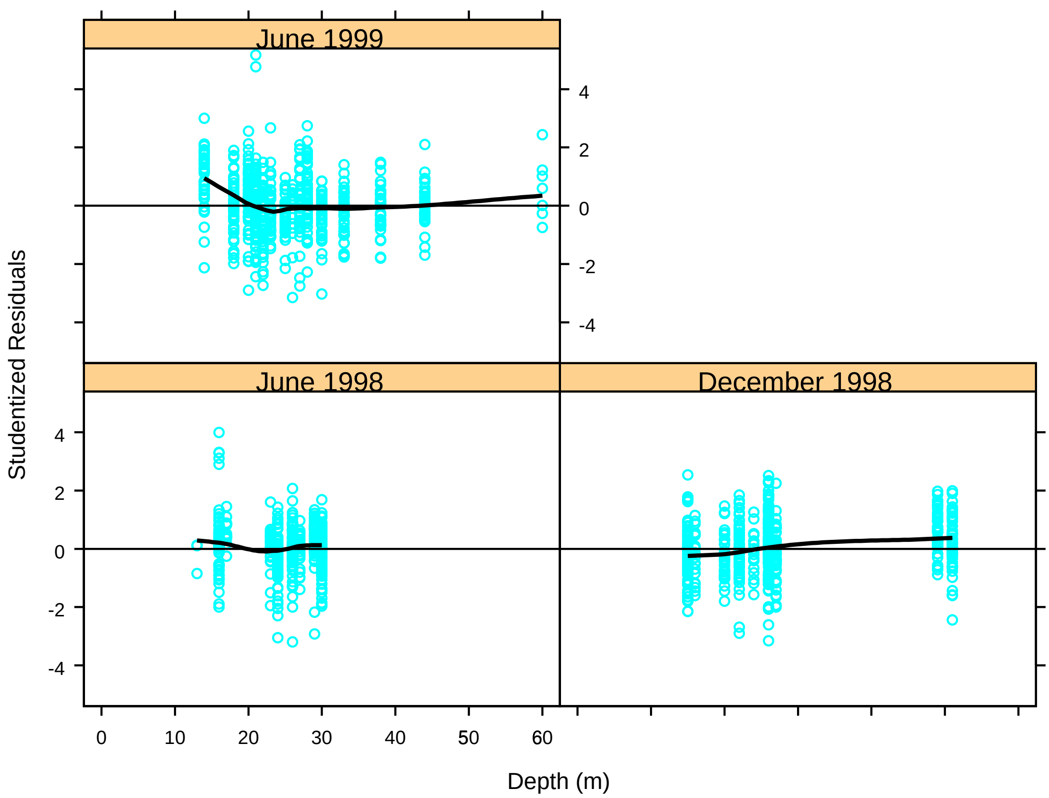

Fig. 22. Studentized residuals from fit of linear model of log(meat weight) as a function of log(shell height) for scallops from June 1999 survey of Scallop production area 5. Loess curve used to detect trend in residuals.

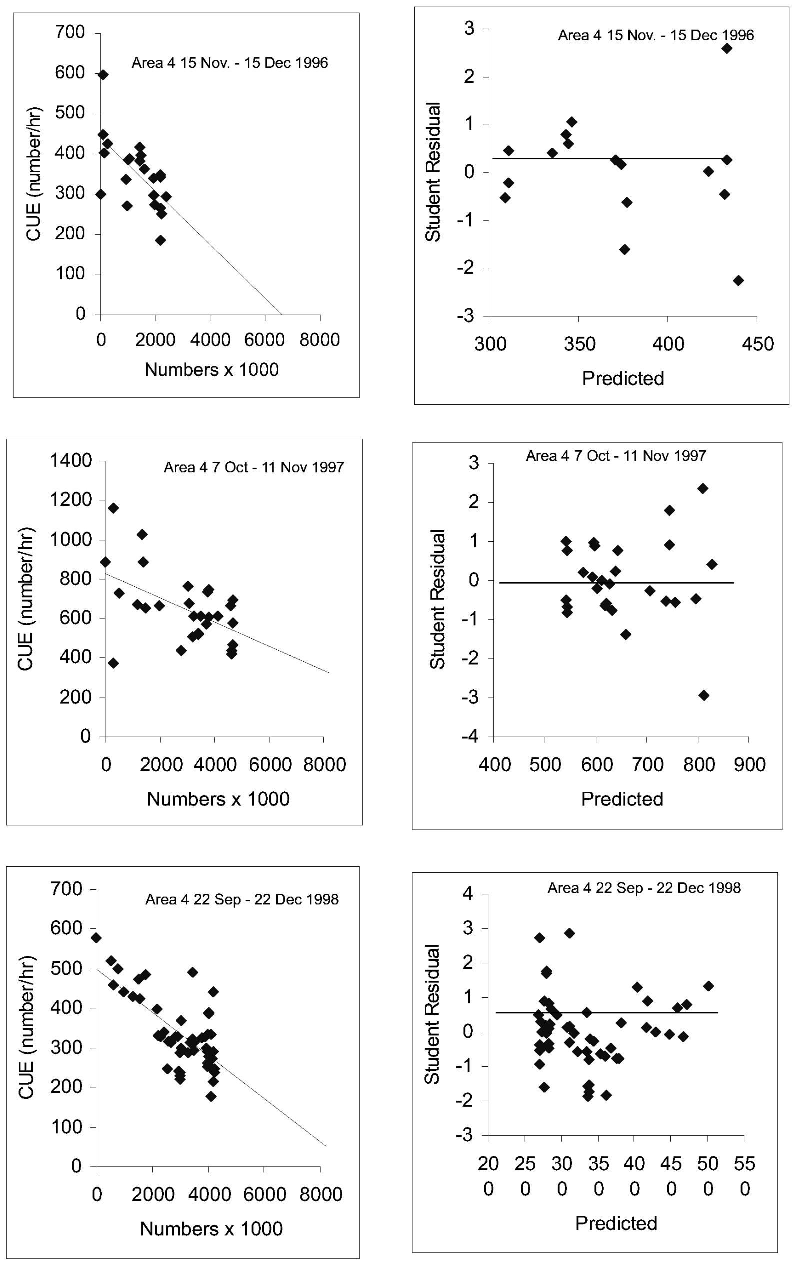

Fig. 23. Analysis of commercial catch rate data. Left panels: Plots of catch per unit effort (CPUE) against cumulative catch. Solid lines represent regression lines used in Leslie analysis. Right panels: Residual plots from regression analyses.

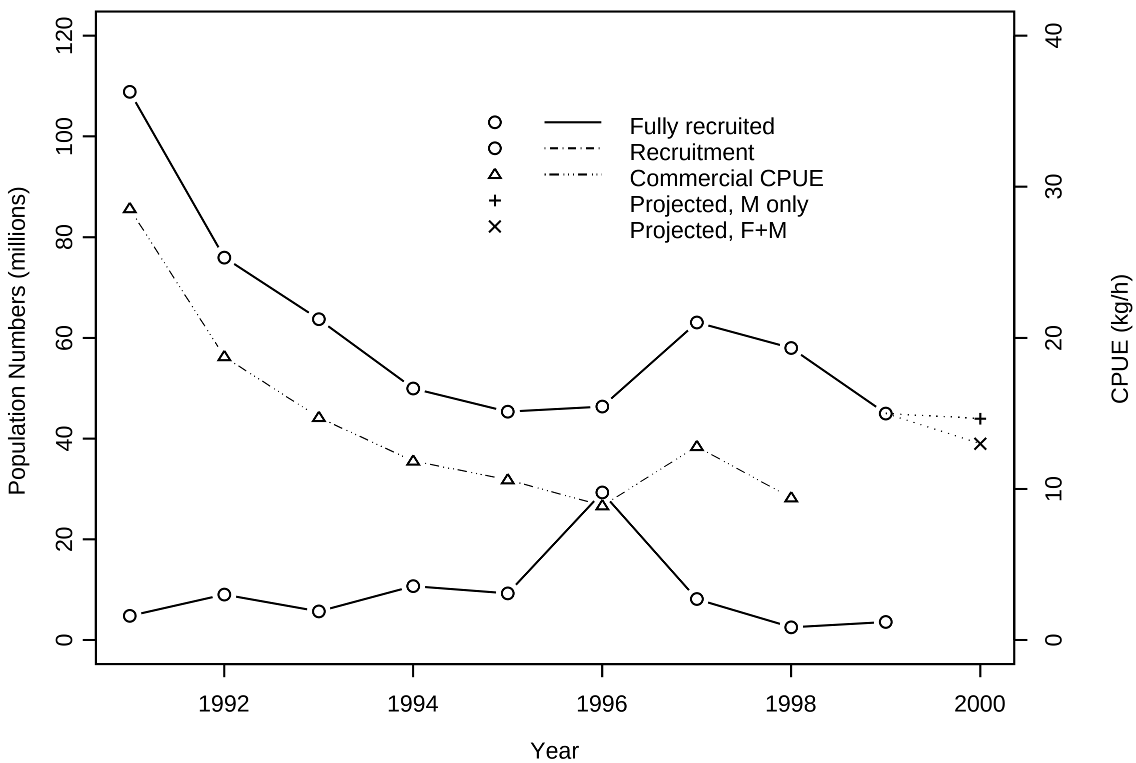

Fig. 24. Predicted population numbers of fully recruited (80 mm + shell height) and recruiting (55–80 mm shell height) scallops in scallop production area 4. Projected, M only refers to the projected population size in 2000 if no fishing occurs. Projected, F+M refers to the projected population size in 2000 if the TAC of 120 t is taken during the 1999 fishing season. Commercial catch-per-unit effort also presented for comparison.

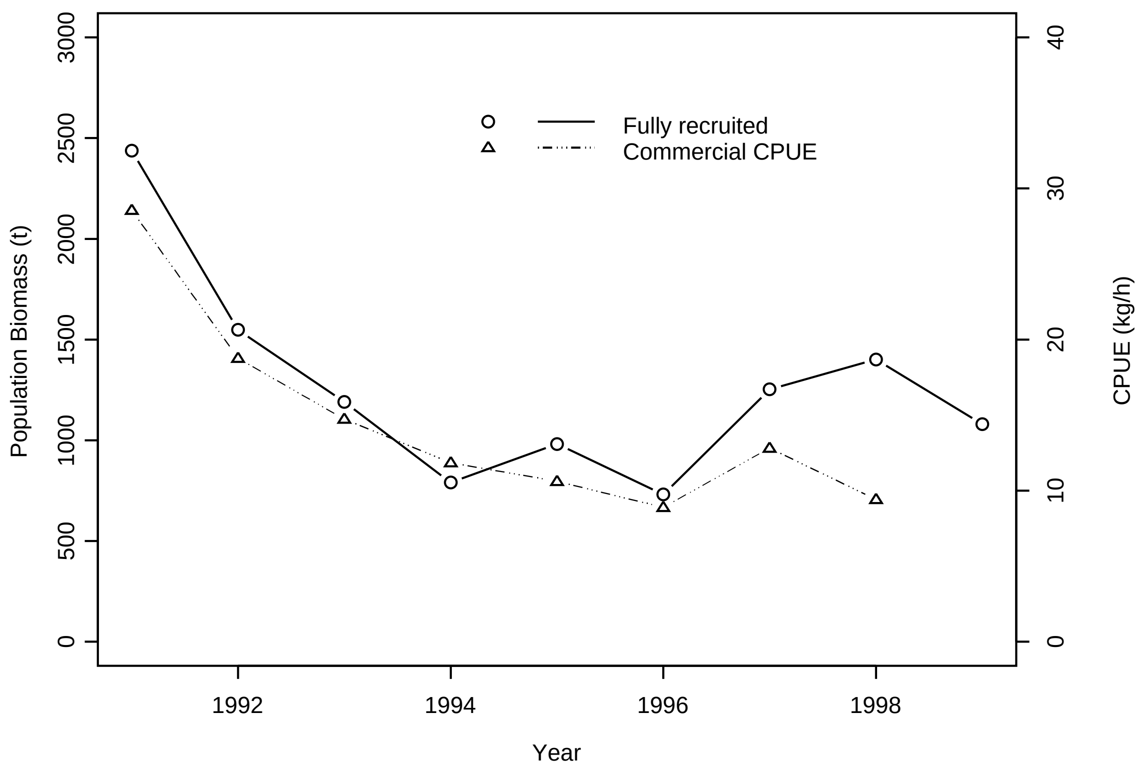

Fig. 25. Predicted population biomass of fully recruited (80 mm + shell height) scallops in scallop production area 4. Commercial catch-per-unit effort also presented for comparison.