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# SPA 4 Scallop stock assessment:  Survey update and stock status

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## Abstract

An area-based management plan comprising of seven scallop production areas was implemented for the Bay of Fundy scallop fishery on 1 January 1997. This document reviews the data from the 1997 fishery and 1998 research survey for Scallop Production Area (SPA) 4 which lies off of Digby, Nova Scotia. A total of 116.1 t was landed in SPA 4 in 1997, exceeding the quota of 100 t by 11 November, with an average catch per unit effort of 12.81 kg/h. Research survey estimates continue to show that the 1992 and 1993 year-classes are strong with the former year-class being recruited to the fishery in 1998. However, the bulk of these year-classes are in areas in which scallops tend to exhibit low yield. The survey does not show any signs of strong recruitment for scallops <80 mm in shell height. The 1998 fishery was opened with a 100 mm shell height restriction, maximum of 40 meats per 500 g and 120 mt total allowable catch. Based on survey estimates of population meat weight, 120 mt implies an exploitation of approximately 18 to 21 percent. The validity of these estimates of exploitation depends upon our estimates of the catchability of scallops to the survey gear which are rudimentary at best.

## Résumé

Le 1$^{er}$ janvier 1997, on a mis en œuvre, pour la pêche au pétoncle dans la baie de Fundy, un plan de gestion zonale englobant sept zones de production du pétoncle. Le présent document passe en revue les données de la pêche de 1997 et le relevé de recherche de 1998 pour la zone de production du pétoncle (ZPP) 4, située au large de Digby, Nouvelle-Écosse. Un total de 116,1 t de pétoncle a été récolté dans la ZPP 4 en 1997; le quota de 100 t a été dépassé dès le 11 novembre, les prises moyennes par unité d'effort se situant à 12,81 kg/h. Les estimations faites à partir des données du relevé de recherche continuent à montrer que les classes d'âge de 1992 et 1993 sont abondantes, la première ayant été recrutée au sein de la population exploitable en 1998. Toutefois, la plus grande partie de ces classes d'âge se retrouve dans des eaux où l'espèce a tendance à montrer un faible rendement. Les données de relevé n'indiquent pas un recrutement important de pétoncles à coquille de moins de 80 mm de longueur. La pêche en 1998 a été régie par une longueur minimum de coquille de 100 mm, un maximum de 40 morceaux de chair par 500 g et un total des prises admissibles (TPA) de 120 tm. D'après des estimations basées sur le relevé du poids des chairs de la population, un TAC de 120 tm laisse supposer un taux d'exploitation d'environ 18 à 21 %. La validité des estimations du taux d'exploitation dépend de nos estimations de la capturabilité du pétoncle avec les engins de pêche des relevés de recherche, pour le moins rudimentaires.

## Introduction

An area-based management plan comprising of seven scallop production areas was implemented for the Bay of Fundy scallop fishery on 1 January 1997. Scallop Production Area (SPA) 4 lies off of Digby, Nova Scotia (Fig. 1) with boundaries defined by a polygon with the following vertices: 44° 48.8 N, 65° 32.3 W; 44° 56.5 N, 65° 36.0 W; 44° 37.3 N, 66° 10.0 W; and 44° 29.9 N, 66° 06.5 W. SPA 4 is equivalent to the former "Inside Fishing Zone" management area but extends to eight miles (instead of six) from shore.

It is difficult to present a consistent history of the current management area prior to 1997 because different parts of the new area have been under different management regimes in the past. The following brief review of the history of the scallop fishery in this area has been abridged from earlier documents (Kenchington et al. 1997, Kenchington and Smith 1997).

The Digby scallop beds have been fished according to seasonal zones prior to 1996. The "Inside Fishing Zone" encompassed an area 6 miles from shore, extending from Parker's Cove to Centreville and was closed by regulation from 1 May to 30 September. The remainder of the Digby beds did not have season restrictions and were collectively referred to as the "Outside Fishing Zone". In 1987, the Inside Fishing Zone was extended to 8 nautical miles from shore (to protect small scallops), to the equivalent boundaries of the present SPA 4. In 1992, the Inside Zone returned to the 6 mile distance from shore. Scallop abundance has been highly variable over the 1986–1996 period and two strong recruitment pulses (1984 and 1985 year-classes) contributed to unprecedented high landings from 1988 through to 1991. While, these recruitment pulses were observed in many parts of the Bay of Fundy, the greatest concentration of scallops occurred in the Inside Fishing Zone. Heavy fishing and an unexplained mass mortality event abbreviated the life expectancies of these year-classes. Landings have declined since 1990. In 1995, the fall fishery in the Inside Fishing Zone regulation was closed to protect broodstock and the few pre-recruit scallops that had been detected.

That part of SPA 4 which was the former Inside Fishing Zone was not fished in 1996 except for a limited fishery in a portion of the area from the Digby Gut to Port Lorne. Fishing was allowed from 15 November to 15 December 1996 and was conducted under a dockside monitoring condition. The meat count was set to a maximum of 40 meats per 500 g. Fishing continued in the six to eight mile section (part of former Outside Fishing Zone) of the current SPA 4 zone, until 1 January 1997 when the new areas were established.

In this document we evaluate the information on the 1997 fishery and the 1998 research vessel survey to predict the current status of the scallop stock in SPA 4. At the time that this document was being prepared for peer review, the proposals

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for the 1998 fishery by the Department of Fisheries and Oceans were to set a 100 mm minimum shell height, a maximum of 40 meats per 500 g and allocate 120 mt total allowable catch. However, the fishery was opened early, prior to the peer review meeting with the above proposals being implemented without change.

Results from the 1997 survey of the previously unsurveyed 0 to 2 mile inshore portion of SPA 4 are also presented here.

## Commercial Fishery

In 1997, the scallop fishery in SPA 4 (Sandy Cove to Parkers Cove) occurred from 7 October to 11 November with a meat count restriction of a maximum of 33 meats per 500 g. Minimum shell height was set to 110 mm with a quota of 100 t. A total of 116.1 t was landed in SPA 4 with an average catch per unit effort of 12.81 kg/h (Table 1). A total of 75 vessels fished in this area. The official landings of 116.1 t is probably an underestimate given the reports of misreporting and illegal fishing.

Landings SPA 4 (metric tons of meat)

| Year | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 |
|------|------|------|------|------|------|------|------|
| SPA 4 | 678.7 | 318.4 | 244.2 | 162.7 | 94.8 | 71.2 | 116.1 |

The distribution of fishing effort (days fished) taken from log books has been mapped for all scallop fishing trips in 1996 (Fig. 2) and 1997 (Fig. 3). The boundaries for SPA 4 are shown on both figures and delineate the fishing effort associated with this management unit. The map for 1996 very clearly shows the exclusion of most of the fishery from Digby Gut to the southern edge of SPA 4. In 1997, the fishery was unrestricted with respect to location in SPA 4 but mainly concentrated activity in the deeper water off of Digby Gut and into the Gulliver's Head area. The major part of the effort was expended in October and fishing locations were located throughout the area (Fig. 4). In November the fishery was reduced to mainly locations in the deeper part of Digby Gut (Fig. 5)

Catch per unit effort has decreased consistently from 1991–1996 but improved in 1997 (Fig. 6). The low estimate in 1996 was probably due to the restricted fishery that year. The higher catch rate in 1997 may reflect fishing in the higher scallop density areas south of Digby Gut.

## Commercial Port Sampling

Port sampling of the commercial catch resulted in 1361 measurements of meat weights from the 1997 fishery (Table 2). Frequency distributions of the meats

presented in Fig. 7 have been scaled to the estimated total number caught in the fishery. Samples taken in November, albeit few in number, appear to indicate that there was a trend towards catching smaller scallops during November (Fig. 7). This trend was opposite to that observed for the 1996 fishery. However, these trends must be interpreted with caution. The port samples from November in 1996 came from a number of locations throughout SPA 4 representing both low (>6 miles off of Gulliver's Head) and high yield areas (Digby Gut and Delaps Cove; Fig. 8). In December, the samples mainly came from high yield areas. Therefore, the meats in the December samples tended to be larger than those in the November samples. The fishery did not change locations substantially over November to December 1996 (Figure not shown here) and the meat size trends reflect differences in the spatial locations of the samples in the two months.

In 1997, the October samples were mainly from mid-shore to inshore areas (Fig. 9) while the November samples came from the deeper offshore areas. While the fishery in November was in deeper water than in October and hence landing smaller meats sizes, the landings overall were quite small in the latter month (Fig. 7).

**Research Vessel Survey**

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

The survey was conducted using the research vessel **J. L. Hart** with four gang gear. The gear configuration consists of 76 cm inside width drags made of 7 rows of 4 mm steel wire rings with 75 mm inside diameter. The rings are knit with rubber washers, 9 across and 3 on the side fastened to an angle iron frame at the mouth and a piece of wood (2 in. by 4 in) or plate steel at the tail end. This gear has been shown to actively select against small scallops which can either avoid the drag path or if caught, escape through the steel rings (Robert and Lundy, 1989). To estimate the relative abundance of small scallops (<80 mm shell height), two of the four drags were lined with 38 mm polypropylene mesh. Previous work has shown that the catch of scallops with shell height 40 mm and less by this gear is not a reliable index of abundance for scallops of these sizes (Kenchington et al. 1997) and estimates are only used as qualitative indicators of potential recruitment. The final estimate of catch numbers for each tow are obtained from the catches of scallops with shell height <80 mm in the lined gear and shell height $\geq$ 80 mm in the unlined gear which are then combined and prorated to conventional 7 gang gear to allow for annual comparisons.

## Abundance Trends

The mean number per tow for all size groups combined and associated standard errors of the means for each stratum are presented in Table 3. The allocation of the number of tows to each stratum was designed to be proportional to the abundance in each stratum in the surveys over the years 1994 to 1996. Using mean abundance as a proxy for the stratum variance this allocation scheme was aimed at increasing the efficiency of the survey design and hence provide as precise an estimate of abundance as possible. Efficiency was measured by comparing the variance from the stratified random design with that expected for a comparable simple random sampling design. The current allocation scheme had improved the efficiency of the 1997 survey over the 1996 survey (39.6 percent reduction from the simple random variance versus 8.21 percent, respectively). This year the efficiency was at 43.3 percent indicating that the allocation scheme continues to work quite well for providing precise estimates.

The highest concentration of scallops continues to be in the strata below Digby Gut towards the mouth of the Bay (Kenchington and Smith, 1997). Overall, the catch of clappers was 6.2 percent of the total catch of live scallops and the higher incidences of clappers were in the Gulliver's Head to Centreville strata. While this percentage is higher than observed in 1997 (4.3 percent) it is lower than those for previous years which ranged from 5.3 to 12.5 percent.

The stratified mean catch per tow by size group is presented in Fig. 10 along with the shell height frequency for the clappers caught during the survey. Most of the live scallops caught in the survey were in the 80 mm and larger size classes. There appears to be little indication of potential incoming recruitment in the <80 mm size range. The majority of the clappers in the survey were in the 100 to 135 mm shell height range and these were mainly found in the Centreville to Gulliver's Head strata.

Industry reports of large numbers of clappers in the Centreville area in 1997 were investigated by the second author. A total of eighteen tows by the Fishing Vessel Julie Ann Joan were observed on 22 October 1997 and the percentage of clappers in the total catch was 12 percent of the live catch in numbers. This is comparable to the 9.8 percent in the Centreville area in the 1998 survey (Table 3). The shell height frequency for live and dead scallops is presented in Fig. 11. The shell height frequency for the clappers in Fig. 11 was very similar to that in Fig. 10 for scallops >80 mm.

Shell height frequencies from the June surveys for 1991 to 1998 are presented in Fig. 12. The line plot on the 1998 panel represents the average shell height frequency for 1991 to 1997. Recruiting year-class(es) are evident in the 1995 (possibly in 1994) panel along with the increase in shell-height of these year-

classes in the subsequent years. These year-classes appear to be mainly in the 80 to 110 mm size classes at present.

The spatial distribution of all sizes combined is portrayed as a contour plot in Fig. 13 and shows the larger survey catches being in the Centreville to Gulliver's Head strata with some smaller concentrations in the deeper water of Digby Gut and Delaps Cove strata. Contours were constructed using Delauney triangulation and inverse distance-weighted interpolation (Black 1998).

The spatial distribution of scallops <80 mm shows some settlement in all strata with the major proportion being in the deeper water of Centreville, Gulliver's Head, Gullivers to Digby Gut and Delaps Cove (Fig. 14). The major portion of those animals that will be recruiting to the fishery in the next year (80–99 mm) are concentrated in the deeper water of the Centreville to Gulliver's Head strata (Fig. 15). Previous reports have identified these animals as being of the relatively strong 1993 year-class (Kenchington et al. 1997, Kenchington and Smith 1997). Based on the parameters of the von Bertalanffy growth model presented in Kenchington et al., (1997) age 5 scallops are expected to have shell heights between 89 and 103 mm over the different strata. This year-class was detected first in the 1995 survey and was consistently found to be mainly distributed in the same strata that they were observed in during the 1998 survey.

Scallops with shell heights of 100 mm or more were more widely distributed than the size class of 80 to 100 mm (Fig. 16). In addition to being abundant in the Centreville to Gulliver's Head strata, there were also concentrations of these size classes in the deeper water of Digby Gut and Delaps Cove. The largest single component of the ≥100 mm size class will be the 1992 year-class which is expected to be between 99 and 111 mm in shell height at age 6. This year-class has been categorized as above average in abundance at earlier ages but not as abundant as the 1993 year-class.

Trends of the survey indices for these three size classes show the appearance of the 1992 and 1993 year-classes in the <80 mm group in 1994 to 1996 and the subsequent increase in the two larger size groups as they increased in shell height (Fig. 17). Currently, there are no signs of any new large year-classes in SPA 4 in the <80 mm size class. The time series in Fig. 17 is broken down by stratum in Fig. 18. The largest increases in the 80–99 mm shell height group are in the Centreville and Centreville to Gulliver's Head strata, while the remaining strata show a decline in the abundance of this size group over that observed in 1997. While most strata show an increase in the ≥100 mm size class, the larger increases are in the Centreville to Gulliver's Head strata and the Digby Gut strata.

## Meat weight/Shell Height Relationships

As in previous documents, meat weight has been predicted from shell height using a regression of the natural logarithms of weight on height. Unlike the previous two years where the entire catch was measured, meats were subsampled in 1998 by taking two weight samples for each 5 mm shell height increment. Parameter estimates for the 1998 data are given in Table 4. The predicted average weight for a scallop with shell height of 100 mm and the resultant meat count are given in the two rightmost columns. The results in this table differ little from previous analysis of data from SPA 4 (e.g., Kenchington et al., 1997) and continue to show that scallops in the Centreville, Centreville to Gulliver's Head and the deeper water of the Gulliver's Head strata exhibit the poorest yield in the area.

The parameter estimates in Table 4 were used to estimate the meat weight at shell height for each tow and the stratified estimate of the total meat weight in the survey area was estimated (Table 5). Total meat weights (t) for the eight years of the survey are given below. The 95 percent bootstrap confidence limits for the 1998 estimate for all sizes were 223.2 and 311.6 t.

Survey estimates of weights of meats (t).

|  | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| All sizes | 438 | 299 | 288 | 215 | 194 | 230 | 236 | 264 |
| ≥100 mm | 350 | 258 | 253 | 191 | 142 | 144 | 160 | 195 |
| ≥110 mm | 271 | 205 | 208 | 153 | 115 | 106 | 158 | 128 |

In 1998 195.2 t (95% CL = 170.1, 223.7) of the 264 t total meat weight was in the ≥100 mm shell height class with a large portion (41 percent) located in the Centreville to Gulliver's Head strata (Table 5). Again, these are the strata that exhibit the poorest yield of all of those in the survey. The next largest portion (25 percent) was located in the Digby Gut stratum. Total meat weights for last year's minimum shell height of 110 mm are also shown for comparison. Approximately 33 percent of the meat weight for shell heights ≥100 mm appears to be due to the 1992 year-class.

Survey estimates of meat weight are expected to be less than the actual amount in the population. The difference between survey and population amounts is assumed to be a function of the selectivity of the survey gear and the availability of the scallops to the gear. In Kenchington et al. (1997) the total weight of meats in the population was estimated to be between 3.0 and 3.5 times that estimated for the survey. These estimates require more study and verification before they can be routinely used.

Survey trends of meat weights for all shell heights and for shell heights ≥100 are compared with the CPUE estimates from the commercial fishery in Fig. 19. The survey estimates were originally expressed as kg per 8 minute tow and have

been recalculated here as kg per hr to correspond to the units of the commercial catch rate. Overall the trends in the survey and commercial catch rates are similar. Differences in magnitude probably reflect the fact that the survey fishes at random stations while the fishery will tend to concentrate in areas of high abundance.

Numbers-at-age

As in previous reports (e.g., Kenchington et al. 1997, Kenchington and Smith 1997), numbers-at-shell height were converted to numbers-at-age using a method called cohort slicing (Table 6). This method was used because actual ages from the shells are not available for all years. Cohort slicing uses a series of von Bertalanffy growth models to estimate area-specific mean shell heights-at-age and then assigns ages to shell heights according to the expected range above and below the mean shell height for each age. This method does not allow for overlap in shell heights between age groups and will tend to misclassify age groups more for older age groups than for younger ones. Even with these shortcomings, the 1992 and 1993 year-classes as identified by this method (boldface in the table) can be tracked in the table and appear to be more abundant than adjacent year-classes.

Total Mortality Estimates

Total mortality estimates (method given in Appendix) have been constructed for this stock using survey catch-at-age for the whole survey. Kenchington and Smith (1997) reported that based on these total mortality rate estimates, the effects of the 1996 fishery were not detectable from the 1997 survey. However, the whole area is not always fished and the fishery in 1996 was confined to the Digby to Parker's cove strata area (Fig. 13). In 1998 the total mortality was estimated by using numbers-at-age estimates calculated as above for each of the zones previously identified according to commercial catch levels (Robert et al. 1985, Kenchington et al., 1997): **Core** Area (Gulliver's Head, Gulliver's Head to Digby, Digby, Digby to Delaps Cove and Delaps Cove strata), **Below** the Core area (Centreville, Centreville to Gulliver's Head Strata) and **Above** the Core area (Parker's Cove). These estimates are presented in Table 7 where the Core area has been further subdivided into **Core A** (Gulliver's Head, Gulliver's Head to Digby strata) and **Core B** (Digby, Digby to Delaps Cove and Delaps Cove strata).

With reference to the entries for 1996–1997 (Table 7) for all the age groups considered, the effect of the 1996 fishery is now evident. While the estimate for total mortality was low or negative for the Core area as a whole, the estimates for Core B which excludes the Core A area which was closed to fishing, show that total mortality ranged from 0.27 for the 4+/5+ groups to 0.66 for the 7+/8+ age groups. These estimates (assuming natural mortality of 0.1) imply exploitation rates of 15 and 41 percent, respectively. In fact exploitation

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appears to be greater than 31 percent for age groups 5 and older in these strata. Total mortality ranged from 0.20 to 0.50 (exploitation rate of 10 to 31 percent) for these same age groups in the Parker's Cove stratum (Above). The Core A strata were not closed to fishing in 1997 (fishery in Fig. 3 and survey in Fig. 14) and total mortality ranged from 0.34 to 0.63 (exploitation rate of 20 to 39 percent) over all age groups. On the other hand, the Core B strata were not heavily fished in 1997 (Fig. 3) and the mortality rates appeared to reflect this (-0.22 to 0.07). It is possible that the recruitment of the 1992 year-class in 1998 may have offset losses due to the 1997 fishery in the Core B area given the concentration of this year-class in this area as shown in Fig. 16. On the other hand the Parker's Cove area did appear to have experienced high mortality rates of 0.55 to 0.65 (exploitation rates of 35 to 40 percent) despite their being little evidence for fishing in that area (Fig. 3).

The validity of these mortality estimates are highly dependent upon the quality of the survey catch-at-age estimates. Given the problems noted earlier with the cohort slicing method for assigning ages, these estimates may have some value in a relative sense but can not be used to estimate absolute estimates of total mortality.

Inshore Survey

The annual survey of SPA 4 does not include the area from the shoreline to two miles out. Currently, abundance estimates for the surveyed area (two to eight miles from the Nova Scotia shore) are extrapolated to include the zero to two mile zone assuming similar densities in the two zones. In 1997 a survey of the inshore area was conducted on the F/V **Nova Delight** (owner: M. Longmire) to determine the scallop density and abundance in the zero to two mile zone. This preliminary survey consisted of 20 tows in the inshore area on 11 September and was conducted according to the protocols outlined above for the June survey. The tows were randomly assigned to the zero to two mile portions of the strata used in the June survey. Estimates of total numbers and numbers by shell height class are presented in Table 8. The majority of the animals were larger than 100 mm in shell height. In fact, 53 percent of these animals were larger than 110 mm. There doesn't appear to be any strong signals for the 1993 year-class in this area. However, none of the shells have been aged so we are uncertain what age-classes we are dealing with here.

The current method of extrapolating abundance over the inshore zone implies that 25 percent of the total abundance would be found there. In 1997, the estimate from the June survey for the zero to two mile zone would be 5,194,744 scallops. The estimate from the inshore survey was considerably less than this (1,464,663) and suggests that our assumption about area extrapolation of abundance is incorrect. We will be conducting another inshore survey with a commercial vessel this September to further investigate the abundance of scallops in the inshore area.

Parameters for the shell height/meat weight regressions are presented in Table 9. Shell height and meat weight measurements were taken from all scallops caught in the survey. Entries marked as NS in the table indicate that the ranges of shell heights in the sample were not broad enough or the sample size was not large enough to obtain a significant estimate of the slope and intercept. Comparison of these estimates with those in Table 4 is not straightforward given that these measurements were taken in September after spawning had occurred while the earlier measurements were made prior to spawning. However, the predicted weight for the 100 mm shell height for the Digby Gut area in Table 9 is slightly less than that predicted for expected meat weight in September for that area (15.56 g) reported by Roddick (1997).

## Summary

- Landings in 1997 of 116 t exceeded the quota of 100 t by 11 November.

- 1998 survey abundance indices indicate that there was little sign of recruitment in the <80 mm shell height class.

- The survey continued to find the above average year-class (1993) which is now in the 80–99 mm shell height class and this year class continues to be abundant mainly in the Centreville to Gulliver's Head (deeper water) strata. Scallop in these strata typically exhibit slower growth and lower yield than in the other strata.

- Abundance indices for scallops with shell heights $\geq 100$ mm (major year-class was 1992) show increases over 1997 but 51 percent in numbers and 41 percent of the meat weight of the scallops in this size class were located in the Centreville to Gulliver's Head strata. The area of next largest concentration was mainly in the deeper waters off of Digby Gut (20 percent by number and 25 percent by weight).

- Based on earlier studies of seasonal changes in meat weight (Kenchington et al. 1994, Roddick et al. 1994, Roddick 1997) it is likely that all scallops with shell height $\geq 100$ mm in the strata from Gulliver's Head to Digby Gut to Parker's Cove will have meat weights in excess of 12.5 g (40/500 count). However, those studies were specific to the Digby area and it is uncertain what the extent of the seasonal changes would be in the poorer yield areas (Centreville to Gulliver's Head).

- Total mortality estimates from survey numbers-at-age data indicate that in 1997 fishing mortality was highest in the Gulliver's Head, Gulliver's Head to Digby and Parker's Cove strata.

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- The 1998 survey estimate of the total weight of meats for scallops with shell heights ≥100 mm is the highest since 1993 again mainly due to the recruitment of the 1992 year-class. However, 41 percent of this total weight is located in the Centreville to Gulliver's Head strata where the 1993 year-class is also located. Restricting the catch to shell heights greater than 100 mm in these areas should protect the 1993 year-class, however enforcement of this restriction by the Department may be problematic.

- At present the TAC of 120 mt can only be evaluated by assuming a catchability for the survey estimate of total meat weight to calculate population estimates. Assuming that the survey estimate of 195 mt (meat weight) represents approximately 29 to 33 percent of the actual population meat weight (due to gear efficiency), this implies a population meat weight of 585 to 680 mt for scallops with shell height ≥100 mm. Therefore, the TAC of 120 mt would correspond to an exploitation rate of approximately 18 to 21 percent.

## Acknowledgments

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**Appendix:**

Total mortality estimates are obtained by taking the log ratio of numbers for one age group (e.g., sum of the numbers of scallops at ages 4 and older) in one year and those for the next age group (e.g., ages 5 and older) in the next year. For example, the total mortality for ages 4 plus in 1996, $Z_{4+,1996}$ was calculated as,

$$Z_{4+,1996} = \log_e \left( \frac{N_{4+,1996}}{N_{5+,1997}} \right).$$

Exploitation rate, which is the proportion of the population caught through fishing, s calculated as (assuming natural mortality equals 0.1),

$$E_{4+,1996} = \left( \frac{Z_{4+,1996} - 0.1}{Z_{4+,1996}} \right) \times \left( 1 - \exp\left( -Z_{4+,1996} \right) \right).$$

Table 1: Commercial catch per unit effort (kg/h) from Class 1 logs (logs with no information missing).

|  | Year | Mean | Std. Dev. | Min | Max | N |
|---|---|---|---|---|---|---|
| Inside | 1990 | 30.66 | 11.4 | 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 |

Table 2: Results of voluntary port sampling program in 1996 and 1997. Column labelled Count refers to meat count per 500 g.

| Year | Month | N | Meat Weight (g) | | | | Count per 500g | No. Vessels |
|---|---|---|---|---|---|---|---|---|
|  |  |  | Mean | S.D. | Min. | Max. |  |  |
| 1996 | November | 1250 | 12.41 | 9.57 | 4.0 | 49.7 | 40.3 | 10 |
| 1996 | December | 584 | 21.06 | 8.73 | 5.5 | 46.8 | 23.7 | 8 |
| 1997 | October | 1168 | 20.78 | 5.79 | 7.1 | 45.4 | 24.1 | 11 |
| 1997 | November | 193 | 14.39 | 4.79 | 6.3 | 29.7 | 34.7 | 3 |

Table 3: Estimates from stratified dredge survey for scallops, June 1998. Mean number per tow is for all size classes. The mean number of clappers is shown as a percentage in brackets after the mean number of live scallops caught per tow.

| Strata | No. of Tows | Proportion of area in stratum | Mean no. per tow (clappers) | Standard error |
|---|---|---|---|---|
| Centreville | 16 | 0.133 | 302.51 (9.8) | 72.063 |
| CV to GH | 12 | 0.067 | 228.59 (5.2) | 80.962 |
| Gulliver's Head | 20 | 0.137 | 156.88 (6.3) | 21.293 |
| GH to DG | 9 | 0.1007 | 66.15 (1.6) | 13.962 |
| Digby Gut | 19 | 0.2007 | 78.86 (3.3) | 13.468 |
| DG to DC | 6 | 0.1007 | 54.51 (1.5) | 3.948 |
| Delaps Cove | 9 | 0.1337 | 66.65 (3.7) | 20.793 |
| Parker's Cove | 9 | 0.1337 | 21.11 (4.4) | 5.311 |
| Stratified estimates | 100 | | 116.03 (6.2) | 12.123 |

Table 4: Parameter estimates for shell height/ meat weight regressions for data from 1998 survey. Sixth column givens the predicted meat weight for scallops in each area with shell heights equal to 100 mm. Last column presents meat counts for predicted meat weights.

| Subarea | N | slope | intercept | $R^2$ | Predicted weight (g) for 100 mm Shell height | Count per 500g |
|---|---|---|---|---|---|---|
| Centreville | 339 | 2.925 | -11.344 | 0.936 | 8.367 | 60 |
| CV-GH | 235 | 3.114 | -12.138 | 0.955 | 9.034 | 55 |
| Gulliver's<88m | 106 | 2.967 | -11.242 | 0.978 | 11.281 | 44 |
| Gulliver's>88m | 295 | 3.119 | -12.072 | 0.970 | 9.870 | 51 |
| GH-DG<88m | 84 | 3.016 | -11.372 | 0.983 | 12.414 | 40 |
| GH-DG>88m | 49 | 3.117 | -11.913 | 0.986 | 11.509 | 43 |
| Digby Gut<88m | 187 | 3.119 | -11.865 | 0.956 | 12.155 | 41 |
| Digby Gut>88m | 142 | 2.991 | -11.268 | 0.983 | 12.261 | 41 |
| DG-DC | 93 | 3.053 | -11.535 | 0.984 | 12.460 | 40 |
| Delap's<88m | 148 | 3.163 | -12.106 | 0.966 | 11.724 | 43 |
| Parkers | 70 | 2.993 | -11.341 | 0.975 | 11.492 | 40 |

Table 5: Stratified estimates of meat weights (t) for June 1998 survey. Meat weights estimated for total catch and for that catch ≥100 mm shell height.

| stratum | Meat weights (t) | | Shell height ≥100 mm | |
|---|---|---|---|---|
| | All Sizes | Shell height ≥100 mm | Proportion of stratum | Proportion of ≥100 mm |
| Centreville | 64.63 | 34.41 | 0.53 | 0.18 |
| CV to GH | 27.45 | 15.88 | 0.58 | 0.08 |
| Gulliver's Head | 43.87 | 28.32 | 0.65 | 0.15 |
| GH to DG | 21.47 | 19.49 | 0.91 | 0.10 |
| Digby Gut | 51.93 | 48.19 | 0.93 | 0.25 |
| DG to DC | 16.50 | 14.49 | 0.88 | 0.07 |
| Delaps Cove | 27.86 | 24.36 | 0.87 | 0.12 |
| Parker's Cove | 10.56 | 10.00 | 0.95 | 0.05 |
| Total (stratified) | 264.27 | 195.14 | | 1.00 |

Table 6: Numbers of scallops (in 1000's) by age estimated from the annual research vessel survey and the cohort-slicing method using the von Bertalanffy growth model. The 1992 and 1993 year-classes are shown in boldface.

|  | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|
| 1 | 73 | 147 | 616 | **1618** | 1671 | 164 | 75 | 201 |
| 2 | 1317 | 417 | 987 | 1567 | **4721** | 1564 | 231 | 409 |
| 3 | 764 | 1625 | 1092 | 2300 | **2138** | **9899** | 1075 | 461 |
| 4 | 2259 | 1516 | 1693 | 1162 | 2887 | **3071** | **4115** | 1180 |
| 5 | 4878 | 1955 | 2963 | 1426 | 2173 | 3355 | **4917** | **5548** |
| 6 | 5462 | 3304 | 2416 | 1711 | 1628 | 1903 | 3067 | **5288** |
| 7 | 5275 | 3039 | 2287 | 2076 | 1430 | 1445 | 2112 | 2678 |
| 8 | 3918 | 2837 | 2172 | 1616 | 988 | 1163 | 1298 | 2151 |
| 9 | 2469 | 2007 | 1593 | 1186 | 812 | 917 | 850 | 890 |
| 10+ | 4340 | 4737 | 5508 | 4250 | 3401 | 2785 | 3040 | 3636 |
| total | 30755 | 21585 | 21328 | 18912 | 21849 | 26267 | 20779 | 22442 |
| 4+ | 28601 | 19395 | 18633 | 13427 | 13319 | 14640 | 19398 | 21370 |
| 5+ | 26342 | 17879 | 16939 | 12265 | 10432 | 11569 | 15284 | 20190 |
| 6+ | 21464 | 15924 | 13976 | 10840 | 8259 | 8214 | 10367 | 14642 |
| 7+ | 16002 | 12620 | 11561 | 9129 | 6631 | 6310 | 7300 | 9355 |

Table 7: Total mortality estimates for each of traditional fishing areas and selected age groups. Below = Centreville + Centreville to Gulliver's Head strata. Core= Area from Gulliver's Head to Delaps Cove stratum. Above = Parker's Cove Stratum. Core A = Gulliver's Head and Gulliver's Head to Digby Gut strata. Core B = Digby Gut to Delaps Cove stratum.

|  | Below | Core | Above | Core A | Core B |
|---|---|---|---|---|---|
| **4+/5+** | | | | | |
| 1991-1992 | -0.19 | 0.44 | - | 0.24 | 0.61 |
| 1992-1993 | 0.14 | 0.24 | -2.40 | 0.44 | 0.07 |
| 1993-1994 | 0.36 | 0.52 | -0.05 | 0.55 | 0.51 |
| 1994-1995 | 0.26 | 0.26 | 0.17 | 0.25 | 0.26 |
| 1995-1996 | 0.21 | 0.10 | 0.15 | 0.17 | 0.06 |
| 1996-1997 | -0.02 | -0.07 | 0.10 | -0.47 | 0.27 |
| 1997-1998 | -0.46 | 0.21 | 0.65 | 0.35 | 0.07 |
| **5+/6+** | | | | | |
| 1991-1992 | -0.18 | 0.47 | - | 0.27 | 0.65 |
| 1992-1993 | 0.26 | 0.35 | -2.28 | 0.58 | 0.15 |
| 1993-1994 | 0.39 | 0.56 | -0.04 | 0.57 | 0.55 |
| 1994-1995 | 0.39 | 0.38 | 0.47 | 0.36 | 0.40 |
| 1995-1996 | 0.23 | 0.24 | 0.25 | 0.35 | 0.17 |
| 1996-1997 | 0.05 | 0.14 | 0.20 | -0.34 | 0.56 |
| 1997-1998 | -0.27 | 0.20 | 0.64 | 0.34 | 0.05 |
| **6+/7+** | | | | | |
| 1991-1992 | -0.17 | 0.47 | - | 0.21 | 0.70 |
| 1992-1993 | 0.36 | 0.40 | -2.30 | 0.66 | 0.17 |
| 1993-1994 | 0.31 | 0.59 | -0.03 | 0.57 | 0.61 |
| 1994-1995 | 0.56 | 0.42 | 0.64 | 0.39 | 0.44 |
| 1995-1996 | 0.33 | 0.26 | 0.09 | 0.41 | 0.17 |
| 1996-1997 | 0.07 | 0.12 | 0.34 | -0.30 | 0.50 |
| 1997-1998 | -0.12 | 0.22 | 0.62 | 0.63 | -0.15 |
| **7+/8+** | | | | | |
| 1991-1992 | -0.31 | 0.48 | - | 0.14 | 0.74 |
| 1992-1993 | 0.30 | 0.38 | 0 | 0.71 | 0.12 |
| 1993-1994 | 0.27 | 0.69 | 0.21 | 0.64 | 0.73 |
| 1994-1995 | 0.76 | 0.39 | 0.75 | 0.40 | 0.39 |
| 1995-1996 | 0.36 | 0.35 | -0.03 | 0.51 | 0.24 |
| 1996-1997 | 0.07 | 0.23 | 0.50 | -0.25 | 0.66 |
| 1997-1998 | -0.06 | 0.16 | 0.55 | 0.58 | -0.22 |

Table 8: Results of inshore survey of 0 to 2 mile zone conducted in September 1997. The column labelled Area refers to the proportion of the total area in that stratum.

| Strata | tows | Area | Numbers per standard tow | | | |
|--------|------|------|-------|--------|----------|---------|
| | | | total | <80 mm | 80–99 mm | ≥100 mm |
| Centreville | 4 | 0.133 | 24.81 | 0.82 | 6.64 | 17.36 |
| CV to GH | 1 | 0.067 | 35.61 | 6.48 | 0.00 | 29.14 |
| Gulliver's Head | 4 | 0.133 | 37.91 | 5.16 | 4.34 | 28.42 |
| GH to DG | 2 | 0.100 | 19.13 | 3.23 | 0.00 | 15.90 |
| Digby Gut | 3 | 0.200 | 45.51 | 2.69 | 2.05 | 40.77 |
| DG to DC | 1 | 0.100 | 25.20 | 0.00 | 0.00 | 25.20 |
| Delaps Cove | 2 | 0.133 | 43.89 | 8.02 | 8.02 | 27.86 |
| Parker's Cove | 2 | 0.133 | 1.54 | 0.00 | 0.00 | 1.54 |
| Stratified mean | | | 30.33 | 3.16 | 2.94 | 24.23 |
| Stratified total | | | 1464663 | 152579 | 142061 | 1170023 |

Table 9: Parameter estimates for shell height/meat weight data from September 1997 inshore survey. Sixth column givens the predicted meat weight for scallops in each area with shell heights equal to 100 mm. Last column presents meat counts for predicted meat weights.

| Subarea | N | slope | intercept | $R^2$ | Predicted weight (g) for 100 mm Shell height | Count per 500g |
|---------|----|-------|-----------|-------|-----------------------------------------------|----------------|
| Centreville | 49 | 3.189 | -12.300 | 0.976 | 10.850 | 46 |
| CV to GH | 18 | 2.742 | -10.062 | 0.983 | 13.022 | 38 |
| Gulliver's Head | 76 | 2.789 | -10.314 | 0.950 | 12.548 | 40 |
| GH to DG | 18 | 3.128 | -11.968 | 0.973 | 11.458 | 44 |
| Digby Gut | 73 | 2.795 | -10.200 | 0.945 | 14.437 | 35 |
| DG to DC | 16 | NS | NS | NS | NS | - |
| Delaps Cove | 38 | 2.889 | -10.725 | 0.926 | 13.201 | 38 |
| Parker's Cove | 2 | NS | NS | NS | NS | - |
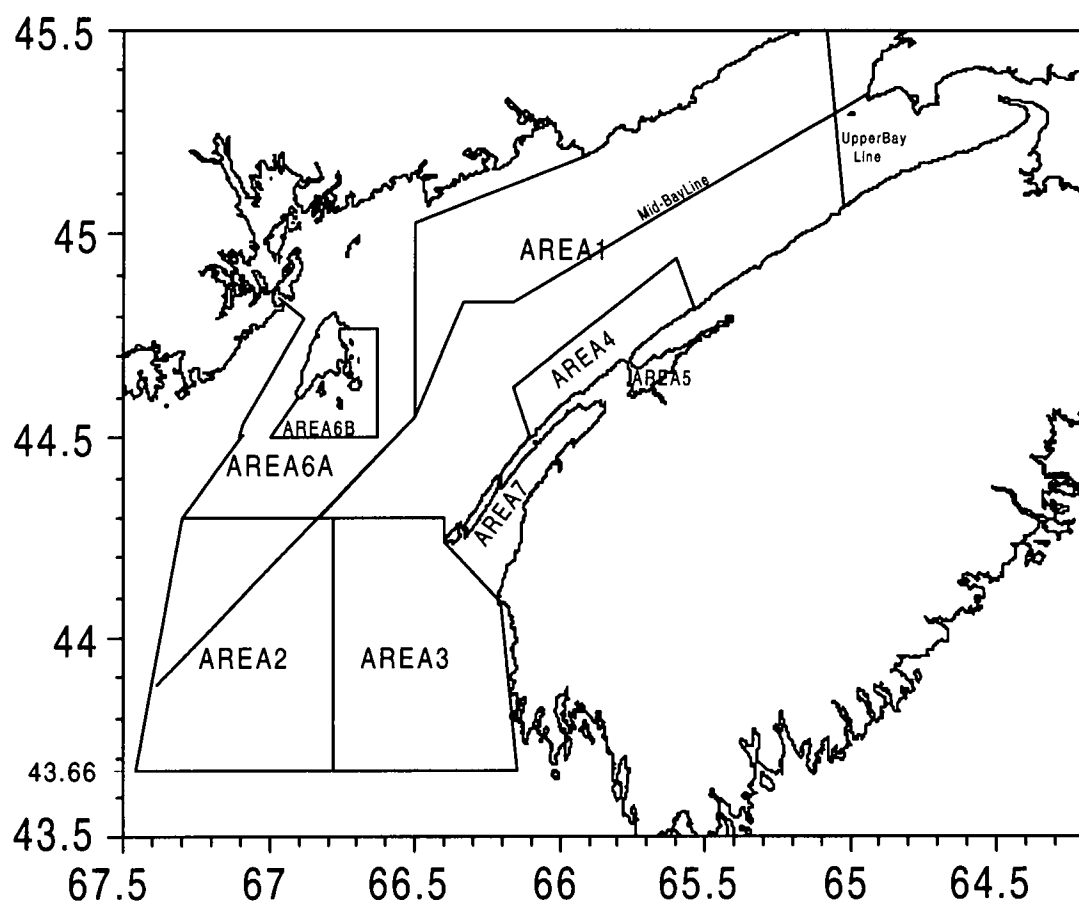
Figure 1: Scallop production areas in the Bay of Fundy (as of 1 January 1997).
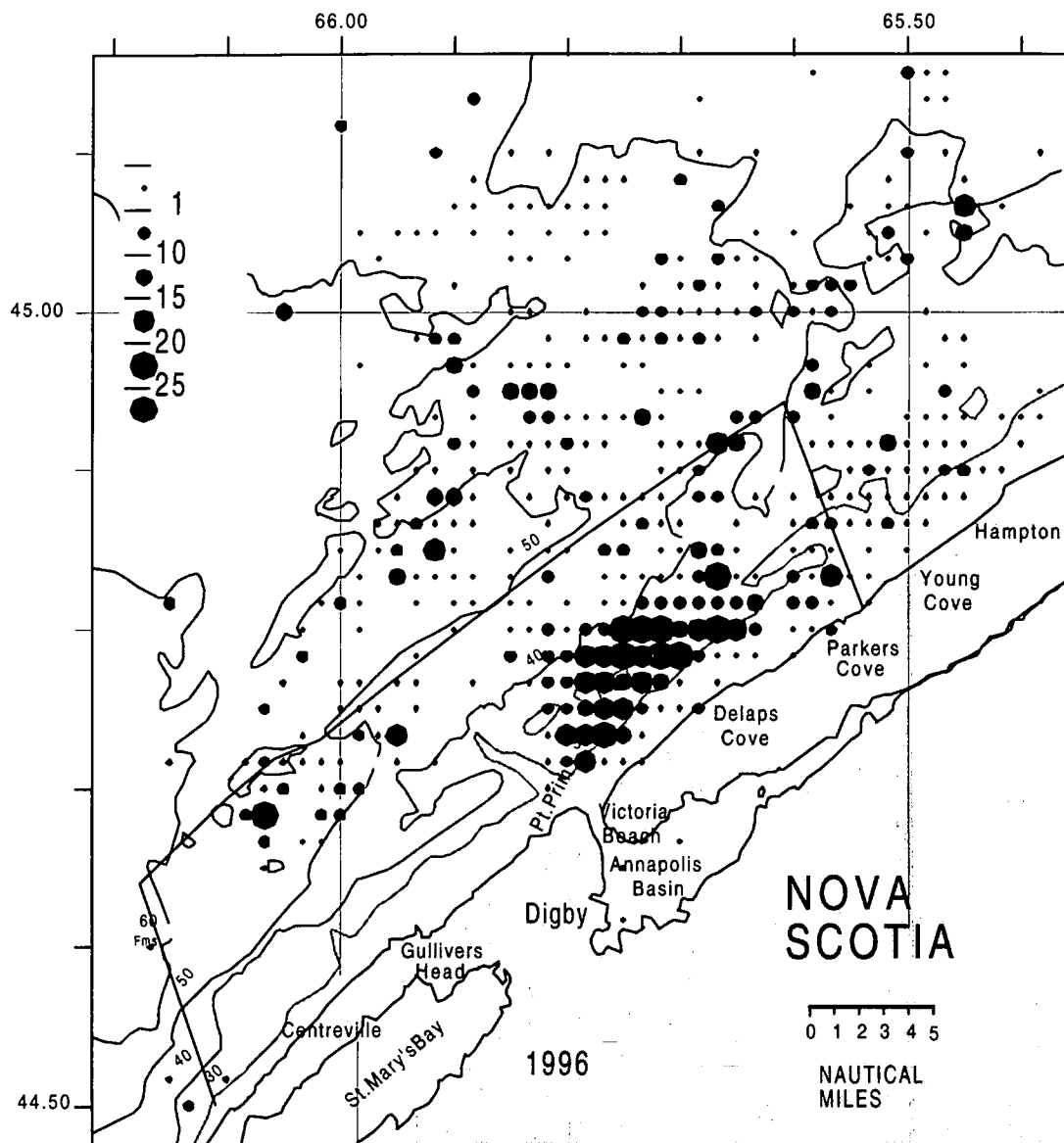
Figure 2: Distribution of fishing locations (days fished) by five minute square as reported from fishing logbooks for all areas in 1996. Increasing symbol size depicts increasing number of days fished. SPA 4 boundaries are shown.
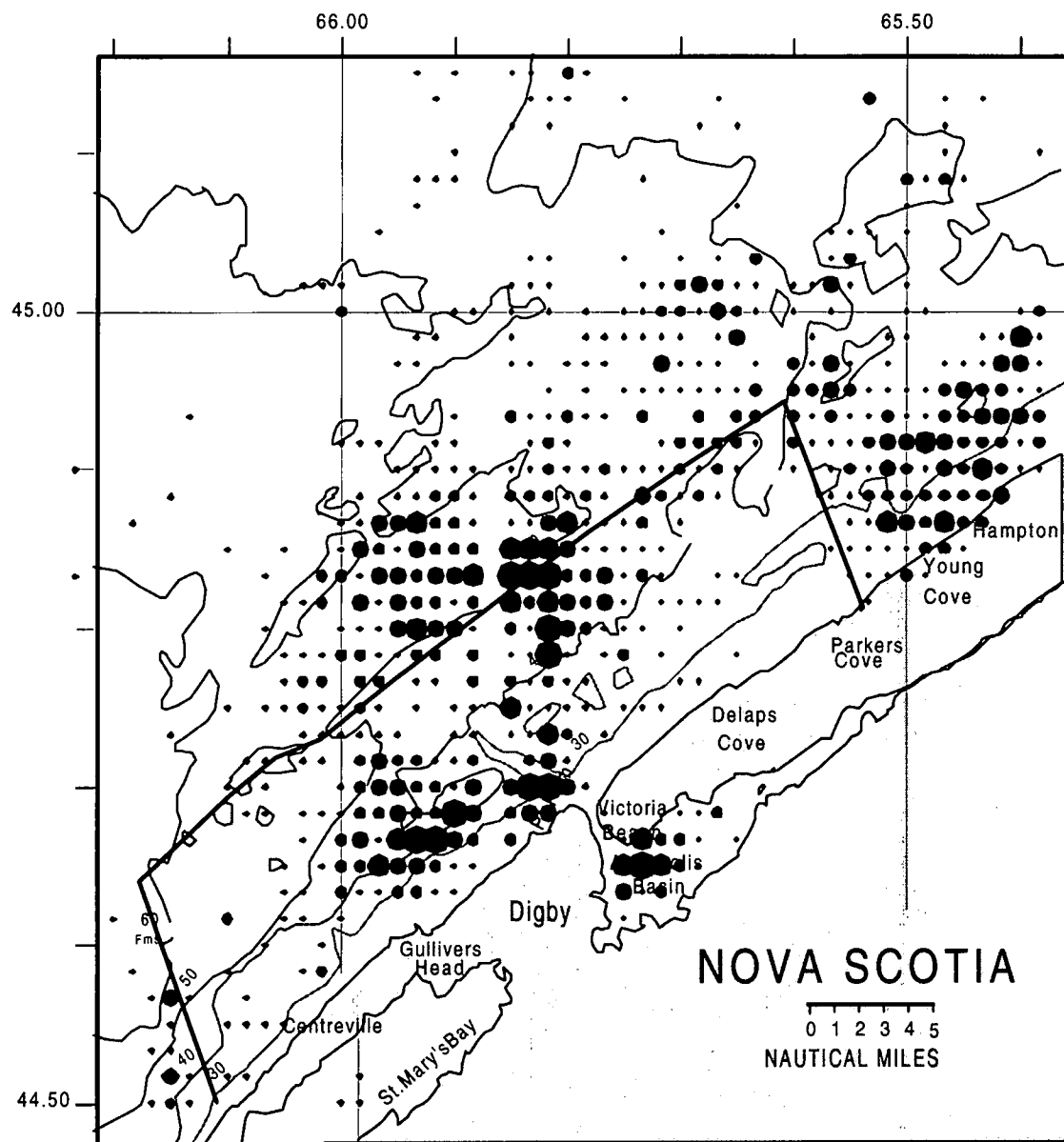
Figure 3: Distribution of fishing locations (days fished) by five minute square as reported from fishing logbooks for all areas in 1997. Increasing symbol size depicts increasing number of days fished. SPA 4 boundaries are shown.

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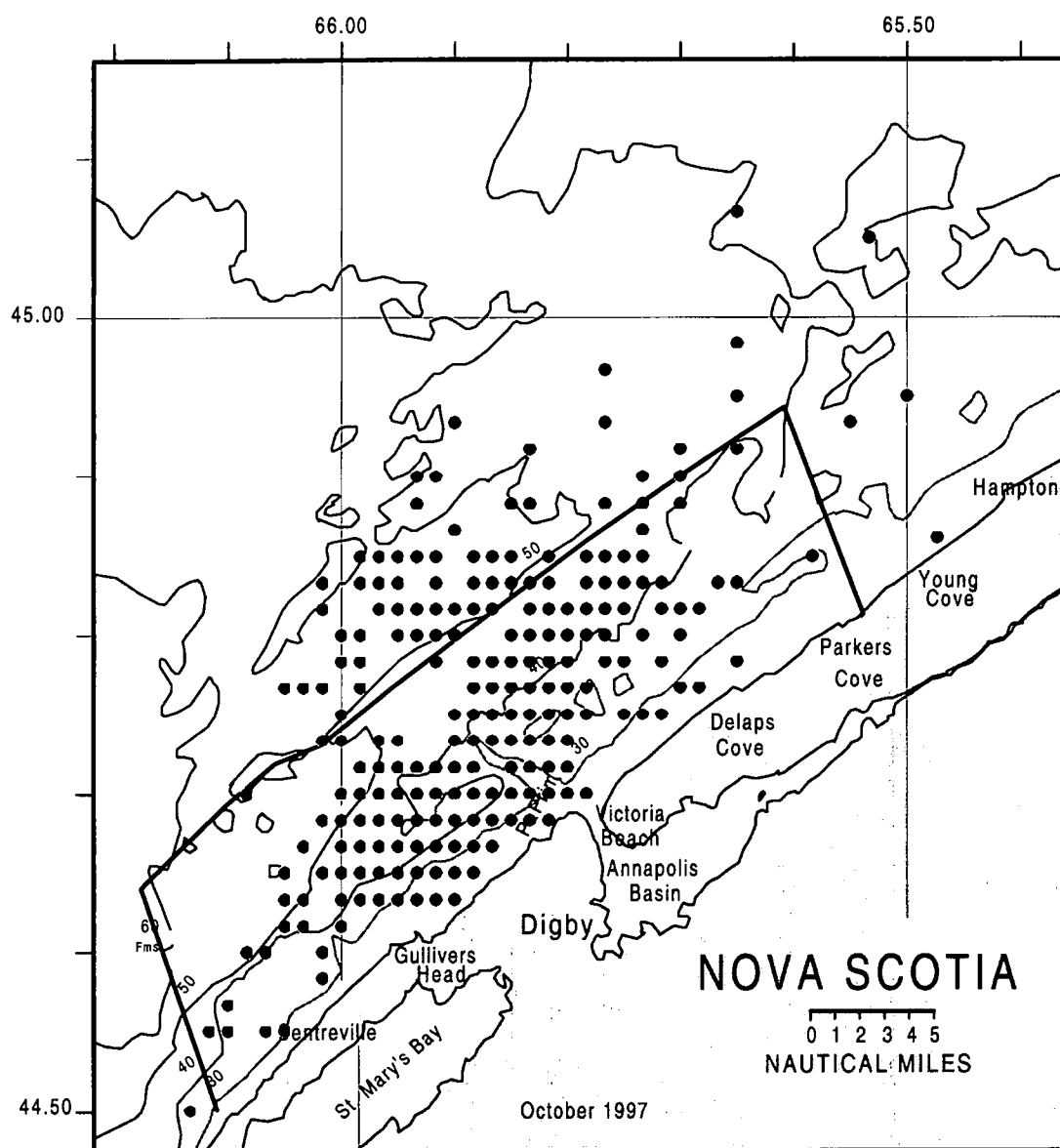
Figure 4: Scallop fishing positions from Class 1 logs in October, 1997.
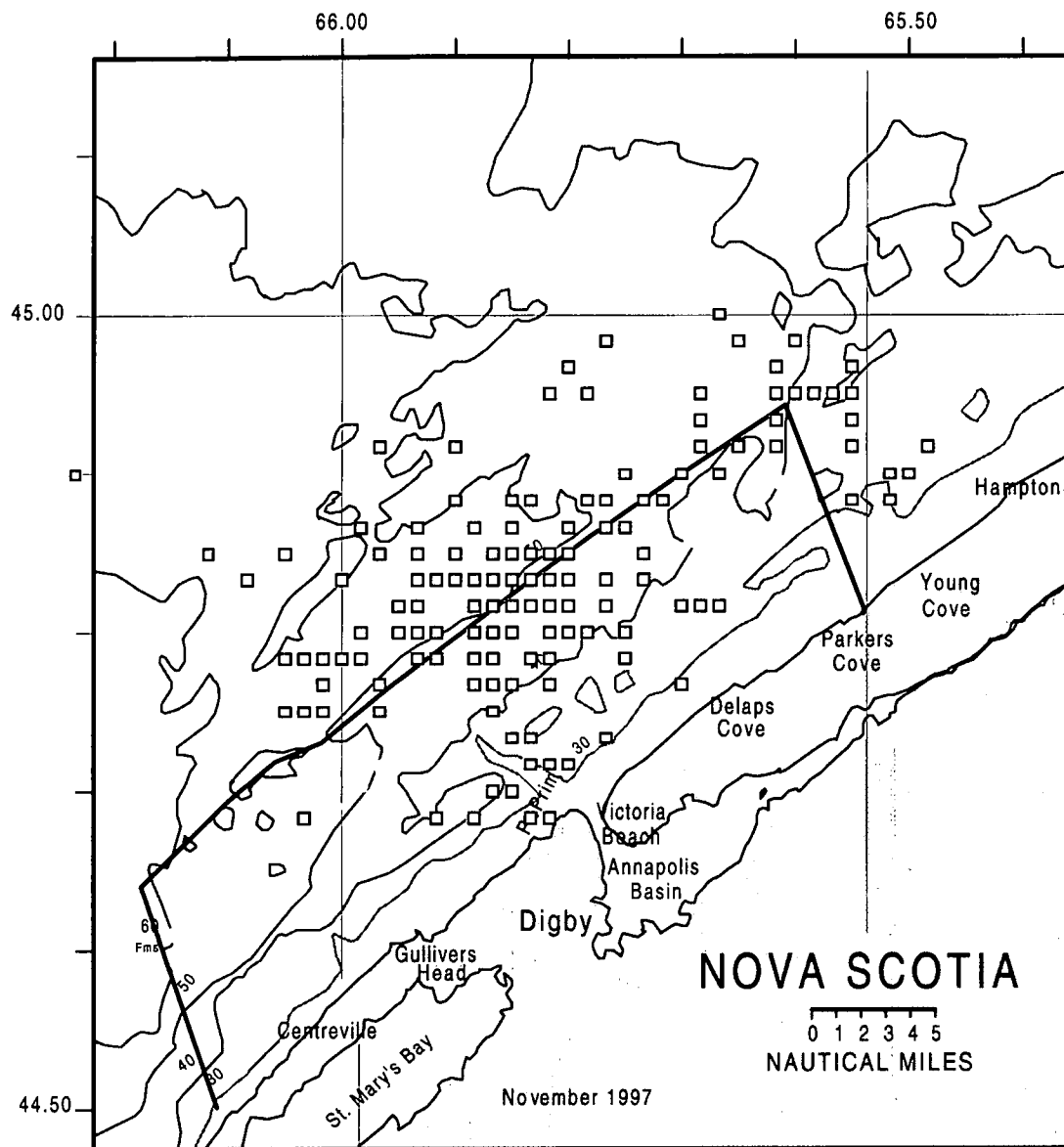
Figure 5: Scallop fishing positions from Class 1 logs from November, 1997.
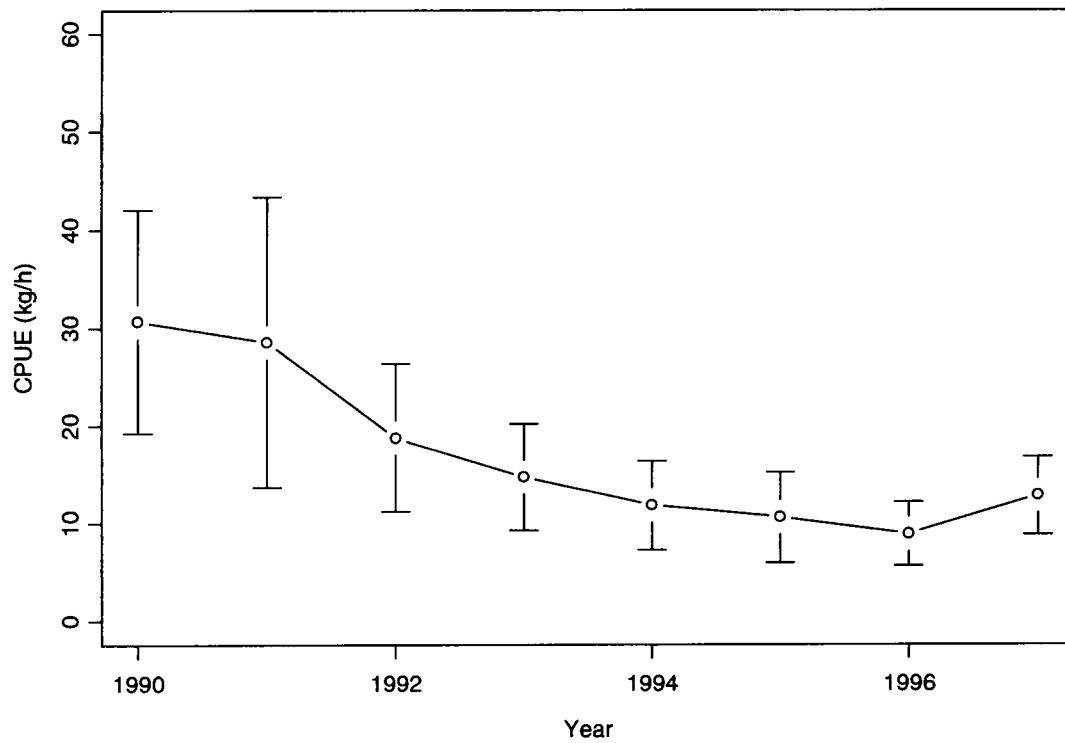
Figure 6: Catch per unit effort for Class 1 logs. Vertical bars indicate ± one standard deviation.
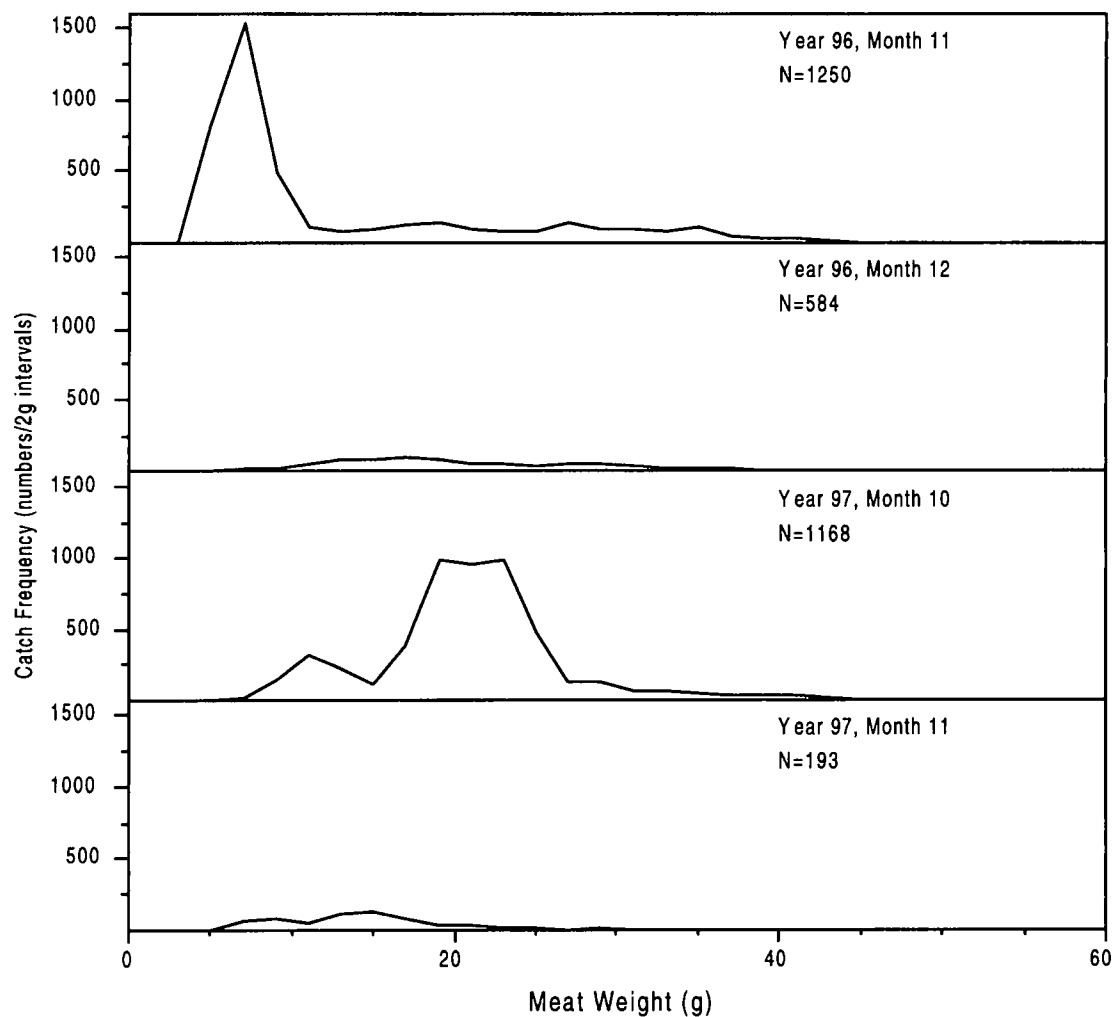
Figure 7: Frequency distribution of meat weights by total number caught from the commercial catch in SPA 4. Sample size of number of meats (N) is indicated for each month sampled.
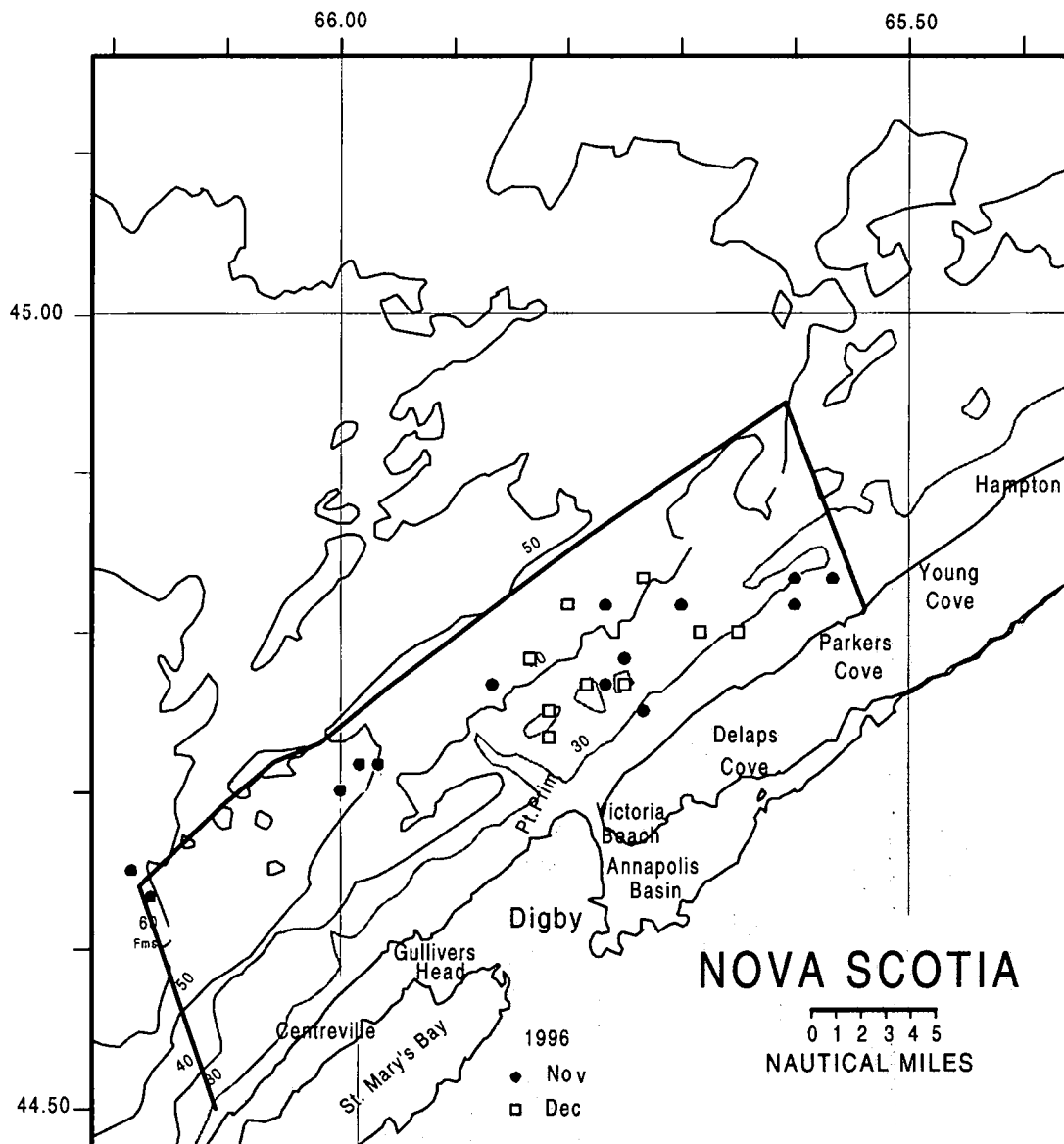
Figure 8: Scallop fishing positions from which port samples were taken in 1996.
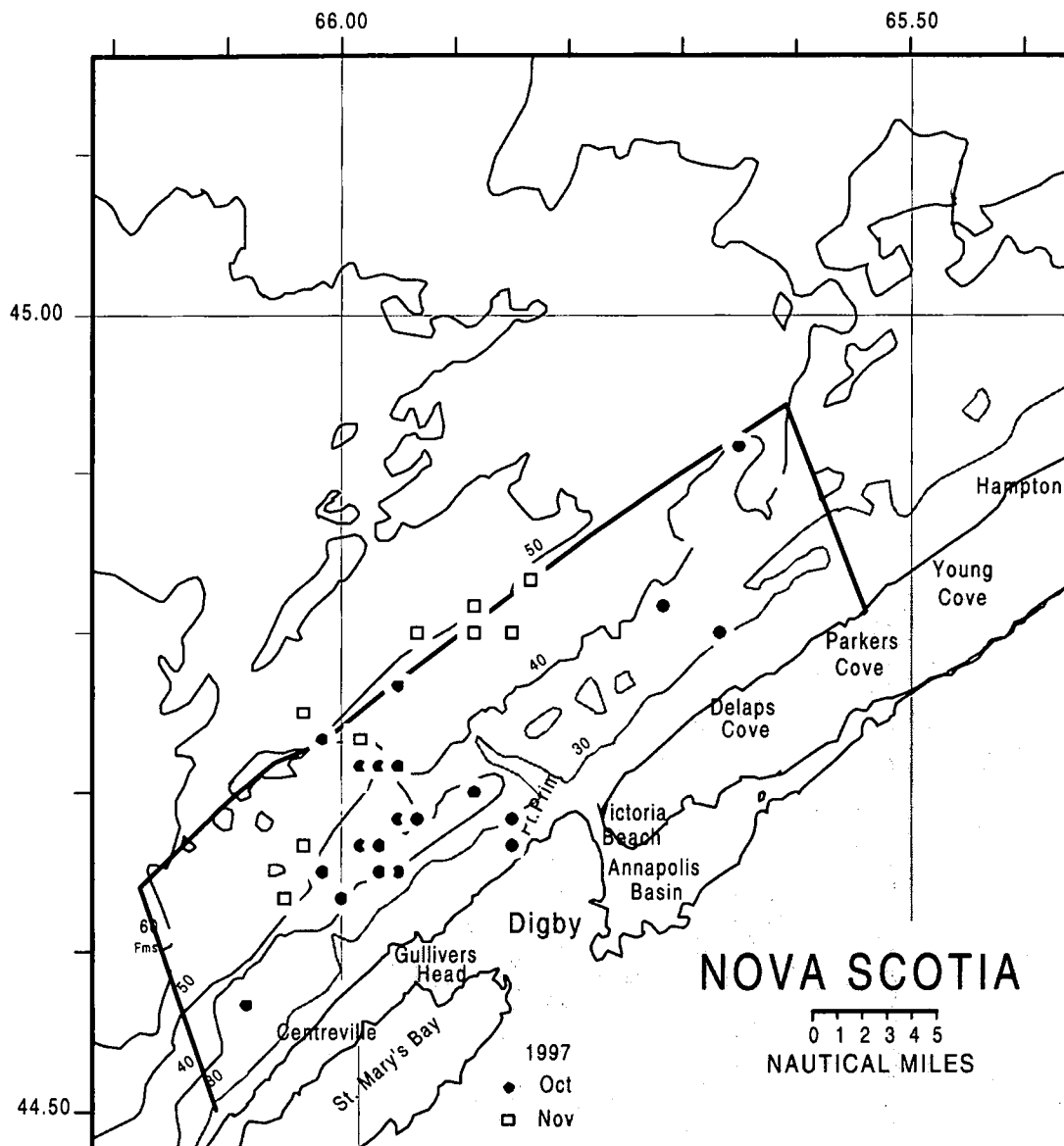
Figure 9: Scallop fishing positions from which port samples were taken in 1997.
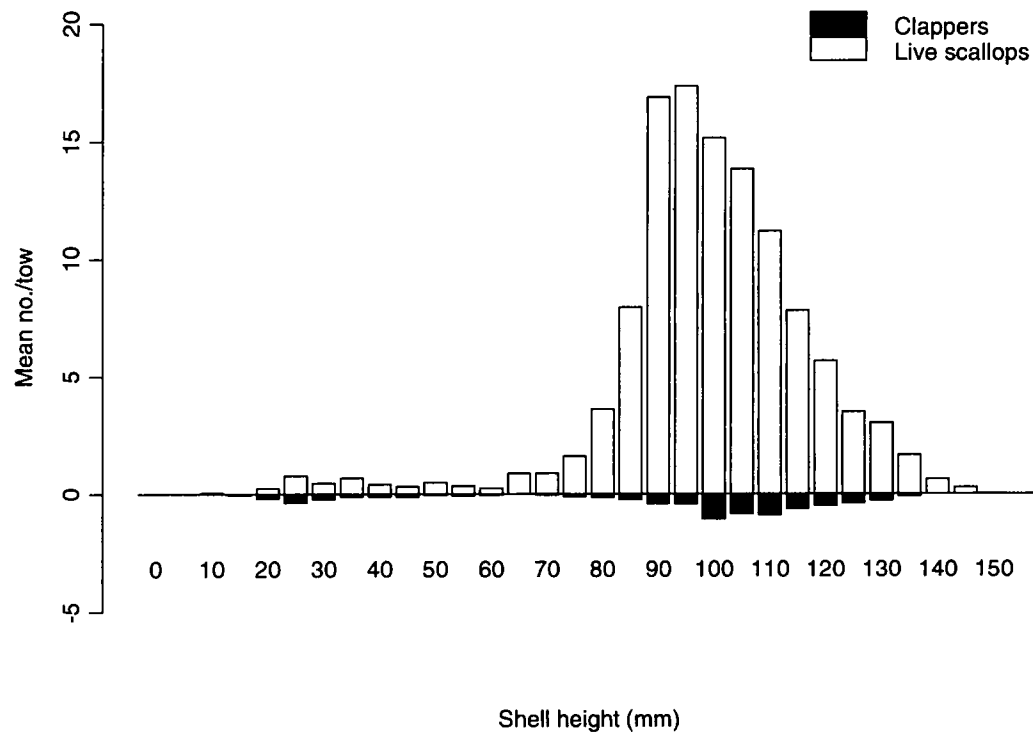
Figure 10: Stratified mean number of scallops per tow by shell height category (5 mm) from June 1998 survey of SPA 4. Stratified mean number of clappers by shell height category is shown on the negative side of the ordinate axis.
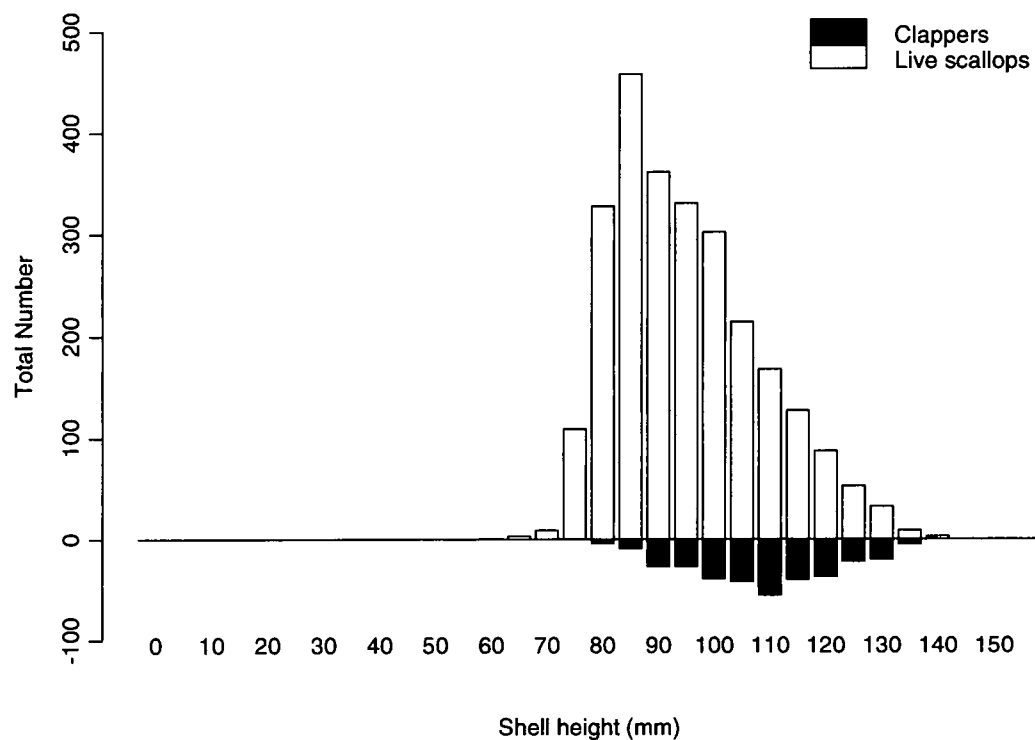
Figure 11: Shell height frequency for total number of live and dead (clappers) scallops caught in 18 tows by FV Julie Ann Joan on 22 October, 1997.
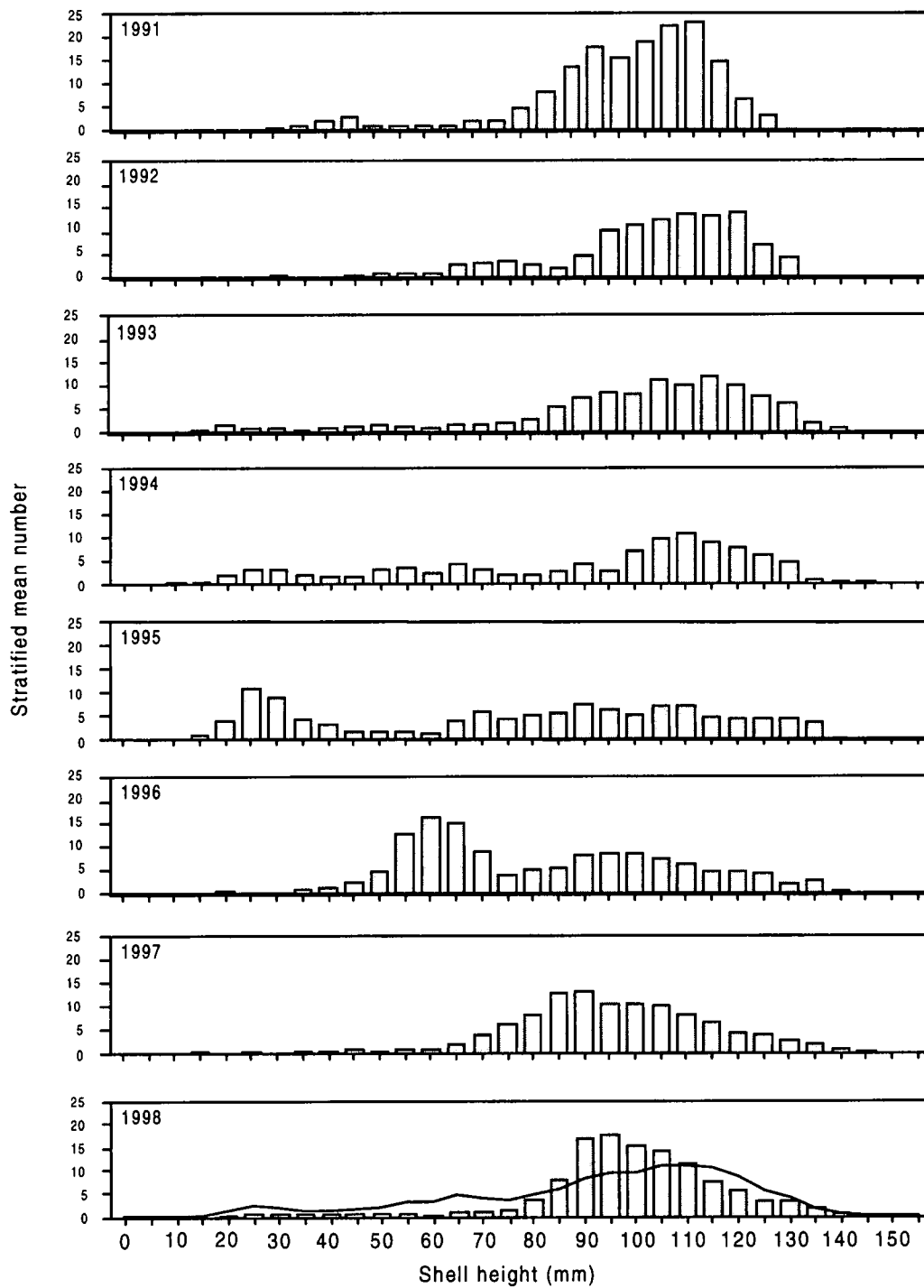
Figure 12: Shell height frequencies (stratified mean number per tow) from the June survey 1991 to 1998. Line plot in 1998 panel refers to the average from 1991 to 1997.
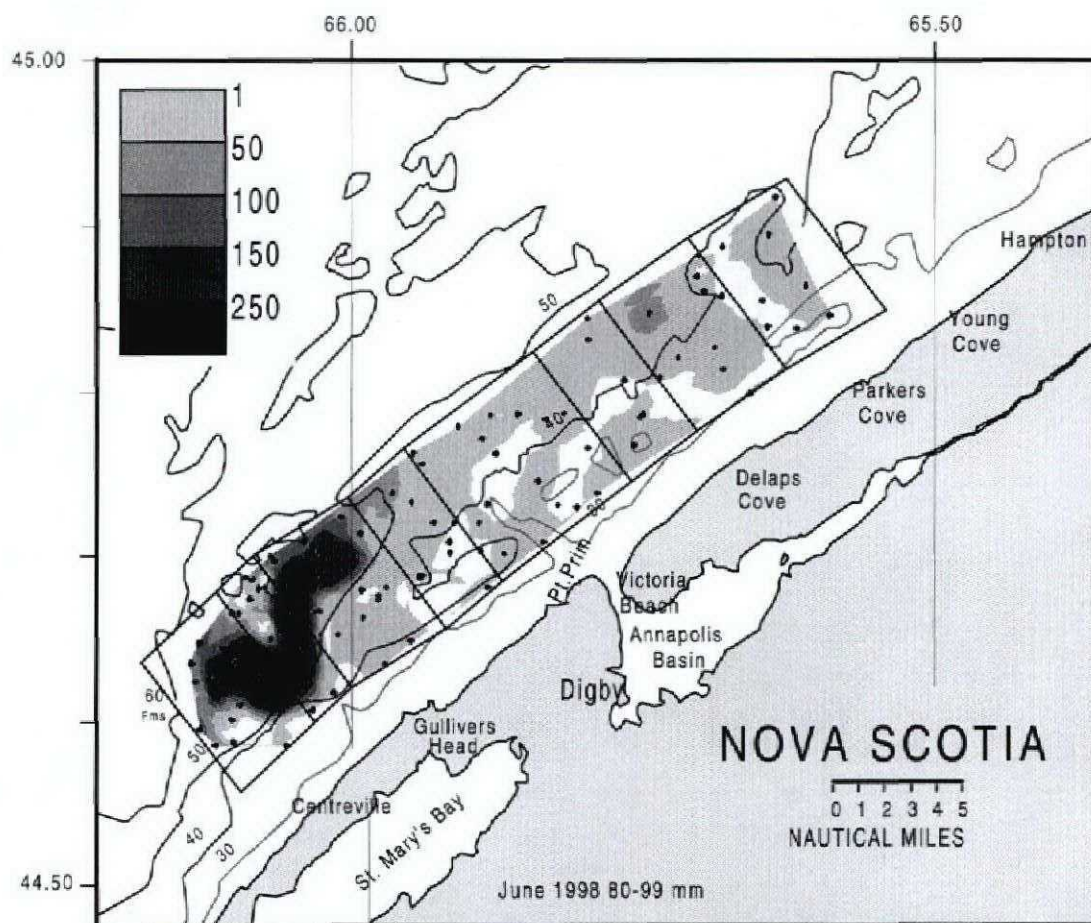
32
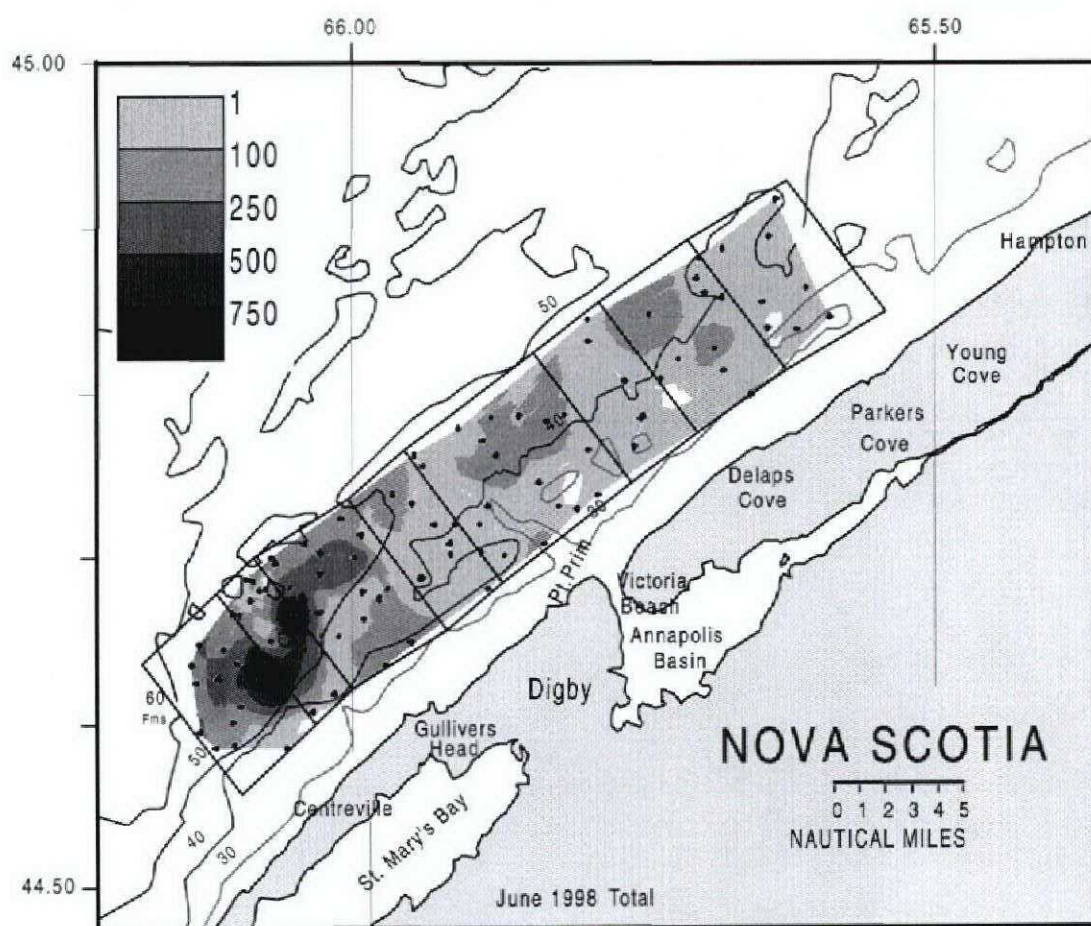
Figure 13: Spatial distribution of scallop catches from survey for all size groups. Contouring was derived using Delauney triangulation and inverse distance weighted interpolation.
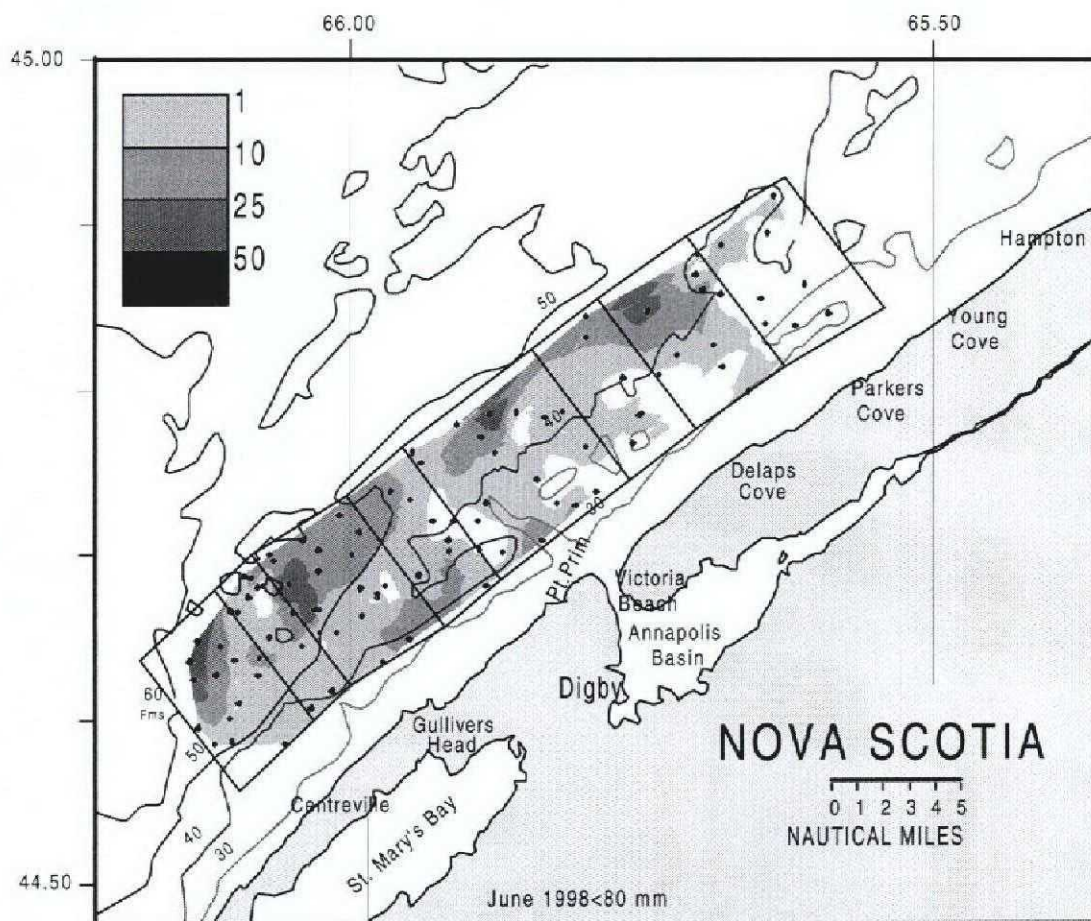
Figure 14: Spatial distribution of scallop catches from survey for animals with shell height <80 mm. Contouring was derived using Delauney triangulation and inverse distance weighted interpolation.
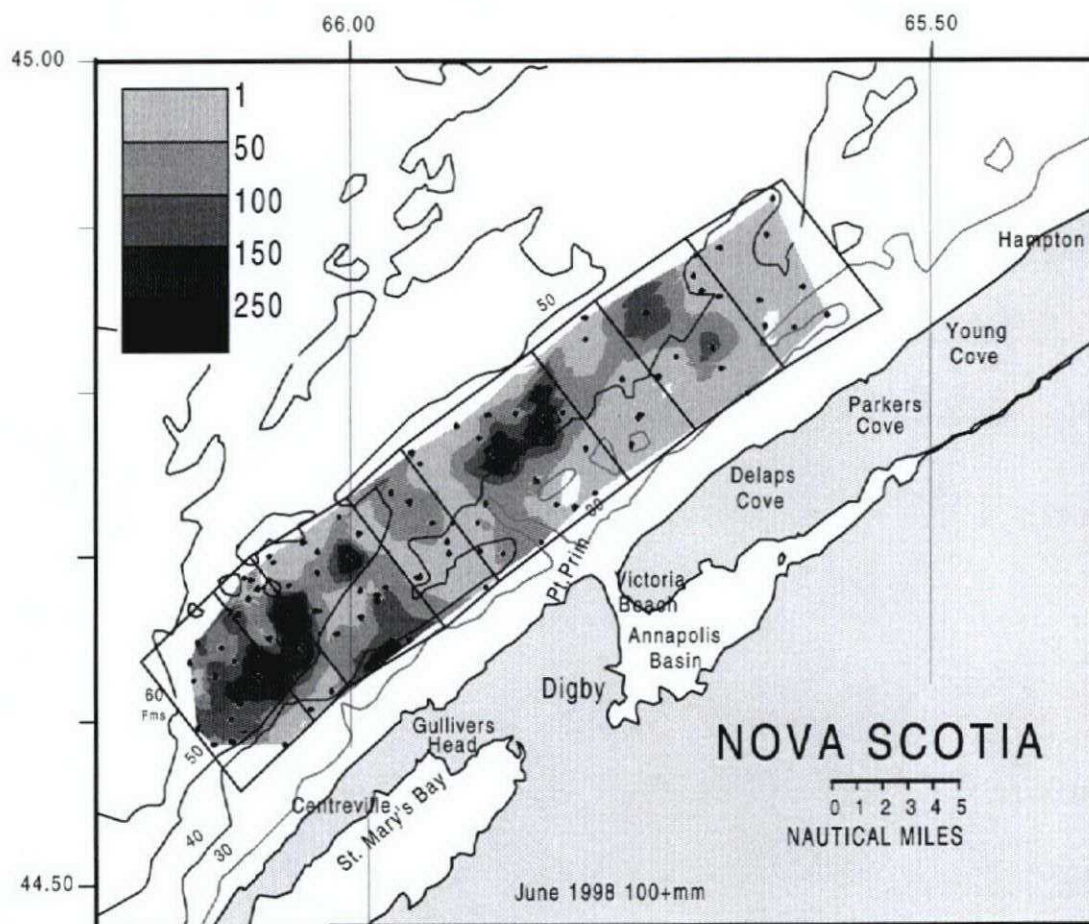
Figure 15: Spatial distribution of scallop catches from survey for animals with shell height 80–99 mm. Contouring was derived using Delauney triangulation and inverse distance weighted interpolation.
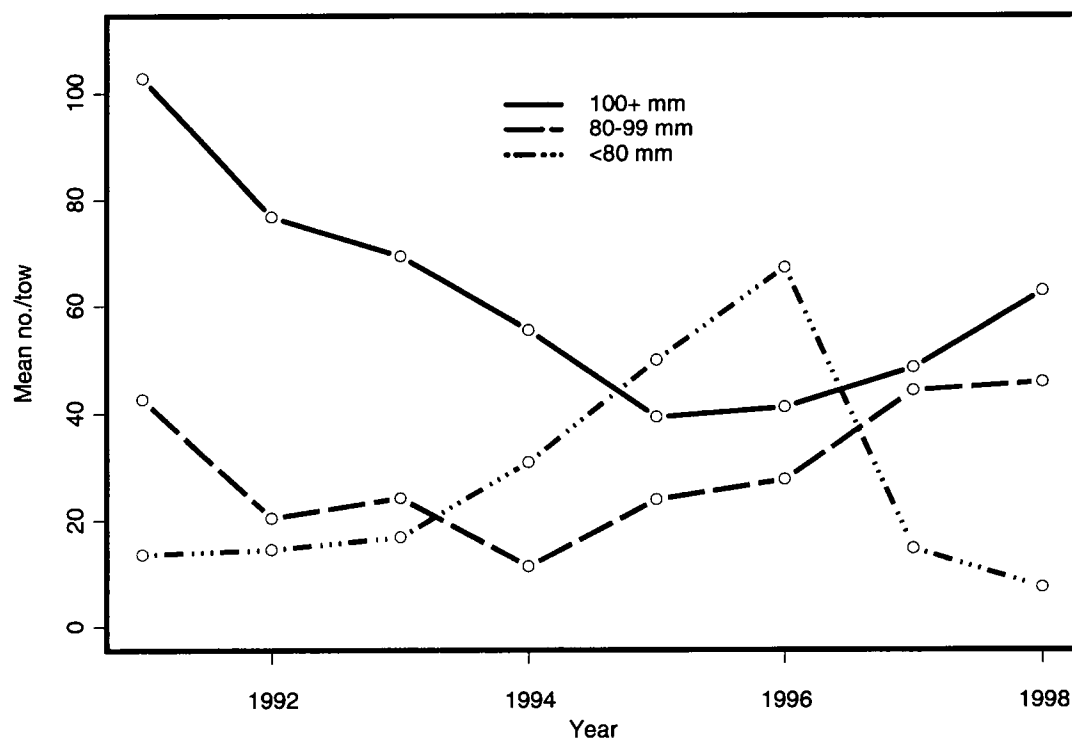
Figure 16: Spatial distribution of scallop catches from survey for animals with shell height ≥100 mm. Contouring was derived using Delauney triangulation and inverse distance weighted interpolation.

Figure 17: Trends of mean number of scallops per tow for three size groups (shell height in mm). Data from dredge survey conducted every June 1991–1998.
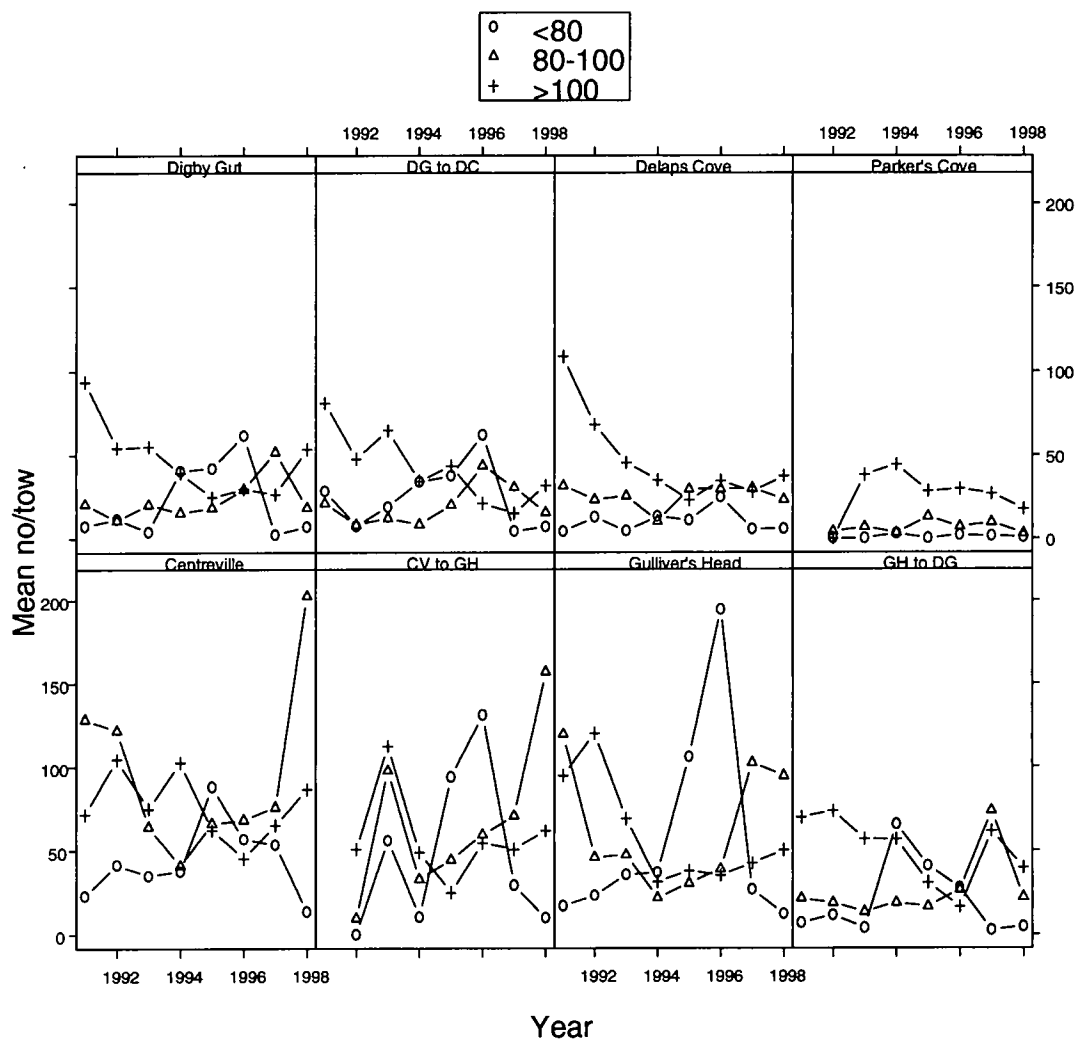
Figure 18: Trends of mean number of scallops per tow for three size groups (shell height in mm) for each stratum in the survey. Data from dredge survey conducted every June 1991–1998. Each panel represents trend within a specific stratum.
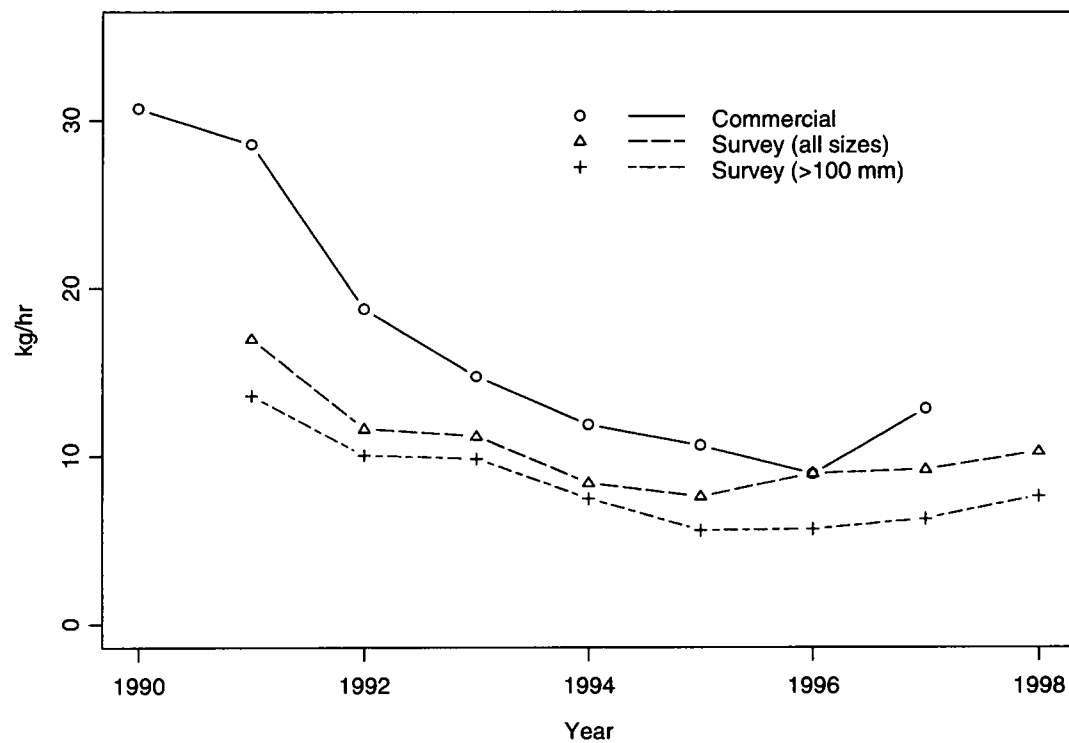
Figure 19: Comparison of catch rates from logbooks (kg/h) and from the survey (converted from kg per 8 minute tow to kg per hour). Survey indices given for all sizes and for animals greater than 100 mm.