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The Effects of a Regulatory Gear Restriction on the Harvest of the Recruiting Year Class in the offshore Sea Scallop, Placopecten magellanicus, Fishery

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THE EFFECTS OF A REGULATORY GEAR RESTRICTION ON THE HARVEST OF THE RECRUITING YEAR CLASS IN THE OFFSHORE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, FISHERY

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To my family and friends, for all their support and encouragement over the years. And to my Uncle Don, who encouraged us to get as many extra letters after our name as possible.

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ABSTRACT

The original sea scallop, *Placopecten magellanicus*, fishery management plan (SSFMP) was implemented in May 1984 to control variability of resource abundance and over exploitation of the scallop stock. This was to be done by controlling age at entry using direct shell height and meat weight regulations. Vessels that shucked scallops at sea were restricted to an average meat count of 30 meats per pound (MPP). Vessels that landed whole scallops were restricted to a 3.5" (89 mm) minimum shell height. There were many problems with this form of management, and these regulations were insufficient to control the harvest of small scallops. In response to this, Amendment #4 was drafted and implemented in March 1994. The amendment changed the focus of the existing management plan to restricting effort of the sea scallop fleet using a limited entry program, days at sea and crew limits, gear restrictions and other supplemental measures.

The major gear restriction required an increase in the minimum ring size used in the offshore scallop dredge. Ring size increased from 3.0" (76 mm) to 3.25" (83 mm) for 1994 and 1995. In January 1996, minimum ring size increased to 3.5" (89 mm). The objectives of this study were to examine the impact of the mandatory increase in ring diameter on the harvest efficiency of the dredge, and assess how this might affect the fishery in terms of yield-per-recruit, spawning stock biomass, and age class structure. In recent years, the year class recruiting to the fishery has been targeted by the fleet and is considered to be carrying the fishery. It is therefore important to determine how a particular year class is affected by the gear modification, especially with respect to recruitment to the gear. The recruitment of a very large year class (1990) during the study period made it possible to assess the performance of the 3.5" ring dredge on a single year class as the scallops grew and recruited to the gear.

Four trips were taken on commercial scallop vessels fishing in the western mid-Atlantic between June 1994 and April 1995. Paired tows were performed using the standard 3.25" ring dredge and the experimental 3.5" ring dredge. Relative efficiency of the 3.5" ring dredge was determined for both harvest efficiency and production efficiency. Harvest efficiency ranged from 62 to 71% relative to 3.25" rings and 36 to 43% relative to 3.0" rings. Production efficiency ranged from 50 to 85% relative to the 3.25" rings. Full recruitment would be delayed for a year to year and a half relative to the smaller rings. Further analyses showed that delaying harvest for this amount of time will lead to substantial increases in yield-per-recruit and spawning stock biomass, and will reduce fishing mortality on small scallops. The data from this study show that, if used properly, the 3.5" ring dredge will be very beneficial to the sea scallop resource and fishery.

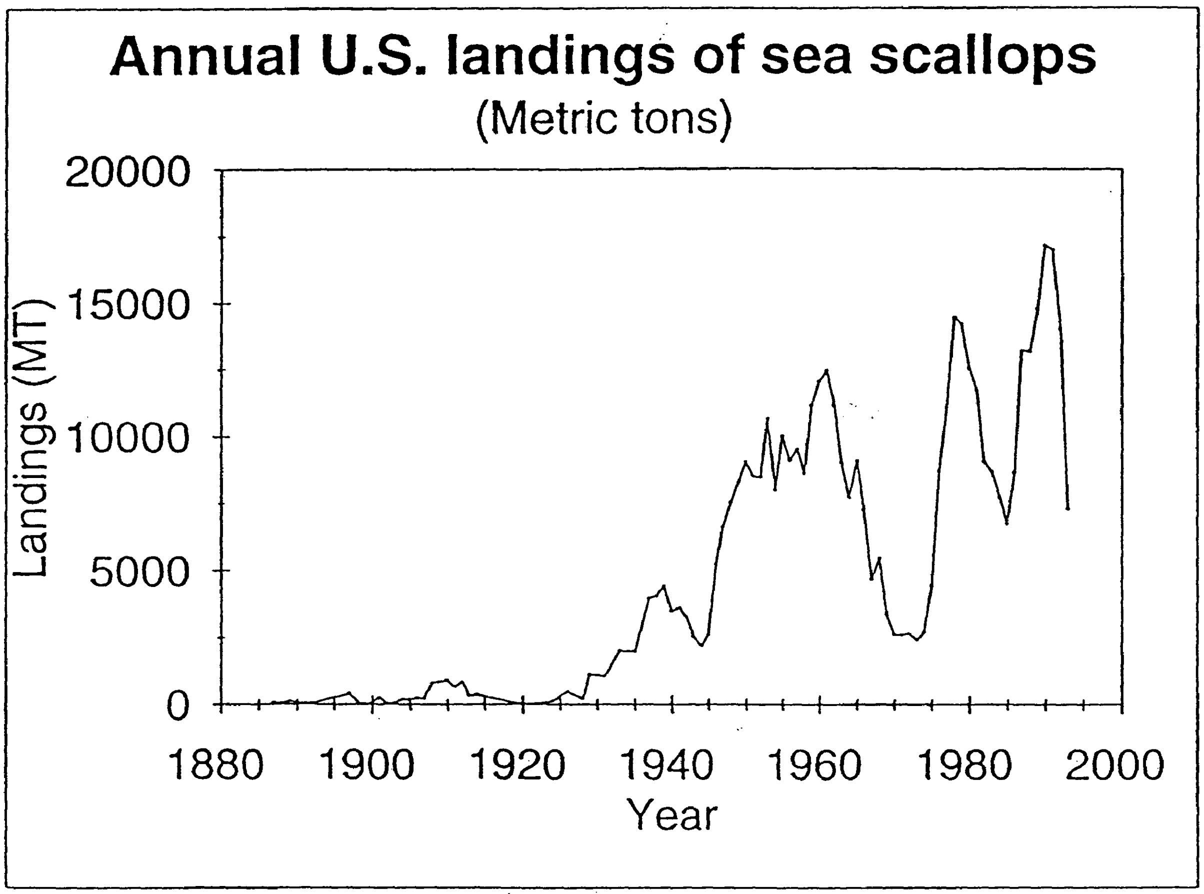
THE EFFECTS OF A REGULATORY GEAR RESTRICTION ON THE HARVEST OF THE RECRUITING YEAR CLASS IN THE OFFSHORE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS*, FISHERY

INTRODUCTION

The sea scallop, *Placopecten magellanicus* (Gmelin), is a commercially important species of mollusc found only in the northwest Atlantic Ocean. Its range extends from the Gulf of St. Lawrence southward to Cape Hatteras, North Carolina (Posgay, 1957). The commercial importance of *P. magellanicus* began with the initiation of a directed fishery in the 1880's (Serchuk *et al.*, 1979). Major expansions of the fishery occurred in the early 1920's when an offshore fishery began in the mid-Atlantic, and again in the 1930's with the discovery of large concentrations of scallops on Georges Bank (Bourne, 1964; Serchuk *et al.*, 1979). Within a few years following World War II, annual landings, coming mostly from Georges Bank, surpassed 5,000 metric tons (Serchuk *et al.*, 1979). In 1990, U.S. landings reached an all time high of 17,174 metric tons, with an ex-vessel value of more than $150 million (NOAA, 1991).

The growth of the fishery (annual landings) has not been consistent over time, but characterized by cyclical periods of high and low annual production (Figure 1). These fluctuations, attributed to varying recruitment coupled with varying fishing pressure

Figure 1 Annual U.S. landings (metric tons) of sea scallop meats from 1887 to 1993 (adapted from Anonymous, 1995).



Annual U.S. landings of sea scallops
(Metric tons)
Landings (MT)
20000
15000
10000
5000
0
1880
1900
1920
1940
1960
1980
2000
Year

(Smolowitz and Serchuk, 1987), became more common during the 1970's, yet the fishery remained unregulated. It was not until 1982 that the New England Fishery Management Council (NEFMC), in conjunction with the Mid-Atlantic (MAFMC) and South Atlantic Fishery Management Councils (SAFMC), developed and imposed a fishery management plan (FMP) for the sea scallop (NEFMC, 1982).

The sea scallop fishery management plan (SSFMP) was developed to address the problems of variability of resource abundance, possible excessive levels of fishing effort, and the possibility of over exploitation in response to increasing consumer demand (NEFMC, 1982). The main objective of the FMP was to maximize the joint economic and social benefits from the harvest and utilization of the sea scallop resource (NEFMC, 1982). Four supplemental objectives included in the plan were as follows: 1) restoration of abundance and age distribution of the adult stocks; 2) enhancement of the yield-per-recruit for each stock; 3) evaluation of the impact of management plan provisions on research, future plan development, and enforcement costs; and 4) minimization of the adverse environmental impacts on stock levels and utilization (NEFMC, 1982).

These objectives were to be obtained by controlling age of entry of the scallops. An average meat count (number of scallop meats per pound) regulation was imposed for vessels that landed shucked meats. Vessels that landed whole, unshucked scallops were regulated by a minimum shell size standard (NEFMC, 1982). Following a one year phase-in period, these restrictions were an average meat count of 30 meats per pound (MPP) and a minimum shell height of 3.5" (89 mm), respectively (NEFMC, 1982). Both regulations had a 10% tolerance limit. That is, meat counts could be as high as 33 MPP, and 40 scallops out of a sample of 400 could be smaller than 3.5" without any penalty being imposed (NEFMC, 1982).

There were several problems with this form of management, and numerous amendments were drafted to alleviate these problems and oversights. One of the more serious of these was caused by the average meat count restriction. Vessels that landed shucked scallop meats were restricted to an average of 30 MPP, but this allowed small scallops to be harvested if they were mixed with larger scallops. For example, twenty 60-count scallops could be mixed with ten 15-count scallops and still comply with the average 30 MPP regulation. Harvesting such small scallops was deleterious to both the fishery and the resource. The first amendment to the original SSFMP was designed to prevent this by requiring a maximum count (minimum size) of 40 MPP; however, this amendment was never put into action (NEFMC, 1993).

Other problems that arose included difficulty in enforcement at sea, questions of equitability between regulations for vessels landing shucked meats and those for vessels landing shell stock, the validity of using biologically resected meat weights to set enforcement levels for commercially shucked meats, and the sufficiency of the 10% meat count increase only between October and January to account for decreases in meat weight in response to spawning activity. These and other problems are discussed in Naidu (1987), Shumway and Schick (1987), Smolowitz and Serchuk (1987, 1988), and Kirkley and DuPaul (1989).

Amendment #4 to the SSFMP was drafted and implemented in March 1994 to alleviate some of the underlying flaws in the 1982 regulations. The new regulations retained the objectives of the 1982 FMP but changed the focus of the plan to restricting fishing effort. In order to do this, the plan called for a limited entry program, days at sea (DAS) limits, crew limits, gear restrictions, and other supplemental measures. Limited entry restricts the number of vessels allowed to fish for scallops. The DAS and crew limits restrict effort of the individual vessels. The primary gear restriction, an increase in dredge ring size, is expected to reduce harvest of small (greater than 50 MPP) scallops.

The gear regulation called for an increase in dredge ring size from 3.0" (76 mm) to 3.25" (83 mm) inside diameter for 1994 and 1995. In January 1996, this increased to 3.5" (89 mm) inside diameter. The desired effect is an increased escapement of small scallops resulting in decreased harvest and mortality. The age at first capture will increase, leading to increased yield-per-recruit of the fishery and other benefits. With the meat count restriction removed, age at first capture will be controlled by regulating the size of scallops captured by the dredge as opposed to the size retained by the crew.

The primary objective of the present study is to assess the impact of the mandatory increase in ring diameter on the harvest efficiency and selectivity of the offshore scallop dredge. The null hypothesis being tested is: H_o $\mu_{3.5} = \mu_{3.25}$ where $\mu_{3.5}$ and $\mu_{3.25}$ are the mean catch per tow of the 1990 year class by the 3.5" and 3.25" ring dredges respectively. The alternative hypothesis is therefore $\mu_{3.5} \neq \mu_{3.25}$.

The second objective is to examine how the change in ring size of the dredge might affect the fishery and the resource in terms of yield-per-recruit, spawning stock biomass, and age class distribution. An important question to be answered is whether or not the increase in ring size will be sufficient to help meet the management objectives of the Plan.

This study is unique from other scallop gear studies in that it focuses analysis on a single year class. Previous scallop gear studies, such as Medcof (1952), Bourne (1965), Caddy (1971), Serchuk and Smolowitz (1980), DuPaul *et al.* (1989), and Kirkley and DuPaul (1994) have analyzed selectivity and efficiency relative to the catch as a whole or for certain size intervals; however, in recent years, *P. magellanicus* has been fished to such an extent that the majority of the catch for a given year is of the recruiting year class (age 3-4) (Serchuk *et al.,* 1979; Brown, 1987; NEFMC, 1993; NEFSC, 1993). It is therefore important to determine how a particular year class is affected by the gear modification, especially with respect to recruitment to the gear. During this study, the largest year class on record in the DelMarVa region, the 1990 year class, was recruiting to the fishery (NEFSC, 1993). This study was designed specifically to follow this large year class, assess the performance of the gear on the single year class, and analyze how the year class recruits to the new gear as the scallops grow. This large year class also facilitated assessment of how the year class structure of the resource might change in response to the new gear.

Materials and Methods

Data Collection

The data for this study were collected during four trips on commercial scallop vessels between June 1994 and April 1995. Sampling trips were taken on the F/V *Carolina Breeze* and the F/V *Stephanie B* in the DelMarVa region of the western Mid-Atlantic (NAFO statistical area 6). Both vessels are approximately 75.5 feet (23.01 m). The *Carolina Breeze* used two 14 foot wide (4.27 m) dredges while the *Stephanie B* used two 13 foot wide (3.96 m) dredges.

The fishing gear used during these experiments was the standard offshore New Bedford style scallop dredge used by most vessels in the fishery (Figure 2). A general overview of the gear is given in Posgay, (1957), and a more detailed description is given in Bourne, (1964). The collecting bag, or chain bag, is constructed of welded steel rings held together by split steel links. For this study, two dredges were used. The standard gear was constructed from 3.25" (83 mm) inside diameter steel rings as used in the fishery. The experimental gear was constructed from 3.5" (89 mm) steel rings. The experimental gear was constructed as similar as possible to the standard ring dredge. Modifications of the dredges were permitted as long as they were legal under Amendment #4.

Data collection was similar to that of Bourne (1965) and DuPaul *et al.* (1988) and is considered to be standard procedure for scallop gear studies. Dredges towed in pairs (one dredge on either side of the vessel) cover the same distance and fish the same population

Figure 2 Typical scallop dredge used in the offshore sea scallop fishery.

(Bourne, 1965). DuPaul *et al.* (1989) found no difference in harvest when dredges were switched from side to side. This made it possible to perform paired tows with the two gears. Discretion as to which side the experimental gear was towed from was left to the captain, but for all trips, the experimental gear was towed from the port side.

A tow log sheet was completed for all tows made during each trip. Tow number, start and end times, start and end LORAN positions, vessel speed, depth fished, and total catch of scallops (number of baskets) by each dredge was recorded. The log was maintained by the captain and first mate. For each sampled tow, a deck log was completed by the chief scientist. Data recorded include tow number, sea conditions, total catch of scallops for each dredge, estimates of by-catch and trash, and shell height frequencies for both retained and discarded scallops.

Typical commercial procedures were carried out on deck by the crew with the exception that catches by the two dredges were kept separate throughout the trip for all tows (sampled and unsampled): that is, from the time they were brought on board, dumped on deck, culled, shucked, placed in chilling totes, bagged up, stored in the ice hold, until offloading was completed. For sampled tows, the crew was allowed to cull out the commercial sized scallops to be retained for shucking. From this, a sample of up to two baskets of scallops (1 basket is approximately 1.5 bushels) was set aside from each dredge for length frequency analysis. The bycatch was sorted by the scientists to retrieve undersized (discard) scallops. In areas of high seed density, the bycatch was subsampled. These discards, along with the sample of commercial sized scallops, were measured using National Marine Fisheries Service (NMFS) scallop measuring boards. The maximum distance from the umbo to the ventral margin of the shell was measured to the nearest 5 mm interval. The data were recorded on the deck log. The commercial scallops were then returned to the crew for processing and the discards thrown overboard.

Scallop meat count (meats per pound) data were also collected during the trips. Meat counts from each dredge were estimated during bag up using a standard 1 pint plastic frosting cup which holds approximately one pound of shucked scallop meats (Smolowitz, 1987; Reidman, 1987). Counts were then recorded on the tow log.

At the end of each trip, the meats from each dredge were offloaded separately. Total production (pounds of scallop meats) was recorded for each dredge.

Scallop samples obtained from commercial scallop vessels and delivered to the laboratory were used to collect shell height:meat weight data. A basket of whole scallops was placed in the ice hold and returned to shore unshucked. When these scallops were shucked, the upper (left) valve of each scallop was measured to the nearest millimeter using a standard fish measuring board, and the respective meat was weighed to the nearest 0.1 gram using an Ohaus CT600 electronic scale.

Data Analysis

In order to compare catches from the different trips, it was necessary to standardize the data to a common unit of effort. The common unit defined in this study was 50 hours of tow time using 13 foot (3.96 m) wide dredges. All equations used to standardize the data are shown in Appendix I. The raw length frequency data were entered into spreadsheet format using QuattroPro version 5.0. Estimates of total catch per tow were calculated using a ratio of catch sampled to total catch in the dredge. These estimates were converted to catch per hour, summed over all tows sampled, and standardized to catch per 50 hours tow time. Catches made on the *Carolina Breeze* using 14 foot (4.27 m) dredges were standardized to 13 foot dredges by multiplying what was caught by the 14 foot dredge by 13/14. The use of a direct ratio to standardize the catch in the 14 foot wide dredge was necessary because data comparing the performance of 13 foot and 14 foot wide dredges was not available. Final estimates of catch were rounded to the nearest integer.

Bartlett's tests were run on the catch data for each trip in order to test for homogeneity of variance (Zar, 1984). A natural logarithm transformation was performed on the heteroscedastic data sets, and the test was repeated. In addition, Wilk-Shapiro tests were performed on all data sets, raw and transformed, to test for normality (Zar, 1984). Comparison of catch by the two dredges for the specific trips was done using a two tailed student's t-test (Zar, 1984). The null hypothesis tested was $\mu_{3.5} = \mu_{3.25}$ where $\mu_{3.5}$ is the mean catch per tow of the 1990 year class by the 3.5" ring dredge and $\mu_{3.25}$ is the mean catch per tow of the 1990 year class by the 3.25" ring dredge. The alternative hypothesis was therefore $\mu_{3.5} \neq \mu_{3.25}$. It was not necessary to standardize the catch data for these tests since the fishing effort for a given trip was the same for both dredges. Normality and variance tests were performed using the Statistix analytical software package, version 4.0. Comparisons of means were run on SAS version 6.09 using *proc ttest*.

Efficiency of fishing gear can be expressed in several ways. DuPaul *et al.* (1989) and Kirkley and DuPaul (1994) measure technical efficiency of the scallop dredge. Technical efficiency measures the ability of the gear to maximize production given a set level of inputs and technology. On the other hand, Caddy (1968, 1971) describes e, the overall efficiency of the dredge as

$$e = \frac{\text{number of scallops caught}}{\text{number of scallops in dredge path}} * 100$$

This can be broken down into efficiency of capture, E, and selectivity, s, which can be defined as follows.

$$E = \frac{\text{number of scallops into the dredge}}{\text{number of scallops in dredge path}} * 100 \quad \text{and} \quad s = \frac{\text{number of scallops caught}}{\text{number of scallops into the dredge}} * 100$$

It can be seen that e = E*s (Caddy, 1971, 1989).

Measurement of technical efficiency and e were beyond the scope of this project. Technical efficiency was not examined for similar reasons as those given in DuPaul *et al.* (1989). Also, in order to estimate e, it is necessary to estimate overall stock abundance or density. This was not done for this study. Instead, a measure of relative efficiency of the 3.5" ring dredge was used. As the name suggests, this measures the efficiency of one gear relative to another gear. The underlying assumption is that scallops will enter the two gears with equal probability. Assuming the two gears differ in only selectivity, catch of smaller scallops will be higher in the smaller ringed gear, and there will be no difference in catch between gear sizes of the larger scallops (those with no chance of escaping) (Millar and Walsh, 1992). Relative efficiency can then be estimated by dividing catch in one gear by catch in the other gear.

For this study, relative efficiency was determined for each trip in terms of both harvest efficiency and production efficiency. Production efficiency was found by dividing the total offload weight of the 3.5" gear by the total offload weight of the 3.25" gear. Harvest efficiency was estimated for each shell height, over all shell heights, and for the 1990 year class. For each shell height, efficiency was determined by dividing the total catch, in number of scallops, of the 3.5" ring dredge at a given shell height by the total catch in the 3.25" ring dredge at the same shell height. These estimates were then smoothed by a moving geometric mean of three (Pope *et al.*, 1975). To determine efficiency for the age group and for all shell heights, catch was summed over the range of shell height intervals being examined. Total catch in the 3.5" ring dredge was then divided by total catch in the 3.25" ring dredge.

The range of shell height intervals used for analysis of the year class was found for each trip using the Petersen method (Jearld, 1983). Year classes were distinguished by the different peaks in the shell height frequency distributions. The modal shell height for the 1990 year class was found and the tails of the normal distribution were estimated by eye. The left tail of the distribution for the April 1995 trip was estimated by counting the number of shell height intervals to the right of the mode and assuming the same number were present on the left side. This was necessary because the 1991 age class shell height distribution overlapped with that of the 1990 year class.

The shell height:meat weight relationships were estimated using SAS 6.09. A log-log transformation was necessary to allow for linear estimation. The model used was

$$\ln(MW) = \ln(a) + b*\ln(SH) + \mu$$

where "ln" is the natural logarithm and μ is the error term which is assumed to be $N(0, \sigma^2)$. Analysis of covariance (ANCOVA) tests were then conducted on the final equations to test for similarity between the equations.

A growth model was also estimated using the catch data from the different trips, including data from a previous trip taken in November 1993 (DuPaul and Kirkley, 1994a and b). It was during this earlier trip that the year class in question was first beginning to recruit to the 3.0" (76 mm) rings used at the time (DuPaul and Kirkley, 1994a). A growth model was estimated using the exponential growth equation. The mean shell height of the specified age class from each of the trips was plotted against the number of days relative to the first sampling trip. It was assumed that daily growth during the trip was minimal, and that, for each trip, all scallops were collected on one day. The first day of fishing on each trip was arbitrarily designated the collection day, and all increments in days are counted from the first day of the first trip to the first day of each successive trip.

The shell height range of the age class was determined as in the relative efficiency estimates, that is, using the Petersen method. Within this age class, the number of scallops at each shell height interval caught during the trip was multiplied by the respective shell height interval midpoint. The products were summed over all shell height intervals within the age class, and the sum was divided by the total number of scallops caught in all tows sampled in the age group, giving the mean shell height of the age group. This procedure was done for all trips except the April 1995 trip. For this trip, the modal shell height was used because, as mentioned before, there was some overlap between the 1990 and 1991 age class distributions.

With these data, the mean shell height (mm) was plotted against time (days) relative to the first day of fishing on the first trip. An estimate of the growth coefficient, G, was found between each trip and over the whole sampling period using the exponential growth equation:

$$L_t = L_0 * \exp[G * (t - t_0)] + \mu$$

where L_t = shell height at time t, L_0 = shell height at time 0, G is the exponential growth rate, and μ is the error term which is assumed to be $N(0, \sigma^2)$. Though using the mean length of the year class for the growth model will lead to heteroscedasticity, it was necessary to use this statistic. It was not possible to use lengths of individual scallops from the 1990 year class because the shell height range of the year class was not known while the trips were being conducted.

RESULTS

Trip Data

Overall:

Between June 1994 and April 1995, four sampling trips lasting 7 to 14 days were conducted aboard two commercial scallop vessels fishing in the DelMarVa region of the western mid-Atlantic Ocean (Figure 3). Of the 759 tows conducted using the experimental gear during these trips, 209 were sampled for shell height data. Table 1 summarizes the tow data for all trips combined. Tow speeds of the sampled tows ranged from 3.8 to 5.0 kts with a mode of 4.5 kts. The most common tow length was 50 minutes with a range of 34 to 75 minutes. Depth fished varied from 17 fm to 43 fm (31.1 to 78.7 m) with a mode of 32 fm (58.6 m) (Table 1).

A total of 167,239 scallops were measured over the course of the four trips - 89,725 and 77,514 for the 3.25 inch and 3.5 inch ring dredges respectively. Tows with large catches of scallops were subsampled, and catch in these tows were extrapolated to estimate catch in the whole tow. Using this method, a total of 184,226 scallops were sampled from the 3.25" ring dredge, and 121,810 scallops from the 3.5" ring dredge.

Trip 1:

The first trip was conducted from June 7 to June 16, 1994 aboard the F/V *Carolina Breeze*. Of the 163 tows conducted using the experimental gear, 60 were sampled. Depth fished of the sampled tows during this trip ranged from 27 to 34 fm (49.4 to 62.2 m). The

Figure 3 Chart of the western mid-Atlantic Ocean. The shaded area represents the study area.

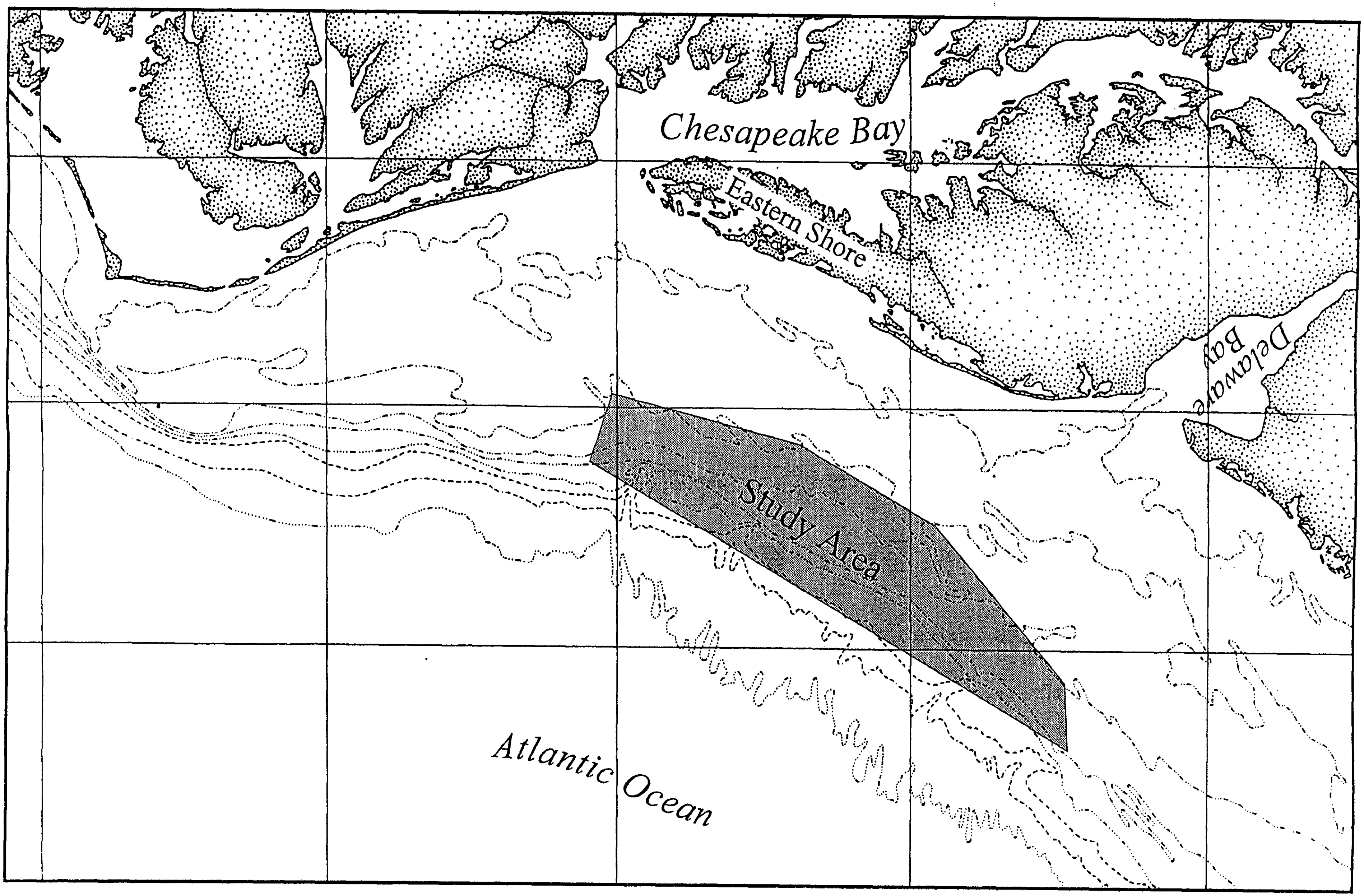

Chesapeake Bay
Eastern Shore
Delaware Bay
Study Area
Atlantic Ocean

Table 1 Summary statistics for depth, tow speed and tow duration for all sampling trips combined.

	Depth (fm)	Tow Speed (kts)	Tow Duration (minutes)
Minimum	17	3.8	34
Maximum	43	5.0	75
Mode	31	4.5	50
Standard Deviation	4.8114	0.2051	8.7708
Coefficient of Variation	15.43	4.6011	16.401

most common depth fished was 33 fm (60.4 m). Modal tow speed was 4.4 kts, with a range of 4.1 to 4.7 kts. Similarly, tow durations lasted from 40 to 70 minutes with the most common duration being 50 minutes (Table 2).

During this trip, 28,137 scallops were measured from the 3.25" ring dredge and 25,752 from the 3.5" ring dredge. The estimated number of scallops, extrapolated from subsampled tows, was 68,149 and 43,321 respectively (Table 3, Figure 4a). Table 3 and Figure 4b show the same data standardized to 50 hours tow time with 13 foot dredges. Production and meats per pound for the 3.25" and 3.5" ring gears were 3633 and 1813 pounds of meats and 57.3 and 53.1 MPP respectively (Table 7).

Trip 2:

The second trip took place from August 13 to August 25, 1994 aboard the F/V *Carolina Tarheel* (currently the F/V *Stephanie B*). A total of 245 tows were conducted, of which 54 were sampled. During this trip, the modal depth fished was 36 fathoms (65.9 m), and the depth range was from 17 to 40 fm (31.1 to 73.2 m). Tow speeds ranged from 3.8 to 4.9 kts. The most common tow speed was 4.3 kts. The most common tow duration was 50 minutes with a range of 34 to 75 minutes (Table 2).

The number of scallops measured was 23,061 and 20,020 for the 3.25" and 3.5" ring dredges respectively. Estimated number of scallops in the sampled tows was 44,603 and 29,469 for the two dredges respectively (Table 4, Figure 5). Production and meats per pound for the whole trip were 3394 and 2621 pounds of meat and 47.5 and 42.9 MPP for the 3.25" and 3.5" ring dredges respectively (Table 7).

Table 2 Summary statistics for depth, tow speed, and tow duration for each trip.

Trip		Depth (fm)	Tow Speed (kts)	Tow Duration (minutes)
June 1994	Minimum	27	4.1	40
	Maximum	34	4.7	70
	Standard Deviation	1.498	0.1555	6.0376
	Coefficient of Variation	4.7708	3.5163	11.299
August 1994	Minimum	17	3.8	34
	Maximum	40	4.9	75
	Standard Deviation	4.6753	0.221	9.7978
	Coefficient of Variation	14.635	5.0359	19.098
November 1994	Minimum	19	4.0	35
	Maximum	42	5.0	75
	Standard Deviation	6.3698	0.236	9.404
	Coefficient of Variation	21.448	5.2461	16.628
April 1995	Minimum	19	4.3	40
	Maximum	43	5.0	75
	Standard Deviation	4.676	0.192	9.1896
	Coefficient of Variation	14.726	4.2526	17.27

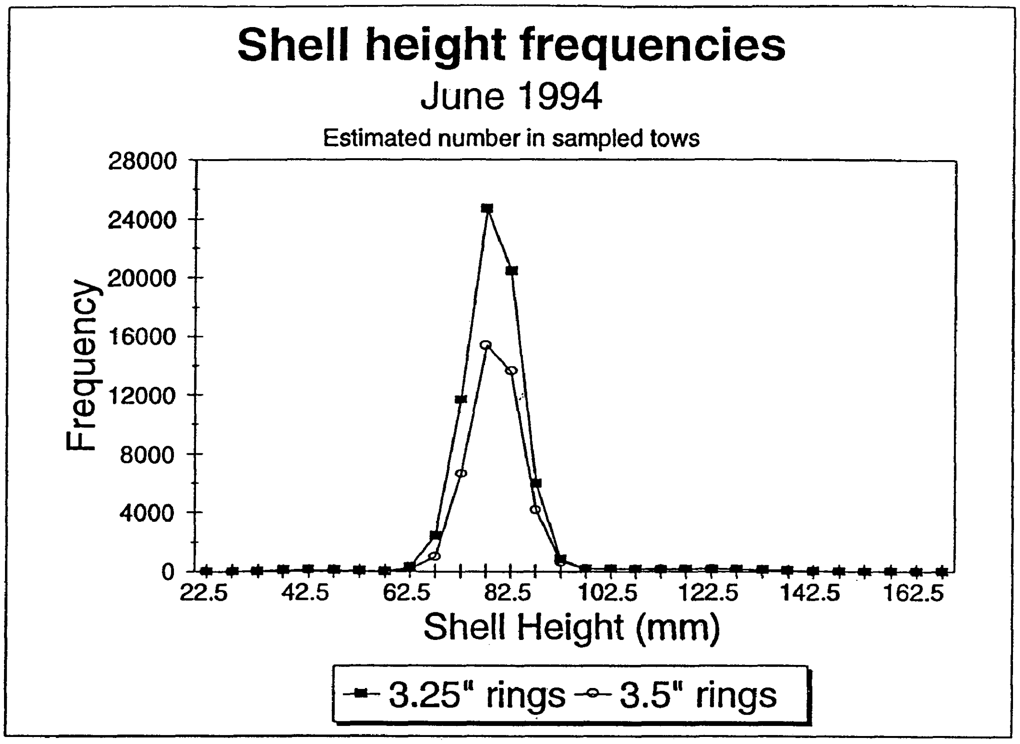
Table 3 Shell height frequency distributions for 3.25" and 3.5" ring dredges from June 1994. Estimated total number of scallops in all tows sampled (using 14 foot wide dredges) and standardized number of scallops in all tows sampled (using 13 foot wide dredges).

Shell height (mm)	Estimated number in 3.25" rings	Estimated number in 3.5" rings	Standardized number in 3.25" rings	Standardized number in 3.5" rings
20-25	1	1	1	1
25-30	3	1	3	1
30-35	30	13	26	12
35-40	103	42	88	36
40-45	124	70	106	61
45-50	97	52	85	44
50-55	42	28	36	23
55-60	25	9	22	8
60-65	296	147	258	130
65-70	2420	985	2107	866
70-75	11689	6636	10128	5796
75-80	24702	15371	21306	13254
80-85	20453	13622	17644	11755
85-90	5963	4129	5153	3581
90-95	856	639	757	561
95-100	184	224	162	199
100-105	180	190	162	171
105-110	167	178	149	163
110-115	130	195	118	174
115-120	171	236	152	214
120-125	157	220	140	196
125-130	170	152	149	135
130-135	98	105	88	96
135-140	63	59	57	54
140-145	22	16	22	14
145-150	2	1	2	1
150-155	1	0	1	0
155-160	0	0	0	0
160-165	0	0	0	0
165-170	0	0	0	0
Totals	68149	43321	58922	37546

Figure 4 Shell height frequency distributions for June 1994 from the mid-Atlantic region for 3.25" and 3.5" ring dredges.

a) Estimated number of scallops in sampled tows.

b) Number of scallops per 50 hours of tow time.


Shell height frequencies
June 1994
Estimated number in sampled tows
Frequency
28000
24000
20000
16000
12000
8000
4000
0
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

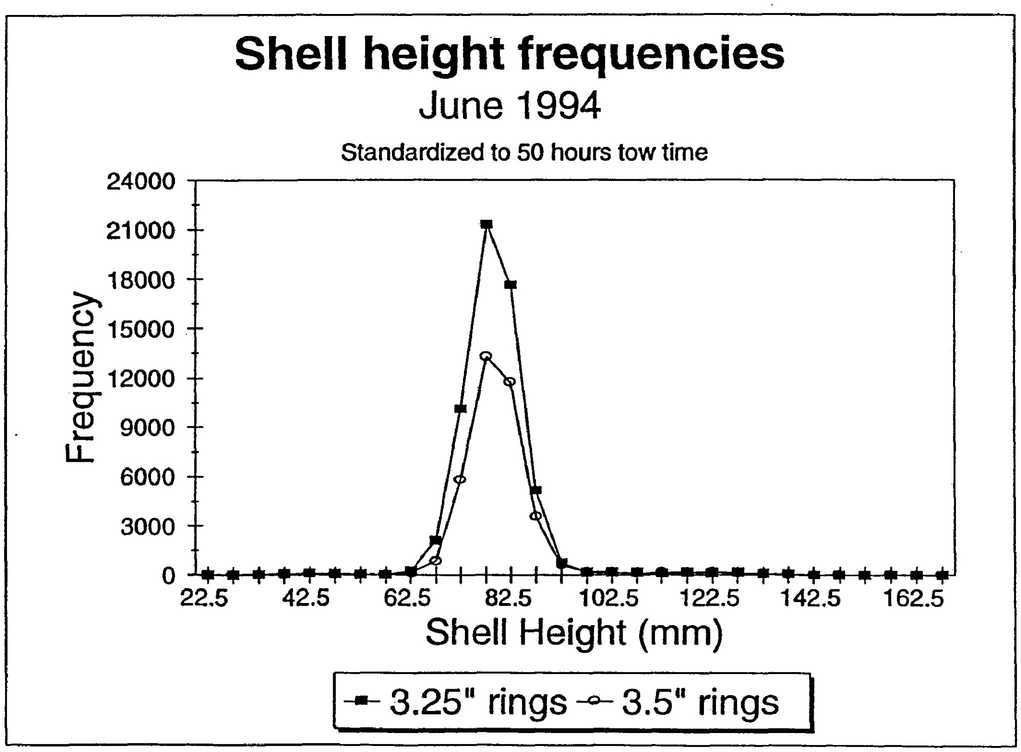

Shell height frequencies
June 1994
Standardized to 50 hours tow time
Frequency
24000
21000
18000
15000
12000
9000
6000
3000
0
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

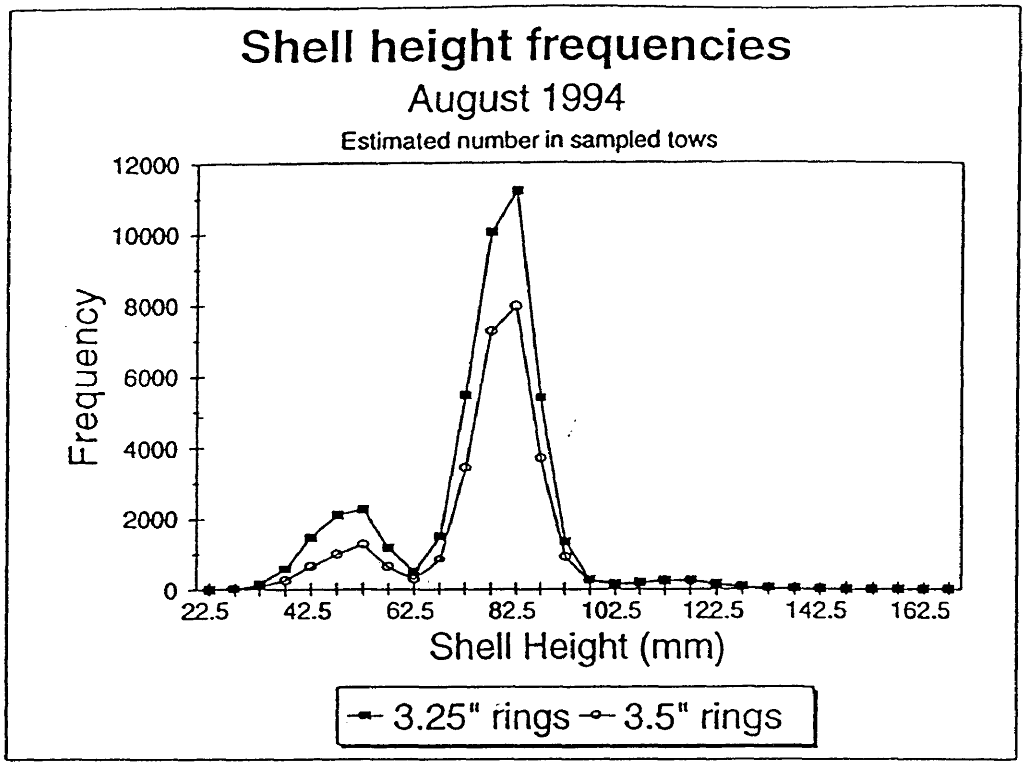
Table 4 Shell height frequency distributions for 3.25" and 3.5" ring dredges from August 1994. Estimated total number of scallops in all tows sampled and standardized number of scallops in all tows sampled.

Shell height (mm)	Estimated number in 3.25" rings	Estimated number in 3.5" rings	Standardized number in 3.25" rings	Standardized number in 3.5" rings
20-25	2	0	2	0
25-30	23	10	21	8
30-35	159	85	147	64
35-40	587	267	527	221
40-45	1464	641	1314	536
45-50	2104	1001	1877	831
50-55	2250	1251	2034	1071
55-60	1176	631	1069	545
60-65	504	278	456	254
65-70	1497	858	1398	813
70-75	5460	3409	5253	3359
75-80	10039	7250	9941	7256
80-85	11197	7937	11294	8123
85-90	5400	3690	5548	3828
90-95	1342	903	1376	942
95-100	278	234	293	246
100-105	145	146	160	161
105-110	177	156	201	175
110-115	243	247	267	270
115-120	259	219	288	236
120-125	144	125	155	135
125-130	79	62	90	68
130-135	46	34	52	39
135-140	17	19	21	21
140-145	7	11	8	15
145-150	2	4	3	4
150-155	2	1	3	1
155-160	0	0	0	0
160-165	0	0	0	0
165-170	0	0	0	0
Totals	44603	29469	43798	29222

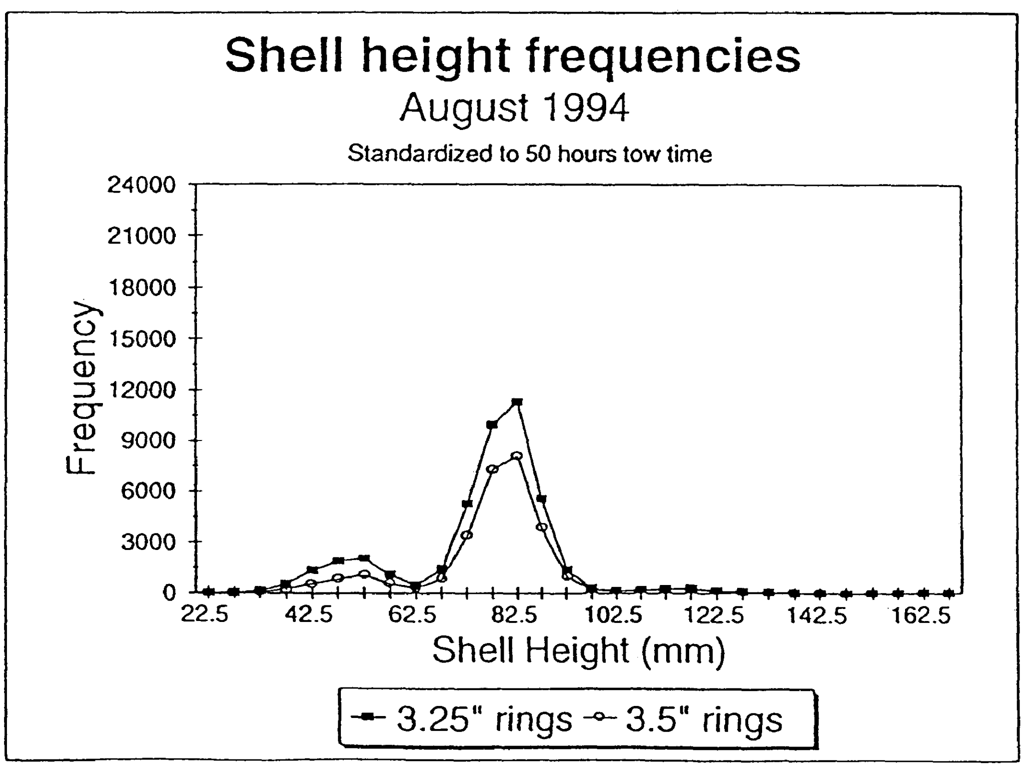
Figure 5 Shell height frequency distributions for August 1994 from the mid-Atlantic region for both 3.25" and 3.5" ring dredges.

a) Estimated number of scallops in sampled tows.

b) Number of scallops per 50 hours of tow time.



Shell height frequencies
August 1994
Estimated number in sampled tows
Frequency
0
2000
4000
6000
8000
10000
12000
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings



Shell height frequencies
August 1994
Standardized to 50 hours tow time
Frequency
0
3000
6000
9000
12000
15000
18000
21000
24000
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

Trip 3:

The third sampling trip was conducted aboard the F/V *Stephanie B* from October 27 to November 7, 1994. A total of 203 tows were completed, and 45 of these were sampled. Fishing depth of the sampled tows during the trip ranged from 19 to 42 fm (34.8 to 76.9 m), with a modal depth fished of 25 fm (45.8 m). The most common tow speed was 4.5 kts. The range of tow speed was from 4.0 to 5.0 kts. Tow duration ranged from 35 to 75 minutes with a modal duration of 60 minutes (Table 2).

The number of scallops measured in the 3.25" and 3.5" ring dredges were 13,657 and 10,144 respectively. When extrapolated to whole tows, the total number of scallops sampled was 22,566 and 14,425 respectively (Table 5, Figure 6). Overall production was 1466 pounds of meats for the 3.25" ring dredge and 990 pounds with the 3.5" ring dredge. Meat counts were 43.7 and 40.2 MPP respectively (Table 7).

Trip 4:

The fourth sampling trip was also conducted aboard the F/V *Stephanie B* from April 25 to May 2, 1995. Fifty of the 148 tows were sampled. For this trip, the most common depth fished was 36 fm (65.9 m). Depths fished ranged from 19 to 43 fm (34.8 to 78.7 m). Speeds ranged from 4.3 to 5.0 kts, with a modal tow speed of 4.5 kts. Tows lasted from 40 to 75 minutes with 50 minute tows being the most common (Table 2).

A total of 46,468 scallops were measured during the 50 tows sampled: 24,870 and 21,598 for the 3.25" and 3.5" ring dredges respectively. The estimated number of scallops in the tows sampled was 48,908 and 34,595 scallops respectively (Table 6, Figure 7). Total

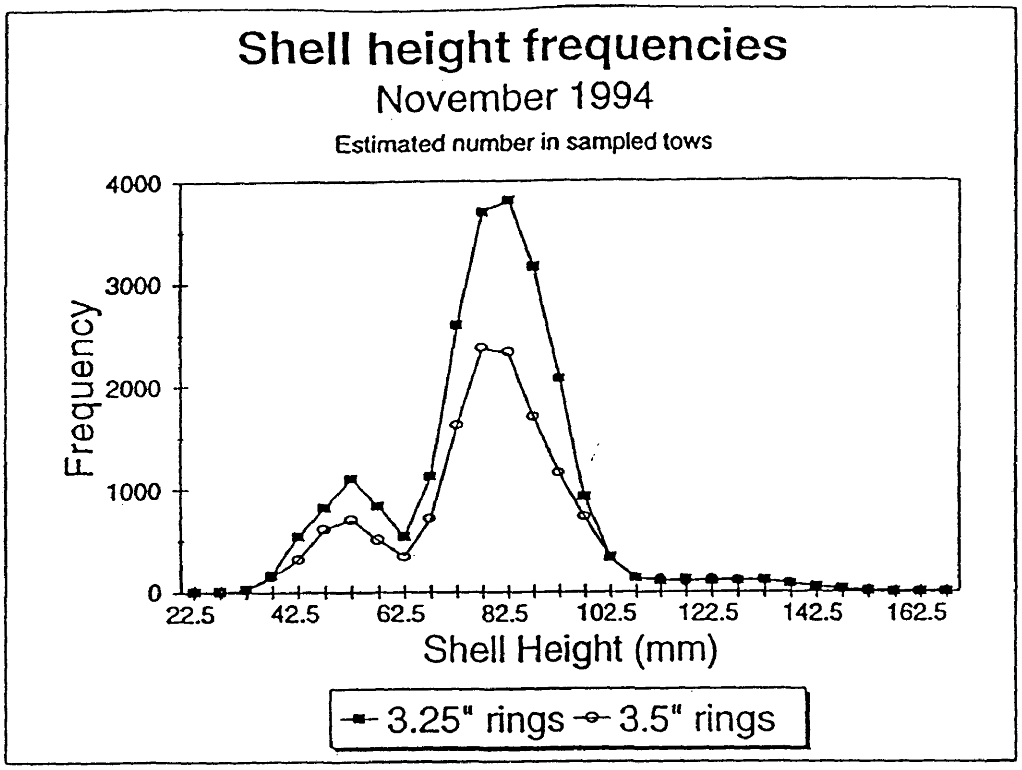
Table 5 Shell height frequency distributions for 3.25" and 3.5" ring dredges from November 1994. Estimated total number of scallops in all tows sampled and standardized number of scallops in all tows sampled.

Shell height (mm)	Estimated number in 3.25" rings	Estimated number in 3.5" rings	Standardized number in 3.25" rings	Standardized number in 3.5" rings
20-25	0	2	0	3
25-30	3	4	3	4
30-35	26	19	27	18
35-40	164	140	163	136
40-45	537	314	533	305
45-50	818	605	822	585
50-55	1099	706	1117	693
55-60	837	504	870	502
60-65	540	342	587	365
65-70	1122	716	1238	755
70-75	2590	1628	2814	1699
75-80	3693	2367	4048	2497
80-85	3811	2326	4284	2541
85-90	3158	1700	3684	1951
90-95	2074	1155	2502	1377
95-100	921	722	1145	895
100-105	333	321	419	404
105-110	136	134	169	167
110-115	105	118	131	148
115-120	119	90	147	112
120-125	101	123	123	148
125-130	105	114	127	143
130-135	111	102	137	124
135-140	75	84	90	106
140-145	48	46	58	57
145-150	29	25	36	28
150-155	8	14	8	16
155-160	1	2	2	2
160-165	1	2	1	2
165-170	1	0	1	0
Totals	22566	14425	25286	15783

Figure 6 Shell height frequency distributions for November 1994 from the mid-Atlantic region for both 3.25" and 3.5" ring dredges.

a) Estimated number of scallops in sampled tows.

b) Number of scallops per 50 hours of tow time.


Shell height frequencies
November 1994
Estimated number in sampled tows
4000
3000
2000
1000
0
Frequency
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

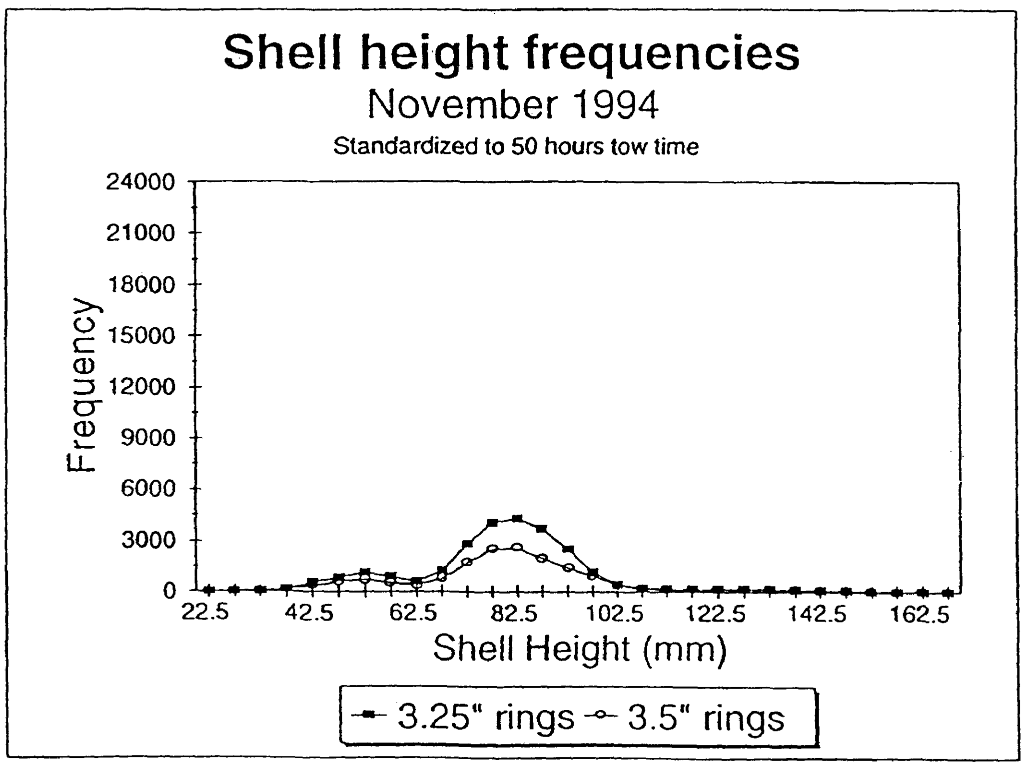

Shell height frequencies
November 1994
Standardized to 50 hours tow time
24000
21000
18000
15000
12000
9000
6000
3000
0
Frequency
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

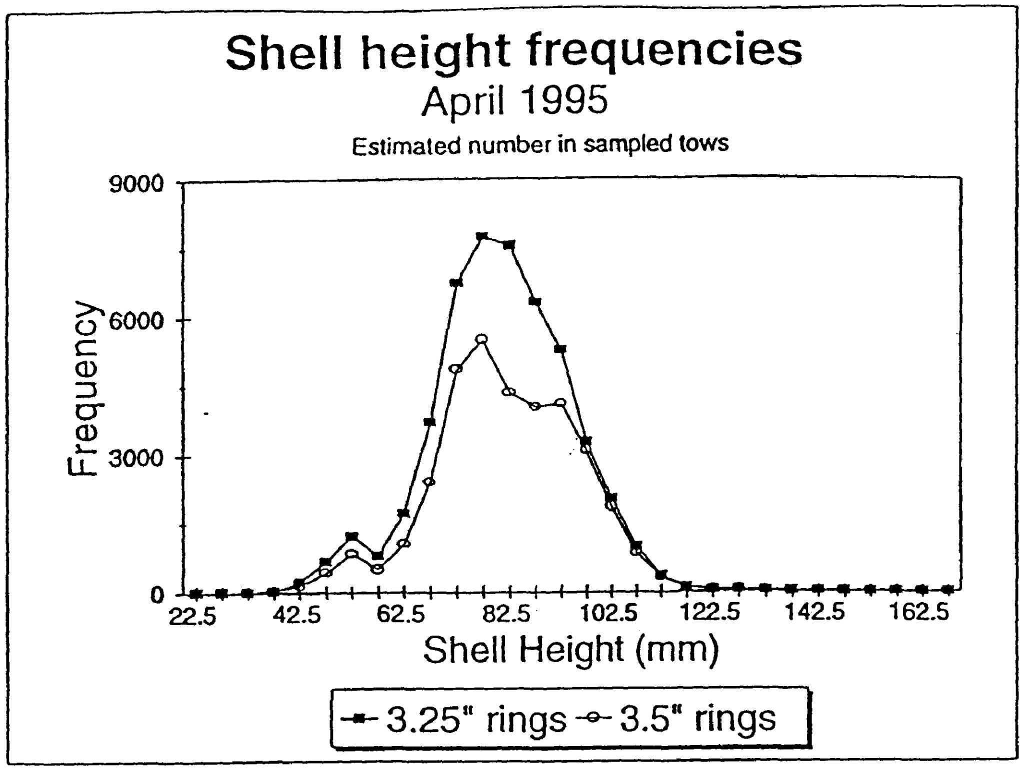
Table 6 Shell height frequency distributions for 3.25" and 3.5" ring dredges from April 1995. Estimated total number of scallops in all tows sampled and standardized number of scallops in all tows sampled.

Shell height (mm)	Estimated number in 3.25" rings	Estimated number in 3.5" rings	Standardized number in 3.25" rings	Standardized number in 3.5" rings
20-25	0	0	0	0
25-30	0	0	0	0
30-35	4	0	5	0
35-40	25	21	31	27
40-45	222	129	292	171
45-50	676	429	914	585
50-55	1228	845	1678	1153
55-60	802	500	989	610
60-65	1720	1044	1876	1161
65-70	3710	2407	3987	2585
70-75	6734	4839	7023	4969
75-80	7736	5496	7890	5632
80-85	7541	4342	7611	4388
85-90	6303	4054	6483	4159
90-95	5270	4102	5671	4447
95-100	3280	3081	3791	3573
100-105	2037	1848	2489	2291
105-110	987	841	1241	1061
110-115	361	315	454	396
115-120	104	95	128	121
120-125	40	63	50	76
125-130	41	58	48	69
130-135	33	45	41	53
135-140	26	20	31	25
140-145	15	11	18	13
145-150	10	5	12	6
150-155	3	5	3	5
155-160	0	0	0	0
160-165	0	0	0	0
165-170	0	0	0	0
Totals	48908	34595	52756	37576

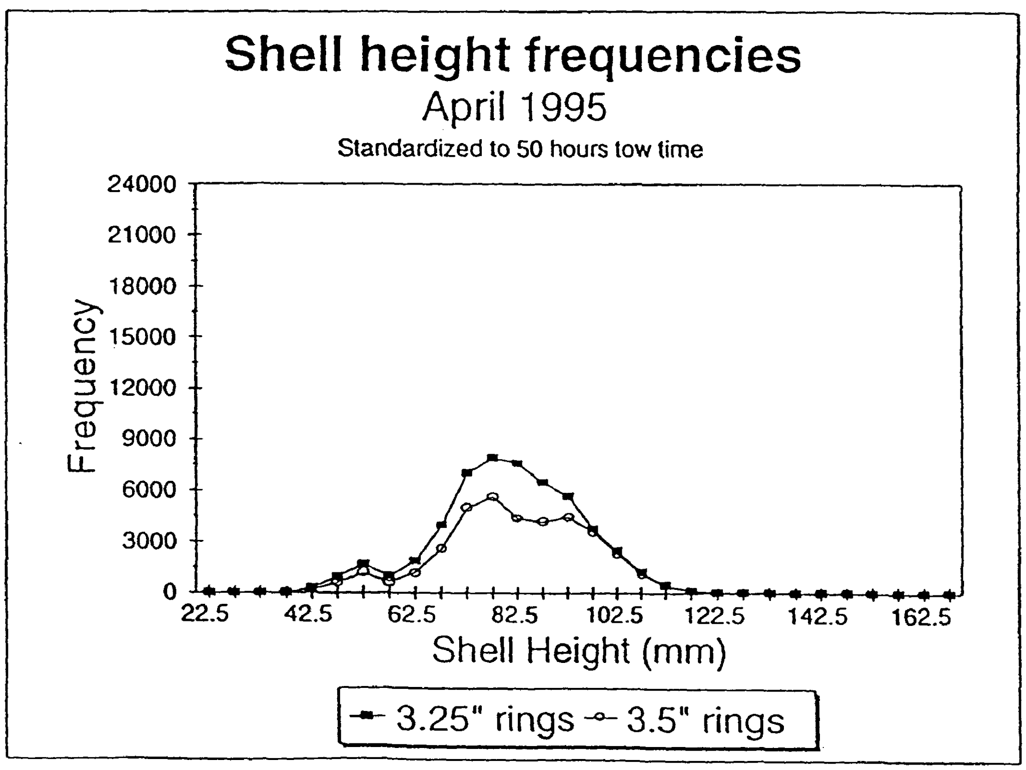
Figure 7 Shell height frequency distributions for April 1995 from the mid-Atlantic region for both 3.25" and 3.5" ring dredges.

a) Estimated number of scallops in sampled tows.

b) Number of scallops per 50 hours tow time.



Shell height frequencies
April 1995
Estimated number in sampled tows
9000
6000
3000
0
Frequency
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings



Shell height frequencies
April 1995
Standardized to 50 hours tow time
24000
21000
18000
15000
12000
9000
6000
3000
0
Frequency
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.25" rings
3.5" rings

production for this trip was 2099 and 1775 pounds of meats for the 3.25" and 3.5" ring gears with meat counts of 35.3 and 31.5 MPP respectively (Table 7).

Catch Data

Results for the Bartlett's and Wilk-Shapiro tests are shown in Table 8. All of the data sets conformed to the normal distribution. Only the November 1994 trip was homoscedastic before transformation. The other three were strongly heteroscedastic ($p < 0.01$), and natural log transformations were performed on the catch data. Further Bartlett's and Wilk-Shapiro tests were run on the transformed data. All trips were found to be homoscedastic and normally distributed after transformation for $\alpha = 0.05$. Only catches for the trip in June, 1994, were very significantly different ($p < 0.0001$). Catches for the other three trips were not significant at the 0.05 level of confidence (Table 8).

Relative Efficiency Data

For all trips combined, the 3.5" ring dredge performed with 66% efficiency relative to the 3.25" ring dredge (Table 9). For each trip separately, overall efficiency of the 3.5" ring dredge ranged from 62 to 71%. For the 1990 year class, the estimates ranged from 60 to 72% (Tables 10 to 13, Figures 8 to 11). Between June and August 1994, relative efficiency for the 1990 year class increased from 63% to 70%. By April 1995, it had increased to 72%. The lowest value of 60% was obtained during the November 1994 trip.

For all trips, 90 to 100% relative efficiency was attained at 102.5 mm shell height. As with other scallop gear studies, catch by the larger ring dredge exceeded that of the

Table 7 Overall production (pounds of scallop meats), meat counts (MPP), and relative production efficiency for the 1990 year class for 3.25" and 3.5" ring scallop dredges for each trip and all trips combined. Production efficiency is the efficiency of production from the 1990 year class for the 3.5" ring dredge relative to the 3.25" ring dredge.

Trip	Production of 3.25" rings (lbs)	MPP of 3.25" rings	Production of 3.5" rings (lbs)	MPP of 3.5" rings	Production Efficiency
June 1994	3633	57.3	1813	53.1	0.50
August 1994	3394	47.5	2621	42.9	0.77
November 1994	1466	43.7	990	40.2	0.68
April 1995	2099	35.3	1775	31.5	0.85
Overall	10592		7199		0.70

Table 8 Results of the Wilk-Shapiro test of normality for catch by both 3.25" and 3.5" ring dredges, Bartlett's test of equality of variance between dredges, and student's t-test for similarity of catch by the two dredges.

Trip	Wilk-Shapiro (3.25" rings)	Wilk-Shapiro (3.5" rings)	Bartlett's test	Student's t-test
June 1994*	0.9155	0.94904	0.3301	<0.001
August 1994*	0.9623	0.8903	0.6413	0.1346
November 1994	0.7592	0.6631	0.0708	0.0544
April 1995*	0.9755	0.9707	0.1818	0.1367

* Natural logarithm transformation performed

Table 9 Relative efficiency of the 3.5" ring scallop dredge. Relative efficiency is efficiency of catch by the 3.5" ring dredge relative to catch by the 3.25" ring dredge. Smoothed efficiency is relative efficiency smoothed with a moving geometric mean of three. Catch is standardized to 50 hours of tow time with 13 foot wide dredges.

Shell height (mm)	3.25" rings	3.5" rings	Relative Efficiency	Smoothed Efficiency
20-25	1	1	1.00	---
25-30	6	3	0.50	0.61
30-35	53	24	0.45	0.49
35-40	206	104	0.50	0.48
40-45	556	264	0.47	0.51
45-50	907	494	0.54	0.54
50-55	1178	709	0.60	0.57
55-60	707	397	0.56	0.59
60-65	773	462	0.60	0.57
65-70	2233	1259	0.56	0.59
70-75	6775	4214	0.62	0.61
75-80	11915	7858	0.66	0.65
80-85	11117	7330	0.66	0.66
85-90	5370	3511	0.65	0.68
90-95	2485	1777	0.72	0.75
95-100	1279	1172	0.92	0.85
100-105	777	729	0.94	0.92
105-110	431	385	0.89	0.95
110-115	242	250	1.03	0.97
115-120	184	180	0.98	1.06
120-125	122	145	1.19	1.05
125-130	108	107	0.99	1.05
130-135	80	79	0.99	0.99
135-140	50	50	1.00	0.97
140-145	26	24	0.92	0.88
145-150	12	9	0.75	1.05
150-155	3	5	1.67	---
155-160	0	0	---	---
160-165	0	0	---	---
165-170	0	0	---	---
All sizes	47596	31542	0.66	

Table 10 Relative harvest efficiency of the 3.5" ring scallop dredge for June 1994. Relative efficiency is efficiency of catch by the 3.5" ring dredge relative to catch by the 3.25" ring dredge. Smoothed efficiency is relative efficiency smoothed with a moving geometric mean of three. Catch is standardized to 50 hours of tow time using 13 foot wide dredges. Shell heights 55 to 100 mm represent the size range of the 1990 year class in June 1994.

Shell height (mm)	3.25" rings	3.5" rings	Relative Efficiency	Smoothed Efficiency
20-25	1	1	1.00	---
25-30	3	1	0.33	0.54
30-35	26	12	0.46	0.40
35-40	88	36	0.41	0.48
40-45	106	61	0.58	0.50
45-50	85	44	0.52	0.58
50-55	36	23	0.64	0.49
55-60	22	8	0.36	0.49
60-65	258	130	0.50	0.42
65-70	2107	866	0.41	0.49
70-75	10128	5796	0.57	0.53
75-80	21306	13254	0.62	0.62
80-85	17644	11755	0.67	0.66
85-90	5153	3581	0.69	0.70
90-95	757	561	0.74	0.86
95-100	162	199	1.23	0.99
100-105	162	171	1.06	1.12
105-110	149	163	1.09	1.19
110-115	118	174	1.47	1.31
115-120	152	214	1.41	1.43
120-125	140	196	1.40	1.21
125-130	149	135	0.91	1.11
130-135	88	96	1.09	0.98
135-140	57	54	0.95	0.87
140-145	22	14	0.64	0.67
145-150	2	1	0.50	---
150-155	1	0	0.00	---
155-160	0	0	---	---
160-165	0	0	---	---
165-170	0	0	---	---
All sizes	58922	37546	0.64	
55-100 mm	57537	36510	0.63	

Figure 8 Harvest efficiency of the 3.5" ring dredge relative to the 3.25" ring dredge for June 1994 in the mid-Atlantic region. A positive X value indicates that the 3.5" ring dredge performed better than the 3.25" ring dredge. Efficiency values for very small and very large scallops may be artificially high or low due to low sample sizes for those shell heights.

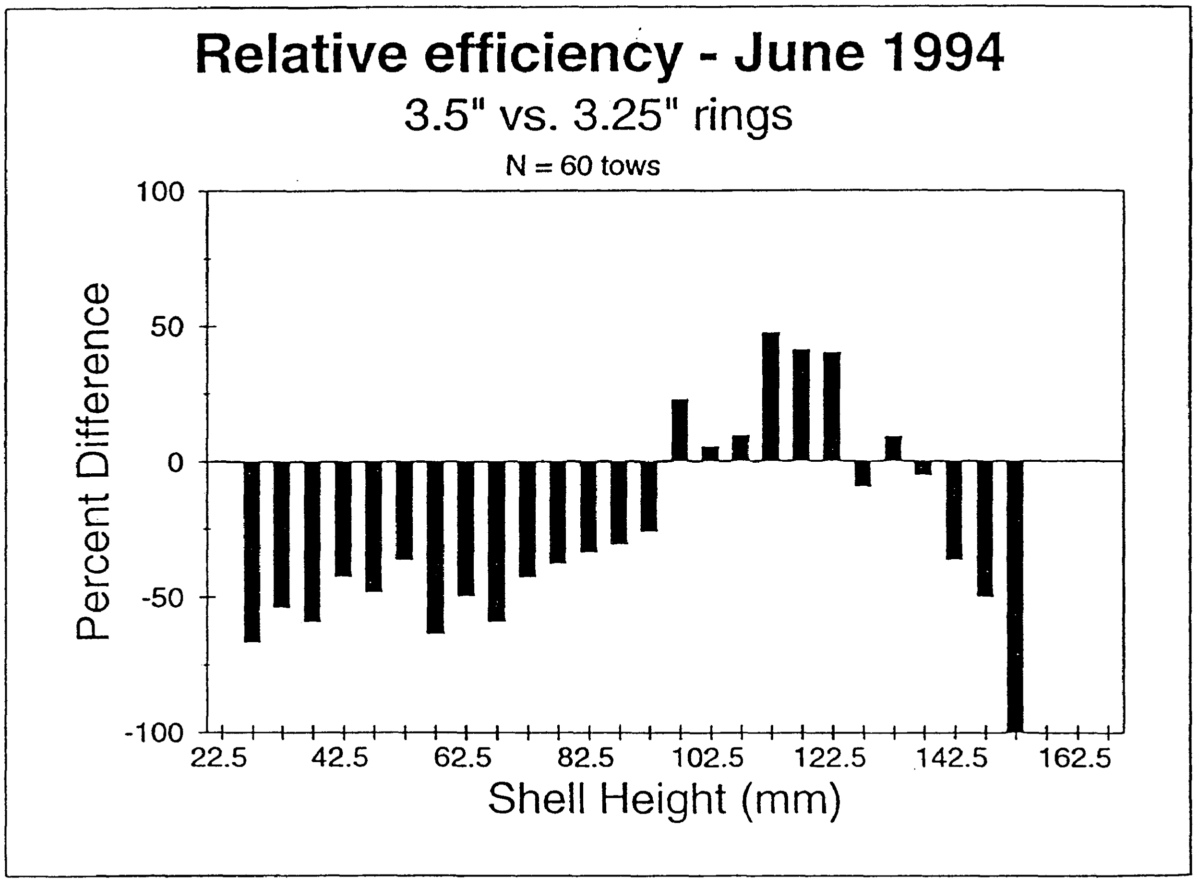

Relative efficiency - June 1994
3.5" vs. 3.25" rings
N = 60 tows
100
50
0
-50
-100
Percent Difference
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)

Table 11 Relative harvest efficiency of the 3.5" ring scallop dredge for August 1994. Relative efficiency is efficiency of catch by the 3.5" ring dredge relative to catch by the 3.25" ring dredge. Smoothed efficiency is relative efficiency smoothed with a moving geometric mean of three. Catch is standardized to 50 hours of tow time using 13 foot wide dredges. Shell heights 60 to 105 mm represent the size range of the 1990 year class in August 1994.

Shell height (mm)	3.25" rings	3.5" rings	Relative Efficiency	Smoothed Efficiency
20-25	2	0	0.00	---
25-30	21	8	0.38	---
30-35	147	64	0.44	0.41
35-40	527	221	0.42	0.42
40-45	1314	536	0.41	0.42
45-50	1877	831	0.44	0.46
50-55	2034	1071	0.53	0.49
55-60	1069	545	0.51	0.53
60-65	456	254	0.56	0.55
65-70	1398	813	0.58	0.59
70-75	5253	3359	0.64	0.65
75-80	9941	7256	0.73	0.69
80-85	11294	8123	0.72	0.71
85-90	5548	3828	0.69	0.70
90-95	1376	942	0.68	0.73
95-100	293	246	0.84	0.83
100-105	160	161	1.01	0.90
105-110	201	175	0.87	0.96
110-115	267	270	1.01	0.90
115-120	288	236	0.82	0.90
120-125	155	135	0.87	0.81
125-130	90	68	0.76	0.79
130-135	52	39	0.75	0.83
135-140	21	21	1.00	1.12
140-145	8	15	1.88	1.36
145-150	3	4	1.33	0.94
150-155	3	1	0.33	---
155-160	0	0	---	---
160-165	0	0	---	---
165-170	0	0	---	---
All sizes	43798	29222	0.67	
60-105 mm	35719	24982	0.70	

Figure 9 Harvest efficiency of the 3.5" ring dredge relative to the 3.25" ring dredge for August 1994 in the mid-Atlantic region. A positive X value indicates that the 3.5" ring dredge performed better than the 3.25" ring dredge. Efficiency values for very small and very large scallops may be artificially high or low due to low sample sizes for those shell heights.

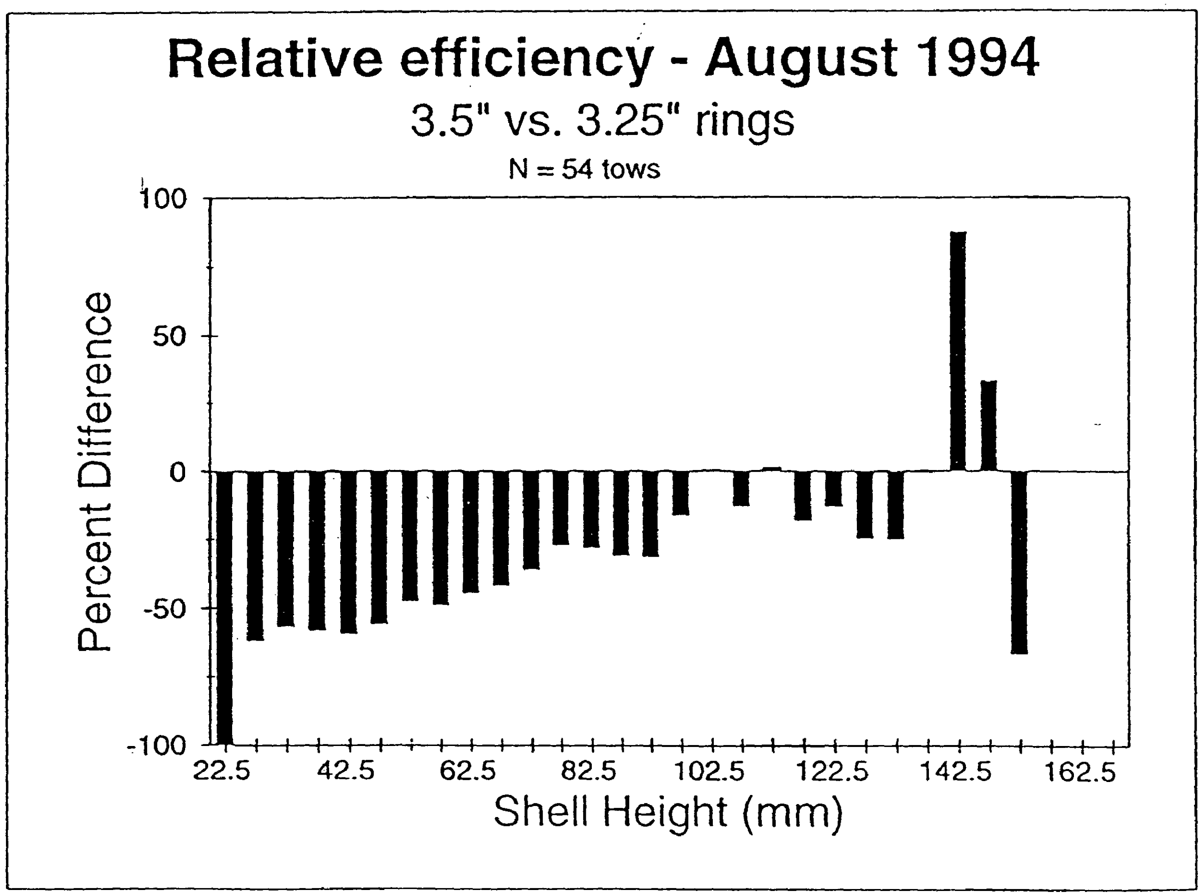

Relative efficiency - August 1994
3.5" vs. 3.25" rings
N = 54 tows
Percent Difference
100
50
0
-50
-100
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)

Table 12 Relative harvest efficiency of the 3.5" ring scallop dredge for November 1994. Relative efficiency is efficiency of catch by the 3.5" ring dredge relative to catch by the 3.25" ring dredge. Smoothed efficiency is relative efficiency smoothed with a moving geometric mean of three. Catch is standardized to 50 hours of tow time using 13 foot wide dredges. Shell heights 60 to 105 mm represent the size range of the 1990 year class in November 1994.

Shell height (mm)	3.25" rings	3.5" rings	Relative Efficiency	Smoothed Efficiency
20-25	0	3	---	---
25-30	3	4	1.33	---
30-35	27	18	0.67	0.91
35-40	163	136	0.83	0.68
40-45	533	305	0.57	0.70
45-50	822	585	0.71	0.63
50-55	1117	693	0.62	0.63
55-60	870	502	0.58	0.61
60-65	587	365	0.62	0.60
65-70	1238	755	0.61	0.61
70-75	2814	1699	0.60	0.61
75-80	4048	2497	0.62	0.60
80-85	4284	2541	0.59	0.58
85-90	3684	1951	0.53	0.56
90-95	2502	1377	0.55	0.61
95-100	1145	895	0.78	0.75
100-105	419	404	0.96	0.91
105-110	169	167	0.99	1.02
110-115	131	148	1.13	0.95
115-120	147	112	0.76	1.01
120-125	123	148	1.20	1.01
125-130	127	143	1.13	1.07
130-135	137	124	0.91	1.06
135-140	90	106	1.18	1.02
140-145	58	57	0.98	0.97
145-150	36	28	0.78	1.15
150-155	8	16	2.00	1.16
155-160	2	2	1.00	1.59
160-165	1	2	2.00	---
165-170	1	0	0.00	---
All sizes	25286	15783	0.62	
60-105 mm	20721	12484	0.60	

Figure 10 Harvest efficiency of the 3.5" ring dredge relative to the 3.25" ring dredge for November 1994 in the mid-Atlantic region. A positive X value indicates that the 3.5" ring dredge performed better than the 3.25" ring dredge. Efficiency values for very small and very large scallops may be artificially high or low due to low sample sizes for those shell heights.

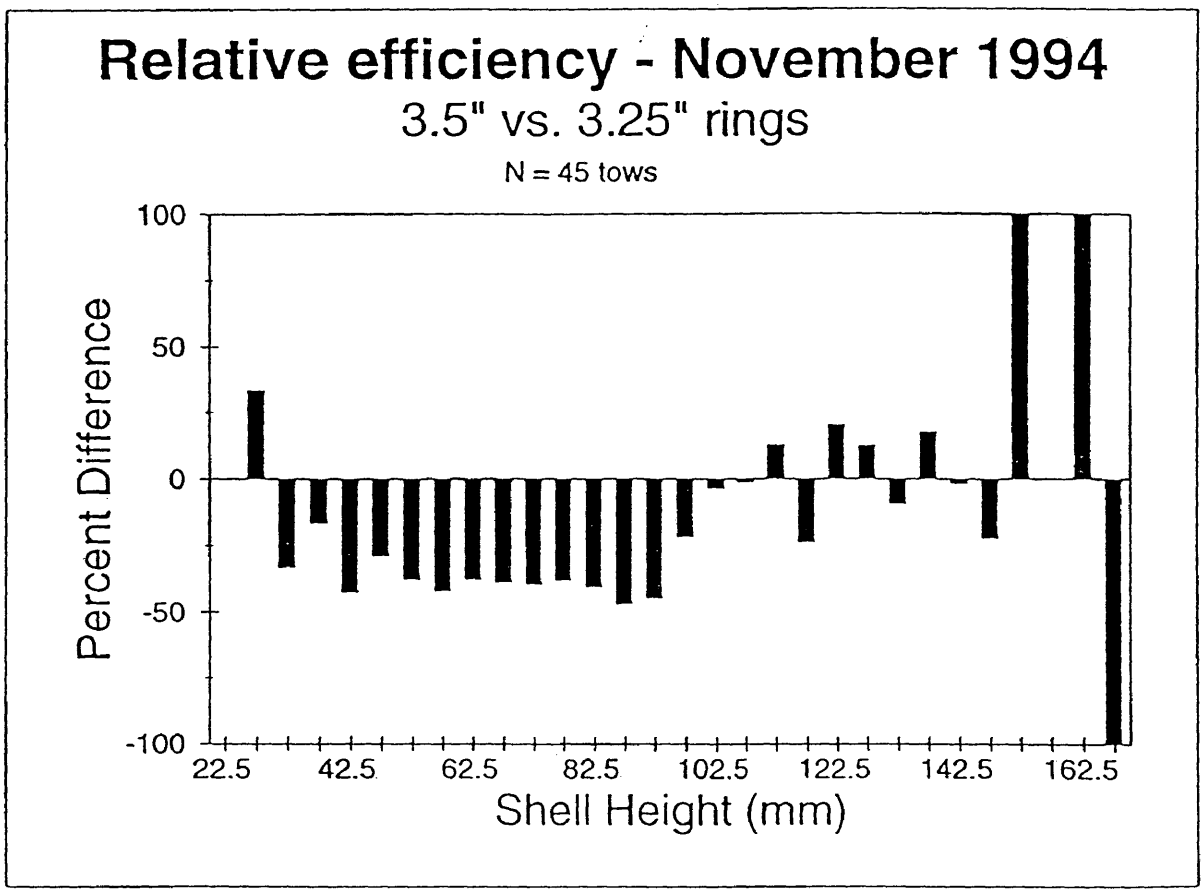
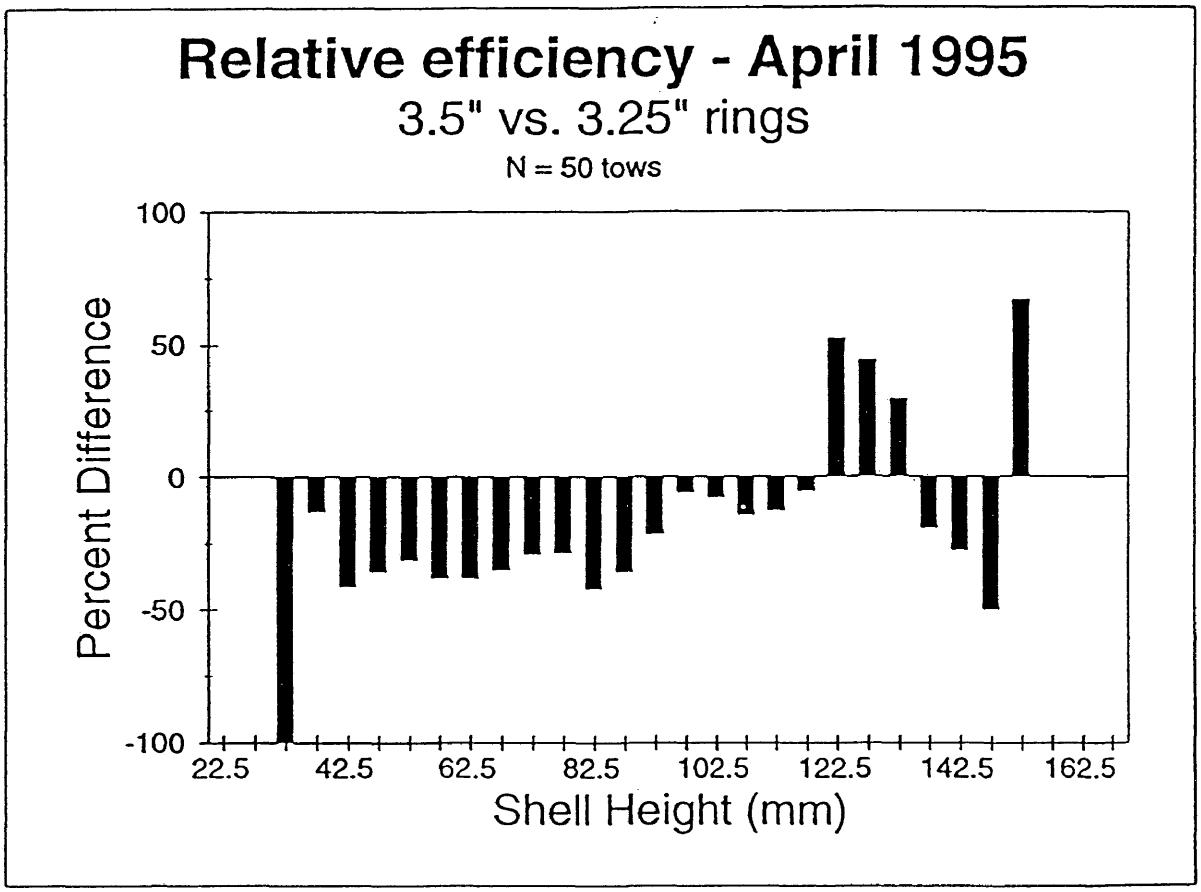

Relative efficiency - November 1994
3.5" vs. 3.25" rings
N = 45 tows
Percent Difference
100
50
0
-50
-100
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)

Table 13 Relative harvest efficiency of the 3.5" ring scallop dredge for April 1995. Relative efficiency is efficiency of catch by the 3.5" ring dredge relative to catch by the 3.25" ring dredge. Smoothed efficiency is relative efficiency smoothed with a moving geometric mean of three. Catch is standardized to 50 hours of tow time using 13 foot wide dredges. Shell heights 70 to 115 mm represent the size range of the 1990 year class in April 1995.

Shell height (mm)	3.25" rings	3.5" rings	Relative Efficiency	Smoothed Efficiency
20-25	0	0	---	---
25-30	0	0	---	---
30-35	5	0	0.00	---
35-40	31	27	0.87	---
40-45	292	171	0.59	0.69
45-50	914	585	0.64	0.64
50-55	1678	1153	0.69	0.65
55-60	989	610	0.62	0.64
60-65	1876	1161	0.62	0.63
65-70	3987	2585	0.65	0.66
70-75	7023	4969	0.71	0.69
75-80	7890	5632	0.71	0.66
80-85	7611	4388	0.58	0.64
85-90	6483	4159	0.64	0.66
90-95	5671	4447	0.78	0.78
95-100	3791	3573	0.94	0.88
100-105	2489	2291	0.92	0.91
105-110	1241	1061	0.85	0.88
110-115	454	396	0.87	0.89
115-120	128	121	0.95	1.08
120-125	50	76	1.52	1.27
125-130	48	69	1.44	1.41
130-135	41	53	1.29	1.14
135-140	31	25	0.81	0.91
140-145	18	13	0.72	0.66
145-150	12	6	0.50	0.84
150-155	3	5	1.67	---
155-160	0	0	---	---
160-165	0	0	---	---
165-170	0	0	---	---
All sizes	52756	37576	0.71	
70-115 mm	42653	30916	0.72	

Figure 11 Harvest efficiency of the 3.5" ring dredge relative to the 3.25" ring dredge for April 1995 in the mid-Atlantic region. A positive X value indicates that the 3.5" ring dredge performed better than the 3.25" ring dredge. Efficiency values for very small and very large scallops may be artificially high or low due to low sample sizes for those shell heights.



Relative efficiency - April 1995
3.5" vs. 3.25" rings
N = 50 tows
Percent Difference
100
50
0
-50
-100
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)

smaller ring dredge for several of the larger shell heights.

Production efficiency followed the same trend as harvest efficiency. It increased between June and August 1994, decreased in November 1994, then increased again in April 1995. The estimates of relative production efficiency for the four trips are 50%, 77%, 68%, and 85% (Table 7).

Shell height:meat weight data

Analysis of covariance tests were run on the regression equations to test for similarity between samples. Several groups of the samples were similar, but there was no discernable pattern to the similarities, making it difficult to combine samples for better, more reliable results. A random effects model (Zar, 1984) was run on LIMDEP with time of collection as the random variable. A reliable fit was observed, and it was decided that this was the best model to use. The model used was:

$$\ln(MW) = -9.7776 + 2.6996 * \ln(SH) \qquad R^2 = 0.7448$$
$$(-73.604) \quad (98.136)$$

where ln(MW) and ln(SH) are the natural logarithms of meat weight and shell height respectively, and the numbers in parentheses below the equation are t-ratios.

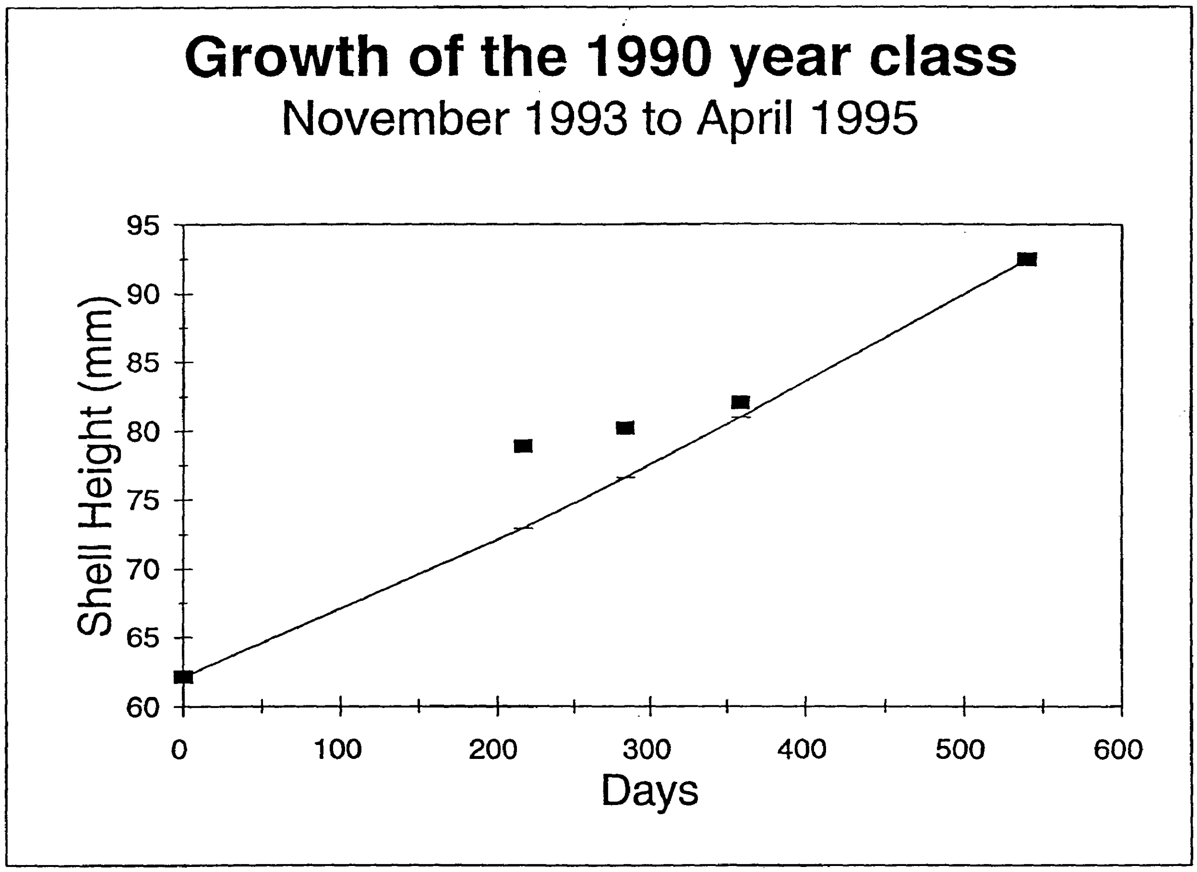
Growth Data

Estimates of the daily growth coefficient range from 2.44E-4 to 10.97E-4 between successive trips. The daily growth coefficient over all trips was 7.36E-4 (Table 14, Figure 12). The periods of most rapid growth occur during the winter and spring. Much slower growth rates over the summer and fall coincide with the end of the spring spawning, recovery, and the fall spawning period.

Table 14 Mean shell height (mm) of the 1990 year class for each trip, time interval (days) between trips, and exponential growth parameter for each trip and over the whole sampling period. The exponential growth equation is $L_t = L_0 * e^{Gt}$ where L_t is length at time t, L_0 is length at time 0, G is the exponential growth parameter, and t is time in days.

Trip	Mean Shell Height (mm)	Interval between trips (days)	Cumulative interval (days)	Exponential growth parameter, G (X10^-4)
November 1993	62.16		0	
June 1994	78.87	217	217	10.97
August 1994	80.17	67	284	2.44
November 1994	82.03	75	359	3.06
April 1995	92.5	181	540	6.64
Overall		540	540	7.36

Figure 12 Exponential growth curve for the 1990 year class of sea scallops between November 1993 and April 1995 in the mid-Atlantic region. The filled squares are the actual shell heights of the individual trips. The fit line is the exponential growth curve between the endpoints. Increments in days are relative to the first fishing day of the first trip and increase to the first day of each successive trip.



Growth of the 1990 year class
November 1993 to April 1995
Shell Height (mm)
95
90
85
80
75
70
65
60
0
100
200
300
400
500
600
Days

DISCUSSION

The Petersen method is often considered inefficient for analysis of some population distributions because of difficulty with overlapping age classes and damping of length frequency distribution modes (Jearld, 1983). This was not a problem for most of the data sets used here since the following year class' (1991) shell height distribution did not overlap and previous year classes (before 1990) had been virtually fished out. Year class overlap did pose a problem with the data set from April 1995 due to differential growth rates, but a modal shell height was apparent and was used.

MULTIFAN was considered as a method for distinguishing age groups, but it has been found that this program does not always confidently identify age classes (Anonymous, 1995). It does not account for variability in length at age, and it often introduces an extra age class to obtain a better fit of the data set (Fournier *et al.*, 1990). For the most part, the year classes were distinct enough to be seen by eye. The only distribution that posed a problem was the left tail of the April 1995 trip, but the method used to determine the left tail of this distribution should not alter the results of the efficiency estimates. The scallops in the overlapping region are of two separate age classes, but because of differential growth rates, they are the same size. Since harvest efficiency is largely a function of size of the scallops, the efficiency estimates of the overlapping region should be no different than if the scallops were all from the same year class.

Originally, statistical comparisons of catch by the different dredges were to be done using a Zellner regression model, also referred to as a seemingly unrelated regression (SUR) model (Zellner, 1962). It is so termed because it is a system of equations that are unrelated except that a shock (change in error) of one equation creates a change in error of the others. In other words, the equations are only related, or linked, by their error terms (Greene, 1990). In this method, regression parameters for a system of equations are all estimated simultaneously using generalized least squares (GLS). This is done using estimates of the respective error terms' variances and covariances obtained from residuals derived from equation by equation application of ordinary least squares (OLS) (Zellner, 1962). This model is at least as efficient, and generally more efficient, as the equation by equation OLS model (Zellner, 1962). Greene (1990) summarizes some instances when the two methods are equally efficient and when the SUR model is more efficient.

Other choices of analysis were comparison of means and ordinary least squares regression. The number of variables present would have made a very large, cumbersome ANOVA with many hypotheses. For this reason, an ANOVA was originally rejected. Ordinary least squares regression was not considered for two reasons. First, as mentioned above, the GLS used in the SUR model is at least as efficient, and often more efficient than OLS. Secondly, this method is also more cumbersome than the SUR. Two separate regressions would have to be estimated from the raw data. A third would then have to be estimated with the pooled data. Regression parameters could then be compared in this way.

Both of these analyses are much more complicated than a SUR model for the data in this experiment. The SUR model was decided as the best option. The model that was to be fit was:

$$\text{Catch}_i = f(\text{effort}_i, \text{depth}_i, \text{speed}_i)$$

where "i" refers to the "i'th" dredge ring size. This model would have been fit for each of the ring sizes and regression parameters would be compared. Further analysis, however, showed there was insufficient variation in the variables to justify doing any regression analyses. Without these variables in the model, comparison of means became much simpler, and a student's t-test was chosen as the method of analysis.

<u>Status of the fishery</u>

In the sea scallop fishery, the year class that is most heavily exploited is the one most recently recruited. It is thought to be approximately 3.5 years old when the majority of the scallops begin recruiting to the fishery in winter and spring. The year class followed in this study is assumed to be the 1990 year class. It was first seen in August 1993 during a NEFSC scallop survey, and again in November 1993 during a trip to assess the efficiency of the 3.25" ring dredge relative to the 3.0" ring dredge (DuPaul and Kirkley, 1994a). The scallop survey found it to be a very large year class - the largest to recruit to DelMarVa in recorded history (NEFSC, 1993). During the November 1993 trip, as many as 25 baskets (35-40 bushels) of these scallops were caught per tow in a single dredge (DuPaul and Kirkley, 1994a and b). The majority of these scallops were 60 to 65 mm and nearly 100 count (100 meats per pound), but larger individuals were already being retained by the fishermen (DuPaul and Kirkley, 1994a).

In March 1994, the first gear regulation went into effect and the ring size used in the dredges increased from 3.0" to 3.25" (76 to 83 mm). The scallops had grown to between 65 and 75 mm modal shell height and were mostly between 60 and 80 count. Gear studies to assess the efficiency of the 3.25" gear relative to the 3.0" gear predicted catch would decrease by as much as 45% on hard bottom (rock, slab). Reductions on soft bottom (sand, mud), such as the mid-Atlantic, might be as slight as 12% (DuPaul and Kirkley, 1994b).

Efficiency

By June 1994, the scallops had grown to a modal size of 75 to 80 mm. Harvest efficiency of the 3.25" ring gear had improved, both due to scallop growth and the fishermen becoming more familiar with the gear. During the first trip in June 1994, the experimental 3.5" ring dredge was 63% as efficient as the standard 3.25" ring dredge at catching scallops of the 1990 year class. Relative efficiency increased to 70% by August 1994 when the scallops were 80 to 85 mm modal shell height. By April 1995, the modal shell height was 90 to 95 mm and efficiency had increased to 72% relative to the standard gear. The increased efficiency was due to growth of the scallops and subsequent increased recruitment to the gear. The relative efficiency plots (Figures 8-11) illustrate that scallops larger than approximately 100 mm are retained with greater than 90% relative efficiency. Using the June 1994 modal shell height of 77.5 mm as a reference point, and applying the growth equation found during this study, it will take the 1990 year class 346 days, or nearly a year, to reach the size of 100 mm where relative efficiency is virtually 100%

While harvest efficiency ranged from 60 to 72% during the study period, production efficiency increased from 50% to almost 85% (Table 7). As with harvest efficiency, production efficiency increased between June and August 1994, decreased in November 1994, and increased again in April 1995. Except for June 1994, production efficiency was greater than harvest efficiency for all trips. Although the 3.5" ring dredge catches fewer scallops, more of the scallops not caught are the smaller, lower yielding scallops. There is less of a decrease in catch of the larger scallops, even within a particular year class. Since there are relatively more of these larger scallops in the catch, the decrease in harvest efficiency of the 3.5" ring dredge is partially compensated. This also affects the average meat counts of scallops harvested by the different dredges. Meat counts by the 3.5" ring dredge were always lower (fewer meats per pound) than for the 3.25" ring dredge (Table 7).

Implications for the fishery and resource

High levels of fishing effort have decreased the abundance of sea scallops, and subsequently, the number of exploitable year classes available to the fishery. This has created the situation where the recruiting year class is carrying the fishery (Serchuk *et al.*, 1979; Brown, 1987; NEFSC, 1993; NEFMC, 1993). Every year, a new year class recruits to the gear and is targeted by the fishery. As one year's cohort is fished out, another begins to recruit to the gear. This is deleterious to the fishery as these scallops are well below their maximum potential in terms of yield-per-recruit and spawning potential. In addition, a year class failure, due to a failed spawn or a mass mortality event, could be devastating.

The new regulations under Amendment #4 should alleviate some of the pressures of having only a single exploitable year class in the fishery. The gear restrictions will reduce the harvest efficiency of the scallop dredge on small scallops and delay full recruitment of scallops to the fishery by as much as one year relative to the 3.25" ring dredge. This increase in age at first capture will enhance yield-per-recruit (YPR) in the fishery. It will also change the age class structure of the resource, as well as increase the potential spawning stock biomass (SSB). Increases in SSB have the potential to greatly decrease the chances for, and the effects of, a year class failure, making the resource more stable and productive.

Yield-per-recruit

Many authors have examined the effects of delaying harvest as a means to increase YPR in terms of meat weight (eg. Posgay, 1958, 1962, 1979; Caddy, 1972a and b; Serchuk *et al.*, 1979; Sinclair *et al.*, 1985). Serchuk *et al.* (1979) and Posgay (1979) both estimated maximum YPR to be attained by harvesting scallops of age 8. At this age, the increase in the meat weight of the resource through growth is approximately equal to the decrease in weight of the resource through natural mortality. Delaying harvest past age 8 would result in a decrease in YPR as natural mortality is larger than somatic growth, and yield would be removed from the resource faster than it was produced. Delaying harvest past age 6 results in only minor increases in YPR as somatic growth slows (Serchuk *et al.*, 1979). It was therefore suggested that harvest should be delayed only until scallops reached age 6.

Posgay (1962) found that delaying harvest from age 5 to age 6 would increase YPR by 18% for a fishing mortality rate (F) of 1.0 and natural mortality rate (M) of 0.09. Using similar parameters (F = 1.0, M = 0.1), Serchuk *et al.* (1979) found YPR to increase by 11% and 15% for Georges Bank and mid-Atlantic scallops respectively. Sinclair *et al.* (1985) predicted an increase of up to 55% if landings consisted of scallops ages 5 through 7 as opposed to ages 4 to 6.

These previous studies all deal with an age at first capture of age 5 and estimate the increases in yield to be obtained by delaying harvest past this age. Since these studies, the age at first capture has decreased to between ages 3 and 4. It is therefore necessary to investigate the changes in yield that could be expected by delaying harvest past age 3.

The minimum cull size in the sea scallop fishery is typically 70 mm (DuPaul and Kirkley, 1994b; Brust *et al.*, 1995). Assuming only scallops 70 mm and larger are selected, by applying the SH:MW relationship found during this study to a frequency distribution similar to that found in June 1994, it can be seen that the 3.25" ring dredge would produce slightly less than 1100 pounds of scallop meats from the 1990 year class (Table 15). If harvest was delayed for one full year, using the growth curve, the SH:MW relationship, 90% relative efficiency, and 10% annual natural mortality (Dickie, 1955; Merrill and Posgay, 1964), the 3.5" ring dredge would yield more than 1850 pounds of meats from the 1990 year class. This is an increase in yield of more than 70%. By allowing growth of the scallops, the increase in meat weight more than compensates for the decrease in catch due to natural mortality and decreased dredge efficiency.

Information from Serchuk *et al.* (1979) predicted similar results by delaying harvest from age 3.5 to age 4.5. Allowing the scallops to grow from 77 to 97 mm, yield increased by 39% in the mid-Atlantic. On Georges Bank, allowing growth between 76 and 98 mm increased yield by 37%. Caddy (1972a) estimated an increase of 65% if harvest was delayed for one year and scallops were allowed to grow from 73 to 92 mm mean size. The estimates from the present study are certainly consistent with these estimates.

Table 15 Production estimates from the 1990 year class starting with a frequency distribution similar to June 1994.

a) Production from harvest at t = 0 using 3.25" ring dredge.

Shell height (mm)	Frequency	Meat weight (g)	Production (g)
57.5	25	3.19	---
62.5	300	4.00	---
67.5	2400	4.92	---
72.5	11700	5.97	69849
77.5	24700	7.14	176358
82.5	20500	8.46	173430
87.5	6000	9.91	59460
92.5	850	11.52	9792
97.5	200	13.28	2656
		Total grams	491545
		Total pounds	1083.65

b) Production from harvest at t = 365 using 3.5" ring dredge.

Shell height (mm) t = 0	Shell height (mm) t = 365	Frequency after 1 year (M = 0.1)	Frequency retained in 3.5" ring dredge	Meat weight (g)	Production (g)
57.5	75.22	23	21	6.59	138.39
62.5	81.76	270	243	8.26	2007.18
67.5	88.3	2160	1944	10.16	19751.04
72.5	94.84	10530	9477	12.32	116756.6
77.5	101.38	22230	20007	14.75	295103.3
82.5	107.93	18450	16605	17.47	290089.4
87.5	114.47	5400	4860	20.48	99532.8
92.5	121.01	765	689	23.79	16391.31
97.5	127.55	180	162	27.42	4442.04
				Total grams	844212
				Total pounds	1861.14

The increase in scallop meat weight from delaying harvest will also decrease meat counts of the catch. During this study period, meat counts decreased from 55 MPP to between 30 and 35 MPP (Table 7). (It is interesting to note that the catch in the 3.5" ring dredge in April 1995 would have been legal under the pre-Amendment #4 meat count restrictions.) These larger scallops often receive a better price at the dock. Using the 3.5" gear therefore has the potential to increase revenues of the fishery, not only through increased landings, but also from the higher prices paid for the larger scallops.

Unfortunately, it is not realistic to believe that the scallops will be left completely unfished for a year in order to grow. The offshore scallop dredge does not perform with knife edge selectivity, and partial recruitment allows the harvest of small scallops. A more likely scenario is that the larger scallops in the age class will be exploited, and there will be continuous harvesting of scallops greater than a certain size as the small ones grow and recruit to the gear. Scallops as small as 70 mm are typically retained in the fishery. Harvest efficiency is only 60% at this size, and many scallops this size will remain in the fishery for up to a year before reaching a size where relative efficiency is virtually 1.0. More scallops this size may remain in the fishery as there is evidence that the minimum cull size of the fishery will increase as the catch of small scallops decreases (Brust *et al.*, 1995). Under this scenario of partial recruitment, however, the increases in yield-per-recruit will not be as high for all scallops, and revenues will not increase quite as much, but after an initial decrease, overall landings and earnings should increase, assuming the year classes are successful.

Effects relative to 3.0" rings

So far, these estimates of harvest and production of the 3.5" ring dredge have been in terms of the 3.25" ring dredge. An important question to ask is how the 3.5" ring dredge will perform relative to the 3.0" ring dredge, as this was the gear used when Amendment #4 was first implemented.

In the fall of 1993, several trips were conducted in order to assess the performance of the 3.25" ring dredge relative to the 3.0" ring dredge. The 1993 gear trials in the mid-Atlantic clearly show the year class being followed in this study (Figure 13). Results from these trips predict that overall efficiency of the 3.25" rings will decrease harvest by as much as 45% on Georges Bank to as little as 12% on the soft bottom in the mid-Atlantic (DuPaul and Kirkley, 1994b).

Efficiency estimates were performed in the same way for the data from November 1993 as for the data obtained during the 1994 and 1995 trips. The estimates of efficiency of the 3.25" rings relative to the 3.0" rings for the 1993 trip in the mid-Atlantic were combined with the 3.5" vs. 3.25" ring estimates to evaluate efficiency of the 3.5" rings relative to the 3.0" rings. During the present study period of approximately 320 days, the 3.5" ring dredge was approximately 66% as efficient as the 3.25" ring dredge at capturing scallops from the 1990 year class (Table 9). Data from the 1993 gear trials show that for scallops 70 mm (minimum cull size of the fishery) to 115 mm (largest size attained by individuals from the 1990 year class during the present study), the 3.25" rings were approximately 60% as efficient as the 3.0" rings in the mid-Atlantic (Table 16). Multiplying these efficiency values, the 3.5" ring dredge would perform with approximately 40% efficiency relative to the 3.0" ring dredge

Figure 13 Shell height frequency distributions from November 1993 from the mid-Atlantic region for both 3.0" and 3.25" ring dredges. Data are from DuPaul and Kirkley, 1994.

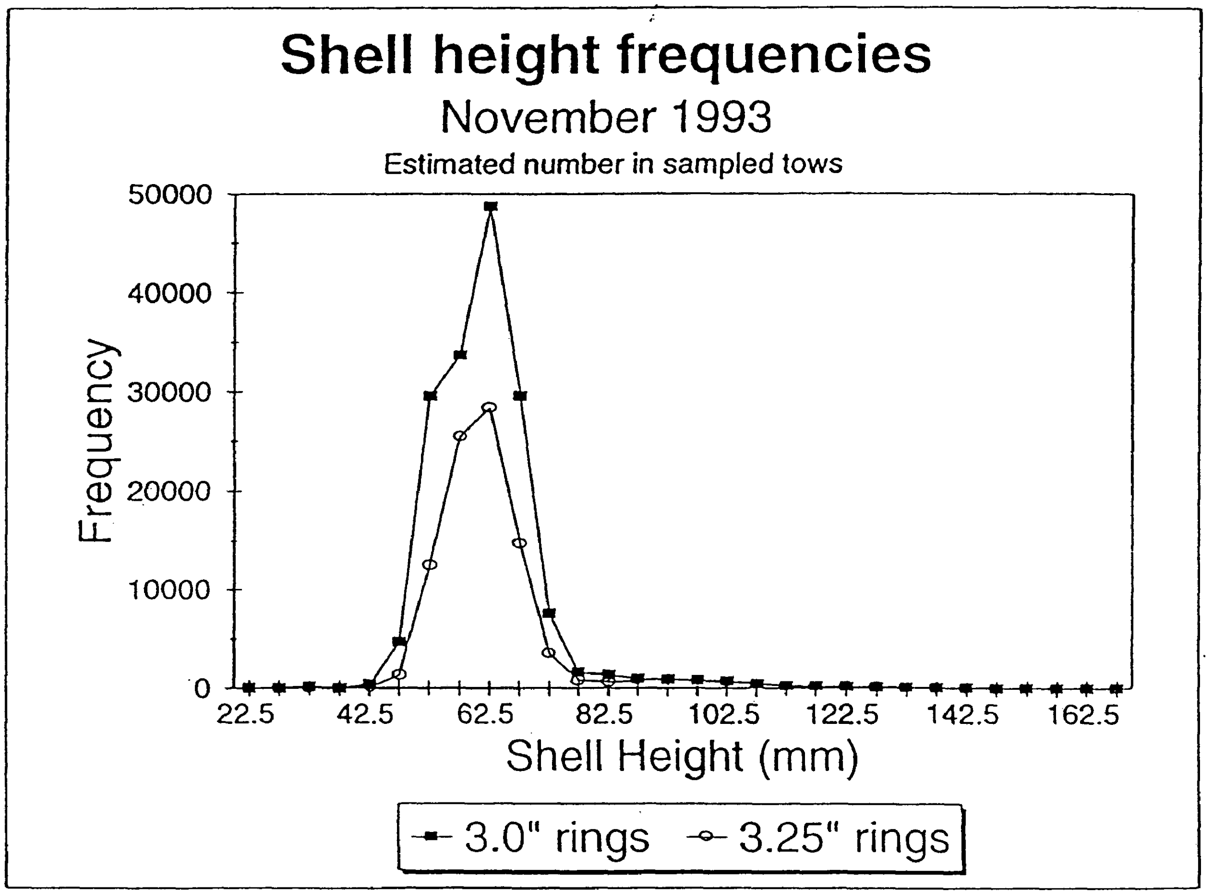

Shell height frequencies
November 1993
Estimated number in sampled tows
Frequency
50000
40000
30000
20000
10000
0
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.0" rings
3.25" rings

Table 16 Relative harvest efficiency of the 3.25" ring scallop dredge for November 1993. Relative efficiency is efficiency of catch by the 3.25" ring dredge relative to catch by the 3.0" ring dredge. Smoothed efficiency is relative efficiency smoothed using a moving geometric mean of three. Shell heights 70 to 115 mm represent the smallest shell height culled in the fishery to the largest size attained by individuals from the 1990 year class during this study.

Shell height (mm)	3.0" rings	3.25" rings	Relative Efficiency	Smoothed Efficiency
20-25	0	0	---	---
25-30	0	0	---	---
30-35	286	0	0.00	---
35-40	14	0	0.00	---
40-45	639	117	0.18	---
45-50	6960	2035	0.29	0.28
50-55	45218	18817	0.42	0.39
55-60	49773	38098	0.50	0.50
60-65	71059	41755	0.59	0.53
65-70	42362	21332	0.50	0.52
70-75	10929	5070	0.46	0.49
75-80	2441	1214	0.50	0.47
80-85	2101	952	0.45	0.56
85-90	1476	1148	0.78	0.71
90-95	1425	1447	1.02	0.90
95-100	1237	1151	0.93	0.94
100-105	1119	989	0.88	0.92
105-110	815	772	0.95	0.93
110-115	475	451	0.95	0.91
115-120	422	352	0.83	0.90
120-125	346	316	0.91	0.93
125-130	290	308	1.06	0.95
130-135	273	242	0.89	0.93
135-140	144	122	0.85	0.61
140-145	156	46	0.29	0.63
145-150	15	15	1.00	0.53
150-155	4	2	0.50	---
155-160	0	0	---	---
160-165	0	0	---	---
165-170	0	0	---	---
Totals	239979	136751	0.57	
70-115 mm	22018	13194	0.60	

for the 1990 year class between ages 3+ and 4+. Furthermore, the efficiency of the 3.5" gear will fluctuate between 36% and 43% relative to the 3.0" gear over that period (Table 17).

Estimates from DuPaul *et al.* (1988) show a decrease in efficiency of only 28 to 39% for the 3.5" gear relative to the 3.0" gear. The differences in these estimates may be attributable to several factors such as weather conditions, resource conditions, bottom type, and captain skills during the time of study (DuPaul *et al.*, 1988; DuPaul and Kirkley, 1994b). In addition, DuPaul *et al.* (1988) use the number of baskets of scallops caught to represent catch in a dredge where the present study used the number of scallops caught.

Estimates of efficiency by shell height were also obtained for these two groups of data (Table 18). For each shell height, the catch by the larger ring dredge was divided by catch of the smaller ring dredge to find relative efficiency. These estimates were smoothed using a moving geometric mean of three (Pope *et al.*, 1975). The 3.5" ring dredge performs with greater than 90% efficiency relative to the 3.0" ring dredge for scallops larger than approximately 115 mm. Full recruitment would be delayed for more than a year and a half when starting from the reference point of 77.5 mm modal shell height. These scallops will therefore not be fully recruited until age 5. Assuming knife edge selectivity, two annual natural mortality episodes of 10% each, and 90% relative efficiency, the 3.5" ring dredge would harvest more than 2400 pounds of scallop meats from the 1990 year class (Table 19). The increase in yield-per-recruit could therefore be as much as 120% when using 3.5" rings and delaying harvest for this amount of time (Table 19).

From these estimates of efficiency, catch was predicted for the 3.0" and 3.5" ring gears for the resource conditions present during the trips each gear was not used. For the

Table 17 Estimated efficiency of the 3.5" rings relative to the 3.0" rings for the whole year and at different times during the year.

Trip	3.25" vs. 3.0" (from DuPaul and Kirkley, 1994)	3.5" vs. 3.25"	3.5" vs. 3.0" (estimated)
June 1994	0.60	0.63	0.38
August 1994	0.60	0.70	0.42
November 1994	0.60	0.60	0.36
April 1995	0.60	0.72	0.43
Overall	0.60	0.66	0.40

Table 18 Efficiency of the 3.5" rings relative to the 3.0" rings at each shell height interval. All estimates are made from smoothed efficiency estimates from previous tables.

Shell height (mm)	3.25" vs. 3.0" rings	3.5" vs. 3.25" rings	3.5" vs. 3.25" rings (estimated)
20-25	---	---	---
25-30	---	0.63	---
30-35	---	0.50	---
35-40	---	0.49	---
40-45	---	0.51	---
45-50	0.28	0.54	0.15
50-55	0.39	0.57	0.22
55-60	0.50	0.59	0.29
60-65	0.53	0.57	0.30
65-70	0.52	0.59	0.31
70-75	0.49	0.61	0.30
75-80	0.47	0.65	0.30
80-85	0.56	0.66	0.37
85-90	0.71	0.68	0.48
90-95	0.90	0.75	0.68
95-100	0.94	0.85	0.80
100-105	0.92	0.92	0.84
105-110	0.93	0.95	0.89
110-115	0.91	0.97	0.88
115-120	0.90	1.07	0.96
120-125	0.93	1.05	0.97
125-130	0.95	1.06	1.00
130-135	0.93	1.00	0.93
135-140	0.61	0.98	0.60
140-145	0.63	0.89	0.56
145-150	0.53	1.05	0.56
150-155	---	---	---
155-160	---	---	---
160-165	---	---	---
165-170	---	---	---

Table 19 Production estimates from the 1990 year class by delaying harvest for 1.5 years relative to June 1994. Initial frequency distribution is similar to that of June 1994. Two annual natural mortality events are assumed to have occurred, and relative dredge efficiency is assumed to be 90% (see Table 15).

Shell Height (mm) t=0	Shell Height (mm) t=550	Frequency after 1.5 years (M = 0.1)	Frequency retained in 3.5" dredge	Meat Weight (g)	Production (g)
57.5	86.19	20	18	9.52	171.36
62.5	93.69	243	219	11.92	2610.48
67.5	101.18	1944	1750	14.68	25690
72.5	108.68	9477	8529	17.80	151816.2
77.5	116.17	20007	18006	21.31	383707.86
82.5	123.67	16605	14945	25.23	377062.35
87.5	131.16	4860	4374	29.57	129339.18
92.5	138.66	689	620	34.36	21303.2
97.5	146.15	162	146	39.61	5781.6
				Total grams Tot. pounds	1097482.2 2419.49

November 1993 trip, catch was predicted for the 3.5" ring gear. Alternatively, for the combined 1994-95 trips, catch by the 3.0" ring gear was predicted (Figure 14). In November 1993, nearly 170,000 fewer scallops would have been harvested if the 3.5" ring dredge had been used. These scallops were mostly discard size, but discard mortality on sea scallops has been estimated to be as high as 15% (Medcof and Bourne, 1964). Delaying capture until the scallops reached a harvestable size would reduce discard mortality. In addition, Brust *et al.* (1995) found that the 3.5" ring dredge caused 35-40% less mechanical damage to discard sized scallops than the 3.25" ring dredge, further reducing discard mortality. The decrease in discard mortality would permit more scallops to be present at a larger size, increasing stock abundance and possibly leading to increased yield in the future.

Using the 3.0" rings through 1994 and 1995 would have allowed the harvest of 55,000 more scallops every 50 hours of tow time. This would be very detrimental to the resource and fishery as meat yield, and therefore economic value, of these scallops would be substantially below maximum potential.

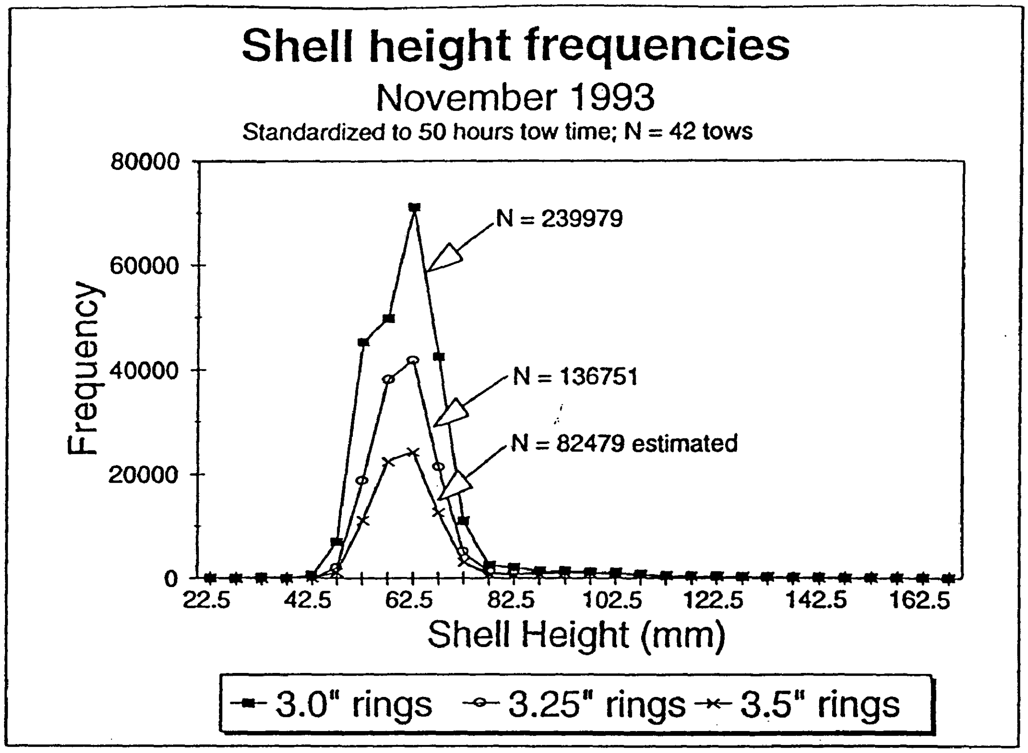
Age class structure and spawning stock biomass

Increases in meat yield and revenues will not be the only benefits realized under the new management scheme. The increase in age at first capture from using the 3.5" ring dredge also has the potential to change the age class structure of the resource. Delaying full recruitment for a year or more will allow older age classes to be present in the fishery. If the 3.5" gear performs with 66% relative efficiency throughout the year on the incoming year class, the remaining 34% will still be present as 4+ scallops. With respect to the 3.0" gear,

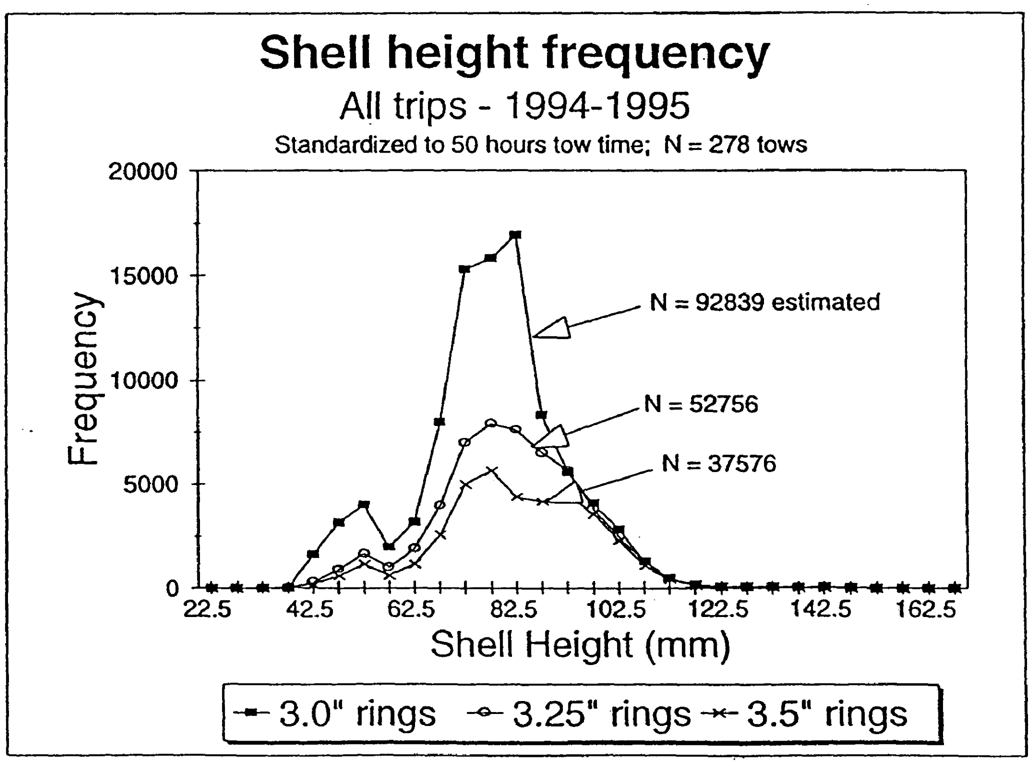
Figure 14 Estimated catch for the 3.0" and 3.5" ring gears for the resource conditions present during the trips they were not used.

a) Catch of the 3.0" and 3.25" ring dredges and estimated catch of the 3.5" ring dredge for November 1993.

b) Catch of the 3.25" and 3.5" ring dredges and estimated catch of the 3.0" ring dredge for the combined 1994-1995 trips.



Shell height frequencies
November 1993
Standardized to 50 hours tow time; N = 42 tows
80000
60000
40000
20000
0
Frequency
N = 239979
N = 136751
N = 82479 estimated
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.0" rings
3.25" rings
3.5" rings



Shell height frequency
All trips - 1994-1995
Standardized to 50 hours tow time; N = 278 tows
20000
15000
10000
5000
0
Frequency
N = 92839 estimated
N = 52756
N = 37576
22.5
42.5
62.5
82.5
102.5
122.5
142.5
162.5
Shell Height (mm)
3.0" rings
3.25" rings
3.5" rings

up to 60% of the year class that would otherwise have been captured could be left at this age. Full recruitment of scallops to the 3.5" gear would not be realized until age 5. Partial recruitment, however, might allow exploitation of 3, 4, and 5 year old scallops.

The altered age class structure of the resource will, in turn, increase the spawning potential of the resource by increasing the spawning stock biomass (SSB) and allowing increased fecundity with age. Most scallops reach sexual maturity by the end of their third year (NEFMC, 1993). Fall spawning generally occurs between late August and December (Posgay and Norman, 1958; MacDonald and Thompson, 1986; DuPaul *et al.*, 1989; Schmitzer, 1990). It is about this time that the faster growing three year old scallops begin recruiting to the 3.0" gear. Most spawn at this time, but 3 year old scallops do not contribute much to the overall fecundity of the resource (McGarvey *et al.*, 1993). High exploitation rates drastically reduce the number of scallops left as four and five year olds, consequently reducing the level of the SSB. The delay in harvest using the 3.5" gear will increase SSB by substantially increasing the number of scallops at ages 4 and 5. These scallops will then be able to contribute to more spawning events.

In addition, it has been found that fecundity of sea scallops increases exponentially with size for several years after reaching sexual maturity (MacDonald and Thompson, 1985b; Langton *et al.*, 1987; Carnegie, 1994). Estimates from Langton *et al.* (1987) show that scallops spawning in their third year (approximately 65 mm) produce approximately 10 million eggs (Table 20). Age 4 (85 mm) and age 5 (110 mm) scallops produce 22 million and nearly 60 million eggs respectively. If harvest is delayed and scallops are allowed to spawn at both ages 3 and 4, overall fecundity would be 3.2 times greater than if only allowed to

Table 20 Age specific fecundity estimates and cumulative fecundity of different aged scallops (from Langton et al., 1987).

Age (years)	Shell height (mm)	Fecundity (x10^6 eggs)	Cumulative fecundity (x10^6 eggs)	Cumulative fecundity with 50% annual exploitation
3	65	10	10	10
4	85	22	32	21
5	110	60	92	36

spawn at age 3. Scallops allowed to spawn in all three years would release 2.9 times as many eggs as those spawning at ages 3 and 4, and more than a 9-fold increase over those only spawning at age 3. As mentioned before, though, it is unlikely that the scallops will be left untouched for a year in order to grow. If half of the scallops are harvested as 3+ scallops, and another half as 4+, fecundity for the resource would still increase 210 and 360% when harvested after age 4 and age 5 respectively relative to harvest at age 3. The benefits in the mid-Atlantic might be even larger since these scallops have been found to reproduce twice annually (DuPaul *et al.*, 1989; Schmitzer, 1990; Schmitzer *et al.*, 1991).

McGarvey *et al.* (1993) found a statistically significant relationship between the number of spawners and recruits for Georges Bank scallop stocks. Increasing the spawning potential of the resource could lead to increases in recruitment. This has the potential to increase overall stock abundance, further increase SSB, and possibly lead to increased future harvest.

These benefits mentioned above - the increase in YPR and SSB, and the change in the age class structure - combined, have the potential to make the resource much more stable and the fishery more productive. Initial decreases in harvest when the 3.5" ring dredge is implemented should be compensated in the long run as full recruitment of the scallops to the gear is achieved at an older age, leading to increases in yield-per-recruit and revenue. The increase in SSB may help return resource abundance to previous stock levels, and allow more exploitable year classes to be present in the fishery. The increase in SSB should also protect against a year class failure by increasing spawning potential and therefore recruitment. In the event of a year class failure, the change in the age class structure should allow harvest to continue on other year classes. This would not be possible under the current resource conditions and level of fishing. The gear change will obviously be very beneficial to the sea scallop resource and fishery as far as yield-per-recruit, revenue, and spawning potential are concerned. The results of increased ring size will also be very important from a management perspective.

Implications for management

The new gear regulations should contribute to meeting the management objectives of the SSFMP. Two of the supplemental objectives of the original SSFMP were to restore the stock to previous abundance levels and age distribution, and to increase yield-per-recruit (NEFMC, 1982). The decrease in dredge efficiency on smaller sized scallops will increase the stock levels by delaying harvest to older and larger scallops. This will also increase the age distribution of the resource and allow at least two exploitable year classes to be present in the fishery assuming successful annual recruitment. The delay in harvest will allow additional growth of the scallops, and yield-per-recruit may increase by as much as 120%. When combined with the other regulations, the increased ring size should allow the management objectives to be realized.

More importantly, the sea scallop fishery is managed with respect to spawning potential of the resource. The resource is said to be overfished if the SSB is reduced to below 5% of an unfished population at equilibrium (5% maximum spawning potential or MSP) (NEFMC, 1993). It is estimated that an F of 0.97, or 60% annual exploitation, will result in 5% MSP. At the time Amendment #4 was drafted, F was estimated to be between 1.5 and

1.8 for scallops four years old and older using 3.0" rings (NEFMC, 1993). Fishing mortality on 3+ year old scallops was also very high and most likely approached similar values.

A fishing mortality rate of 1.6 results in an exploitation rate of approximately 80%. Designating this annual exploitation rate to all scallop sizes between ages 3 and 5, and combining this value with the estimates of efficiency of the 3.5" ring dredge to the 3.0" ring dredge, it was possible to estimate new exploitation rates and fishing mortality values for these sizes for the 3.5" ring dredge (Table 21). It can be seen that fishing mortality rates will be substantially below the overfishing definition of 0.97 for small scallops. F will not reach 0.97 until scallops are 95 to 100 mm shell height. Fishing mortality will be higher for larger scallops and will reach 1.5 for fully recruited, 115 mm scallops, but the increase in ring size from 3.0" to 3.5" is a very crucial step in decreasing F to 0.97. Coupled with the other regulations, the new gear restriction could allow the fishery to attain or even fall below, the overfishing definition of 5% MSP for all harvestable shell heights.

Table 21 Estimates of annual exploitation rates and fishing mortality on 3 to 5 year old scallops using the 3.5" ring dredge. Fishing mortality (F) was assumed to be 1.6 for all scallop sizes. Harvest efficiency values are efficiency of the 3.5" rings relative to the 3.0" rings.

Shell height (mm)	Exploitation rate	Relative efficiency	New exploitation rate	New fishing mortality
62.5	0.80	0.30	0.24	0.27
67.5	0.80	0.31	0.25	0.29
72.5	0.80	0.30	0.24	0.27
77.5	0.80	0.30	0.24	0.27
82.5	0.80	0.37	0.30	0.35
87.5	0.80	0.48	0.38	0.48
92.5	0.80	0.68	0.54	0.79
97.5	0.80	0.80	0.64	1.02
102.5	0.80	0.84	0.67	1.11
107.5	0.80	0.89	0.71	1.24
112.5	0.80	0.88	0.70	1.22
117.5	0.80	0.96	0.77	1.46
122.5	0.80	0.97	0.78	1.50

SUMMARY AND CONCLUSIONS

Amendment #4 to the sea scallop fishery management plan was adopted in order to eliminate problems with the original management plan initiated in 1982. The original plan used direct meat count and shell height regulations to control the size of scallops harvested (age at entry). This form of management had many problems, and small scallops were still being exploited. Amendment #4 was implemented in 1994 in order to reduce the mortality on these small scallops. One of the major regulations was a gear restriction which increased the size of the rings used in the standard offshore dredge. Age at entry will now be controlled by controlling the size of scallops susceptible to capture.

The ring size used in the offshore dredge increased from 3.0" to 3.25" in March 1994, and increased to 3.5" in January 1996. The data collected during this study show that the gear restriction will be beneficial to the resource and the fishery and help meet the objectives of the sea scallop FMP. If used properly, the larger rings will decrease the efficiency of the fishing gear on small scallops, delay harvest, and increase age at entry.

The 3.5" ring dredge will perform with approximately 66% efficiency throughout the year on the recruiting year class, relative to the 3.25" ring dredge. Full recruitment to the gear will not occur until scallops are 100 mm. This will delay harvest from age 3+ until 4+. The increase in scallop meat weight during this time will increase overall harvest by up to 70%, and meat counts will decrease from 50-60 MPP to 30-35 MPP. This will lead to increased revenues as larger scallops receive a better price at the dock. Relative to the 3.0" ring dredge, full recruitment could be delayed until 115 mm (age 5), and yield could increase as much as 120%.

The delay in harvest will allow more scallops to spawn at ages 4 and 5. This, coupled with increased fecundity with size could increase spawning potential by more than 900%. This may increase annual recruitment, possibly increasing stock levels and therefore future harvests. The increased number of 4 and 5 year old scallops will alter the age class distribution of the fishery and increase the number of exploitable year classes.

The delay in harvest should also decrease the fishing mortality of sea scallops. Coupled with the other regulations stated in Amendment #4, fishing mortality of the resource may drop to below the overfishing definition of 5% MSP.

All these benefits will make the resource, and therefore the fishery, much more stable and productive. Harvest levels will decrease initially, but the long term benefits should far outweigh the short term losses. The delay in harvest will potentially increase overall yield of the year class, increasing revenues. Increased spawning and recruitment potential could lead to increased stock abundance and harvest.

Appendix I

Equations for standardizing total catch

For i and j = tow number 1 to n (depending on trip) and shell height interval 1 to 21 respectively -

Estimate total catch:

$$\text{proportion sampled}_i = \text{number of baskets sampled}_i \,/\, \text{total number of baskets caught}_i \quad (1)$$

$$\text{total number of scallops retained}_{ij} = \text{number of scallops sampled}_{ij} \,/\, \text{proportion sampled}_i \quad (2)$$

$$\text{total number of scallops caught}_{ij} = \text{number of scallops retained}_{ij} + \text{number of scallops discarded}_{ij} \quad (3)$$

Equations (1) and (2) assume that shell height composition is similar for all baskets caught in a given dredge for a given tow.

Standardize to an hour of tow time:

$$\text{total scallops caught per hour}_{ij} = \text{total scallops caught}_{ij} \,/\, (\text{tow time}_i/60) \quad (4)$$

Standardize to 50 hours tow time:

$$\Sigma\text{total total scallops caught per hour}_j \,/\, (\text{number of tows in trip}/50)$$

where the summation is over all tows in a trip.

Standardize to 13 foot dredge (first trip only):

$$\text{Total scallops caught}_{ij} \,/\, (14/13)$$

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