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THE EFFECTS OF A REGULATORY GEAR RESTRICTION ON THE RECRUITING YEAR CLASS IN THE SEA SCALLOP, *PLACOPECTEN MAGELLANICUS* (GMELIN, 1791), FISHERY

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ABSTRACT In 1994, Amendment 4 to the sea scallop (*Placopecten magellanicus*) fishery management plan was adopted, which restricted fishing effort by controlling vessel days at sea, crew size, and gear size. Dredge ring size was increased from 76.2 mm (3.0″) to 82.6 mm (3.25″) in March 1994, and again to 88.9 mm (3.5″) in January 1996 to increase the age of entry of scallops into the fishery. Between June 1994 and April 1995, four trips were taken on commercial scallop vessels in the western mid-Atlantic to determine harvest efficiency of 88.9-mm dredge rings relative to 82.6-mm dredge rings used in the fishery at the time. Our study focused on the abundant and nearly ubiquitous 3-year-old, 1990 year class. At the time, individuals in this year class were approaching the size (70 mm) of both full recruitment to the gear and recruitment into the fishery. Relative harvest efficiency of this year class ranged from 60% to 72% over the study period. The 88.9-mm rings were found to be 90% efficient when scallops had grown to a size of 100–105 mm. The 88.9-mm ring dredge would therefore delay full recruitment of the 1990 year class for almost 1 y relative to the 82.6-mm ring dredge. Analysis shows that this delay could increase yield-per-recruit by almost 10% and spawning stock biomass by 40% to 60%. Benefits of the gear modifications will only be fully realized when used in conjunction with other measures that reduce or stabilize fishing effort.

KEY WORDS: sea scallop, relative harvest efficiency, ring size, *Placopecten magellanicus*

INTRODUCTION

The fishery for the Atlantic sea scallop *Placopecten magellanicus* (Gmelin 1791) began in the United States in the mid-Atlantic region in the 1920s and expanded in the 1930s with the discovery of large concentrations of scallops on Georges Bank (Bourne 1964, Serchuk et al. 1979). Commercial landings increased rapidly following World War II, and reached a peak of 17,174 metric tons of meats valued at over $145 million in 1990 (NOAA 1991).

Despite high levels of exploitation and fluctuating annual landings, the first fishery management plan (FMP) for the sea scallop was not in place until 1982 (NEFMC 1982). Objectives of the original sea scallop FMP were to be achieved by controlling the age at entry of the scallops into the fishery. An average meat count restriction of not more than 30 meats per pound (MPP) was enforced for vessels that landed shucked meats. For vessels landing shell stock, a minimum shell size was set at 88.9 mm (3.5 inches).

Several amendments were made to the FMP to correct perceived inadequacies and enforcement difficulties; however, the FMP remained relatively unchanged until 1994. Many of these problems with the original sea scallop FMP are discussed by Naidu (1987), Shumway and Schick (1987), Smolowitz and Serchuk (1987, 1988), DuPaul et al. (1989), Kirkley and DuPaul (1989), and Schmitzer et al. (1991). One major problem of the 1982 FMP was the attempt to manage a fishery that extends over a wide geographic area based on a single parameter of the animal, the adductor muscle size. Size of the adductor muscle has been found to vary widely between resource areas, water depths, seasons, and within the reproductive cycle (Haynes 1966, Shumway & Schick 1987, DuPaul et al. 1989), and this confounded management efforts.

In March 1994, Amendment 4 to the sea scallop FMP was implemented to replace existing MPP restrictions. Amendment 4 restricted fishing effort by limiting vessel days at sea, crew size, the size of the fishing gear, and entry of new vessels into the fishery. Age at entry controls were implicitly imposed by increasing the size of the scallop dredge rings and the mesh of the scallop trawl nets (NEFMC 1993). The primary gear restriction of Amendment 4 increased the minimum ring size of the dredge from 76.2 mm (3.0″) to 82.6 mm (3.25″) for 1994 and 1995, and to 88.9 mm (3.5″) beginning January 1, 1996. Previous gear trials have shown that increasing dredge ring size or trawl mesh size allows an increased escapement of smaller-sized scallops (Medcof 1952, Bourne 1965, Smolowitz & Serchuk 1988, DuPaul et al. 1988, DuPaul et al. 1989).

In this paper we present an assessment of the effects of an increase in dredge ring size on aspects of selectivity, harvesting efficiency, and delay of entry into the fishery. The study targeted the very large 1990 year class of scallops (NEFSC 1993). We found that an increase in scallop dredge ring size will increase escapement of small, pre-recruit scallops less than 70 mm and will delay entry of scallops greater than 70 mm into the fishery. This regulatory measure could lead to substantial increases in yield and spawning potential of specific year classes of scallops.

MATERIALS AND METHODS

Data Collection

Data for this study were collected during four trips aboard commercial scallop vessels (June, August, and November 1994 and April 1995), each lasting 7 to 14 days. Sampling was conducted aboard the fishing vessel (F/V) *Carolina Breeze* and the F/V *Stephanie B* in the Delaware/Maryland/Virginia region of the western mid-Atlantic (NAFO statistical area 6, Fig. 1). Both vessels are approximately 23.01 m (75.5 feet) in length. Catches were sampled from 209 of the 759 tows conducted with the experimental gear.

The fishing gear used during these experiments was the standard offshore New Bedford style scallop dredge used by most vessels in the fishery. Posgay (1957) provides a general overview of the gear, and a more detailed description is given in Bourne (1964). For each trip, the control gear was constructed from 82.6-mm (3.25″) rings, the size used in the fishery at the time of the study. The experimental gear was constructed from 88.9-mm (3.5″)

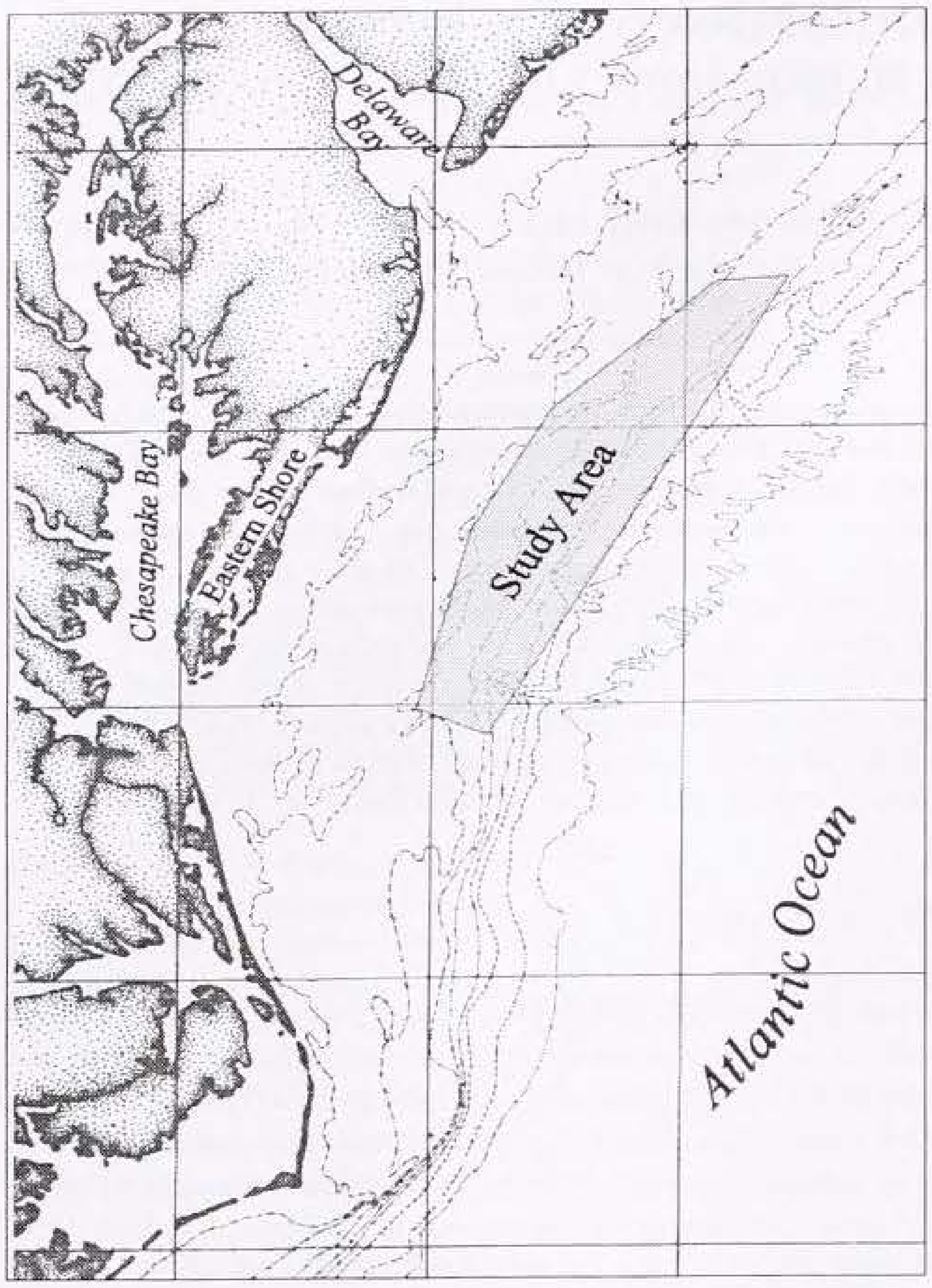

Figure 1. Location of sampling efforts in the Mid-atlantic region.

rings. Both vessels used are capable of towing two dredges simultaneously. Since studies have shown that there is no statistical difference in catch for dredges towed in pairs (Bourne 1965, DuPaul et al. 1989), the control and experimental gears were towed simultaneously. The *Carolina Breeze* towed two 4.27-m-(14-foot) wide dredges, and the *Stephanie B* towed two 3.96-m-(13-foot) wide dredges.

Data collection methodology was similar to that of Bourne (1965) and DuPaul et al. (1989). Sampling procedures were designed to allow usual commercial operating procedures, except that catches from the two dredges were kept separate throughout the trip. For sampled tows, the crew was allowed to cull out the commercial-sized scallops. The remaining bycatch was then sorted to retrieve undersized or discarded scallops. Up to two baskets (1 basket is approximately 1.5 bushels) of commercial-sized scallops, and at least a portion of the discards were retained from each dredge for shell height frequency sampling. Shell height, the maximum distance from the umbo to the ventral margin of the shell, was measured to the nearest 5-mm interval using National Marine Fisheries Service scallop measuring boards.

Six one-basket samples of scallop shell stock were obtained from commercial scallop vessels between February and May 1994 to collect shell height and meat weight data. Each sample represented a single trip by a single vessel. When these scallops were shucked, the upper (left) valve was measured to the nearest millimeter using a measuring board, and the respective meat was weighed to the nearest 0.1 g using an Ohaus CT 600 electronic scale.

Data Analysis

To compare catches from the different trips, the data were standardized to a common unit of effort equal to 50 h of tow time using a 3.96-m wide dredge using the following equations:

$$N_{ij} = (n_{ij}/b_j) \times B_j \tag{1}$$

$$SPH_{ij} = N_{ij} \Big/ \left({}^{T_j}/_{60}\right) \tag{2}$$

$$SC_i = \sum_{j=1}^{ST} SPH_i \Big/ \left({}^{ST}/_{50}\right) \tag{3}$$

where N_{ij} = the total number of scallops at shell height i in tow j; n_{ij} = the number of scallops sampled at shell height i in tow j; b_j = the number of baskets sampled in tow j; B_j = the total number of baskets in tow j; SPH_{ij} = the number of scallops caught per hour at shell height i in tow j; T_j = tow time in minutes of tow j; SC_i = standardized number of scallops caught at shell height i for the trip; and ST = the number of tows sampled during the trip.

For data from the trip using the 4.27-m-wide dredges, n_{ij} was multiplied by 13/14 to standardize to a 3.96-m-wide dredge before using the above equations.

Harvest efficiency of scallops from the 1990 year class was determined for the 88.9-mm ring dredge relative to the 82.6-mm ring dredge for each 5-mm shell height interval within the year class and for the year class as a whole. This was done by dividing the number of scallops caught in the larger ring dredge by the number caught in the smaller ring dredge. Efficiency estimates for the individual shell height intervals were then smoothed using a moving geometric mean of three (Pope et al. 1975, Serchuk & Smolowitz 1980, DuPaul et al. 1989).

The range of the shell height intervals used for the year class was found using the Petersen method (Jearld 1983). Year classes were distinguished by different peaks in the shell height frequency distributions for scallops from all trips, except the April 1995 trip. In April 1995, the 1991 year class distribution overlapped slightly with the 1990 year class distribution. The 1990 year class was delineated by finding the modal shell height of the year class and visually estimating the right tail of the distribution. It was then assumed that the number of size classes present on each side of the mode was the same.

The conventional allometric or shell height:meat weight model was estimated using SAS software (version 6.09). A log-log transformation was necessary to allow estimation of the relation using ordinary least squares. A random effects model was run, with time of collection being the random variable, in order to combine the samples and obtain a common shell height:meat weight relationship. The model can be expressed as:

$$\ln(MW) = \ln(a) + b \times \ln(SH) + u \tag{4}$$

where "ln" is the natural logarithm, MW and SH are meat weight and shell height respectively, and the error term u is $N(0, \sigma^2)$.

Scallop growth was estimated by applying an exponential growth model to catch data collected during different trips, including data from a trip taken in November 1993 (DuPaul & Kirkley 1994a, DuPaul & Kirkley 1994b). It was during the November 1993 trip that the 1990 year class first started to recruit to the 76.2-mm ring dredge used at the time (DuPaul & Kirkley 1994a). The growth model can be expressed as

$$SH_t = SH_0 \times \exp[G \times (t - t_0)] \tag{5}$$

where SH_t is shell height at time t, SH_0 is shell height at time 0, and G is the exponential growth coefficient.

The mean shell height of the specified age class from each of the trips was plotted against number of days relative to the first sampling trip. It was assumed that daily growth of scallops during each trip was minimal, and that for each trip, all scallops were collected on one day. The first day of each sampling trip was arbitrarily designated the collection day. All increments in days were counted from the first day of the first trip to the first day of each successive trip.

Results of the efficiency, growth, and shell height:meat weight calculations were used to examine the effects increasing ring size to 88.9 mm might have on yield-per-recruit (YPR) of the fishery. The YPR calculations assume only scallops 70 mm and larger are retained by the fishermen. The June 1994 trip was used as a reference point, and the catch in the 82.6-mm ring dredge during that trip was assumed to be a representative sample of the shell height frequency distribution of the year class. Catch in the 82.6-mm ring dredge in June 1994 was multiplied by 10 to give an arbitrary initial abundance of the year class (N_0). Values of fishing mortality (F) and natural mortality (M) were set at $F = 1.5$ (NEFMC 1993) and $M = 0.1$ (Dickie 1955, Merrill & Posgay 1964) for a full year (0.75 and 0.05, respectively, over 6 mo). The year was broken into two 6-mo periods, and the equation

$$N_t = N_0 \times e^{-F \times t} \tag{6}$$

was applied to find population size at time $t = 6$ mo. At the end of each 6-mo period, the remaining population (N_t) was reduced by the natural mortality rate to find the N_0 for the next period. The growth coefficient was applied to the scallops comprising the new N_0 to obtain the new shell height frequency distribution. These calculations were repeated four times to simulate harvest over a 2-y period (0–6, 6–12, 12–18, and 18–24 mo). Catch for each period was estimated from $C = N_0 - N_t$. The shell height:meat weight model was applied to the harvest at each shell height for each repetition and was summed over all repetitions to finds landings for the entire period.

To estimate landings for the 88.9-mm ring dredge, similar methods were used except that the catch was adjusted by the relative efficiency at each shell height. N_t was found as $N_0 - C$, and then reduced by the natural mortality rate to give N_0 for the next period.

Spawning potential (in terms of overall fecundity of each animal) was estimated using residual reproductive value (RRV) (MacDonald 1984). RRV takes into consideration the probability of a scallop surviving between successive spawning events. The probability of survival between ages X and X + 1 is multiplied by the fecundity at age X + 1. Overall fecundity was found as the sum of fecundity at age X plus the RRV of fecundity at age X + 1.

RESULTS

Relative Efficiency

Harvest by each of the ring sizes during each of the trips is shown for each shell height standardized to 50 h of tow time in Table 1. Estimates of relative harvest efficiency by the 88.9-mm ring dredge ranged from 60% to 72% over the study period (Table 2). Examination of the efficiency estimates by shell height (Table 3) indicated that scallops from the 1990 year class would be captured with 90% to 100% relative efficiency when they reach 100 to 105 mm shell height. Harvest by the larger ring dredge exceeded harvest by the smaller ring dredge for several of the larger shell heights, but then decreased. With the exception of the November 1994 trip, relative efficiency increased for larger scallops. The unusually large decrease in efficiency in November 1994 is not readily explainable, but has been observed and documented during other gear trial studies (DuPaul et al. 1989).

Shell Height: Meat Weight and Growth

Six one-basket samples of scallop shell stock were obtained between February and May 1994 for use in shell height:meat weight analysis. Each sample represented a single trip by a single vessel. A random effects model was run, with time of collection being the random variable, in order to combine the samples and obtain a common shell height:meat weight relationship. The relationship found is shown below. The values under the equation are the t values for the coefficients.

$$\ln(MW) = -9.7776 + 2.6996 \times \ln(SH) \; (-73.604) \; (98.136) \tag{7}$$

The estimates of the daily growth coefficient between successive trips are shown in Table 4. The overall estimate for the daily

TABLE 1.

Shell height frequency distributions for the 82.6- and 88.9-mm ring dredges for each trip, standardized to 50 h of tow time. The values in bold denote the 1990 year class. (Scallops smaller than 55 mm and larger than 110 mm caught by the gear are not shown.)

Shell Height (mm)	June 1994 (82.6 mm)	June 1994 (88.9 mm)	August 1994 (82.6 mm)	August 1994 (88.9 mm)	Nov 1994 (82.6 mm)	Nov 1994 (88.9 mm)	April 1995 (82.6 mm)	April 1995 (88.9 mm)
55–60	**22**	8	1069	545	870	502	989	610
60–65	**258**	**130**	**456**	**254**	**587**	**365**	1,876	1,161
65–70	**2,107**	**866**	**1,398**	**813**	**1,238**	**755**	**3,987**	**2,585**
70–75	**10,128**	**5,796**	**5,253**	**3,359**	**2,814**	**1,699**	**7,023**	**4,969**
75–80	**21,306**	**13,254**	**9,941**	**7,256**	**4,048**	**2,497**	**7,890**	**5,632**
80–85	**17,644**	**11,755**	**11,294**	**8,123**	**4,284**	**2,541**	**7,611**	**4,388**
85–90	**5,153**	**3,581**	**5,548**	**3,828**	**3,684**	**1,951**	**6,483**	**4,159**
90–95	**757**	**561**	**1,376**	**942**	**2,502**	**1,377**	**5,671**	**4,447**
95–100	**162**	**199**	**293**	**246**	**1,145**	**895**	**3,791**	**3,573**
100–105	162	171	**160**	**161**	**419**	**404**	**2,489**	**2,291**
105–110	149	163	201	175	169	167	**1,241**	**1,061**

TABLE 2.

Relative harvest efficiency estimates for the 1990 year class during each trip and for all trips combined.

Trip Date	Modal Shell Height (mm)	Catch in 82.6-mm Ring Dredge	Catch in 88.9-mm Ring Dredge	Relative Harvest Efficiency
June 1994	77.5	57,537	36,510	0.63
August 1994	82.5	35,719	24,982	0.70
November 1994	82.5	20,721	12,484	0.60
April 1995	92.5	42,653	30,916	0.72
Overall		47,596	31,542	0.66

growth coefficient (G = 0.000736) was used for all growth calculations in this paper.

YPR and Spawning Potential

Applying the shell height:meat weight relationship to the shell height frequency distribution of the 1990 year class observed in June 1994 results in approximately 490 kg of meats. Delaying harvest by 1 y (assuming knife-edge selectivity) would yield approximately 844 kg of meats, assuming M = 0.1 and relative efficiency is 90%. This is an increase in yield of more than 70%. The offshore scallop dredge, however, does not perform with knife-edge selectivity. When size-specific relative efficiency is considered over a 2-y period, yield from the larger ring dredge was approximately 8.3% more than the smaller ring dredge (Table 5). Based on analysis of cumulative fecundity of scallops ages 3 and 4 using residual reproductive values, increases in fecundity were estimated to range from 43% to 59% higher when the 88.9-mm ring dredge is used and more scallops are present to spawn at age 4 (Table 6).

DISCUSSION

When Amendment 4 became effective in March 1994, the sea scallop resource was considered to be overfished if spawning stock biomass (SSB) was below 5% of that of an unfished population. The optimum level of fishing mortality relative to the SSB threshold definition ($F_{5\%}$) was determined to be 0.97 (NEFMC 1993). A 1997 review of the sea scallop resource found that fishing mortality in the Mid-Atlantic had been above the overfishing definition since 1985 (NEFSC 1997). Higher than sustainable levels of fishing effort decreased the abundance of sea scallops, and subsequently, the number of exploitable year classes available to the fishery. This created the situation where the fishery is highly dependent on the recruiting year class (Serchuk et al. 1979, Brown 1987, NEFSC 1993, NEFMC 1993). When there are limited exploitable year classes, a fishery may be detrimentally affected by continued exploitation.

Gear regulations contained in Amendment 4 were implemented primarily to lower fishing mortality on small scallops and delay age at entry into the fishery. Data from this study suggest that the 88.9-mm rings will achieve these goals and also improve yield per recruit in the fishery and increase SSB of the scallop stock. The 88.9-mm dredge rings were anticipated to be an important factor in reducing fishing mortality to below the overfishing definition and meeting the management objectives, when used in conjunction with the other management measures.

Relative Selectivity, Efficiency, and Age at Entry

The year class targeted during this study was the largest year class on record to recruit to the Delaware/Maryland/Virginia region (NEFSC 1993). As many as 25 baskets (35–40 bushels) of these scallops were caught per tow in a single dredge during a sampling trip in November 1993 (DuPaul & Kirkley 1994a, Du-

TABLE 3.

Smoothed efficiency values by shell height for each trip and for all trips combined. The values in bold print denote the shell height range of the 1990 year class during each trip.

Shell Height (mm)	June 1994	August 1994	November 1994	April 1995	Overall
50–55	0.49	0.49	0.63	0.65	0.57
55–60	**0.49**	0.53	0.61	0.64	0.59
60–65	**0.42**	**0.55**	**0.60**	0.63	0.57
65–70	**0.49**	**0.59**	**0.61**	**0.66**	0.59
70–75	**0.53**	**0.65**	**0.61**	**0.69**	0.61
75–80	**0.62**	**0.69**	**0.60**	**0.66**	0.65
80–85	**0.66**	**0.71**	**0.58**	**0.64**	0.66
85–90	**0.70**	**0.70**	**0.56**	**0.66**	0.68
90–95	**0.86**	**0.73**	**0.61**	**0.78**	0.75
95–100	**0.99**	**0.83**	**0.72**	**0.88**	0.85
100–105	1.12	**0.90**	**0.91**	**0.91**	0.92
105–110	1.19	0.96	1.02	**0.88**	0.95
110–115	1.31	0.90	0.95	0.89	0.97
115–120	1.43	0.90	1.01	1.08	1.06
120–125	1.21	0.81	1.01	1.27	1.05

TABLE 4.

Estimates of the exponential growth parameter (G) for the 1990 year class for each trip and for all trips combined.

Trip Date	Mean Shell Height (mm)	Interval Between Trips (days)	Cumulative Interval (days)	Growth Coefficient ($\times 10^{-4}$)
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	92.50	181	540	6.64
Overall		540	540	7.36

Paul & Kirkley 1994b). The majority of these scallops were 60–65 mm and averaged 100 MPP. Larger individuals from this year class were already being retained by the fishermen (DuPaul & Kirkley 1994a).

Amendment 4 increased the ring size used in the scallop dredge initially from 76.2 to 82.6 mm, and subsequently to 88.9 mm. DuPaul and Kirkley (1994a, 1994b) have shown that the 82.6-mm ring dredge decreased efficiency of the scallop dredge (in terms of number of baskets caught) by 12% on soft bottom (sand and mud) to 45% on hard bottom of cobble, relative to the 76.2-mm ring dredge. During the present study, harvest efficiency of the 88.9-mm ring dredge relative to the 82.6-mm ring dredge (in terms of number of scallops caught) ranged from 60% to 72% (Table 2).

For this study, full recruitment (retention) to the experimental gear was considered to be reached when 90% efficiency relative to the 82.6-mm ring dredge was attained. For example, 90% to 100% relative efficiency was reached when scallops were 100–105 mm shell height (Table 3). Using the June 1994 modal shell height of 77.5 mm as a reference point, and by applying the estimated growth equation determined in this study, it would take the 1990 year class 346 days, or nearly a year to reach the size of 100 mm and thus be fully retained by the 88.9-mm ring dredge.

YPR

Many studies have examined the effects of delaying harvest as a means to increase YPR in terms of meat weight in the scallop fishery (e.g., Posgay 1958, Posgay 1962, Caddy 1972a, Caddy 1972b, Posgay 1979, Serchuk et al. 1979, Sinclair et al. 1985). Posgay (1979) and Serchuk et al. (1979) estimated that maximum YPR is attained by harvesting 8-year-old scallops. Serchuk et al. (1979), however, suggest that scallops be harvested when they reach age 6, since delaying harvest past this age results in only minor additional increases in YPR. Previous studies have shown that an increase in age at first capture from age 5 to age 6 will result in an increase in YPR of 10% to 20% (Posgay 1962, Serchuk et al. 1979; Table 7). Delaying harvest from age 4 to age 5 will increase YPR by as much as 50% (Sinclair et al. 1985). By the early 1990s, age at first capture had decreased to between ages 3 and 4. It is, therefore, important to investigate the changes in yield that could be expected by delaying harvest to age 4 or older.

TABLE 5.

Estimates of yield (kilograms) over a 2-y time period using the 82.6- and 88.9-mm ring dredges.

Time Period	82.6-mm Rings	88.9-mm Rings
0–6 mo	2,236.53	1,463.82
6–12 mo	1,524.88	1,546.34
12–18 mo	984.35	1,639.49
18–24 mo	634.99	1,178.42
Total	5,380.75	5,828.07

Assuming knife-edge selectivity and no changes in commercial culling size and shucking capacity, delaying harvest from age 3 to age 4 would increase yield in the fishery by nearly 75%. These conclusions are consistent with those presented in other studies that examined YPR for similar sized scallops (Table 7). The offshore scallop dredge, however, does not perform with knife-edge selectivity, and partial recruitment results in the capture and shucking of small scallops. When partial recruitment is considered in the analysis, and fishing mortality of $F = 1.5$ and natural mortality of $M = 0.1$ are assumed, the 88.9-mm ring dredge would increase yield no more than 10% (Table 5).

Our results indicate that advances in yield made possible by gear changes have to be optimized with additional measures to reduce fishing mortality and effort. Posgay (1979) concluded that a cull size of age 5 (95 mm) was too young and the fishing mortality ($F = 0.7$) was too high to achieve maximum yield for the Georges Bank scallop resource during the 1960s. Currently, in the mid-Atlantic fishery, age at recruitment is younger and fishing mortality is higher than on Georges Bank in the 1960s. Increasing ring size to 88.9 mm can increase the yield in the fishery, but additional measures to decrease fishing mortality and effort must be implemented in order to attain the maximum YPR.

Spawning Potential and Spawning Stock Biomass

Data from this study show the larger ring dredge has the potential to improve scallop SSB, which has been depressed due to high exploitation rates, drastically reducing the number of age 4 and 5 scallops. Scallops are sexually mature by the end of their third year (NEFMC 1993), and fall spawning generally occurs between late August and December (Posgay & Norman 1958, MacDonald & Thompson 1986, DuPaul et al. 1989, Schmitzer 1990). It is during this period that the faster growing 3-year-old scallops begin to recruit to the 76.2-mm gear. Most scallops spawn at this time, but the 3-year-old scallops do not contribute significantly to the overall fecundity of the resource (McGarvey et al. 1993). Even considering partial recruitment, the larger dredge rings will decrease harvest of age 3 scallops and allow more scallops to spawn at age 4. Because fecundity of sea scallops increases exponentially with size for several years after first reaching sexual maturity (MacDonald & Thompson 1985, Langton et al. 1987, Carnegie 1994), the delay in harvest should increase the overall fecundity of the resource (Table 6). In addition, McGarvey et al.

TABLE 6.

Estimates of residual reproductive value (RRV) assuming 10% natural mortality and 66% harvest efficiency between ages 3 and 4.

Reference	Study Area	Age (y)	RRV (millions of eggs)	Cumulative Fecundity (millions of eggs)
MacDonald 1984	Sunnyside,	3	4.95	4.95
	Newfoundland	4	2.59	7.54
Langton et al. 1987	Boothbay, Maine	3	9.30	9.30
		4	3.96	13.26
MacDonald and	New Jersey	3	5.49	5.49
Thompson 1986		4	3.24	8.73

(1993) found a statistically significant relationship between the number of spawners and recruits for Georges Bank scallop stocks. Delaying harvest by using the larger rings could therefore lead to increases in overall stock abundance and concomitant increases in SSB.

Conclusions

The effects of increasing dredge ring size are strongly dependent on the amount of fishing effort in the study area. A decrease in fishing effort would increase the benefits of the larger ring size, while increasing effort would reduce the positive effects of the larger rings. Analysis conducted for this study suggest that the 88.9-mm dredge rings should provide many benefits to the sea scallop fishery and resource, and combined with the other regulations defined in Amendment 4, should have helped achieve several of the objectives outlined in the FMP. The benefits of the larger ring size suggested by this study have not been realized, however. This is most likely due initially to management measures for other species, and subsequently, similar measures for scallops.

In December 1994, the use of mobile fishing gear, including sea scallop dredges, was prohibited in certain areas of Georges Bank (Closed Area I and Closed Area II) and southern New England (Nantucket Lightship Closed Area) in order to allow severely depleted groundfish stocks to rebuild (NEFSC 1997). Much of the fishing effort previously targeting scallops on Georges Bank was displaced to the southern New England and mid-Atlantic regions, which remained open. Fishing effort substantially increased in these regions (NEFSC 1997). In April 1998, at the request of the New England Fishery Management Council, the Secretary of Commerce closed two additional areas in the mid-Atlantic to scallop fishing to protect small scallops. Recently, the NEFMC (1997) determined that fishing mortality on scallops is still above the overfishing definition, and the closure of these 1,900 square miles in the mid-Atlantic only concentrates fishing effort into the remaining open areas.

Modifications to scallop fishing gear designed to reduce the harvest of small scallops and advance the age of entry can be an important management tool, but are most effective when used in conjunction with measures to reduce or stabilize fishing effort and mortality. Data from this study suggest that increasing scallop dredge ring size can decrease mortality of small scallops and postpone recruitment of scallops to the commercial fishery. The delay in recruitment can lead to increases in fishery yield and spawning potential of the resource. The potential benefits of the recent gear modifications, however, have been diminished due to increased fishing effort in the area. In order to realize the full benefits of increasing scallop dredge ring size, the gear restrictions must be associated with measures to stabilize or decrease fishing mortality and fishing effort.

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TABLE 7.

Results of previous sea scallop yield-per-recruit (YPR) studies.

Reference	Study Area	Age (size) at First Capture	Harvest Delayed Until	Percent Increase in YPR
Posgay 1962	Georges Bank	5	6	18
Serchuk et al. 1979	Georges Bank	5	6	11
Serchuk et al. 1979	Mid-Atlantic	5	6	15
Sinclair et al. 1985	Georges Bank	4	5	55
Serchuk et al. 1979	Georges Bank	(76 mm)	(98 mm)	37
Serchuk et al. 1979	Mid-Atlantic	(77 mm)	(97 mm)	39
Caddy 1972a	Georges Bank	(73 mm)	(92 mm)	65
Present study	Mid-Atlantic	3+ (72.5 mm)	4+ (100 mm)	74

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