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ABSTRACT During August and September 1997 and May 1998, three comparative fishing experiments were conducted aboard commercial sea scallop trawl and dredge vessels to assess the efficacy of gear restrictions found in Amendment 4 to the Sea Scallop Fishery Management Plan (SSFMP). This amendment involved certain gear restrictions including minimum mesh and ring sizes and maximum gear widths and was intended to equate the performance of sea scallop trawls and dredges with respect to size selectivity and efficiency. Statistical analysis indicated that selectivity and efficiency were not equal for the two gear types. While absolute gear size selectivity could not be estimated, there was clear evidence of differential relative size selectivity between the two gears. Relative harvest efficiency values shifted at 90 to 95 mm shell height. Trawl vessels were more efficient capturing sea scallops less than 90 mm, and dredge vessels were more efficient capturing sea scallops greater than 90 mm. This shift in relative harvest efficiency coupled with an observed cull size at 70 to 75 mm shell height resulted in the trawl vessels being more dependent on age 3 sea scallops with shell heights of 70 to 90 mm. Operational differences observed between the two gear types restricted sea scallop trawl vessels to areas of smooth substrate. Large differences in both relative efficiencies and operational requirements will present considerable impediments to the desired outcomes of having equivalent performance between gear types.

KEY WORDS: sea scallops, *Placopecten magellanicus*, fishing gear, relative efficiency

INTRODUCTION

Wild populations of the sea scallop, *Placopecten magellanicus*, occur exclusively on the continental shelf of the northwestern Atlantic Ocean from the Canadian Maritimes to Cape Hatteras, North Carolina (Posgay 1957). Within the Exclusive Economic Zone (EEZ) of the United States, the commercial sea scallop fleet is comprised of vessels using both dredges and modified otter trawls. During 1998, dredge vessels operating coastwide, accounted for 90% of total landings, while trawl vessels focused operations on the softer substrates of the mid-Atlantic resource area tallied the remaining 10%. Total sea scallop landings for 1998 were 5,549 metric tons of shucked meats valued at $74.8 million (NEFMC 1999).

Sea scallop landings peaked in 1990 when a record high 17,500 metric tons of shucked meats worth $149 million were landed (NEFMC 1999). The sea scallop fishery, however, has historically been characterized by cycles of high and low production due to fluctuations in recruitment and varying levels of fishing effort (Dickie 1955). The onset of more frequent and extreme fluctuations in landings during the late 1960s and early 1970s, coupled with dramatic increases in ex-vessel prices, effort, and capital prompted federal regulatory measures (NEFMC 1982). Since May 1982, the sea scallop fishery was managed under the provisions found in the Sea Scallop Fishery Management Plan (SSFMP).

Regulatory measures found in the SSFMP initially focused on controlling age at entry in an effort to maximize yield per recruit (NEFMC 1982). Regulations required an average meat count for shucked scallop meats and a minimum size for shell-stocked sea scallops (sea scallops landed in the shell). These regulations, however, proved to be inadequate and resulted in the continued exploitation of small sea scallops (>40 meats per pound, MPP), high levels of fishing mortality (F), and allegations of inequity between dredge and trawl vessels (Naidu 1987, Shumway and Schick 1987, DuPaul et al. 1989b, 1990, Kirkley and DuPaul 1989, Schmitzer et al. 1991). To address these problems, Amendment 4 to the SSFMP, adopted in 1994, changed the management strategy to an effort control program in an attempt to reduce F by 70% over a 7 year rebuilding period (NEFMC 1993). The primary measures of Amendment Number 4 included the establishment of a limited access fishery and the institution of days at sea restrictions (NEFMC 1993). Supplemental measures included gear restrictions, crew size limits, vessel replacement restrictions, and catch limits for non-permitted vessels (NEFMC 1993).

Although the management strategy was changed by Amendment 4, the objective of establishing age at entry was again addressed. Modifications to the two gear types in the fishery replaced the meat count and shell height restrictions in an attempt to control age at entry. These modifications would theoretically allow juvenile sea scallops (<70-mm shell height) to escape the gear, rather than relying on the crew to discard them. Sea scallop dredges were required to meet specific criteria of ring size, chafing gear, twine tops, and maximum dredge width. The configuration of sea scallop otter trawls were restricted on the basis of minimum mesh size, mesh orientation, and maximum trawl sweep.

The gear restrictions found in Amendment 4 were guided by the assumption that these modifications would result in equivalent performance between trawls and dredges with respect to size selectivity and harvest efficiency. Equivalent performance of the two gear types addresses a management objective attempting to control sea scallop age at first capture and a policy mandate that requires equity between user groups. There are no data to support the assumption that Amendment 4 gear restrictions would achieve the desired result. Comparisons of sea scallop dredge and trawl gear have been conducted by Kirkley (1986) and DuPaul et al. (1989c), however, the gear consisted of smaller mesh and ring dimensions than required by Amendment 4.

The objective of this study was to examine size selectivity and relative efficiency of sea scallop trawls and dredges as regulated under Amendment 4 to the SSFMP. This comparison will establish whether Amendment 4 gear restrictions are effective in both controlling sea scallop age at entry to the fishery.

and results in the equitable treatment of user groups operating in the U.S. sea scallop fleet.

MATERIALS AND METHODS

The study area was located along the continental shelf off the East Coast of the United States from Sandy Hook, New Jersey to the Virginia/North Carolina border (Figure 1). Water depths in the study area ranged from 25 to 45 fathoms (46–82 m). Seabed topography and substrate composition were uniform throughout the area, dominated by level expanses of mud and sand with scattered areas of large boulders. This general area is considered a traditional sea scallop fishing ground, however, specific areas for the comparative fishing experiments were located using the local knowledge of the participating commercial vessel captains.

Gear deployment and vessel design constraints prevented a dredge and an otter trawl from being towed by the same vessel simultaneously. The comparison of the two gear types was conducted by sampling with both a commercial dredge vessel and a commercial otter trawl vessel. Utilizing the parallel fishing method the two vessels fished the same ground at the same time and sampled from a single population of sea scallops (Pope et al. 1975). To ensure that the criteria of the sampling design was met, data from tows which were sampled, but did not occur in the same area at the same time were subsequently excluded from analysis. The study consisted of three comparative fishing cruises conducted as an adjunct to normal commercial fishing trips between August 1997 and May 1998. The only modification to a commercial fishing trip being that both vessels operate in the same area at the same time and use Amendment 4 compliant fishing gear.

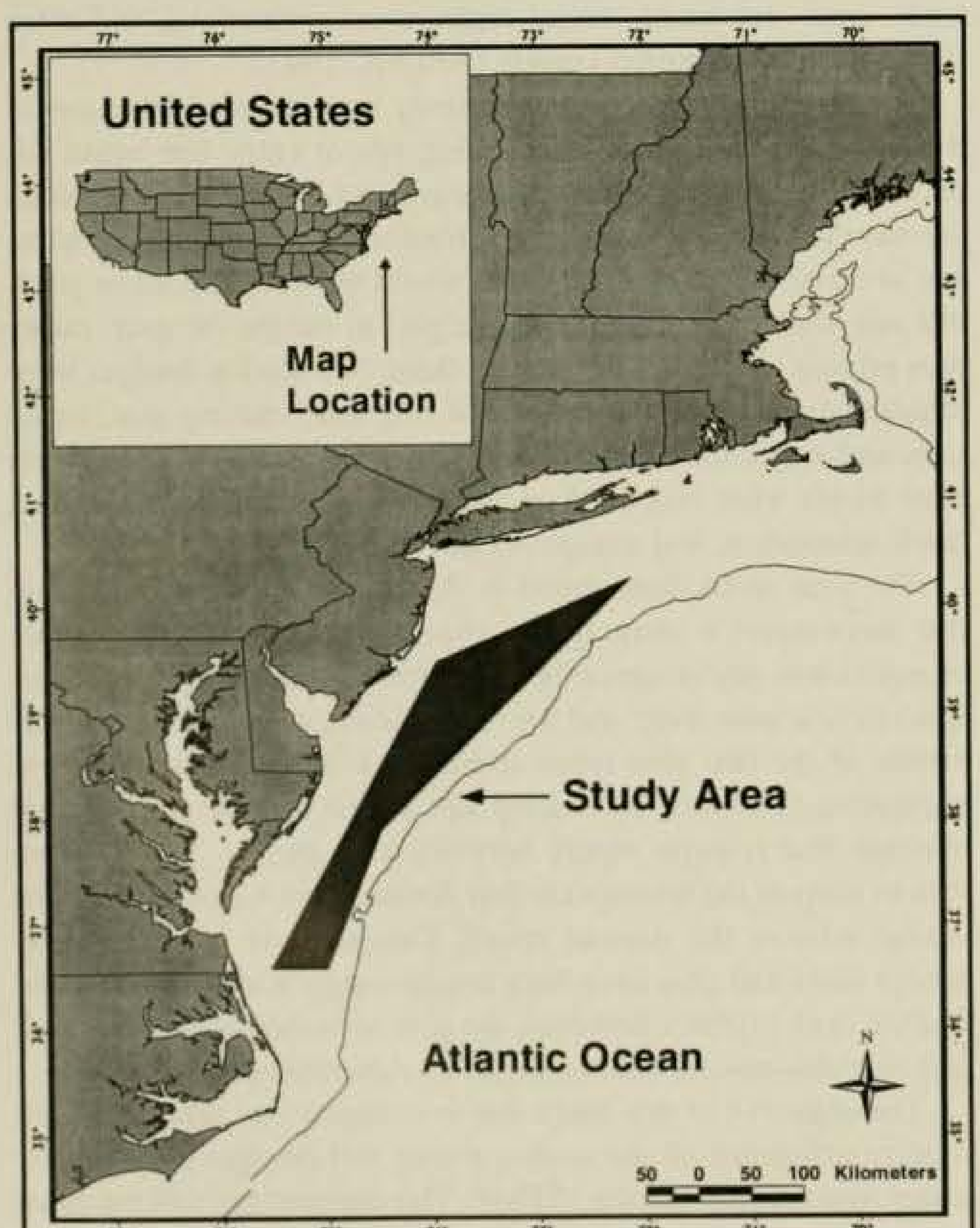

Figure 1. Map depicting the location of the three comparative trips.

A description of the New Bedford style offshore sea scallop dredge is given by Posgay (1957) and Bourne (1964). Pursuant to Amendment 4 restrictions, the chain bags of all dredges were knit with rings that had an inside diameter no greater than 3.50" (89 mm). Standard 5.50" (140 mm) diamond mesh twine tops were used on all dredges, and split tire shingles were used on the bottom of the chain bags as chafing gear.

The sea scallop otter trawl vessels utilized two trawls towed from separate warps. Wood trawl doors with dimensions of 120" × 40" (3.05 × 1.01 m) were attached directly to the wings of the nets. Steel sleds (approximately 400 lb. [181 kg]) in place of trawl doors were used on the inner wings of the two nets. The bodies and codend of the trawls consisted of 5.50" (140 mm) diamond mesh. Varying configurations of sweep chains ranging from 1/2" (12.7 mm) to 5/8" (15.9 mm) were used on the footropes of the trawls. A 1/2" (12.7 mm) tickler chain was also used. Chafing gear consisted of a doubled 1-m piece of nylon attached to each mesh on the belly of the codend. The length of warp fished varied with depth, but generally was held at a warp length/depth ratio of 3:1.

Deck operations were conducted under near normal commercial fishing conditions. For all tows, the catch from each gear was dumped on the deck, culled, shucked, bagged, and placed on ice or frozen until the termination of the trip. For comparative tows that were sampled, the crew culled the catch for sea scallops to be retained for shucking. A subsample of up to two baskets (1 basket equals approximately 1.5 bushels [53 L]) of retained sea scallops were set aside for length frequency analysis. Discarded sea scallops were subsampled as appropriate depending on the volume of trash and number of discards present. A shell height for each sampled scallop was taken in 5 mm intervals from the umbo to the ventral margin of the shell using a NMFS sea scallop measuring board.

Catch data were standardized to reflect harvest per unit area covered by the fishing gear. Linear distance traveled for each tow was calculated as the product of towing speed and tow duration. Area swept for each tow was estimated as the product of linear distance traveled and gear width. Dredge width varied between trips and was either 14 ft. (4.6 m) or 15 ft. (4.5 m). Trawl mouth spread was calculated as one-half the average of the headrope and the footrope (DeAlteris 1998). Kostyunin (1971) reported the fishing spread of modern trawl nets to be from 45% to 50% of the headline length corroborates this estimate. The estimates of area swept by the gear were then converted to hectares (1 ha = 10,000 m^2).

Relative harvest efficiency was calculated as the percentage difference in the number of sea scallops captured per hectare by the trawl relative to the dredge for each shell height size class. Relative production efficiency was examined with respect to the number of sea scallops harvested, production of scallop meats (grams), and average MPP at both observed cull sizes and at hypothetical cull sizes of 70, 80, and 90 mm shell heights. To estimate production of scallop meats and MPP, a shell height:meat weight allometric relationship for the mid-Atlantic region was applied to the midpoints of the shell height intervals (NEFMC 1982):

$$W = 5.929 \times 10^{-6} L^{3.234}.$$

L = shell height and W = meat weight. Statistical differences in mean number of sea scallops harvested, mean production rates, and average MPP between the gear types were determined by a two tailed Student's t test at the 5% significance level.

Size selectivity in the sea scallop fishery occurs as two different

TABLE 1.

Summary of operational procedures for comparative gear trials.

	Trip 1		Trip 2		Trip 3	
Date	August 8 through 18, 1997		September 8 through 18, 1997		May 13 through 18, 1998	
Area	Virginia Beach, VA		Hudson Canyon		Chincoteague, VA	
Vessel	Stephanie B.	Triangle I	Carolina Breeze	Capt. AT	Carolina Clipper	Triangle I
Gear	Dredge	Trawl	Dredge	Trawl	Dredge	Trawl
Tows on trip	199	80	286	99	121	48
Comparative tows	77	34	49	30	29	14
Scallops measured	31,689	47,385	13,685	22,665	24,455	24,929

processes: that imposed by the type and characteristics of the fishing gear and that imposed by the crew culling the catch. Estimates of relative size selectivity and efficiency were inferred for the two gear types from the numbers of sea scallops harvested and shell height frequency distributions. The size selection characteristics of the crew were determined by collecting the data in a manner that differentiated between sea scallops that were retained for shucking or discarded. The crew size selection curve was calculated as the ratio of the number of sea scallops retained by the crew for shucking to the total number of sea scallops captured for each shell height. Linear regression of normal deviates versus shell height was performed to determine the 25%, 50%, 75%, and 100% retention shell heights and selection range. Selection range was defined as the difference between the 75% and 25% retention shell heights.

RESULTS

Trip Data

Data for the study was collected on three comparative fishing trips during August and September of 1997 and May of 1998. Each comparative trip was considered an individual set of trials due to differences in geographic location and sea scallop abundance and size composition. Operational procedures for each set of trials are shown in Table 1. Sea scallop shell height frequencies for each individual trip are shown in Figure 2.

Crew Size Selection

The estimated selectivity parameters for sea scallops retained by the crew for shucking with associated size selectivity curves are shown in Table 2 and Figure 3. Although the size composition of the target species varied considerably over the three trips, crew size selection remained relatively constant. The shell height at which a scallop had a 50% chance of being retained for shucking (L_{50}) ranged from 69.3 to 77.5 mm. Scallop sizes from L_{75} to L_{25} ranged from 3.6 to 12.0 mm, which indicated that the crew selection process was relatively knife edged. Size selection of sea scallops was complete (L_{100}) at shell heights that ranged from 79.4 to 109.7 mm. However, larger sea scallops (>90 mm) classified as discards were probably the result of oversights by the crew.

Relative Efficiency

Relative harvest efficiency for each trip is shown in Figure 4. The relative harvest efficiencies of the gear types were approximately equal at a shell height range of 85 to 95 mm. Sea scallop catch per unit effort at a shell heights of 85 to 95 mm were not statistically different ($P > 0.05$) between gears for all three trips. Trawl vessels harvested sea scallops less than 85 to 95 mm shell height more efficiently and sea scallops greater than 85 to 95 mm shell height less efficiently relative to the dredge vessels. Relative harvest efficiency values for small sea scallops (<30 mm shell height) and large sea scallops (>130 mm shell height) meant little as sample sizes were limited.

Catch statistics for each trip calculated using the observed culling practices of the crew are shown in Table 3. Length frequency distributions for sea scallops taken by dredges and trawls vessels differed appreciably. However, the total number of sea scallops harvested and retained per hectare swept by the trawl gear was not statistically significant ($\alpha = 0.05$). Greater numbers of larger sea

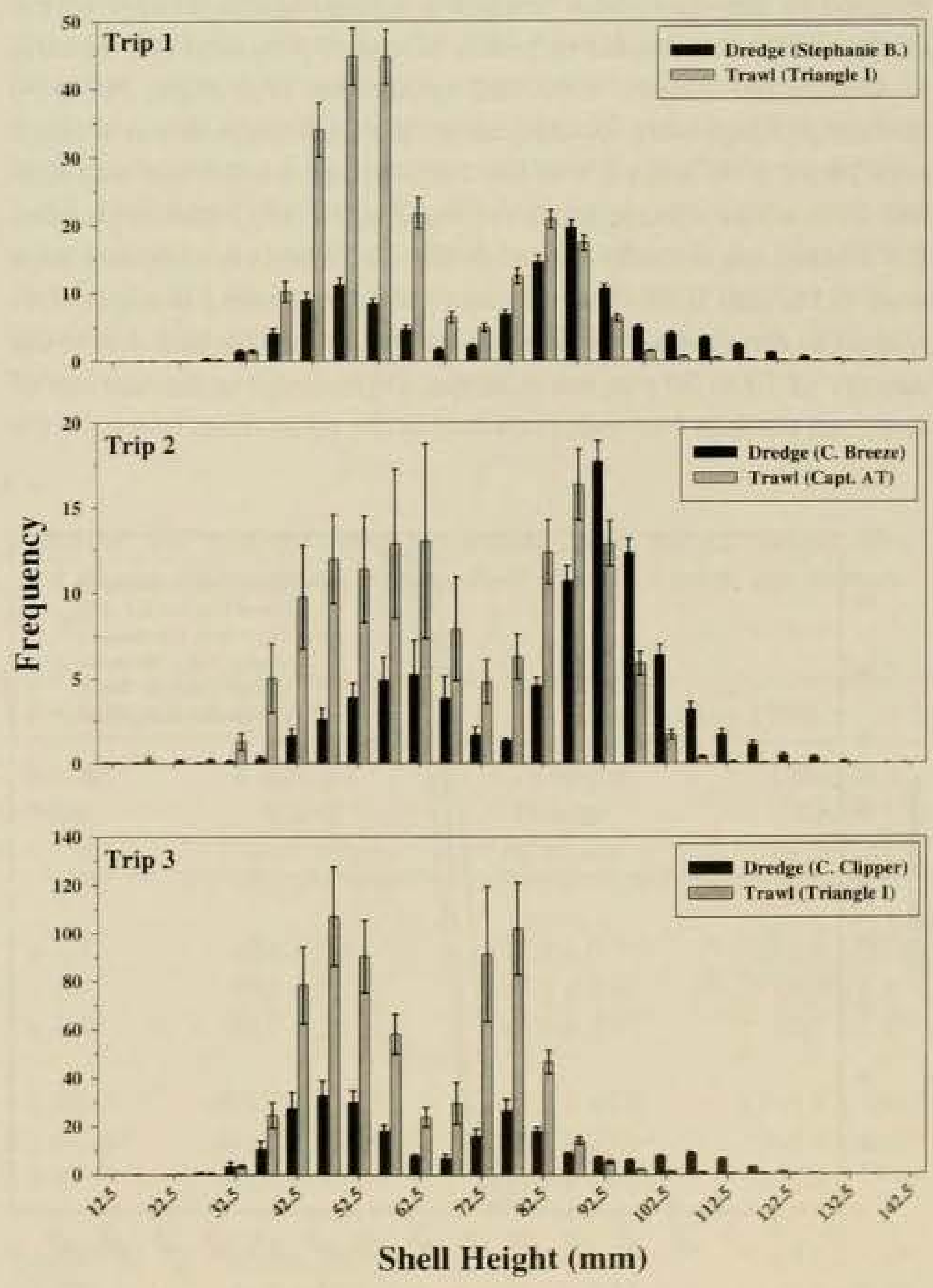

Figure 2. Shell height frequency distributions (mean ± SE) for each comparative trip standardized to one hectare covered by the gear.

TABLE 2.

Crew size selection lengths for all comparative gear trips. Values represent shell heights in millimeters at which a scallop had a 25%, 50%, 75%, and 100% probability of being retained by the crew for shucking.

	Trip 1 (August 1997)		Trip 2 (September 1997)		Trip 3 (May 1998	
	Stephanie B. Dredge	Triangle I Trawl	C. Breeze Dredge	Capt. AT Trawl	C. Clipper Dredge	Triangle I Trawl
Selection lengths						
L_{25}	73.0	71.8	67.5	68.0	70.5	74.3
L_{50}	76.5	75.9	69.3	71.6	76.5	77.5
L_{75}	80.0	80.0	71.1	75.2	82.5	80.6
L_{100}	95.9	98.6	79.4	91.3	109.7	94.9
Selection range L_{75}–L_{25}	7.0	8.2	3.6	7.2	12.0	6.3

scallops with larger meats harvested by the dredge vessel resulted in significantly higher ($P < 0.05$) production rates during August 1997. Differences in production rates for September 1997 and May 1998 were not statistically significant at the 5% level. MPP from the trawl vessels were significantly higher ($P < 0.05$) than meat counts from the dredge vessels for all trips.

The trawl vessel on the May 1998 trip took 35.4% more sea scallops per hectare than the dredge vessel. This difference was due to large numbers of 70 to 90 mm shell height sea scallops which constituted 92% and 58% of the catches of the trawl and dredge boats, respectively. Larger meats from the greater numbers of 90+ mm sea scallops captured by the dredge boat, however, resulted in the trawl boat being 8% less efficient relative to the dredge boat with respect to grams of meats produced per hectare.

During the August 1997 and September 1997 trips, 70 to 90 mm sea scallops were less abundant. Sea scallops in this size range constituted 57% and 62% of the catch by the trawl boats and 32% and 28% of the dredge boats for the August 1997 and September 1997 trips, respectively. Trawl boats on these two sampling trips were 6.5% and 0.7% less efficient than those using dredges with respect to the number of sea scallops caught per hectare due to the paucity of 70 to 90 mm sea scallops. Differences in the number of large sea scallops harvested resulted in the trawl boats being 27.4% and 25.3% less efficient relative to the dredge boats with respect to grams of scallop meats produced per hectare.

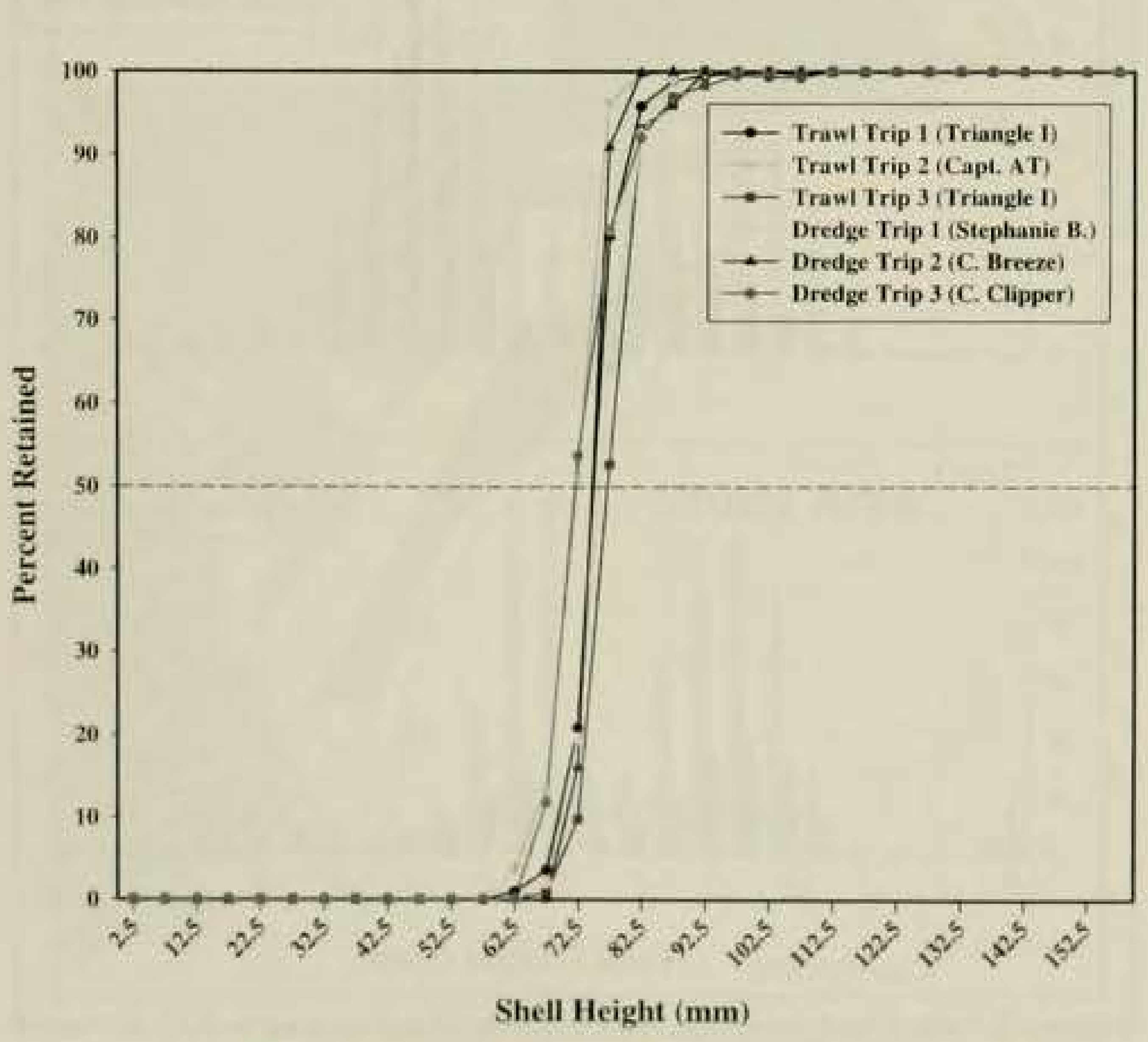

Figure 3. Size selection curves for the crew culling process.

Relative Efficiency at 70, 80, and 90 mm Shell Heights

Relative production efficiency was also examined by imposing hypothetical culling sizes of 70, 80, and 90 mm shell heights to examine the effects of possible changes in scallop age at entry to the fishery. This analysis further demonstrated the effect that differential catch compositions had on the comparison between the

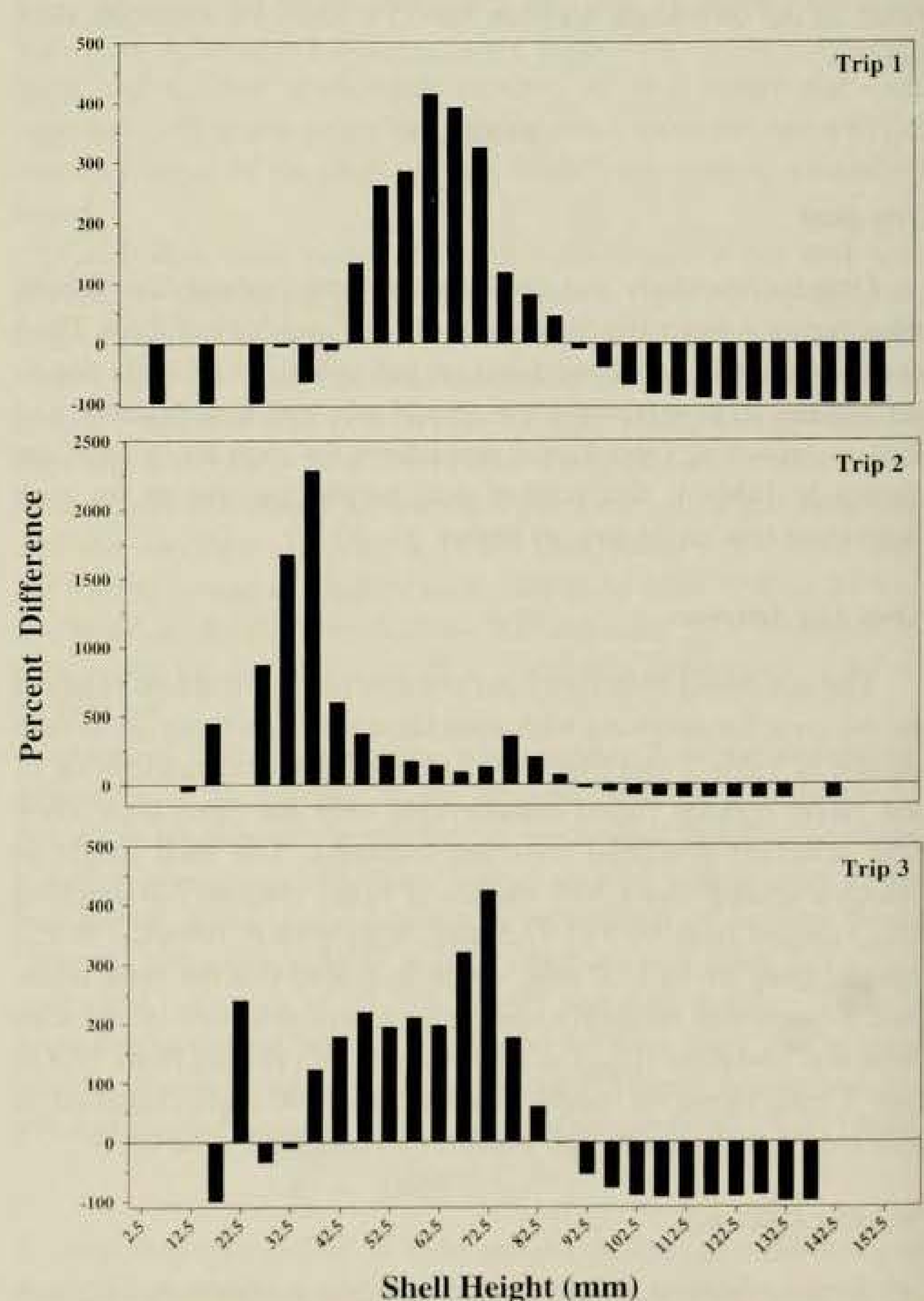

Figure 4. Relative harvest efficiency of the 5.50″ (140 mm) diamond mesh sea scallop otter trawl relative to the 3.50″ (89 mm) ring sea scallop dredge for all comparative trips.

TABLE 3.

Mean number of sea scallops harvested, mean grams of scallop meats produced, and average meats per pound (MPP) for all comparative gear trips. Values were calculated using the observed culling practices of the crew with the data standardized to reflect catch per hectare covered by the gear.

	Trip 1 (August 1997)		Trip 2 (September 1997)		Trip 3 (May 1998)	
	Stephanie B. Dredge (n = 34)	Triangle I Trawl (n = 77)	C. Breeze Dredge (n = 30)	Capt. AT Trawl (n = 49)	C. Clipper Dredge (n = 29)	Triangle I Trawl (n = 14)
Harvest (#/ha.)	69.0 ± 2.4	64.5 ± 3.7	59.9 ± 2.8	59.5 ± 5.5	96.4 ± 7.7	130.5 ± 17.3
Production (grams/ha.)	1,068.4 ± 33.5*	776.1 ± 42.6*	908.5 ± 44.8	687.9 ± 61.9	1,298.0 ± 73.4	1,194.2 ± 141.9
MPP	35.6 ± 0.4*	44.4 ± 0.6*	35.9 ± 0.6*	46.8 ± 1.4*	45.0 ± 1.1*	56.3 ± 0.7*

two gear types. Catch statistics for each trip calculated using the imposed cull sizes of 70, 80, and 90 mm shell are shown in Table 4.

During August and September of 1997, the sea scallop resource consisted of few age 3 sea scallops (70–90 mm sea scallops) and relatively low numbers of age 3+ (>90 mm)sea scallops. For these two trips, the total number of sea scallops caught per hectare was not significantly different ($P > 0.05$) at the 70 and 80 mm shell height cull sizes. When the cull size was increased to 90 mm, the dredge vessels captured significantly more ($P < 0.05$) sea scallops per hectare than did the trawl vessels. The dredge vessels were able to produce significantly more ($P < 0.05$) scallop meats at all culling sizes. These results reflected the differing relative harvest efficiencies and sea scallop abundance and size distribution at the time of the two trips.

The trawl vessel captured and produced significantly more ($P < 0.05$) sea scallops and meats than the dredge vessel at the 70 mm cull size in May 1998 due to the presence of large numbers of 70 to 90 mm sea scallops. When the cull size was increased to 90 mm and 70 to 90 (age 3) sea scallops were excluded from the analysis, dredge vessels captured and produced significantly more ($P < 0.05$) sea scallops and scallop meats relative to than the trawl vessels. Meat counts from the trawl vessels were significantly higher ($P < 0.05$) than meat counts from the dredge vessels for all trips at all culling sizes.

DISCUSSION

The sea scallop resource is in a constant state of flux as a result of variable recruitment, rapidly growing individuals, and high rates of fishing mortality. Sea scallop abundance and size distribution can change dramatically, even during the time scale of this study (August 1997 to May 1998). Despite the changing resource conditions, two general patterns were observed during the three trips. The two resource conditions differed with respect to the presence or absence of an age 3 (70–90 mm shell height) recruiting year class of sea scallops.

Sea scallops recruit to the fishery at 3 years of age. Three year old sea scallops, which in the mid-Atlantic region have a shell height of roughly 70 to 90 mm, represent an important age class in the fishery. As sea scallops grow to 70 to 75 mm shell height, they begin to be retained by commercial vessels (DuPaul and Kirkley 1995, DuPaul et al. 1995). Recent high levels of fishing mortality have reduced the abundance of older sea scallops in the population, and 3-year-old sea scallops that recruit to the gear each year have primarily supported the fishery (Serchuk et al. 1979, NEFMC 1993).

TABLE 4.

Mean number of sea scallops harvested, mean grams of scallop meats produced, and average meats per pound (MPP) for all comparative gear trips. Values are calculated using assumed culling sizes of 70, 80, and 90 mm shell heights, standardized to reflect catch per hectare covered by the gear.

	Trip 1 (August 1997)		Trip 2 (September 1997)		Trip 3 (May 1998)	
	Stephanie B. Dredge (n = 34)	Triangle I Trawl (n = 77)	C. Breeze Dredge (n = 30)	Capt. AT Trawl (n = 49)	C. Clipper Dredge (n = 29)	Triangle I Trawl (n = 14)
Harvest (#/ha.)						
Cull at 70 mm	71.7 ± 2.5	70.0 ± 4.0	61.5 ± 2.9	60.6 ± 5.6	110.1 ± 9.7*	264.7 ± 50.5*
Cull at 80 mm	67.9 ± 2.3	59.2 ± 3.4	58.4 ± 2.7	49.6 ± 5.1	67.3 ± 3.4	71.3 ± 6.8
Cull at 90 mm	46.6 ± 1.5*	26.5 ± 1.7*	43.2 ± 2.3*	20.9 ± 2.2*	40.0 ± 2.1*	10.3 ± 1.0*
Production (grams/ha.)						
Cull at 70 mm	1,088.6 ± 34.3*	816.2 ± 44.5*	918.1 ± 45.4*	688.7 ± 62.1*	1,399.5 ± 84.8	2,111.1 ± 354.7
Cull at 80 mm	1,062.0 ± 33.3*	743.4 ± 41.4*	897.6 ± 44.88*	611.7 ± 60.0*	1,096.5 ± 53.3*	768.6 ± 70.7*
Cull at 90 mm	834.3 ± 28.6*	397.0 ± 24.9*	734.2 ± 43.3*	311.7 ± 32.5*	824.0 ± 45.1*	170.3 ± 15.4*
MPP						
Cull at 70 mm	36.7 ± 0.4*	46.0 ± 0.7*	36.9 ± 0.7*	46.4 ± 1.3*	47.4 ± 1.2*	63.7 ± 1.1*
Cull at 80 mm	34.9 ± 0.4*	41.3 ± 0.3*	35.1 ± 0.6*	41.0 ± 0.9*	35.6 ± 0.5*	48.2 ± 0.2*
Cull at 90 mm	30.0 ± 0.3*	34.0 ± 0.1*	31.3 ± 0.4*	33.6 ± 0.4*	25.8 ± 0.4*	31.3 ± 0.7*

Shell height distributions for trips 1 and 2 portray a population that was characterized by a low abundance of age 3 sea scallops. The absence of large numbers of 3-year-old sea scallops had a large impact on the relative production rates of the two regulated gear types. The reduced ability of the trawl to capture sea scallops greater than 90 mm relative to the dredge, coupled with a minimum observed crew cull size of roughly 70 to 75 mm resulted in trawl boats being dependent upon 3-year-old sea scallops for production. In the absence of large numbers of age 3 sea scallops, production rates of the dredge vessels in terms of numbers of sea scallops captured per unit area and weight of scallop meats produced exceeded those from the trawl vessels during the first two trips.

During August 1997 (trip 1), large numbers of 40 to 60 mm shell height sea scallops were observed in the catches of both the dredge and the trawl. Growth of this cohort over the next 9 months resulted in these sea scallops attaining a shell height range whereby they were recruiting into the fishery the following spring. During the May 1998 trip, age 3 sea scallops from this cohort were captured in numbers 5 to 6 times greater than the previous trips in 1997. The presence of this strong age 3 year class had a profound effect on the relative production rates of the dredge and trawl vessels. When age 3 sea scallops were present in large numbers, the trawl vessels catch per hectare was 35.4% greater than that of the dredge vessel. The observed shift in relative harvest efficiency and the resulting ramifications in relation to production rates demonstrated an inherent inequality between the two regulated gear types.

Irrespective of changing resource conditions, a significant shift in relative harvest efficiency at 90 to 95 mm shell height was observed over all three trips. Trawl vessels were more efficient at capturing sea scallops less than 90-mm shell height relative to the dredge vessels. At shell heights greater than 90 mm, the trawl vessels were observed to operate less efficiently relative to dredge vessels. This shift in relative harvest efficiency had a large effect on catch compositions and ultimately production rates. The magnitude of the observed differences were dependent on the resource conditions at the time and location of the study. DuPaul et al. (1989c) observed similar results in comparing pre-Amendment 4 scallop trawls and dredges. At approximately 90 mm shell height, the 3 inch (76 mm) ring dredge started to perform more efficiently relative to the trawl nets used in the study.

The shift in relative harvest efficiency may be explained by behavioral characteristics of the sea scallop. Sea scallops less than 100 mm shell height have been found to be highly mobile (Caddy 1968, Dadswell and Weihs 1990), and have been observed to elicit a flight response at the approach of a dredge (Caddy 1968, Worms and Latienge, 1986). As scallops grow larger than 100 mm, mobility decreases and these larger animals become sedentary, living in shallow depressions created in the substrate (Bourne 1964). A dredge which is designed to scrape the substrate may be able to capture larger sea scallops (>100 mm shell height) found in slight depressions in the substrate. A trawl that skims over the substrate may not be able to capture these larger sea scallops as efficiently as the dredge.

Size Selectivity

Gear selectivity occurs as a scallop enters a trawl or dredge on the sea floor. Selection properties of the gear dictate whether a scallop escapes or is captured, and is primarily a function of scallop size relative to the mesh or ring size in the trawl or dredge. Sea scallops that are too small to be retained by the gear pass through spaces in the meshes, rings, or inter-ring spaces. Selection by the crew occurs when the catch is dumped on deck and the crew culls the catch for sea scallops to be retained for shucking. Under Amendment 4, no meat count restrictions exist and it is up to the discretion of the captain and crew to establish the size of sea scallops that are retained for shucking.

Traditional size selectivity studies are based on a comparison between length frequency distributions from an experimental (selective) versus a control (non-selective) gear. The non-selective gear provides an estimate of the size distribution of the animals that pass through the meshes or rings of the experimental gear. Covered codends, small mesh codends, and small mesh liners represent some non-selective devices utilized in the literature (Hodder and May 1965, Pope et al. 1975, Serchuk and Smolowitz 1980, DuPaul et al. 1989a, Wileman et al. 1996). The length frequency distribution from the non-selective gear is then compared with the catch from the experimental gear to generate a size selection curve.

A non-selective gear was not used to determine absolute selectivity in this study. The data collected represented the catch from two experimental (selective) gear configurations. With no estimate of the length frequency distribution of sea scallops that passed through the rings of the dredge and meshes of the trawl, absolute selection curves could not be generated. Millar (1995) states that comparative gear selectivity experiments in which no control is used can not provide conclusive evidence of any selection curve because any fit to the data can arise from an infinity of selection curve models. In the absence of an estimate of absolute gear selectivity, relative gear selectivity can be inferred from length frequency distributions, catch compositions, and relative efficiency estimates.

Results of the crew size selectivity analysis suggest a standard for minimum retention size. DuPaul and Kirkley (1995) reported that sea scallops begin to be retained by the fishery at roughly 70 to 75 mm shell height. Our findings corroborate this observation, as the L_{50} values over all trips ranged from 69.3 to 77.5 mm. DuPaul et al. (1995) and DuPaul and Kirkley (1995) observed that crew culling practices changed in response to a dominant year class that grew over the course of the study period. In this study, however, no shift in sea scallop size selection was observed even though the size composition of the catch varied widely over the three trips.

Implications for the Fishery and Management

Controlling age at entry is one management strategy used to maximize yield per recruit and increase the spawning potential of the managed population. Serchuk et al. (1979) estimated that maximum yield per recruit for sea scallops is attained at an age of first capture of 8 years. Only minor increases are realized as age at first capture increases from ages 6 to 8. While it may be unrealistic to delay the age at first capture to 8 or even 6 year old sea scallops, significant benefits in terms of yield per recruit can be realized if sea scallops are allowed to reach age 4 before recruiting to the fishery. Serchuk et al. (1979) estimated an increase of 39% in yield per recruit for mid-Atlantic sea scallops if harvested at 97 mm as opposed to 77 mm shell height. Similarly, Caddy (1972) estimated a 65% increase in yield per recruit if sea scallops were allowed to grow from 73 to 92 mm shell height. The harvest of 3-year-old sea scallops compromises the management objective of maximizing yield per recruit.

In addition to increasing yield per recruit, delaying age at first capture from age 3 to 4 also adds to reproductive potential in terms of egg production. Age 3 sea scallops produce from 10 to 13.5 million eggs, while 4-year-old sea scallops will produce as many as 22 to 34 million eggs (MacDonald and Thompson 1985, Langton et al. 1987). While exact fecundity estimates vary, age 4 sea scallops can produce 2 to 3 times more eggs than age 3 sea scallops. McGarvey et al. (1993) found a statistically significant spawner-recruit relationship for sea scallops on Georges Bank, and determined that age 3 and to some extent age 4 sea scallops did not measurably contribute to egg production and recruitment on Georges Bank. The harvest of age 3 sea scallops may at best represent a large reduction in spawning potential or possibly the removal of animals before they have had a chance to reproductively contribute to the population.

Equity

The examination of equity between different regulated gear types found in Amendment 4 was an objective of this study and was predicated on relative size selectivity and efficiency. Analyses of shell height frequencies, catch compositions, and relative harvest efficiency indicated that regulated trawls and dredges appear quite different in relation to both size selectivity and harvest efficiency.

Future attempts at equating dredges and trawls in relation to size selectivity could be accomplished through comparative gear research. Studies utilizing differing diamond or square mesh sizes would result in the escape of greater numbers of pre-recruit (<70 mm shell height). Previous comparative gear studies demonstrated that modifications such as increasing ring and mesh sizes reduced, but did not eliminate, the capture of smaller sea scallops, and often reduced overall harvest efficiency (DuPaul et al. 1989c, DuPaul and Kirkley 1995).

While size selection properties of sea scallop gear seem to be broad, the crew culling process has been shown to be very selective. Assuming the majority of sea scallops that are discarded survive the capture and culling process, the crew culling process in combination with more selective gear types has the potential to be an effective tool in controlling scallop size at entry into the fishery process (Medcof and Bourne 1964, DuPaul et al. 1995, DuPaul and Kirkley 1995).

Sea scallop trawls were observed to have a reduced ability to capture sea scallops greater than 90 mm relative to standard sea scallop dredges. This differential harvest pattern coupled with an observed minimum culling size at 70 to 75 mm implies that trawl vessels will depend, in a large part, on age 3 sea scallops for landings. If the resource consists of large numbers of sea scallops less than 90-mm shell height, dredge vessels will be at a competitive disadvantage relative to trawl vessels. Management strategies have clearly pointed to the objective of restoring the abundance and age distribution of the adult stocks (NEFMC 1982). If resource composition is restored in the future, sea scallops greater than 90 mm will represent a larger proportion of the resource. The ability of dredge vessels to more efficiently harvest sea scallops larger than 90 mm shell height dredge vessels will result in a competitive advantage for dredge vessels relative to trawl vessels. This generalization is dependent upon the relative abundance of scallop size classes present in the population.

The reduced ability of trawls to capture sea scallops greater than 90 mm shell height relative to the dredge may make equating the two gears difficult. Future trawl design modifications may be able to reduce the catch of small sea scallops, but results from this and previous studies suggest that current trawl designs may not be able to harvest larger sea scallops as efficiently as scallop dredges (DuPaul et al. 1989c). Once trawl and dredge designs are engineered to have similar selectivity patterns, the issue of harvest efficiency could be addressed. Harvest efficiency is partly a function of gear width, or the area over the bottom that the gear can cover. Currently, gear width is mandated to be a maximum of 30 ft. (9.0 m) of dredge width and 144 ft. (43.2 m) of trawl sweep. Modifications of gear width could possibly equilibrate the two gears in relation to relative harvest efficiency.

The comparison of relative efficiency and size selectivity of the two regulated gear types represents the first comparative level of analysis on how dredge and trawl vessels operate. To adequately compare the two gears, a broader view of how dredge and trawl vessels operate at the fleet level should be examined. Trawl vessels hold 22% of the total permits in the fishery and account for 10% to 15% of the annual landings. Trawl landings for the 1998 to 1999 fishing year were 1.29 million pounds, or 11% of the total landings (NEFMC 1999). Trawl vessels tend to operate out of ports in the mid-Atlantic region and are operationally limited to working in areas of smooth, clean bottom. As a result of this limitation, trawl vessels can operate in only a fraction of the area that is available to the dredge boats. Therefore, only a limited portion of the scallop resource is subject to harvest by sea scallop trawl gear. Intense fishing activity by trawl vessels in this limited resource area may result in dramatic localized effects to incoming year classes of 70 to 90 mm shell height sea scallops.

This study demonstrated that the assumptions that formed the basis of the gear regulations found in Amendment 4 were not entirely correct. Clearly, if a management objective is to require that sea scallop trawls and dredges have equivalent size selection and relative efficiency, more comparative gear research is a necessity. In general, quantifying the role that different fishing gears have on the utilization of the sea scallop resource is an objective yet to be fully achieved.

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