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A Comparison of Size Selectivity and Relative Efficiency of Sea Scallop Trawls and Dredges

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A Comparison of Size Selectivity and Relative Efficiency of Sea Scallop Trawls and Dredges

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David B. Rudders

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of
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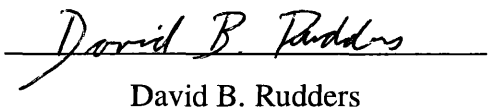

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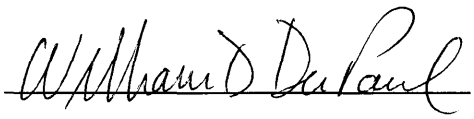

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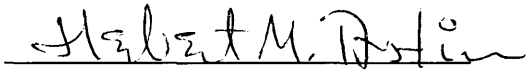

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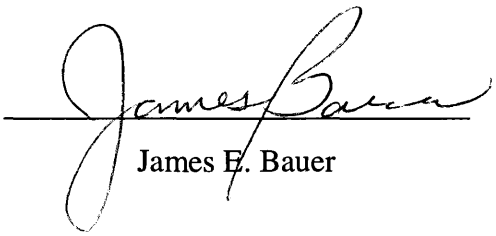

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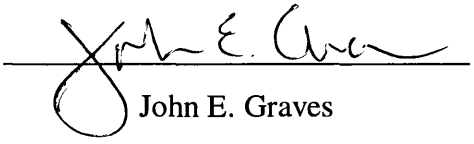

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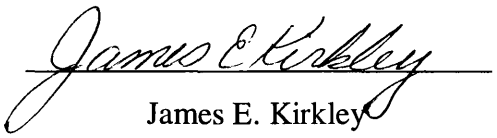

James E. Kirkley

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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). Restrictions that included minimum mesh and ring sizes and maximum gear widths were assumed to equate sea scallop trawls and dredges with respect to size selectivity and efficiency. Results indicated that the two regulated gear types were not equal in either respect. Absolute gear size selectivity could not be estimated, however relative size selectivity patterns inferred from shell height frequencies, catch compositions, and relative efficiencies suggest broad yet different size ranges of scallops captured by each gear type. Relative harvest efficiency values demonstrated a shift at roughly 90 mm shell height. Trawl vessels were more efficient at capturing scallops less than 90 mm, while the dredge vessels were more efficient capturing scallops greater than 90 mm. This shift in relative harvest efficiency coupled with an observed cull size at roughly 70-75 mm shell height had a profound effect on both relative production rates and catch composition. The differing harvest patterns observed in this study may make equating current trawl and dredge designs difficult.

A Comparison of Size Selectivity and Relative Efficiency of Sea Scallop Trawls and Dredges

INTRODUCTION

Wild populations of the sea scallop, *Placopecten magellanicus*, occur exclusively on the continental shelf and coastal regions of the northwestern Atlantic Ocean. The mollusc ranges from the Canadian Maritimes to Cape Hatteras, North Carolina (Posgay, 1957). South of Cape Cod sea scallops are found in offshore waters at depths between 40-200 meters (22-110 fathoms), while north of Cape Cod, scallops can inhabit inshore waters just below the low tide mark. Most commercially important scallop beds are located at depths of 40-100 meters (22-55 fathoms). The Gulf of Maine, Georges Bank, and the mid-Atlantic represent the major U.S. commercial sea scallop resource areas (NEFMC, 1982).

Commercial sea scallop landings began around 1880 with the initiation of a small, inshore fishery in the Gulf of Maine. Landings remained low until large, offshore scallop beds were discovered off the mid-Atlantic Bight in the 1920s and on Georges Bank in the 1930s. Annual landings by the combined U.S. and Canadian fleets have fluctuated around the 10,000 metric ton harvest level since 1953 (Serchuk *et al.*, 1979). In 1990, a record high 17,500 metric tons of shucked meats, worth $149 million were landed (NMFS, 1998).

The sea scallop fishery has been characterized by cycles of high and low production due to fluctuations in recruitment and varying levels of fishing effort (Dickie, 1955). As early as 1940, New England scallopers recognized the need to reduce fishing effort and sponsored effort restrictions for the fleet (NEFMC, 1982). 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, prompted federally mandated regulatory measures. In 1982 the New England Fishery Management Council (NEFMC), in conjunction with both the Mid-Atlantic Fishery Management Council (MAFMC) and the South Atlantic Fishery Management Council (SAFMC), implemented the Sea Scallop Fishery Management Plan (SSFMP).

The main objective of the FMP was to maximize the joint social and economic benefits from the utilization of the sea scallop resource (NEFMC, 1982). The FMP also contained four sub-objectives: (1) restoration of the abundance and age distribution of the adult stocks to reduce the year-to-year fluctuations in stock abundance caused by

variation in recruitment; (2) enhancement of yield per recruit; (3) evaluation of the impact of FMP provisions on research, development, and enforcement; (4) minimization of adverse environmental impacts on sea scallops (NEFMC, 1982).

In an effort to maximize yield per recruit, the fishery was initially regulated by establishing scallop age at entry. A maximum meat count for shucked scallops and a minimum shell height for shellstocked scallops were instituted. Shucked scallops were required to have a maximum meat count of 30 meats per pound (MPP) for the time period between February 1 and September 30. To account for spawning activity, the maximum meat count was raised to 33 MPP between October 1 and January 31. The minimum size for shellstocked scallops was 3.50" (89 mm). These measures were subject to an enforcement tolerance level of 10%.

The maximum meat count regulation proved to be inadequate for a number of reasons. The meat count standard did not effectively address the spatial and temporal variability in meat weights for scallops of the same shell height (Shumway and Schick, 1987) and the semi-annual spawning cycle observed in the mid-Atlantic region (DuPaul, *et al.,* 1989b, Schmitzer *et, al.,* 1991). Commercial fishery practices including at-sea shucking and handling of the catch resulted in both losses and gains in meat weight (Naidu, 1987, Kirkley and DuPaul, 1989). Compliance problems, which included the mixing of high count scallops (>30 MPP) with low count scallops (≤30 MPP) and soaking procedures to facilitate the uptake of fresh water also contributed to the failure of the meat count standard (DuPaul, *et al.,* 1989a, DuPaul, *et al.,* 1990). These factors resulted in the difficult enforcement of the meat count standard, the continued exploitation of small scallops (>30 MPP), and reduced biomass gains through growth.

Since 1990, high levels of effort have resulted in estimates of fishing mortality which surpassed F_{max} (the level of fishing mortality that produces maximum yield per recruit) for all resource areas (NEFMC, 1993). Due to exponential growth, a new year class of scallops recruits to the fishery each season. Scallops recruit to the fishery at three years of age and 70 mm shell height. The relationship between age and shell height is shown in Figure 1 (NEFMC, 1982). Age three scallops represent an important year class for the fishery. With older, larger scallops at usual low abundance due to high levels of fishing mortality, three year old animals constitute a large portion of annual

landings. As a result of low abundance of older scallops and variable recruitment, marked fluctuations in abundance as indicated by landings became more common and extreme during the late 1980s and early 1990s (NMFS, 1998).

To remedy the failure of the meat count standard, high levels of F, and reliance of one cohort for the fishery, Amendment #4 was drafted by the NEFMC in 1993. This regulation changed the management system from a meat count standard to effort controls in an attempt to reduce fishing mortality from F=2.24 to a target of F=0.71, or a 70% reduction over a seven year period. Primary measures to reduce effort included the establishment of a limited access fishery and days at sea (DAS) restrictions. Supplemental measures included gear restrictions, limiting crew size to seven members, vessel replacement restrictions, and catch limits for vessels not in the limited access program (NEFMC, 1993).

Gear restrictions found in Amendment #4 were intended to control age at entry and would theoretically allow juvenile scallops (<70 mm) to escape the gear, rather than relying on the crew to discard them after capture. Substantial damage and associated mortality are caused by the capture, handling, and culling processes (DuPaul *et al.*, 1995). Juvenile scallop discard mortality estimates range from 7.3% to 20% (Medcof and Bourne, 1964, DuPaul *et al.*, 1995; DuPaul and Kirkley, 1995).

Two gear types are utilized in the sea scallop fishery. The first and most common gear type is the New Bedford style scallop dredge, which is described in detail by both Bourne (1964) and Posgay (1957). In 1998, 229 of the 295 vessels included in the limited access fishery were listed as dredge vessels (Jones, 1998). From 1982 to 1993, dredge vessels accounted for an average of 91% of the effort, in terms of annual DAS for the sea scallop fleet (Rago *et al.,* 1997).

The scallop dredge was mandated to meet specific criteria under Amendment #4. Ring size was incrementally increased from 3.00" (76 mm) to 3.25" (83 mm) and finally to 3.50"(89 mm) over a two-year time period from 1994 to 1996 (NEFMC, 1993). Regulations prohibited the use of donut spacers and dictated the number and arrangement of chain links to join the rings in the net bag. A 5.50" (140 mm) twine top was made mandatory, and the total width of the dredge(s) could not exceed 30 feet (9.16 m).

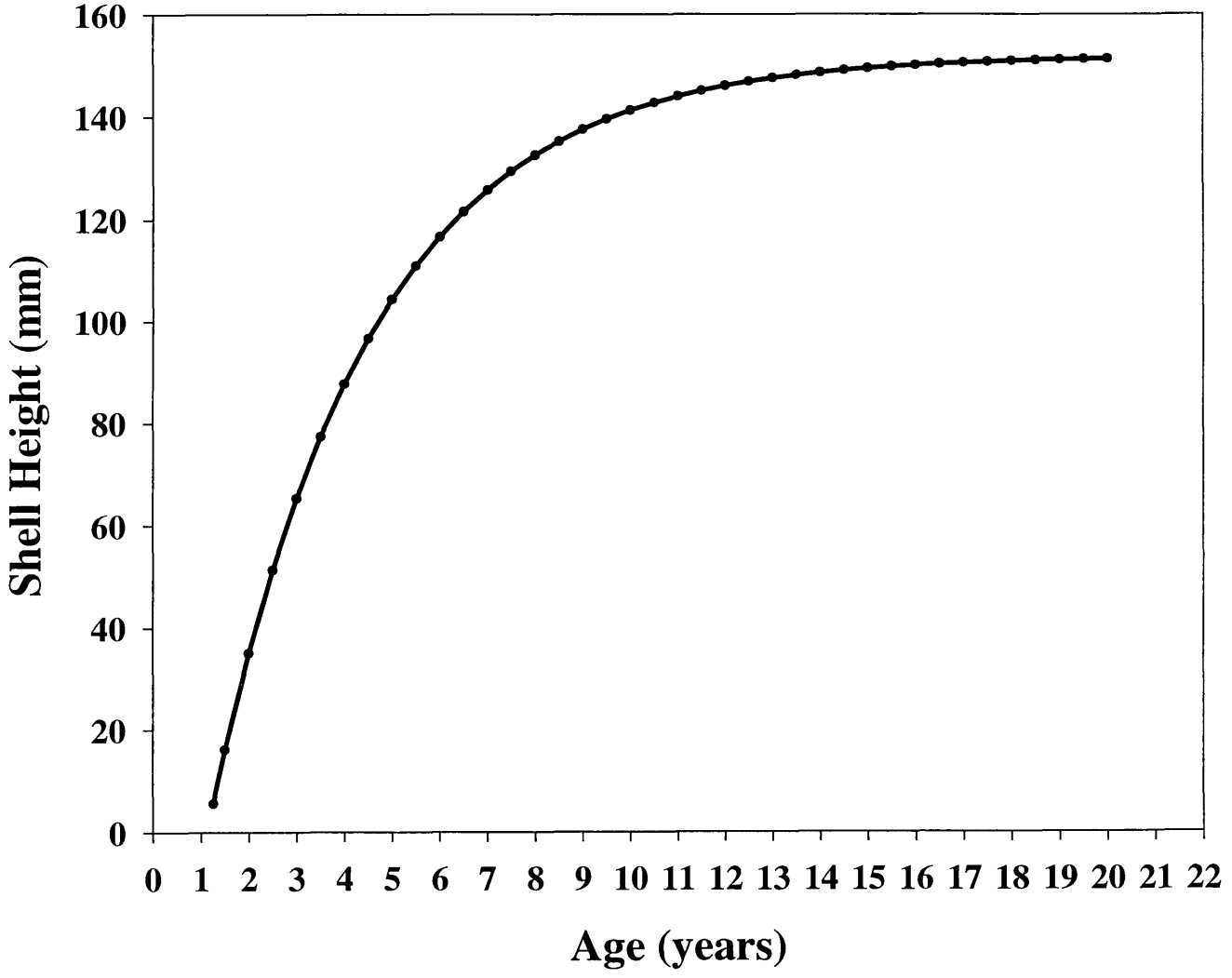
The second type of gear in the sea scallop fishery is the otter trawl. A general description of an otter trawl is given in Pitcher and Hart (1982). In 1998, 66 of the 295 vessels included in the limited access fishery were listed as trawl vessels (Jones, 1998). Of these 66 vessels, 50 are characterized as "occasional" or "part-time" to the fishery (Jones, 1998). This classification represents the diversified nature of trawl vessels involved in the fishery. Trawl vessels have annually accounted for an average of 9.8% of the total effort in the fishery in terms of days at sea for the period from 1982-1993 (Rago *et al.,* 1997).

Gear restrictions were imposed on the trawl sector of the sea scallop fleet under Amendment #4. These regulations were influenced by mesh size restrictions in place for both the New England groundfish and summer flounder *(Paralicthyes dentatus)* fisheries. These fishes represent high levels of bycatch in the scallop fishery. Changes to scallop trawl gear regulations correspond with mesh regulations for the groundfish and summer flounder fisheries, and dictate that sea scallop otter trawls must be composed of a minimum of 5.50" (140 mm) diameter mesh in both the body and codend of the net. The total sweep of the net(s) can not exceed 144 feet (44 m).

The regulations set for sea scallop trawl gear found in Amendment #4 were, in part, guided by the assumption that the size selectivity of a 3.50" (89 mm) ring corresponds to the size selectivity of the 5.50" (140 mm) diamond mesh. Similarly, an assumption also existed that equated the harvest efficiency of 144 (44 m) feet of trawl sweep with 30 feet (9.16 m) of dredge width. There are, however, no data to support or refute either of these two assumptions.

In setting the specific restrictions on the two gear types, the issue of equity must be considered. The Magnuson-Stevens Fishery Conservation and Management Act of 1996 prohibits bias of one group or gear type over another group or gear type in a fishery. Comparing the fishing performance (relative efficiency and size selectivity) of sea scallop trawls and dredges will elucidate the relative attributes or detriments and equity of the gear restrictions found in Amendment #4. In addition, this information will help to establish whether the gear restrictions for scallop trawls fulfill the management objective of controlling age at entry. This information is vital for the continuing evolution of management strategies for the sea scallop fishery.

Figure 1 Relationship between age (years) and shell height (mm) for scallops in the mid-Atlantic region.


160
140
120
100
80
60
40
20
0
Shell Height (mm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Age (years)

MATERIALS AND METHODS

Approach

In order to accurately estimate the relative efficiency and relative size selectivity of sea scallop otter trawls and dredges regulated by Amendment #4, it was necessary to operate the two gears on the same fishing grounds at the same time. Vessel design limitations prevent a dredge and an otter trawl from being towed by the same vessel simultaneously. To sample with both gears concurrently, both a dredge and a trawl vessel were utilized. This experimental design is the parallel fishing method, and requires two ships fishing the same ground over an extended period of time (Pope *et. al.*, 1975). For this study the parallel fishing method was modified slightly so that both vessels followed the same tow direction in close proximity during the same time period. It was assumed that if this criterion were met then both gears would sample from the same population of sea scallops.

The study consisted of two trips in August and September of 1997 and one trip in May of 1998. Commercial sea scallop vessels from the Hampton Roads area of Virginia were contracted to conduct the gear trials. These vessels operate primarily in the mid-Atlantic resource area, and provided the capital, knowledge, and crew necessary to carry out the study. Fishing gear used in this project complied with Amendment #4 restrictions, and at-sea modifications were allowed as long as compliant with Amendment #4. The choice of fishing grounds was left to the discretion of the vessel captains.

Data Collection

While at sea, both a tow log and deck log were maintained. The tow log, compiled by the captain and/or first mate, contained information pertaining to the operation of the fishing boat and gear. The tow log included: (1) tow number, (2) date, (3) time at the beginning and end of each tow, (4) location (LORAN) at the beginning and end of each tow, (5) vessel speed, (6) depth, (7) duration of each tow, (8) harvest (baskets) by each gear (port-starboard), and (9) comments on the tow.

The deck log was maintained by the chief scientist, and contained information pertaining to the biological parameters of the catch. Information recorded in the deck log

included: (1) harvest volume (baskets), (2) shell-height frequency distribution in 5 mm intervals of both retained and discarded scallops, and (3) volume estimates (baskets) of trash and miscellaneous invertebrates.

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, placed in chilling totes, bagged, and placed on ice or frozen until offloaded at the termination of the trip. Of the sampled tows, the crew culled the catch for scallops to be retained for shucking. A sub-sample of up to two baskets (1 basket equals approximately 1.5 bushels) of retained scallops were set aside for length frequency analysis. The scientific staff then sorted through the debris for discarded scallops. Depending on the volume of trash and numbers of juveniles present, a fraction of the juveniles were retained for length frequency analysis. Shell height measurements were taken at 5 mm intervals from the umbo to the ventral margin of the shell for each sampled scallop using a National Marine Fisheries Service sea scallop measuring board.

Data Analysis

The parallel fishing method, as defined in this study, requires that both vessels conduct fishing operations following the same tow line during the same time period. To ensure that the criterion of the design is met, tows which were sampled but did not occur along the same tow line at the same time were subsequently excluded from analysis.

Since the two gears are different with regard to physical characteristics (area covered by the gear) and how they are fished (duration of the tow), it was necessary to standardize the catch data to common units of effort. Total estimated catch per tow was calculated by using a ratio of sampled catch to total catch per tow. Total estimated catch for each shell height interval for each tow was divided by the corresponding tow time recorded in the tow log. This standardization method reflects harvest on a per hour basis.

Catch data were also standardized to reflect harvest on an area covered basis. A linear distance traveled for each tow was calculated by multiplying the towing speed by the towing time. This value was then multiplied by the width of each gear. Dredge width varied between trips and was either 14 ft. (4.6 m) or 15 ft. (4.5 m). The estimate of the trawl mouth spread was calculated as 1/2 the average of the headrope and the sweep

(DeAlteris, 1998). Kostyunin (1971) reported the fishing spread of modern trawl nets to be from 45-50% 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).

Both standardization approaches are different, yet important ways to view the comparison between the two gear types. Standardizing by time yielded results that were indicative of actual fishing operations, but did not account for operational variables such as vessel speed and width of gear. Standardizing by area fished, factored in vessel speed and width of gear, yet was independent of time.

Relative Efficiency

Relative harvest efficiency was examined with respect to the number of animals captured per hectare by the trawl and the dredge for each shell height interval. For each shell height, a percent difference was calculated by dividing the difference in total catch between the trawl and dredge by the total catch of the dredge. These values represent the harvest efficiency per shell height interval for the trawl relative to the dredge. Statistical differences in mean catches by each gear over each shell height were determined by a two tailed student's t-test.

Relative production efficiency was examined with respect to the number of scallops harvested, production of scallop meats (grams), and average meats per pound (MPP) at both observed cull sizes and the imposed cull sizes of 70, 80, and 90 mm shell height. To estimate production of scallop meats and MPP, a shell height:meat weight relationship for the mid-Atlantic region was applied to the midpoints of the shell height intervals (NEFMC, 1982): $W= 5.929 * 10^{-6}L^{3.234}$

Where L=shell height, and W=meat weight

The estimated meat weight for each shell height interval was multiplied by the average catch for that corresponding shell height. This resulted in an estimate of the average weight of scallop meats produced for each shell height. Statistical differences in mean number of scallops harvested, mean production rates and average MPP between the gear types were determined by a two tailed student's t-test.

Size Selectivity

Size selectivity in the sea scallop fishery occurs as two different processes: gear selectivity and crew selectivity. The experimental design of this study does not provide the information to adequately estimate absolute gear size selectivity. To assess gear size selectivity, an estimate of the scallops that entered the gear and subsequently escape is necessary. The use of a non-selective gear is required to accomplish this, however in this study two experimental, size selective gears were used. No estimate of the size frequency of scallops escaping the gear was obtained. Estimates of relative gear size selectivity, however, were inferred from shell height frequencies, catch compositions, and relative efficiency estimates.

The process of crew size selection results from the crew culls the catch brought on deck, and establishes a minimum size that will be retained for processing. By collecting the data in a manner that differentiates between scallops that are destined to be processed or discarded, the size selection characteristics of the crew can be determined. This analysis was accomplished by obtaining a ratio of the number of scallops retained by the crew for processing to the total number of scallops captured for each shell heights, over all shell heights. Plotting this ratio (as a percent) against shell heights results in the crew size selection curve. 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 is defined as the difference between the 75% and 25% retention shell heights.

RESULTS

Trip Data

Data for this study was obtained during three comparative gear trips between the period of August 1997 and May 1998. The duration of the trips ranged from 8-19 days. All trips were conducted in the mid-Atlantic resource area on continental shelf waters between Sandy Hook, New Jersey and the Virginia/North Carolina border (Figure 2). Summary statistics for all trips relating to towing speed, tow length, and depth fished are presented in Table 1.

Trip 1

The first trip was conducted during August 1997 in an area east of the Virginia/North Carolina border. The scallops in this area at that time were characterized by a high abundance of pre-recruits (<70 mm shell height), and a moderate abundance of recruits (>70 mm). Weather conditions were generally calm to moderate with short periods of rough seas and high winds.

The trawl vessel contracted for comparative gear trip 1 was the F/V Triangle I from the Wanchese Fish Co. out of Phoebus, Virginia. The Triangle I is a steel hull western rig (stern ramp and dual net reel) sea scallop trawler approximately 77 ft. (23.46 m) length over all (LOA). The Triangle I departed Phoebus, Virginia on August 7, 1997 and returned to port on August 19, 1997. A total of 80 tows were made during the course of the trip. The scientific staff sampled 36 tows, 34 of which were included in the final analysis of the data. Towing time ranged from 115-195 minutes with a mean of 159 minutes. Towing speed ranged from 2.8-3.0 kts. with a mean of 2.81 kts. The depth fished ranged from 27-42 fathoms (49.4-76.9 m) with a mean of 31.5 fathoms (57.6 m).

The dredge vessel contracted for comparative gear trip 1 was the F/V Stephanie B. from Seaford, Virginia. The Stephanie B is a wood hull vessel of approximately 75.5 ft. (23.01 m) LOA rigged to tow two New Bedford style sea scallop dredges. The Stephanie B. departed Seaford, Virginia on August 7, 1997 and returned to port on

August 19, 1997. A total of 199 tows were made during the course of the trip. The scientific staff sampled 87 tows, 77 of which were included in the final analysis of the data. Towing time ranged from 50-85 minutes with a mean of 63.9 minutes. Towing speed ranged from 4.0-4.9 kts. with a mean of 4.4 kts. The depth fished ranged from 27-45 fathoms (49.4-82.3 m) with a mean of 31.3 fathoms (57.3 m).

Totals of 50,310 and 34,505 scallops were measured over the course of the trips on the trawl and dredge vessels, respectively. Tows with large catches of retained and discarded scallops were sub-sampled. Catches from these tows were expanded to estimate the total catch for the tow. Expanding the catches from the sub-sampled tows yielded an estimate of 225,212 scallops in the sampled tows for the trawl vessel and 68,942 scallops in the sampled tows for the dredge vessel. Shell height frequencies from each vessel, standardized to reflect catch on both a per hour and a per hectare basis are shown in Table 2 and Figure 3. Size composition of the catch for selected shell heights is shown in Table 5.

Trip 2

The second trip was conducted during September 1997 in an area east of Delaware Bay. Operations shifted southward to the location of the first trip for a period of two days. The scallops in the area off Delaware Bay at that time were characterized by a very low abundance of pre-recruits (<70 mm shell height) and a low abundance of recruits (>70 mm). Weather conditions were generally moderate to very rough, with periods of extreme conditions that were sufficient to suspend fishing activity.

The trawl vessel contracted for comparative gear trip 2 was the F/V Capt. AT, from the Chesapeake Bay Packing Co. fleet in Newport News, Virginia. The Capt. AT is a steel hull western rig (stern ramp and single net reel) sea scallop trawler of approximately 77 ft. (23.46 m) LOA. The Capt. AT departed Newport News, Virginia on September 6, 1997 and returned to port on September 24, 1997. A total of 99 tows were made during the course of the trip. The scientific staff sampled 44 tows, 30 of which were included in the final analysis of the data. Towing time ranged from 80-180 minutes with a mean of 119 minutes. Towing speed ranged from 2.8-3.0 kts. with a mean of 2.89

kts. The depth fished ranged from 29-43 fathoms (53.0-78.7 m) with a mean of 38 fathoms (69.5 m).

The dredge vessel contracted for comparative gear trip 2 was the F/V Carolina Breeze from Seaford, Virginia. The Carolina Breeze is a wood hull vessel approximately 75.5 ft. (23.46 m) LOA rigged to tow two New Bedford style sea scallop dredges. The Carolina Breeze departed Seaford, Virginia on September 4, 1997 and returned to port on September 21, 1997. A total of 286 tows were made during the course of the trip. The scientific staff sampled 85, 49 of which were included in the final analysis of the data. Tow times ranged from 16.8-64.8 minutes with a mean of 57.6 minutes. Towing was a constant 4.6 kts. The depth fished ranged from 27-41 fathoms (49.4-75.0 m)with a mean of 36 fathoms (65.8 m).

Totals of 31,451 and 20,870 scallops were measured over the course of the trips on the trawl and dredge vessels, respectively. Expanding the catches from the sub-sampled tows yielded an estimate of 87,070 scallops in the sampled tows for the trawl vessel and 45,395 scallops in the sampled tows for the dredge vessel. Shell height frequencies from each vessel, standardized to reflect catch on both a per hour and a per hectare basis are shown in Table 3 and Figure 4. Size composition of the catch for selected shell heights is shown in Table 5.

Trip 3

The third trip was conducted during May 1998 in an area east of Chincoteague, Virginia. The scallops in this area at this time were characterized by a high abundance of pre-recruits (<70 mm shell height) and recruits (>70 mm). The presence of a large recruiting year class (age 3 scallops, 70-90 mm shell height) was also evident. Weather conditions were generally calm to moderate.

The trawl vessel contracted for comparative gear trip 3 was the F/V Triangle I. The Triangle I departed Phoebus, Virginia on May 13, 1998 and returned to port on May 20, 1998. A total of 48 tows were made during the course of the trip. The scientific staff sampled 14, 14 of which were included in the final analysis of the data. Tow times ranged from 120-145 minutes with a mean of 125 minutes. Towing speed ranged from 3.0-3.3

kts. with a mean of 3.17 kts. The depth fished ranged from 37-41 fathoms (67.7-75.0 m) with a mean of 39 fathoms (71.3 m).

The dredge vessel contracted for comparative gear trip 3 was the F/V Carolina Clipper from Seaford, Virginia. The Carolina Clipper is a steel hull vessel of approximately 88 ft. (27.3 m) LOA rigged to tow two New Bedford style sea scallop dredges. The Carolina Clipper departed Seaford, Virginia on May 13, 1998 and returned to port on May 22, 1998. A total of 121 tows were made during the course of the trip. The scientific staff sampled 29, all 29 of which were included in the final analysis of the data. Towing times ranged from 62-110 minutes with a mean of 81 minutes. Towing speed ranged from 4.2-5.0 kts. with a mean of 4.71 kts. The depth fished ranged from 36-40 fathoms (65.8-73.2 m) with a mean of 38 fathoms (69.5 m).

Totals of 24,929 and 24,455 scallops were measured over the course of the trips on the trawl and dredge vessels, respectively. Expanding the catches from the sub-sampled tows yielded an estimate of 115,013 scallops in the sampled tows for the trawl vessel and 44,023 scallops in the sampled tows for the dredge vessel. Shell height frequencies from each vessel, standardized to reflect catch on both a per hour and a per hectare basis are shown in Table 4 and Figure 5. Size composition of the catch for selected shell heights is shown in Table 5.

Fishing Gear

The fishing gear used in this project complied with the restrictions specified in Amendment #4. Comparative gear trips 1 and 2 featured 14 ft. (4.6 m) dredges, while 15 ft. (4.5 m) dredges were used on trip 3. 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 chain bags as chafing gear.

The sea scallop otter trawl vessels utilized paired trawls. This configuration consisted of two nets towed from separate warps. Wood trawl doors with dimensions of 120"x40" were used. The sweep of the nets varied between trips. On both comparative gear trips one and two, 65 ft. (21.3 m) nets were used, while both a 66 ft. (19.8 m) net and

a 72 ft. (21.6 m) net were used on trip 3. The trawls consisted of 5.50" (140 mm) diamond mesh in both the bodies and codends of the nets. Varying configurations of sweep chains ranging from 1/2" to 5/8" were used on the footropes of the trawls. A 1/2" tickler chain was also used. Varying configurations of chafing gear consisting of a doubled one meter piece of nylon was used liberally on the belly of the codends to prevent excessive wear. The length of warp fished varied with depth, but generally was held at a warp length/depth ratio of 3:1.

Figure 2 Dates and locations of comparative gear trips.

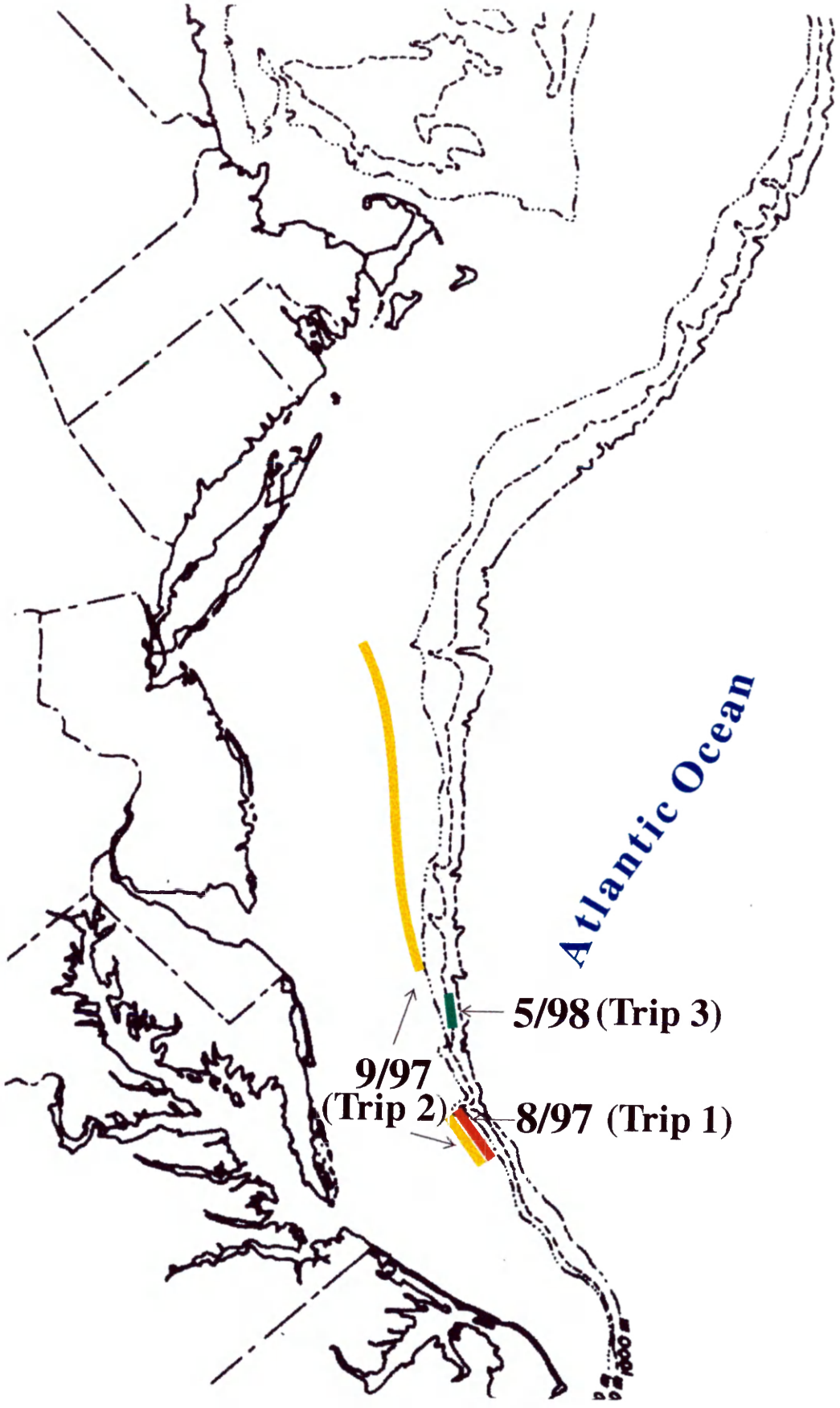

Atlantic Ocean
5/98 (Trip 3)
9/97
(Trip 2)
8/97 (Trip 1)

Table 1 Summary statistics of tow time, tow speed and depth fished for all comparative gear trips.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
Tow time (min.)						
Maximum	85.2	195.0	16.8	180.0	109.8	145.2
Minimum	50.0	115.0	64.8	80.0	61.8	120
Mean	63.9	159.0	57.6	119.0	80.9	125.7
S.D.	8.5	22.0	7.7	16.9	9.8	8.0
Tow speed (kts.)						
Maximum	4.9	3.0	4.6	3.0	5.0	3.3
Minimum	4.0	2.8	4.6	2.8	4.2	3.0
Mean	4.4	2.81	4.6	2.9	4.7	3.17
S.D.	0.2	0.03	0.0	0.1	0.2	0.1
Depth (fathoms)						
Maximum	45.0	42.0	41.0	43.0	40.0	41.0
Minimum	27.0	27.2	27.0	29.0	36.0	37.0
Mean	31.3	31.5	35.9	38.0	38.2	39.1
S.D.	3.3	3.8	4.6	4.25	1.1	1.1

Table 2 Average catches of two 14 ft. dredges (n= 77 tows) and a paired otter trawl consisting of two 65 ft. nets (n=34 tows) on comparative gear trip 1 (August 7-19, 1997). Catches have been standardized to reflect catch per hour and catch per hectare. Variance is plus/minus one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of the trawl and dredge vessels at that particular shell height.

Shell height (mm)	Dredge Trip 1 F/V Stephanie B. catch/hour	Trawl Trip 1 F/V Triangle I catch/hour	Dredge Trip 1 F/V Stephanie B. catch/hectare	Trawl Trip 1 F/V Triangle I catch/hectare
0-5	0.0	0.0	0.0	0.0
5-10	0.18 ± 0.16	0.0	0.03 ±0.02	0.0
10-15	0.0	0.0	0.0	0.0
15-20	0.07 ± 0.06	0.0	0.01 ±0.01	0.0
20-25	0.0	0.0	0.0	0.0
25-30	0.09 ± 0.09	0.04 ± 0.04	0.01 ± 0.01	0.0
30-35	0.31 ± 0.16	0.58 ± 0.26	0.04 ± 0.02	0.05 ± 0.03
35-40	2.56 ± 0.69	1.99 ± 0.83	0.35 ± 0.1	0.20 ± 0.08
40-45	10.00 ± 2.19	15.03 ± 2.76	1.42 ± 0.32	1.42 ± 0.26
45-50	28.02 ± 4.45*	105.25 ± 16.33*	4.05 ± 0.65*	10.14 ± 1.56*
50-55	61.99 ± 6.75*	347.91 ± 42.27*	9.06 ± 1.01*	34.05 ± 4.02*
55-60	77.59 ± 7.51*	456.03 ± 44.44*	11.15 ± 1.06*	44.83 ± 4.24*
60-65	57.90 ± 5.6*	449.68 ± 42.39*	8.36 ± 0.79*	44.77 ± 4.08*
65-70	29.26 ± 3.12*	217.35 ± 23.54*	4.57 ± 0.65*	21.73 ± 2.28*
70-75	10.18 ± 1.08*	63.00 ± 8.28*	1.65 ± 0.28*	6.36 ± 0.81*
75-80	14.90 ± 1.58*	47.08 ± 5.69*	2.15 ± 0.23*	4.81 ± 0.59*
80-85	46.41 ± 4.57*	123.90 ± 10.88*	6.76 ± 0.67*	12.41 ± 1.10*
85-90	100.55 ± 6.24*	213.33 ± 14.47*	14.55 ± 0.92*	20.79 ± 1.38*
90-95	135.77 ± 6.6*	180.67 ± 12.08*	19.65 ± 0.96	17.30 ± 1.15
95-100	74.46 ± 3.36	65.80 ± 5.31	10.68 ± 0.50*	6.23 ± 0.49*
100-105	34.05 ± 2.61*	15.21 ± 1.35*	4.89 ± 0.40*	1.44 ± 0.13*
105-110	27.39 ± 2.01*	6.21 ± 0.50*	3.92 ± 0.29*	0.59 ± 0.05*
110-115	23.22 ± 1.54*	4.16 ± 0.49*	3.32 ± 0.21*	0.39 ± 0.05*
115-120	15.86± 1.16*	1.80 ± 0.28*	2.27 ± 0.16*	0.16 ± 0.03*
120-125	7.38 ± 0.79*	0.48 ± 0.13*	1.07 ± 0.12*	0.04 ± 0.01*
125-130	3.59 ± 0.56*	0.13 ± 0.06*	0.53 ± 0.08*	0.01 ± 0.01*
130-135	1.23 ± 0.29*	0.07 ± 0.05*	0.18 ± 0.04*	0.01 ± 0.0*
135-140	0.40 ± 0.16*	0.02 ± 0.02*	0.06 ± 0.02*	0.0*
140-145	0.04 ± 0.03	0.0	0.01 ± 0.0	0.0
145-150	0.02 ± 0.02	0.0	0.0	0.0
150-155	0.01 ± 0.01	0.0	0.0	0.0
155-160	0.0	0.0	0.0	0.0
160-165	0.0	0.0	0.0	0.0
165-170	0.0	0.0	0.0	0.0

Figure 3 Shell height frequencies for the trawl vessel F/V Triangle I and the dredge vessel F/V Stephanie B. on comparative gear trip 1 (August 8-18, 1997). Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of trawl and dredge vessel. (A). Represents catches from both vessels standardized to one hour of towing time. (B). Represents catches from both vessels standardized to one hectare covered by the gear.

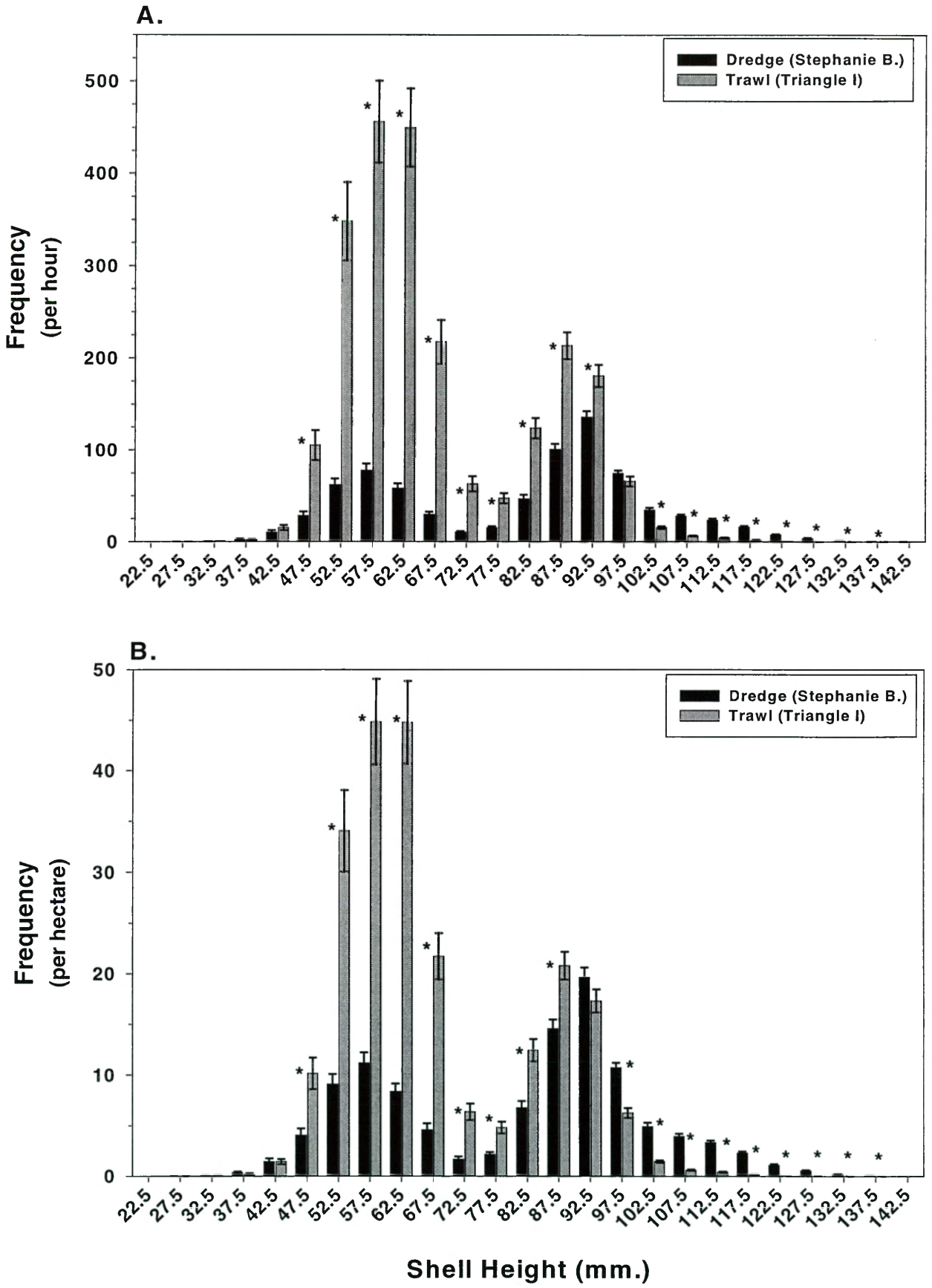

A.
Dredge (Stephanie B.)
Trawl (Triangle I)
Frequency
(per hour)
500
400
300
200
100
0
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
87.5
92.5
97.5
102.5
107.5
112.5
117.5
122.5
127.5
132.5
137.5
142.5
B.
Dredge (Stephanie B.)
Trawl (Triangle I)
Frequency
(per hectare)
50
40
30
20
10
0
Shell Height (mm.)

Table 3 Average catches of two 14 ft. dredges (n= 49 tows) and a paired otter trawl consisting of two 65 ft. nets (n=30 tows) on comparative gear trip 2 (September 4-24, 1998). Catches have been standardized to reflect catch per hour and catch per hectare. Variance is plus/minus one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of the trawl and dredge vessels at that particular shell height.

Shell height (mm)	Dredge Trip 2 F/V C. Breeze. catch/hour	Trawl Trip 2 F/V Capt. AT catch/hour	Dredge Trip 2 F/V C. Breeze catch/hectare	Trawl Trip 2 F/V Capt. AT catch/hectare
0-5	0.0	0.0	0.0	0.0
5-10	0.0	0.07 ± 0.07	0.0	0.01 ± 0.01
10-15	0.24 ± 0.18	0.20 ± 0.15	0.03 ± 0.02	0.02 ± 0.01
15-20	0.24 ± 0.14	2.02 ± 1.73	0.03 ± 0.02	0.20 ± 0.17
20-25	0.0	1.06 ± 0.87	0.0	0.10 ± 0.08
25-30	0.12 ± 0.07*	1.54 ± 0.78*	0.02 ± 0.01	0.15 ± 0.08
30-35	0.84 ± 0.47*	12.91 ± 5.05*	0.11 ± 0.06*	1.26 ± 0.49*
35-40	2.07 ± 0.85*	51.56 ± 20.65*	0.28 ± 0.12*	5.00 ± 2.01*
40-45	11.89 ± 2.85*	101.20 ± 31.12*	1.64 ± 0.39*	9.73 ± 3.03*
45-50	18.63 ± 4.64*	127.75 ± 28.09*	2.57 ± 0.64*	11.95 ± 2.59*
50-55	28.25 ± 5.88*	123.62 ± 34.41*	3.89 ± 0.81*	11.35 ± 3.12*
55-60	35.36 ± 9.81*	141.44 ± 48.15*	4.87 ± 1.35	12.87 ± 4.37
60-65	37.82 ± 14.64	143.14 ± 62.92	5.21 ± 2.02	13.02 ± 5.71
65-70	27.78 ± 9.32	86.06 ± 33.33	3.83 ± 1.28	7.87 ± 3.03
70-75	12.18 ± 3.27*	51.10 ± 13.73*	1.68 ± 0.45*	4.77 ± 1.29*
75-80	9.67 ± 1.07*	64.73 ± 13.46*	1.33 ± 0.15*	6.23 ± 1.32*
80-85	33.12 ± 3.46*	128.17 ± 19.11*	4.56 ± 0.48*	12.36 ± 1.88*
85-90	77.60 ± 6.53*	169.76 ± 20.99*	10.68 ± 0.90*	16.31 ± 2.07*
90-95	128.41± 8.66	134.77± 13.55	17.68 ± 1.19*	12.86 ± 1.32*
95-100	89.46 ± 5.89*	61.75 ± 7.19*	12.32 ± 0.81*	5.87 ± 0.69*
100-105	46.28 ± 4.26*	17.51 ± 2.96*	6.37 ± 0.59*	1.67 ± 0.29*
105-110	22.95 ± 3.35*	3.82 ± 0.82*	3.16 ± 0.46*	0.36 ± 0.08*
110-115	12.37 ± 2.13*	1.01 ± 0.28*	1.70 ± 0.29*	0.09 ± 0.03*
115-120	7.87 ± 1.72*	0.38 ± 0.15*	1.08 ± 0.24*	0.04 ± 0.01*
120-125	3.29 ± 0.93*	0.09 ± 0.07*	0.45 ± 0.13*	0.01 ± 0.01*
125-130	2.25 ± 0.63*	0.02 ± 0.02*	0.31 ± 0.09*	0.0*
130-135	0.77 ± 0.33*	0.02 ± 0.02*	0.11 ± 0.05	0.0
135-140	0.04 ± 0.04	0.06 ± 0.06	0.0	0.01 ± 0.01
140-145	0.04 ± 0.04	0.0	0.01 ± 0.01	0.0
145-150	0.0	0.0	0.0	0.0
150-155	0.0	0.0	0.0	0.0
155-160	0.0	0.0	0.0	0.0
160-165	0.0	0.0	0.0	0.0
165-170	0.0	0.0	0.0	0.0

Figure 4 Shell height frequencies for the trawl vessel F/V Capt. AT and the dredge vessel F/V Carolina Breeze on comparative gear trip 2 (September 4-24, 1997). Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of trawl and dredge vessel. (A). Represents catches from both vessels standardized to one hour of towing time. (B). Represents catches from both vessels standardized to one hectare covered by the gear.

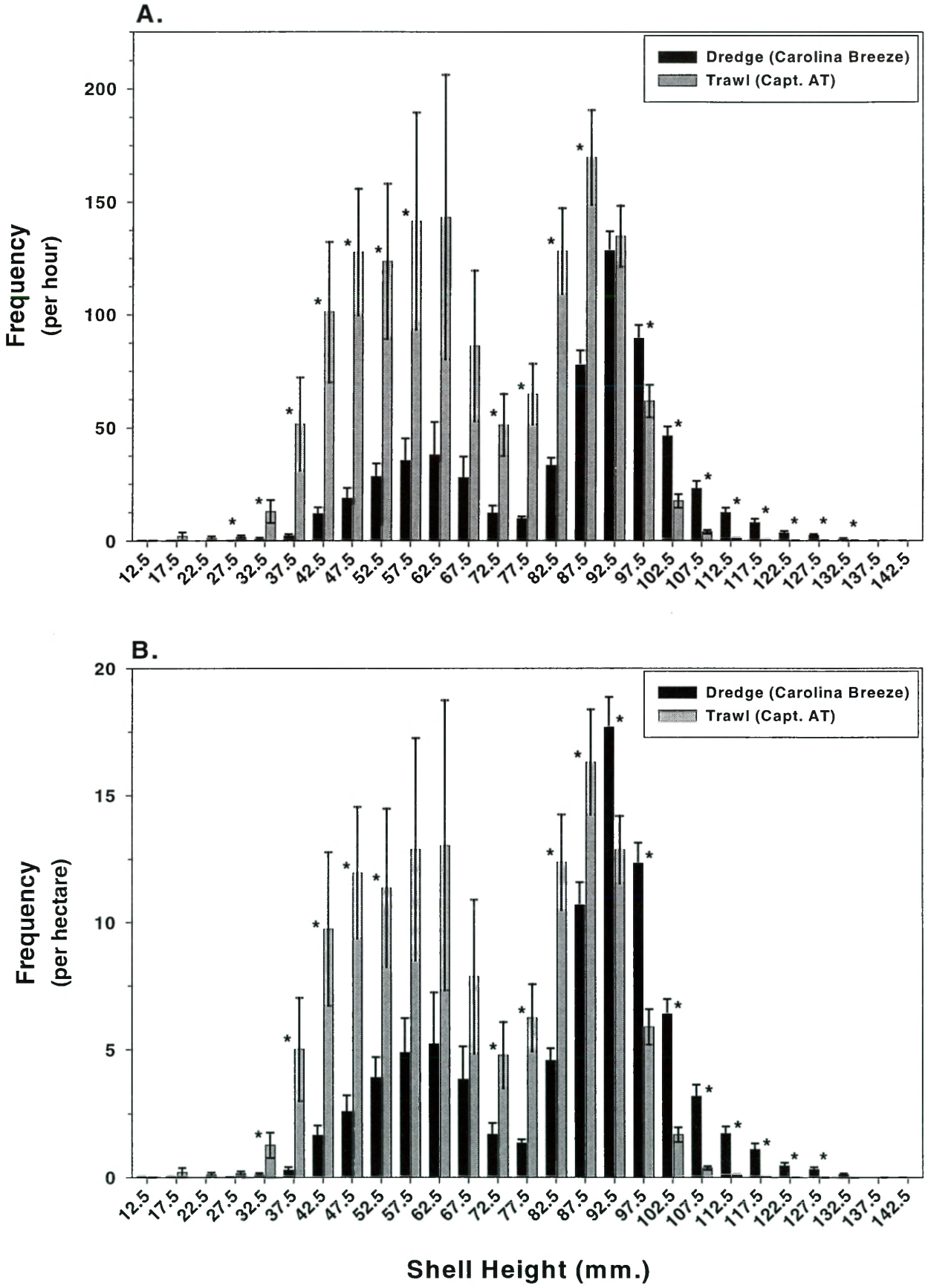

A.
Dredge (Carolina Breeze)
Trawl (Capt. AT)
Frequency
(per hour)
200
150
100
50
0
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
87.5
92.5
97.5
102.5
107.5
112.5
117.5
122.5
127.5
132.5
137.5
142.5
B.
Dredge (Carolina Breeze)
Trawl (Capt. AT)
Frequency
(per hectare)
20
15
10
5
0
Shell Height (mm.)

Table 4 Average catches of two 15 ft. dredges (n= 29 tows) and the paired otter trawl consisting of 66 and 72 ft. nets (n=14 tows) on comparative gear trip 3 (May 13-22, 1998). Catches have been standardized to reflect catch per hour and catch per hectare. Variance is plus/minus one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of the trawl and dredge vessels at that particular shell height.

Shell height (mm)	Dredge Trip 3 F/V C. Clipper catch/hour	Trawl Trip 3 F/V Triangle I catch/hour	Dredge Trip 3 F/V C. Clipper. catch/hectare	Trawl Trip 3 F/V Triangle I catch/hectare
0-5	0.0	0.0	0.0	0.0
5-10	0.0	0.0	0.0	0.0
10-15	0.0	0.0	0.0	0.0
15-20	0.62 ± 0.46	0.0	0.08 ± 0.06	0.0
20-25	0.41 ± 0.29	2.29 ± 1.55	0.05 ± 0.04	0.18 ± 0.12
25-30	4.54 ± 2.40	4.48 ± 3.16	0.55 ± 0.29	0.36 ± 0.25
30-35	30.59 ± 13.29	43.74 ± 8.83	3.73 ± 1.61	3.51 ± 0.70
35-40	87.31 ± 28.4*	310.35 ± 66.35*	10.71 ± 3.46*	24.88 ± 5.30*
40-45	223.21 ± 56.34*	977.69 ± 198.45*	27.55 ± 6.92*	78.58 ± 15.90*
45-50	265.58 ± 50.93*	1326.89 ± 252.8*	32.91 ± 6.26*	107.10 ± 20.60*
50-55	243.09 ± 39.27*	1120.80 ± 184.9*	30.27 ± 4.84*	90.70 ± 15.12*
55-60	146.81 ± 20.05*	719.72 ± 100.89*	18.31 ± 2.47*	58.39 ± 8.29*
60-65	62.36 ± 7.07*	294.22 ± 47.12*	7.77 ± 0.87*	23.97 ± 3.97*
65-70	55.77 ± 14.89*	369.51 ± 108.47*	6.88 ± 1.80*	29.79 ± 8.7*
70-75	130.21 ± 25.44*	1136.57 ± 349.1*	16.07 ± 3.04*	91.50 ± 28.01*
75-80	215.61 ± 38.28*	1261.32 ± 240.5*	26.73 ± 4.65*	102.02 ± 19.25*
80-85	146.15 ± 12.99*	575.04 ± 57.42*	18.25 ± 1.58*	46.78 ± 4.8*
85-90	72.06 ± 4.70*	175.33 ± 18.76*	9.00 ± 0.57*	14.23 ± 1.53*
90-95	57.05 ± 4.79	65.89 ± 8.78	7.11 ± 0.57	5.36 ± 0.72
95-100	46.59 ± 3.72*	25.08 ± 1.92*	5.82 ± 0.45*	2.04 ± 0.16*
100-105	60.89 ± 4.89*	13.68 ± 2.03*	7.58 ± 0.58*	1.12 ± 0.17*
105-110	71.01 ± 5.29*	10.06 ± 1.61*	8.90 ± 0.66*	0.82 ± 0.13*
110-115	49.63 ± 3.74*	4.62 ± 1.17*	6.25 ± 0.48*	0.38 ± 0.10*
115-120	24.00 ± 2.42*	5.07 ± 1.46*	3.03 ± 0.31*	0.42 ± 0.13*
120-125	8.33 ± 2.05*	1.17 ± 0.55*	1.05 ± 0.26*	0.09 ± 0.04*
125-130	1.80 ± 0.70	0.32 ± 0.22	0.23 ± 0.09*	0.02 ± 0.02*
130-135	0.50 ± 0.31	0.0	0.06 ± 0.04	0.0
135-140	0.16 ± 0.12	0.0	0.02 ± 0.02	0.0
140-145	0.0	0.0	0.0	0.0
145-150	0.0	0.0	0.0	00
150-155	0.0	0.0	0.0	0.0
155-160	0.0	0.0	0.0	0.0
160-165	0.0	0.0	0.0	0.0
165-170	0.0	0.0	0.0	0.0

Figure 5 Shell height frequencies for the trawl vessel F/V Triangle I and the dredge vessel F/V Carolina Clipper on comparative gear trip 3 (May 13-22, 1998). Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean catches of trawl and dredge vessel. (A). Represents catches from both vessels standardized to one hour of towing time. (B). Represents catches from both vessels standardized to one hectare covered by the gear.

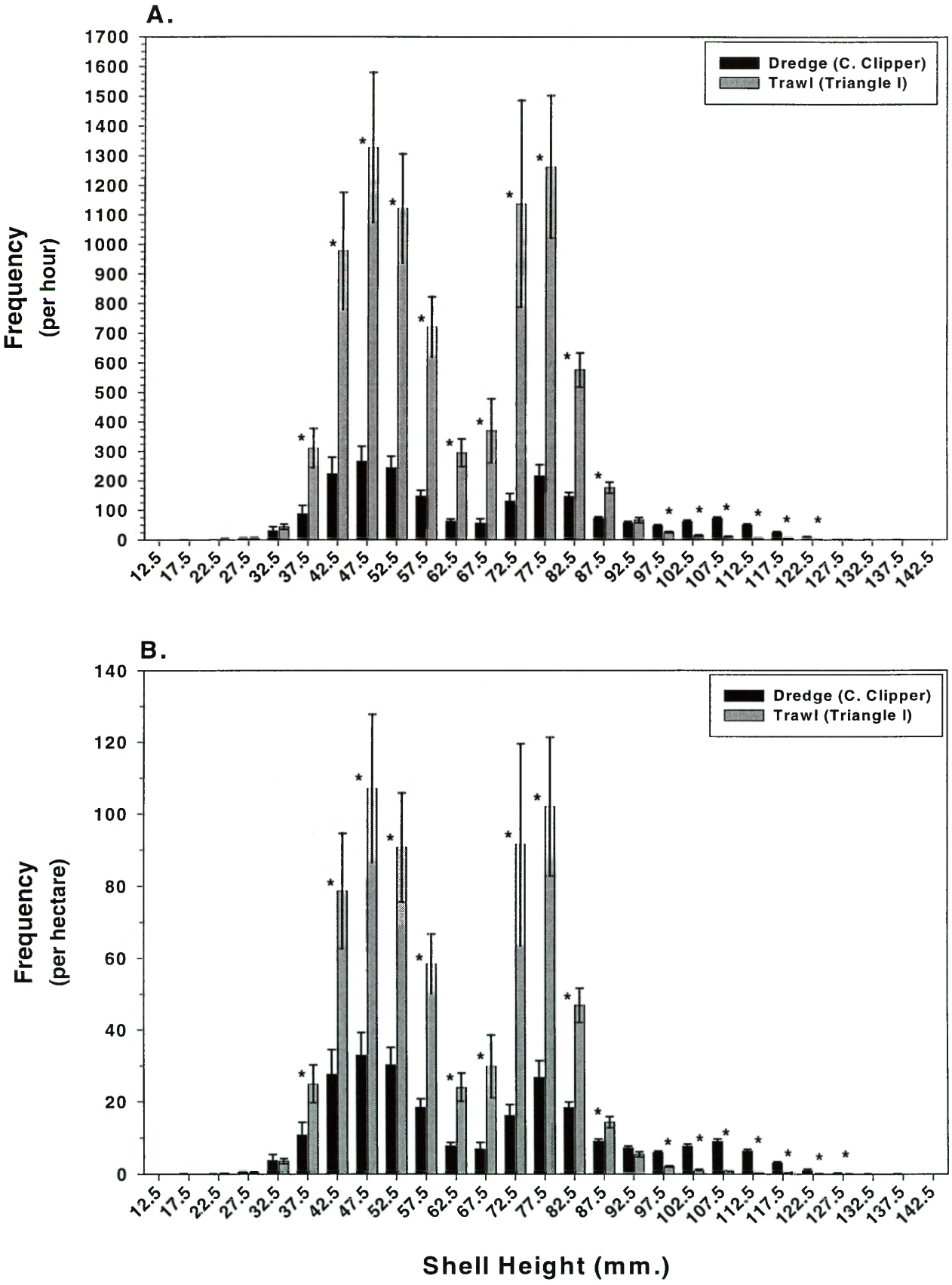

A.
Frequency
(per hour)
Dredge (C. Clipper)
Trawl (Triangle I)
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
87.5
92.5
97.5
102.5
107.5
112.5
117.5
122.5
127.5
132.5
137.5
142.5
B.
Frequency
(per hectare)
Dredge (C. Clipper)
Trawl (Triangle I)
140
120
100
80
60
40
20
0
Shell Height (mm.)

Table 5 Size composition of the catch. Values represent the percentage of total average catch of scallops at selected shell heights. Selected shell heights are: ≤70 mm (discards), ≤90 mm, ≥90 (age 4+).

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	dredge n=29	trawl n=14
≤70 mm (discards)	35.1	68.8	26.8	55.6	55.9	61.2
≤90 mm	57.6	88.1	48.5	84.6	84.0	98.5
≥90 (age 4+)	42.4	11.8	51.5	15.4	15.9	1.5

Crew Size Selection

Crew size selection lengths of scallops retained by the crew for shucking with accompanying size selectivity curves are shown in Table 6 and Figure 6. In August 1997 the trawl vessel, F/V Triangle I had a selection range of 8.2 mm with an L_{50} of 75.9 mm. The dredge vessel, F/V Stephanie B., had a selection range of 7 mm, with an L_{50} of 76.5 mm. The shell height at 100% retention was 95.9 mm and 98.6 mm for the dredge and trawl vessels, respectively.

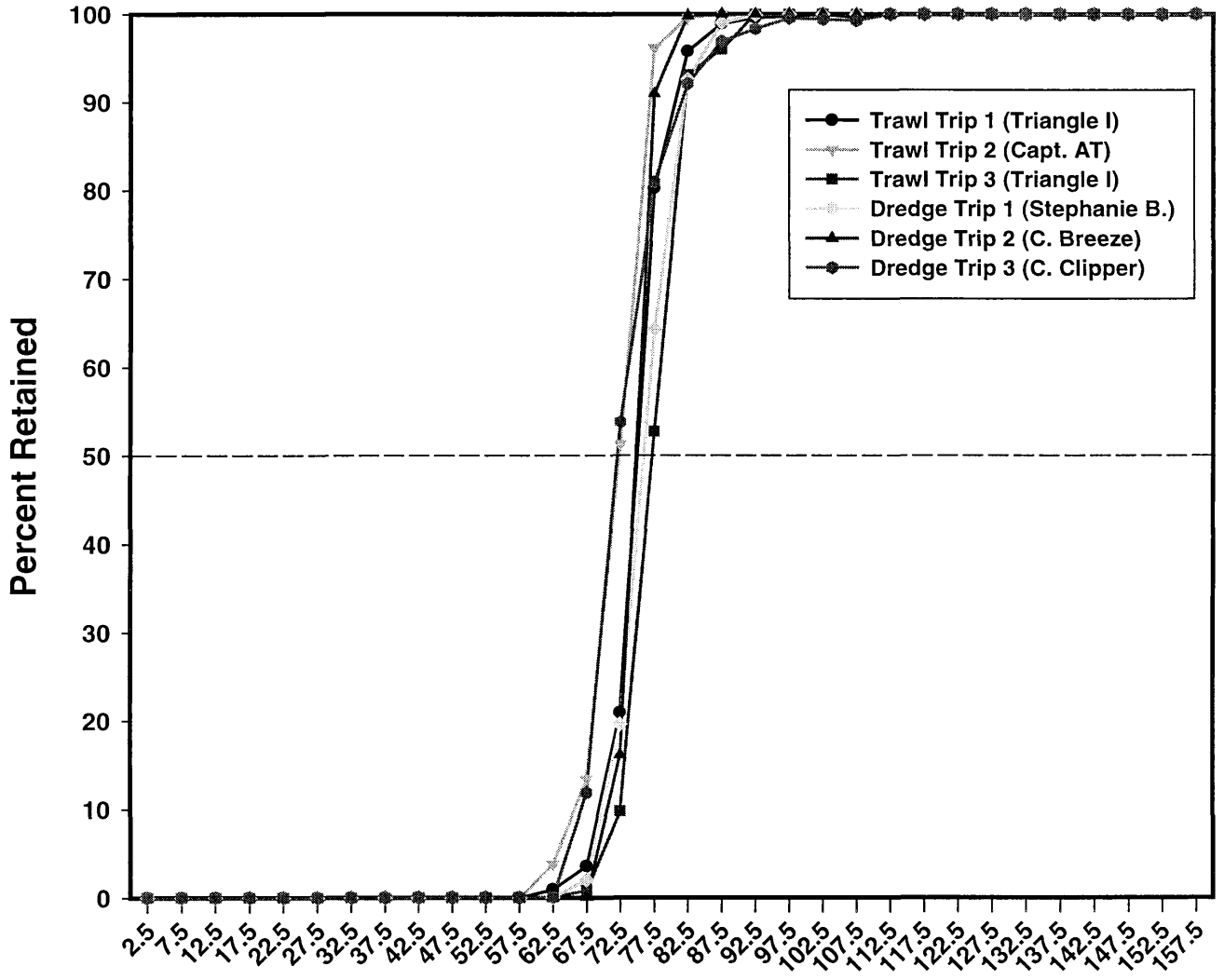
During September 1997, the trawl vessel, F/V Capt. AT had a selection range of 7.2 mm and an L_{50} of 91.3 mm. The shell height at 100 % retention was 91.3 mm. The dredge vessel F/V Carolina Breeze had a selection range of 3.6 mm and an L_{50} of 69.3 mm. The shell height at 100% retention was 79.3 mm.

During May 1998, the trawl vessel, F/V Triangle I had a selection range of 6.3 mm and an L_{50} of 77.5 mm. The shell height at 100 % retention was 94.9 mm. The dredge vessel F/V Carolina Clipper had a selection range of 12.0 mm and an L_{50} of 76.5mm. The shell height at 100% retention was 109.7 mm.

Table 6 Crew size selection lengths for all comparative gear trips. Values represent shell heights in mm at which a scallop had a 25%, 50%, 75%, and 100% probability of being retained by the crew for shucking. Selection range represents the difference between L_{75} and L_{25}.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge	trawl	dredge	trawl	dredge	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_{25}-L_{75}	7.0	8.2	3.6	7.2	12.0	6.3

Figure 6 Size selection curves for the crew culling process. The dashed line denotes the shell height at which a scallop has a 50% chance of being retained for harvest (L_{50}).


Percent Retained
100
90
80
70
60
50
40
30
20
10
0
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
67.5
72.5
77.5
82.5
87.5
92.5
97.5
102.5
107.5
112.5
117.5
122.5
127.5
132.5
137.5
142.5
147.5
152.5
157.5
Trawl Trip 1 (Triangle I)
Trawl Trip 2 (Capt. AT)
Trawl Trip 3 (Triangle I)
Dredge Trip 1 (Stephanie B.)
Dredge Trip 2 (C. Breeze)
Dredge Trip 3 (C. Clipper)

Relative Efficiency

Relative harvest efficiency expressed as the percent difference in average number of scallops captured per hectare by the trawl relative to the dredge over all shell heights is shown in Tables 7-9 and Figures 7-9. These results exhibit a pattern over all three comparative gear trips. The relative harvest efficiencies of the two pieces of gear were approximately equal at a shell height range of 85-95 mm. The trawl vessels harvested scallops less than 85-95 mm shell height more efficiently and scallops greater than 85-95 mm shell height less efficiently relative to the dredge on all three trips.

Relative production efficiency for each trip was calculated using the observed culling practices of the crew to characterize: mean number of scallops harvested, mean grams of meats produced, and average MPP. Results with the catch data standardized both on a per time and a per hectare basis are shown in Tables 10 and 11. Percent differences in number of scallops harvested and grams of meats produced with respect to both standardizations are shown in Table 12. The contributions of age 3 scallops (70-90 mm shell height) contributed to average catches both in terms of numbers harvested and grams of meats produced are shown in Table 13.

During August 1997, percent differences in average catch per hour of the trawl vessel F/V Triangle I relative to the dredge vessel, F/V Stephanie B. was +48.8% in terms of numbers harvested and +8.1% in terms of grams produced. Standardizing the data to reflect area covered by the gear, percent difference in average catch of the trawl vessel relative to the dredge vessel was -6.5%, in terms of numbers harvested and -27.4% in terms of grams produced. Average meat counts for the trawl vessel were 9.2 MPP higher than the dredge vessel (trawl 45.9 vs. dredge 36.7). Three year old scallops contributed 57% by number and 48.2% by weight of the average catch from the trawl boat and 32% by number and 21.7% by weight to the average catch from the dredge boat.

During September 1997, percent differences in the average catch per hour of the trawl vessel F/V Capt. AT relative to the dredge vessel, F/V Carolina Breeze were +42.9% in terms of numbers harvested and +7.6% in terms of grams produced. Percent differences in average catch per hectare of the trawl vessel relative to the dredge vessel were –0.7%, in terms of numbers harvested and –25.3% in terms of grams produced. Average meat counts for the trawl vessel were 9.6 MPP higher than the dredge vessel

(trawl 46.4 vs. dredge 36.8). Age 3 scallops contributed 62% by number, and 52.8% by weight to the average catch from the trawl boat and 28% by number and 19.2% by weight to the average catch from the dredge boat.

During May 1998, percent differences in average catch per hour of the trawl vessel F/V Triangle I relative to the dredge vessel, F/V Carolina Clipper was +119% in terms of numbers harvested and +42.3% in terms of grams produced. Percent differences in the average catch per hectare of the trawl vessel relative to the dredge vessel were +35.4%, in terms of numbers harvested and -8.0% in terms of grams produced. Average meat counts for the trawl vessel were 16.4 MPP higher than the dredge vessel (trawl 63.8 vs. dredge 47.4). Three year old scallops contributed 92% by number and 87.5% by weight of the average catch from the trawl boat and 58% by number and 37% by weight to the average catch from the dredge boat

Relative production efficiency was also examined by imposing culling sizes at 70, 80, and 90 mm shell heights to characterize: mean number of scallops harvested, mean grams of meats produced and average meats per pound. Results with the catch data standardized on both a per time and a per hectare basis are shown in Tables 14 and 15 and Figures 10-15. Percent differences in number of scallops harvested and grams of meats produced with respect to both standardizations are shown in Tables 16 and 17. The percentages that age 3 scallops (70-90 mm shell height) contributed to average catches both in terms of numbers harvested and grams of meat are shown in Table 18.

During the August 1997 trip, percent differences in average catch per hour of the trawl vessel F/V Triangle I relative to the dredge boat, F/V Stephanie B. was +45.6%, +30.0% and -15.0% in terms of number of scallops harvested and +11.6%, +4.2% and -29.1% in terms of grams of meat produced at the three imposed cull sizes of 70, 80, and 90 mm shell height. Percent differences in average catch per hectare of the trawl vessel relative to the dredge vessel were -2.4%, -12.8%, and -43.1% in terms of numbers of scallops harvested, and -25.0%, -30.0%, and -52.0% in terms of grams of meats produced. Average MPP were 46.0, 41.3, and 34.0 for the trawl boat, and 36.7, 34.9, and 30.0 for the dredge boat at the three cull sizes, respectively. Age 3 scallops comprised 61.9% by number and 51.2% by weight of the average catch of the trawl boat. That same

year class contributed 35.7% by number and 23.3% by weight to the average catch of the dredge boat.

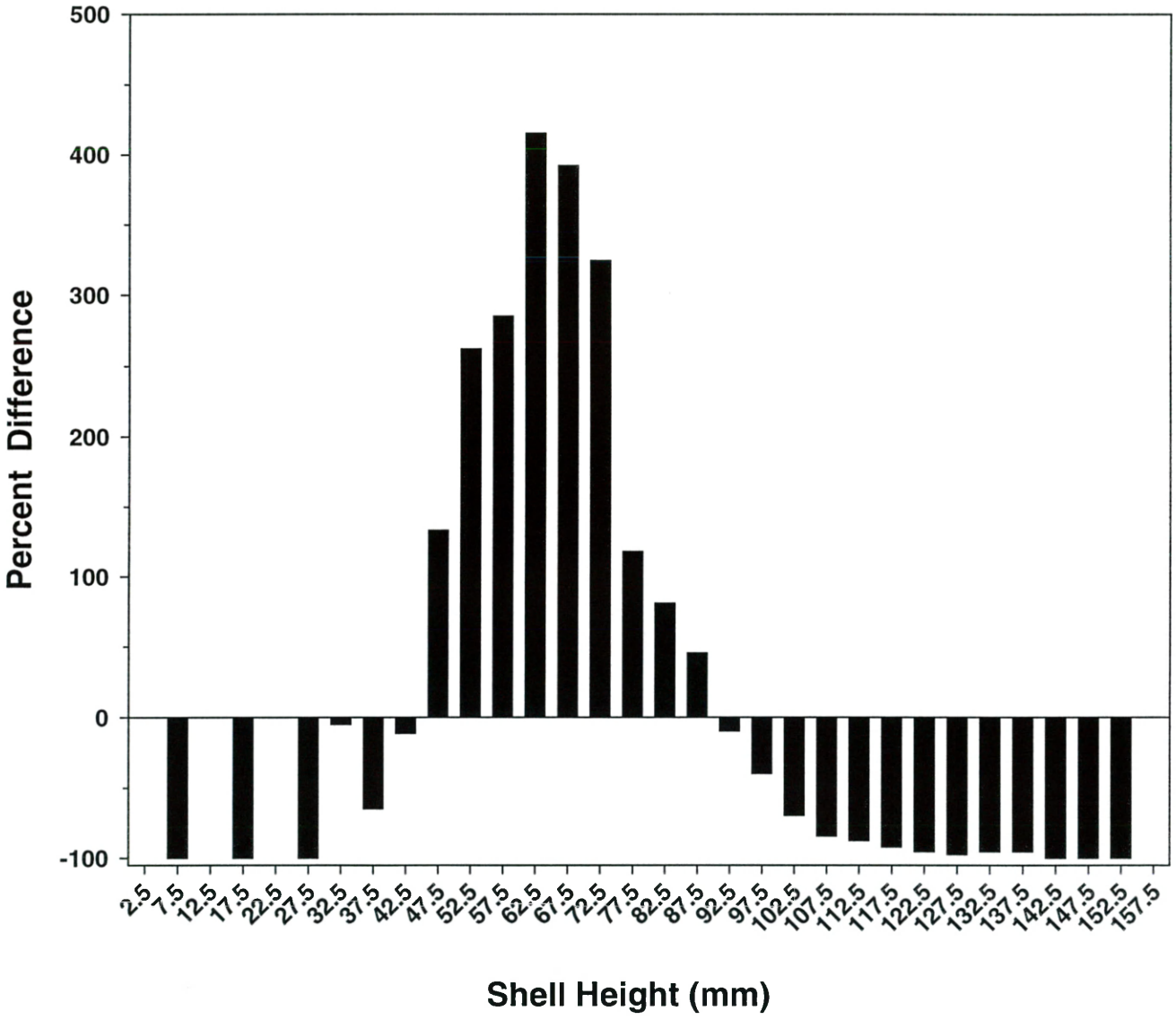
Results from September 1997 were similar to those from August 1997. Percent differences in average catch per hour of the trawl vessel, F/V Capt. AT relative to the dredge vessel, F/V Carolina Breeze were +41.8%, +21.9%, and -30.0% in terms of number of scallops harvested and +8.0%, -1.9%, and -38.5% in terms of production of grams of meats at the three imposed cull sizes, respectively. Standardizing the data to reflect one hectare covered by the gear, percent differences in average catch of the trawl vessel relative to the dredge vessel were -1.5%, -15.0%, and -51.6% in terms of numbers of animals harvested and -24.9%, -31.8%, and -57.5% in terms of grams produced. Average MPP were 46.4, 41.0, and 33.6 for the trawl boat, and 36.9, 35.1, and 31.3 for the dredge boat at the three cull sizes, respectively. Three year old scallops comprised 65.4% by number and 54.5 by weight of the average catch of the trawl boat, while that cohort contributed 29.7% by number and 20.0% by weight to the average catch of the dredge boat.

During May 1998, percent differences in average catch per hour for the trawl vessel, F/V Triangle I relative to the dredge vessel, F/V Carolina Clipper were +270.0%, +62.8% and -60.0% in terms of number of scallops harvested and +132.7%, +7.8% and -68.2% in terms of grams of scallop meats produced at cull sizes of 70, 80, and 90 mm shell heights, respectively. Percent differences in average catch per hectare of the trawl relative to the dredge were +140.4%, +5.9%, and -74.3% in terms of number harvested, and +50.8%, -29.9%, and -97.9% in terms of grams of meats produced. Average MPP were 63.7, 48.2, and 31.3, and for the trawl boat, and 47.4, 35.6, and 25.8 for the dredge boat at the three culling sizes. The average catch of the trawl boat was composed of 96.5% by number and 92.0% by weight of age 3 scallops, while the average catch of the dredge boat consisted of 63.8% by number and 41.3% by weight of scallops from that same year class.

Table 7 Relative harvest efficiency of the 5.50" diamond mesh sea scallop trawl relative to the 3.50" ring sea scallop dredge on comparative gear trip 1 (August 1997). Relative harvest efficiency is expressed as the percent difference in average catch per hectare between the trawl vessel, F/V Triangle I, and dredge vessel, F/V Stephanie B. relative to the catch from the dredge vessel.

Shell height (mm)	F/V Stephanie B. estimated catch/ha	F/V Triangle I estimated catch/ha	Nominal Reduction	Percent Difference
0-5	0.00	0.00	0.00	---
5-10	0.02	0.00	-0.02	-100.00
10-15	0.00	0.00	0.00	---
15-20	0.01	0.00	-0.01	-100.00
20-25	0.00	0.00	0.00	---
25-30	0.01	0.00	-0.01	-100.00
30-35	0.05	0.04	-0.00	-4.91
35-40	0.37	0.13	-0.24	-64.76
40-45	1.49	1.32	-0.17	-11.26
45-50	4.09	9.55	5.45	133.19
50-55	9.10	32.94	23.84	261.90
55-60	11.33	43.60	32.27	284.87
60-65	8.45	43.51	35.07	415.20
65-70	4.25	20.90	16.65	392.03
70-75	1.44	6.11	4.67	324.47
75-80	2.13	4.63	2.50	117.84
80-85	6.66	12.05	5.39	80.94
85-90	14.31	20.81	6.50	45.46
90-95	19.38	17.51	-1.87	-9.66
95-100	10.52	6.34	-4.17	-39.69
100-105	4.80	1.47	-3.34	-69.44
105-110	3.92	0.61	-3.31	-84.42
110-115	3.32	0.42	-2.90	-87.46
115-120	2.25	0.18	-2.07	-92.01
120-125	1.01	0.05	-0.96	-95.33
125-130	0.50	0.01	-0.49	-97.37
130-135	0.16	0.01	-0.15	-95.33
135-140	0.05	0.00	-0.05	-95.37
140-145	0.01	0.00	-0.01	-100.00
145-150	0.00	0.00	-0.00	-100.00
150-155	0.00	0.00	-0.00	-100.00
155-160	0.00	0.00	0.00	---
160-165	0.00	0.00	0.00	---
165-170	0.00	0.00	0.00	---

Figure 7 Relative harvest efficiency of the 5.50" diamond mesh sea scallop otter trawl relative to the 3.50" ring sea scallop dredge for comparative gear trip 1 (August, 1997). A positive value indicates that the trawl more efficiently harvested scallops for that particular shell height relative to the dredge. A negative value indicates that the trawl was less efficient relative to the dredge for that shell height. Values for small scallops (<30 mm shell height) may not be representative due to low sample sizes from those shell heights.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102.5
107.5
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132.5
137.5
142.5
147.5
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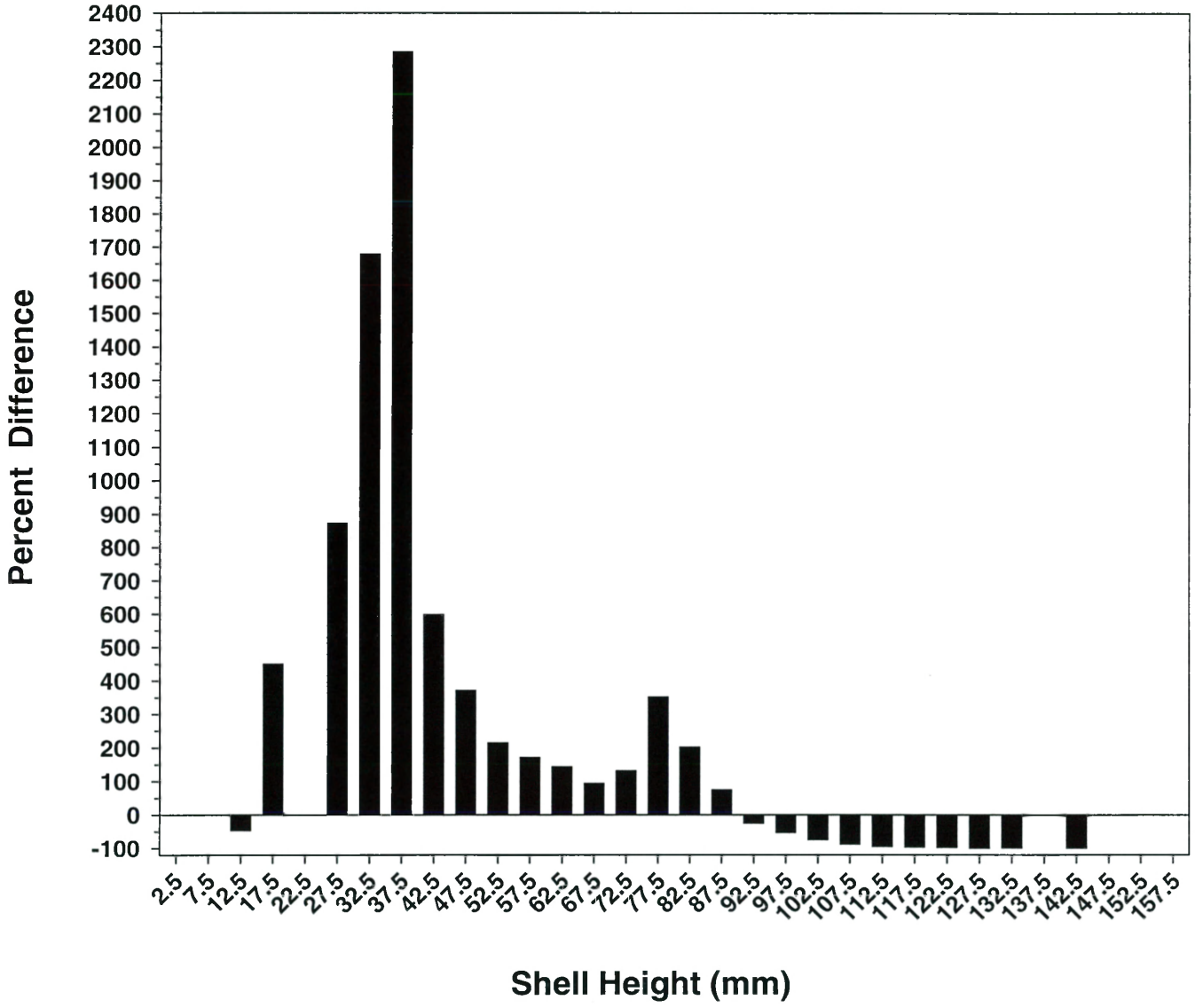
157.5
Shell Height (mm)

Table 8 Relative harvest efficiency of the 5.50" diamond mesh sea scallop trawl relative to the 3.50" ring sea scallop dredge on comparative gear trip 2 (September 1997). Relative harvest efficiency is expressed as the percent difference in average catch per hectare between the trawl vessel, F/V Triangle I, and dredge vessel, F/V Stephanie B. relative to the catch from the dredge vessel.

Shell height (mm)	F/V C. Breeze estimated catch/ha	F/V Capt. AT estimated catch/ha	Nominal Reduction	Percent Difference
0-5	0.00	0.00	0.00	---
5-10	0.00	0.01	0.01	---
10-15	0.04	0.02	-0.02	-45.98
15-20	0.04	0.19	0.16	449.17
20-25	0.00	0.10	0.10	---
25-30	0.01	0.14	0.13	872.30
30-35	0.07	1.25	1.18	1678.05
35-40	0.21	4.95	4.74	2284.35
40-45	1.40	9.75	8.35	597.13
45-50	2.46	11.57	9.11	370.41
50-55	3.82	11.99	8.17	214.17
55-60	4.82	13.04	8.22	170.38
60-65	5.38	13.07	7.69	142.93
65-70	4.23	8.18	3.95	93.23
70-75	1.85	4.28	2.43	131.16
75-80	1.25	5.65	4.40	351.63
80-85	4.14	12.49	8.35	201.87
85-90	9.82	17.13	7.31	74.41
90-95	17.58	13.21	-4.37	-24.86
95-100	12.93	6.11	-6.82	-52.76
100-105	6.77	1.72	-5.05	-74.61
105-110	3.24	0.39	-2.85	-88.02
110-115	1.68	0.09	-1.59	-94.46
115-120	1.01	0.04	-0.97	-96.25
120-125	0.38	0.01	-0.37	-97.53
125-130	0.28	0.00	-0.28	-99.43
130-135	0.10	0.00	-0.10	-98.45
135-140	0.01	0.01	0.00	0.32
140-145	0.01	0.00	-0.01	-100.00
145-150	0.00	0.00	0.00	---
150-155	0.00	0.00	0.00	---
155-160	0.00	0.00	0.00	---
160-165	0.00	0.00	0.00	---
165-170	0.00	0.00	0.00	---

Figure 8 Relative harvest efficiency of the 5.50" diamond mesh sea scallop otter trawl relative to the 3.50" ring sea scallop dredge for comparative gear trip 2 (September 1997). A positive value indicates that the trawl more efficiently harvested scallops for that particular shell height relative to the dredge. A negative value indicates that the trawl was less efficient relative to the dredge for that shell height. Values for small scallops (<30 mm shell height) may not be representative due to low sample sizes from those shell heights.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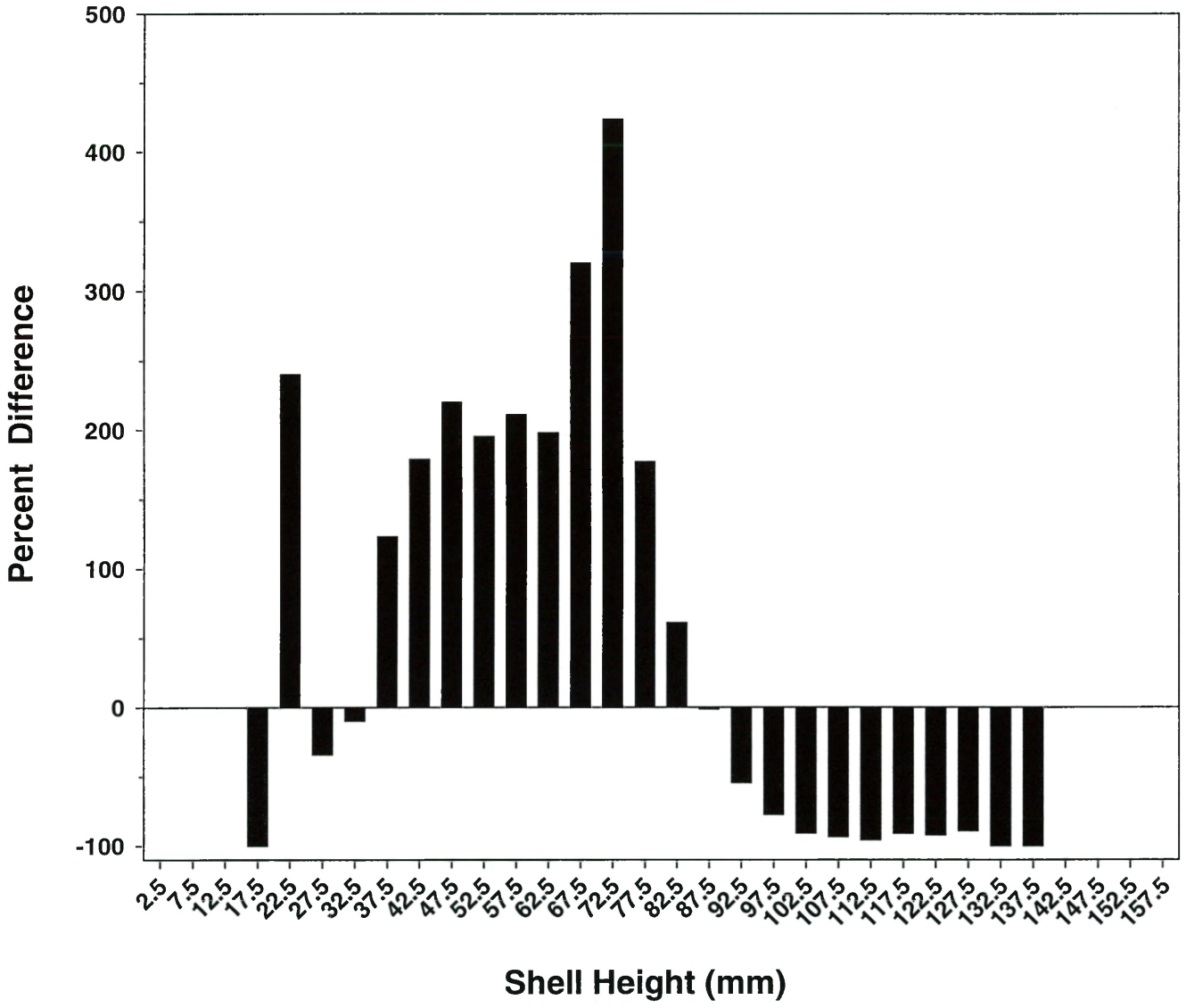
152.5
157.5
Shell Height (mm)

Table 9 Relative harvest efficiency of the 5.50" diamond mesh sea scallop trawl relative to the 3.50" ring sea scallop dredge on comparative gear trip 3 (May 1998). Relative harvest efficiency is expressed as the percent difference in average catch per hectare between the trawl vessel, F/V Triangle I, and dredge vessel, F/V Stephanie B. relative to the catch from the dredge vessel.

Shell height (mm)	F/V C. Clipper estimated catch/ha	F/V Triangle I estimated catch/ha	Nominal Reduction	Percent Difference
0-5	0.00	0.00	0.00	---
5-10	0.00	0.00	0.00	---
10-15	0.00	0.00	0.00	---
15-20	0.08	0.00	-0.08	-100.00
20-25	0.05	0.17	0.12	240.18
25-30	0.57	0.37	-0.19	-34.28
30-35	3.80	3.43	-0.37	-9.78
35-40	10.89	24.30	13.41	123.20
40-45	27.72	77.29	49.57	178.79
45-50	32.99	105.62	72.63	220.20
50-55	30.31	89.45	59.14	195.10
55-60	18.49	57.45	38.96	210.63
60-65	7.84	23.35	15.51	197.74
65-70	6.94	29.14	22.20	319.86
70-75	16.14	84.49	68.35	423.52
75-80	26.70	73.97	47.27	177.02
80-85	18.15	29.19	11.04	60.86
85-90	8.94	8.81	-0.13	-1.41
90-95	7.02	3.19	-3.83	-54.60
95-100	5.78	1.29	-4.49	-77.63
100-105	7.57	0.69	-6.88	-90.87
105-110	8.77	0.56	-8.21	-93.58
110-115	6.17	0.26	-5.91	-95.86
115-120	3.02	0.26	-2.76	-91.29
120-125	0.99	0.08	-0.92	-92.43
125-130	0.21	0.02	-0.19	-89.40
130-135	0.05	0.00	-0.05	-100.00
135-140	0.02	0.00	-0.02	-100.00
140-145	0.00	0.00	0.00	---
145-150	0.00	0.00	0.00	---
150-155	0.00	0.00	0.00	---
155-160	0.00	0.00	0.00	---
160-165	0.00	0.00	0.00	---
165-170	0.00	0.00	0.00	---

Figure 9 Relative harvest efficiency of the 5.50" diamond mesh sea scallop otter trawl relative to the 3.50" ring sea scallop dredge for comparative gear trip 3 (May 1998). A positive value indicates that the trawl more efficiently harvested scallops for that particular shell height relative to the dredge. A negative value indicates that the trawl was less efficient relative to the dredge for that shell height. Values for small scallops (<30 mm shell height) may not be representative due to low sample sizes from those shell heights.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102.5
107.5
112.5
117.5
122.5
127.5
132.5
137.5
142.5
147.5
152.5
157.5
Shell Height (mm)

Table 10 Mean number of scallops harvested, mean grams of scallop meats produced, and average meats per pound (MPP) from tows included in analysis for all comparative gear trips. Values are calculated using observed culling practices aboard the trawl and dredge vessels. Data has been standardized to reflect catch per hour of towing time. Error values represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	dredge n=29	trawl n=14
Harvest (#/hr.)	447.4 ± 16.0*	666.1 ± 38.0*	435.1 ± 20.2*	622.1 ± 55.8*	733.6 ± 64.7*	1609.5 ± 215.6*
Production (grams/hr.)	7412.1 ± 226.5	8015.7 ± 444.7	6597.3 ± 324.8	7099.27 ± 625.1	10389.3 ± 618.4*	14783.4 ± 1755.0*
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*

Table 11 Mean number of scallops harvested, mean grams of scallop meats produced, and average meats per pound (MPP) from tows included in analysis for all comparative gear trips. Values are calculated observed culling practices aboard the trawl and dredge vessels. Data has been standardized to reflect catch per hectare covered by the gear. Error values represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	dredge n=29	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.)	1068.4 ± 33.5*	776.1 ± 42.6*	908.5 ± 44.8	678.9 ± 61.9	1298.0 ± 73.4	1194.2 ± 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*

Table 12 Relative efficiency values of the 5.50" diamond mesh sea scallop otter trawl versus the 3.50" ring sea scallop dredge. Values represent the percent difference in the average catches of the trawl vessel relative to the dredge vessel in terms of both number of animals harvested and grams of meats produced. Average catches using the observed culling practices of the crew have been standardized to both one hour towing time and one hectare covered by the gear.

	Number of scallops harvested per hour	Number of scallops harvested per hectare	Weight of scallops produced per hour	Weight of scallops produced per hectare
Trip 1 August 1997	+48.8	-6.5	+8.1	-27.4
Trip 2 September 1997	+42.9	-0.7	+7.6	-25.3
Trip 3 May 1998	+119.4	+35.4	+42.3	-8.0

Table 13 Percentages of 3 year old scallops in the catches of the trawl and dredge vessels relative to total number harvested and total weight produced. Values represent the percentages of age 3 scallops present in terms of both number of animals and grams of meats produced from catches with observed culling practices of the crew. Age 3 scallops are defined as scallops having a shell height of 70-90 mm.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	dredge n=29	trawl n=14
Percentage of age 3 scallops in catch relative to total number harvested	32.0	57.0	28.0	62.0	58.0	92.0
Percentage of age 3 scallops in catch relative to total grams produced	21.7	48.2	19.2	52.8	37.0	85.7

Table 14 Mean number of scallops harvested, average grams of scallop meats produced, and average meats per pound (MPP) from tows included in analysis for all comparative gear trips. Values are calculated using assumed culling sizes of 70, 80, and 90 mm. The data has been standardized to reflect catch per hour towing time. Error values represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	Dredge n=29	trawl n=14
Production (grams/hr.)						
Cull at 70 mm	7545.4 ± 230.5	8427.8 ± 463.2	6667.3 ± 329.2	7201.5 ± 626.7	11208.6 ± 716.1*	26082.0 ± 4427.6*
Cull at 80 mm	7368.9 ± 225.5	7680.3 ± 433.4	6518.5 ± 324.8	6392.5 ± 605.7	8760.2 ± 441.7	9451.0 ± 842.3
Cull at 90 mm	5797.8 ± 194.7*	4109.3 ± 266.8*	5331.3 ± 314.2*	3274.2 ± 334.9*	6578.8 ± 367.6*	2091.8 ± 177.3*
Harvest (#/hr.)						
Cull at 70 mm	495.5 ± 16.9*	721.8 ± 41.4*	446.3 ± 21.1*	633.2 ± 57.0*	884.0 ± 81.1*	3274.1 ± 630.2*
Cull at 80 mm	470.4 ± 15.7*	611.8 ± 35.3*	424.4 ± 19.9	517.4 ± 51.2	538.2 ± 28.4*	876.3 ± 81.8*
Cull at 90 mm	323.4 ± 10.5*	274.6 ± 18.0*	313.7 ± 16.7*	219.4 ± 22.3*	320.0 ± 17.6*	125.9 ± 11.3*
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*

Table 15 Mean number of scallops harvested, mean grams of scallop meats produced, and average meats per pound (MPP) from tows included in analysis for all comparative gear trips. Values are calculated using assumed culling sizes of 70, 80, and 90 mm. The data has been standardized to reflect catch per hectare covered by the gear. Error values represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	Trawl n=49	dredge n=29	trawl n=14
Production (grams/ha.)						
Cull at 70 mm	1088.6 ± 34.3*	816.2 ± 44.5*	918.1 ± 45.4*	688.7 ± 62.1*	1399.5 ± 84.8	2111.1 ± 354.7
Cull at 80 mm	1062.0 ± 33.3*	743.4 ± 41.4*	897.6 ± 44.8*	611.7 ± 60.0*	1096.5 ± 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*
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*
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*

Figure 10 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Triangle I and the dredge vessel F/V Stephanie B. on comparative gear trip 1 (August 1997). The data has been standardized to one hour towing time. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hour (grams). (B) Number of scallops harvested per hour. (C) Average MPP.

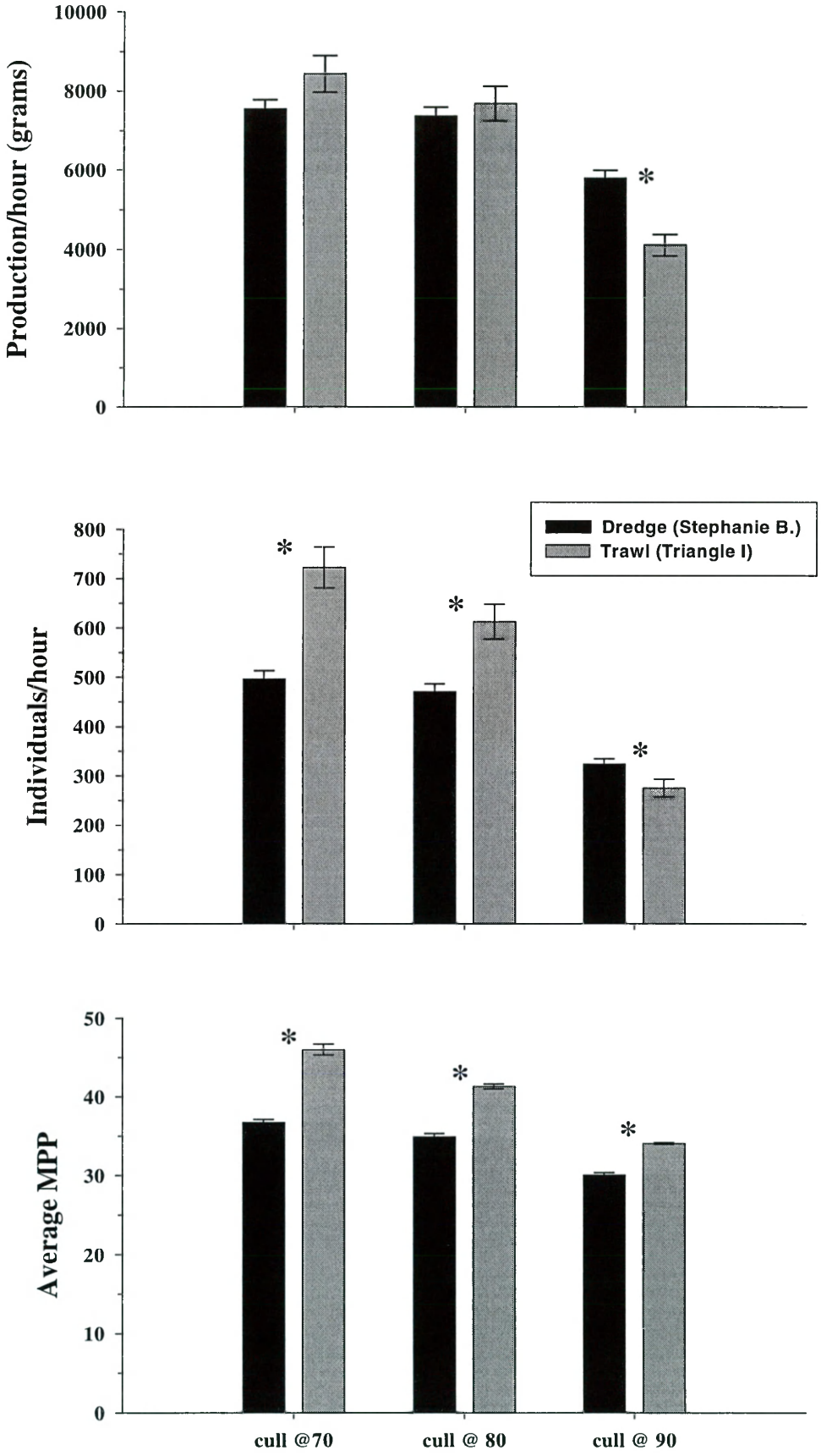
Production/hour (grams)
10000
8000
6000
4000
2000
0
*
Individuals/hour
800
700
600
500
400
300
200
100
0
*
*
*
Dredge (Stephanie B.)
Trawl (Triangle I)
Average MPP
50
40
30
20
10
0
*
*
*
cull @70
cull @ 80
cull @ 90

Figure 11 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Capt. AT and the dredge vessel F/V Carolina Breeze on comparative gear trip 2 (September 1997). The data has been standardized to one hour towing time. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hour (grams). (B) Number of scallops harvested per hour. (C) Average MPP.

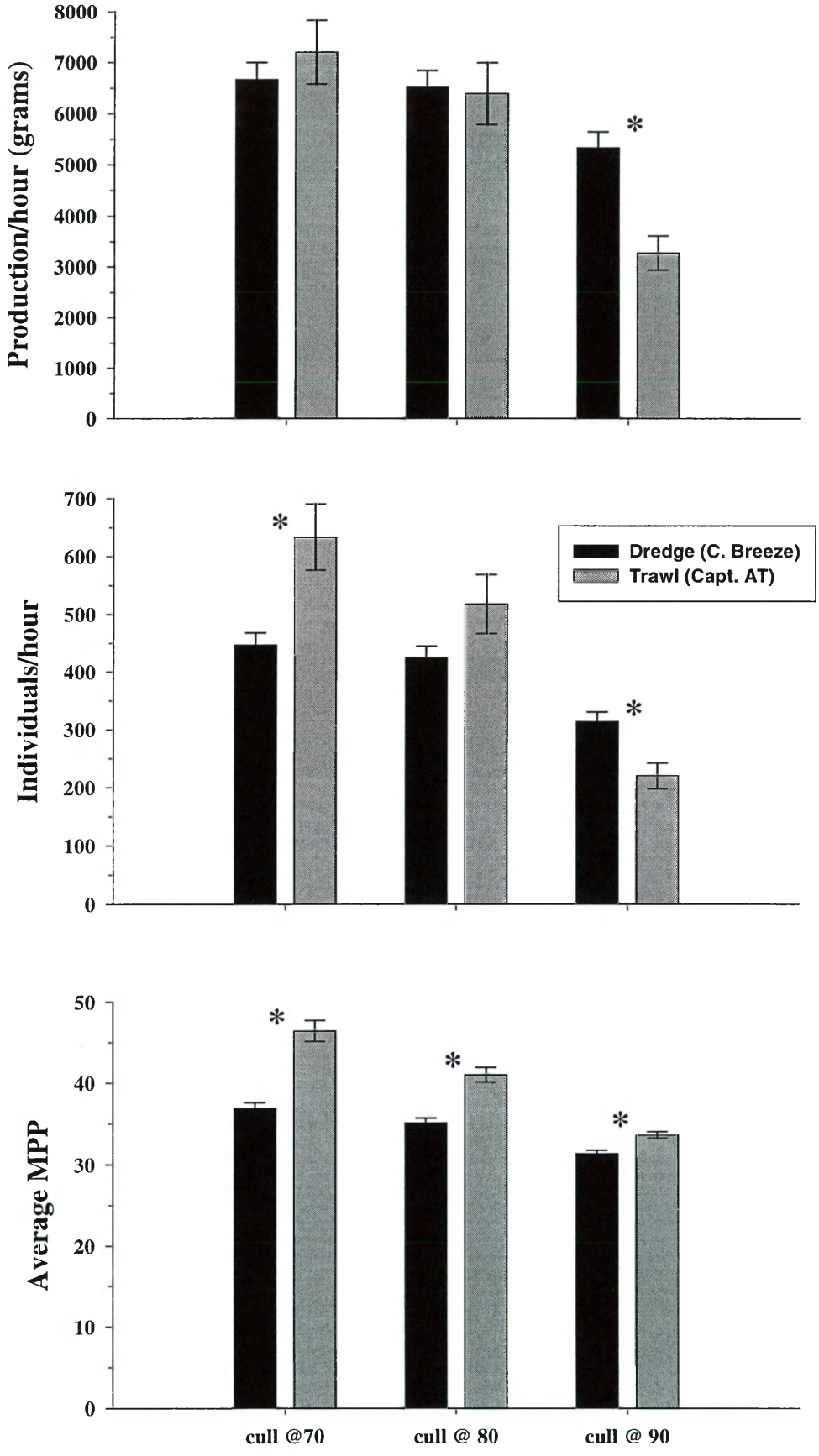
Production/hour (grams)
8000
7000
6000
5000
4000
3000
2000
1000
0
*
Individuals/hour
700
600
500
400
300
200
100
0
*
*
Dredge (C. Breeze)
Trawl (Capt. AT)
Average MPP
50
40
30
20
10
0
*
*
*
cull @70
cull @ 80
cull @ 90

Figure 12 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Triangle I and the dredge vessel F/V Carolina Clipper on comparative gear trip 3 (May 1998). The data has been standardized to one hour towing time. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hour (grams). (B) Number of scallops harvested per hour. (C) Average MPP.

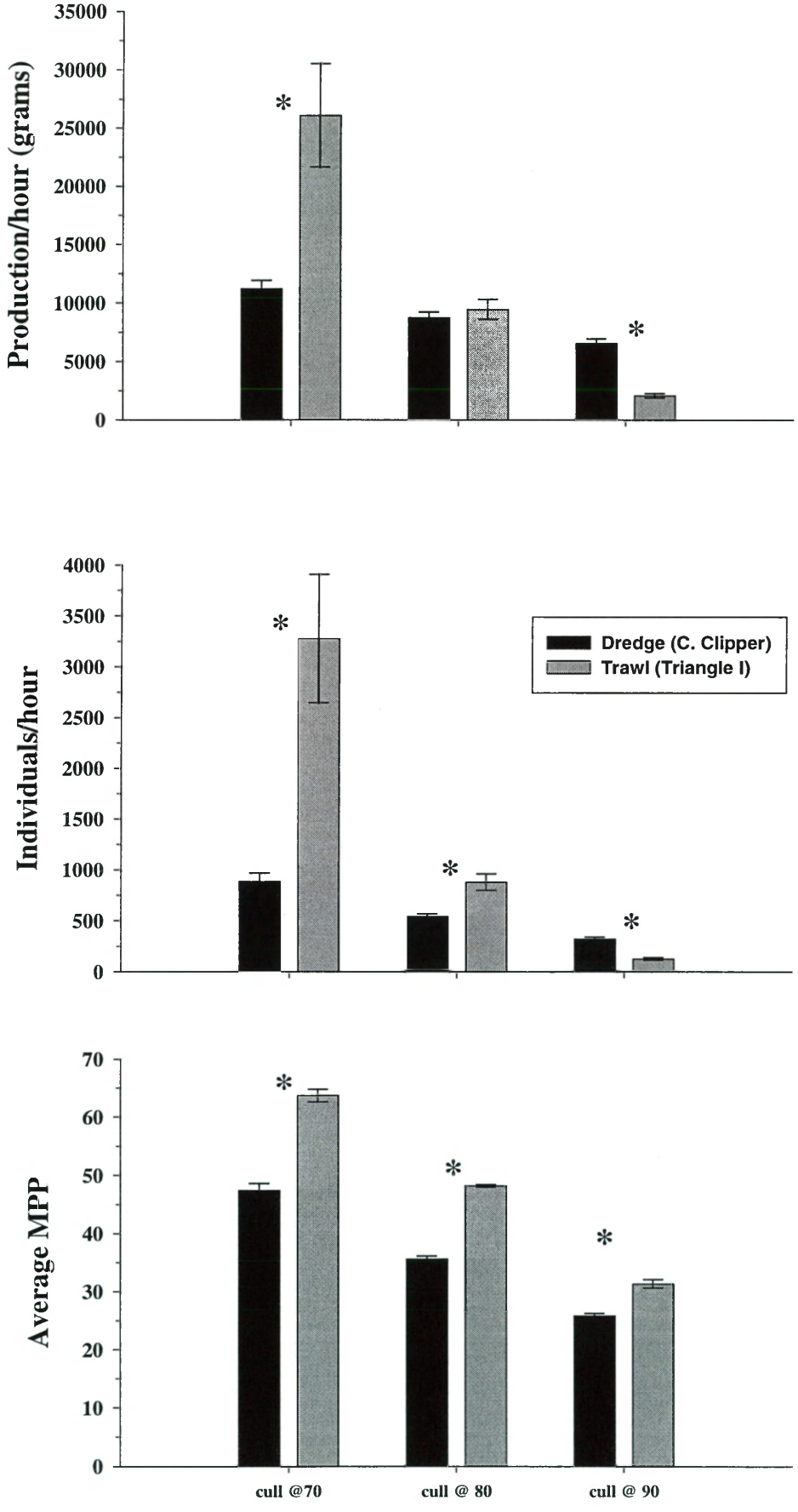
Production/hour (grams)
35000
30000
25000
20000
15000
10000
5000
0
*
*
Individuals/hour
4000
3500
3000
2500
2000
1500
1000
500
0
*
*
*
Dredge (C. Clipper)
Trawl (Triangle I)
Average MPP
70
60
50
40
30
20
10
0
*
*
*
cull @70
cull @ 80
cull @ 90

Table 16 Relative efficiency values of the 5.50" diamond sea scallop otter trawl versus the 3.50" ring sea scallop dredge. Values represent the percent difference in the average catches of the trawl vessel relative to the dredge vessel in terms of both numbers of animals harvested and grams of meats produced. Average catches using assumed cull sizes of 70, 80, and 90 mm shell heights have been standardized to one hour towing time.

	Trip 1 Aug. 1997	Trip 2 Sept. 1997	Trip 3 May. 1998
Harvest (#/hr.)			
Cull at 70 mm	+45.6	+41.8	+270.0
Cull at 80 mm	+30.0	+21.9	+62.8
Cull at 90 mm	-15.0	-30.0	-60.0
Production (grams/hr.)			
Cull at 70 mm	+11.6	+8.0	+132.7
Cull at 80 mm	+4.2	-1.9	+7.8
Cull at 90 mm	-29.1	-38.5	-68.2

Table 17 Relative efficiency values of the 5.50" diamond sea scallop otter trawl versus the 3.50" ring sea scallop dredge. Values represent the percent difference in the average catches of the trawl vessel relative to the dredge vessel in terms of both numbers of animals harvested and grams of meats produced. Average catches using assumed cull sizes of 70, 80, and 90 mm shell heights have been standardized to one hectare covered by the gear.

	Trip 1 Aug. 1997	Trip 2 Sept. 1997	Trip 3 May 1998
Harvest (#/ha)			
Cull at 70 mm	-2.4	-1.5	+140.4
Cull at 80 mm	-12.8	-15.0	+5.9
Cull at 90 mm	-43.1	-51.6	-74.3
Production (grams/ha.)			
Cull at 70 mm	-25.0	-24.9	+50.8
Cull at 80 mm	-30.0	-31.8	-29.9
Cull at 90 mm	-52.4	-57.5	-97.9

Figure 13 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Triangle I and the dredge vessel F/V Stephanie B. on comparative gear trip 1 (August 1997). Data has been standardized to one hectare covered by the gear. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hectare (grams). (B) Number of scallops harvested per hectare. (C) Average MPP.

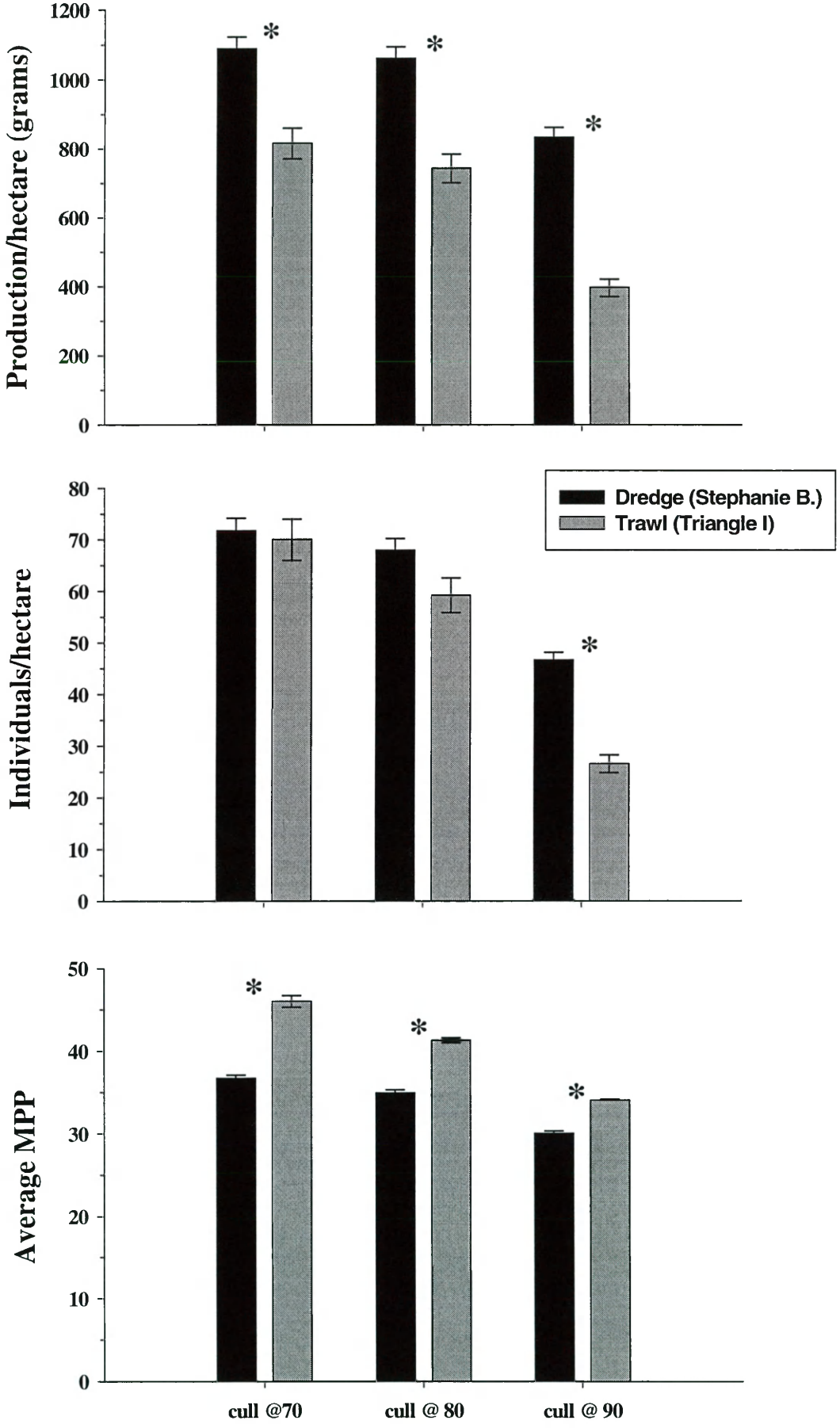
Production/hectare (grams)
1200
1000
800
600
400
200
0
Individuals/hectare
80
70
60
50
40
30
20
10
0
Dredge (Stephanie B.)
Trawl (Triangle I)
Average MPP
50
40
30
20
10
0
cull @70
cull @ 80
cull @ 90

Figure 14 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Capt. AT and the dredge vessel F/V Carolina Breeze on comparative gear trip 2 (September 1997). The data has been standardized to one hectare covered by the gear. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hectare (grams). (B) Number of scallops harvested per hectare. (C) Average MPP.

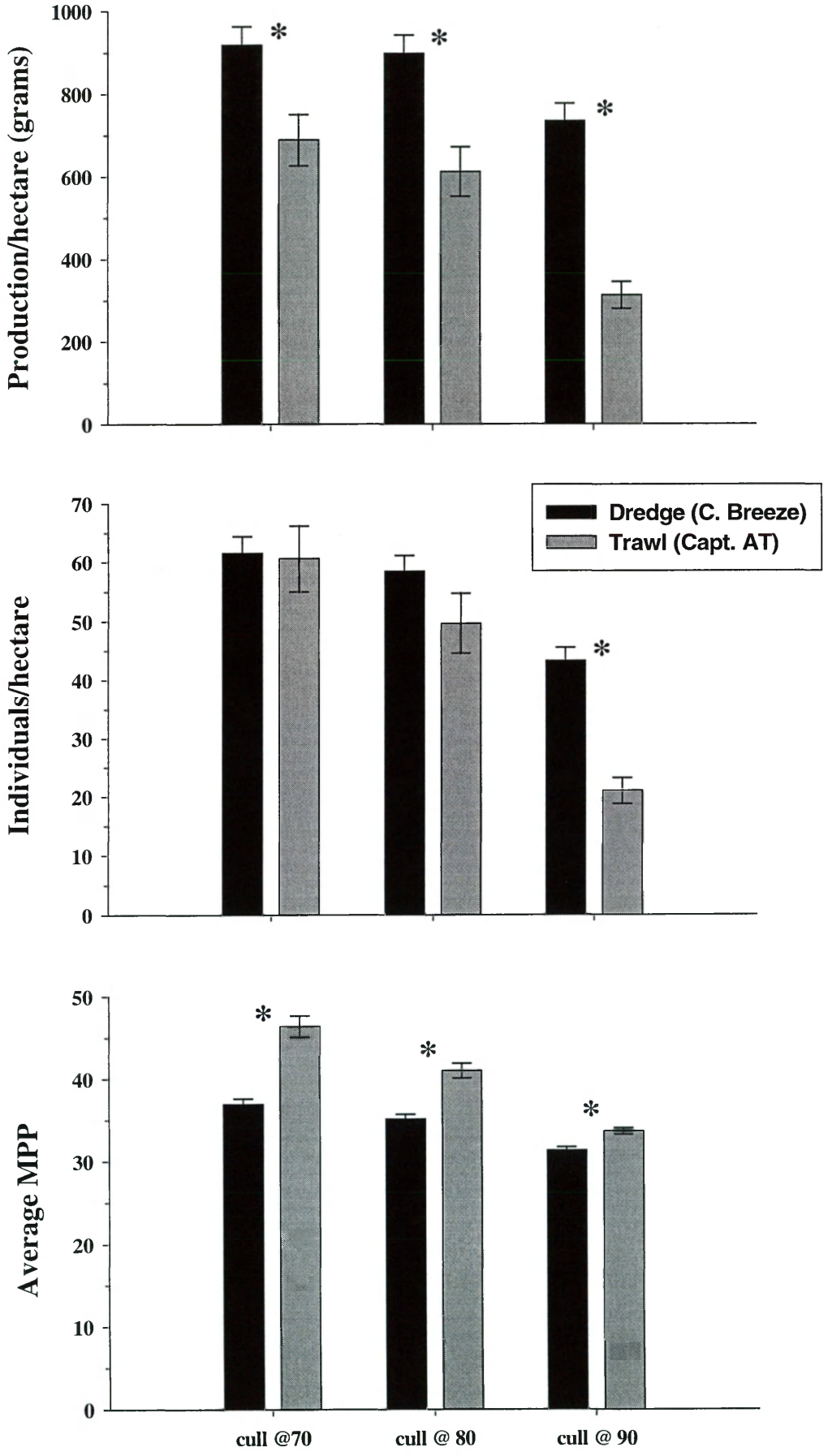
Production/hectare (grams)
1000
800
600
400
200
0
Individuals/hectare
70
60
50
40
30
20
10
0
Dredge (C. Breeze)
Trawl (Capt. AT)
Average MPP
50
40
30
20
10
0
cull @70
cull @ 80
cull @ 90

Figure 15 Mean production of scallop meats, mean number of individuals harvested and average MPP for the trawl vessel F/V Triangle I and the dredge vessel F/V Carolina Clipper on comparative gear trip 3 (May 1998). The data has been standardized to one hectare covered by the gear. Values are calculated from assumed cull sizes of 70, 80, and 90 mm shell heights. Error bars represent one standard error of the mean. A * indicates a statistically significant difference ($p<0.05$) between the mean harvest, mean production or average MPP of the trawl and dredge vessel for that comparative gear trip. (A) Production of scallop meats per hectare (grams). (B) Number of scallops harvested per hectare. (C) Average MPP.

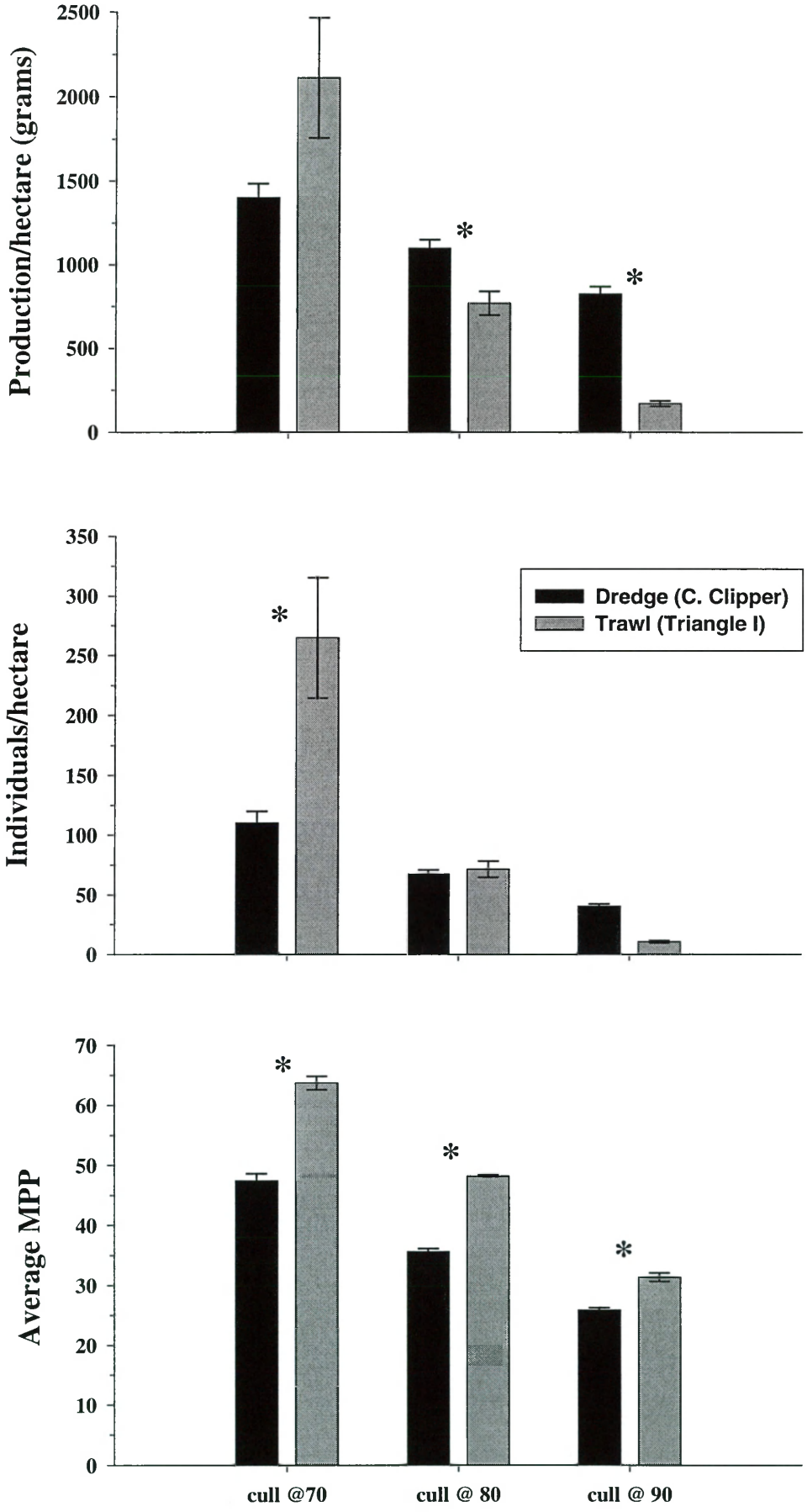
Production/hectare (grams)
2500
2000
1500
1000
500
0
*
*
Individuals/hectare
350
300
250
200
150
100
50
0
*
Dredge (C. Clipper)
Trawl (Triangle I)
Average MPP
70
60
50
40
30
20
10
0
*
*
*
cull @70
cull @ 80
cull @ 90

Table 18 Percentages of 3-year-old scallops in the catches of the trawl and dredge vessels relative to the total number harvested, and total weight prodeuced. Values represent the percentages of age 3 scallops present in terms of both number of animals and grams of meats produced from catches with assumed culling size of 70 mm shell height. Age 3 scallops are defined as scallops having a shell height of 70-90 mm.

	Trip 1 (Aug. 1997)		Trip 2 (Sept. 1997)		Trip 3 (May 1998)	
	Stephanie B.	Triangle I	C. Breeze	Capt. AT	C. Clipper	Triangle I
	dredge n=34	trawl n=77	dredge n=30	trawl n=49	dredge n=29	trawl n=14
Percentage of age 3 scallops in catch relative to total number harvested	35.7	61.9	29.7	65.4	63.8	96.5
Percentage of age 3 scallops in catch relative to total grams produced	23.2	51.2	20.0	54.5	41.3	92.0

DISCUSSION

As a fishery that is characterized by variable recruitment, rapidly growing individuals, and high rates of fishing mortality, the sea scallop resource composition is in a constant state of flux. Resource conditions can change dramatically, and have significant influences on the outcome, even during the time scale of this study (August, 1997-May, 1998). Despite the changing resource structure, however, two general scenarios were observed during the three sampling trips. These two scenarios differed with respect to the presence or absence of a recruiting year class of scallops.

Sea scallops recruit to the fishery at three years of age. Three year old scallops, which in the mid-Atlantic region have a shell height of roughly 70–90 mm represent an important age class in the fishery. As scallops grow to 70-75 mm shell height, they begin to be retained by commercial vessels (DuPaul and Kirkley, 1995; DuPaul *et al.,* 1995). High levels of fishing mortality have reduced the abundance of adult scallops in the population. As a result, three year old scallops that recruit to the gear each year support the fishery for that particular season (Sechuk *et al.*, 1979; NEFMC, 1993).

Shell height distributions for trips 1 and 2 portray a resource that was characterized by a low abundance of age three scallops (Figures 3 and 4). The absence of large numbers of three year old scallops had a large impact on the relative production rates of the two regulated gear types. The reduced ability of the trawl to capture scallops greater than 90 mm relative to the dredge, coupled with a minimum observed crew cull size of roughly 70-75 mm resulted in trawl boats being dependant upon three-year-old scallops for production relative to dredge vessels. In the absence of large numbers of age three scallops, production rates of the dredge vessels in terms of numbers of scallops captured and weight of scallop meats produced exceeded those from the trawl vessels during the first two sampling trips.

In the area of trip one during August 1997, large numbers of age two scallops were observed in the catches of both the dredge and the trawl (Figure 3). Rapid growth of this cohort over the next nine months resulted in these scallops attaining a shell height range where they would begin to be retained by the fishery the following spring. During the May 1998 trip three year old scallops from the aforementioned cohort were captured in numbers 5-6 times greater than the previous two trips (Figure 5). The presence of this

strong age three year class had a profound effect on the relative production rates of the dredge and trawl vessels. When age 3 scallops were present in large numbers, the trawl vessel captured scallops with as much as 270% greater efficiency relative to the dredge vessel. The observed shift in relative harvest efficiency and the resulting ramifications in relation to production rates demonstrate an inherent inequality between the two regulated gear types.

Irrespective of resource conditions, a distinct shift in relative harvest efficiency at 90-95 mm shell height was observed over all three trips. Trawl vessels were more efficient at capturing 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 the dredge. This shift in relative harvest efficiency had a large effect on relative catch compositions and ultimately production rates. DuPaul *et al.* (1989c) observed similar results in comparing pre-Amendment #4 scallop trawls and dredges. At approximately 90 mm shell height, the 3.00 inch (76 mm) ring dredge started to perform more efficiently relative to the trawl nets used in the study.

The underlying mechanism for the observed shift in relative harvest efficiency is not well understood. One possible explanation could stem from scallop behavior. Underwater observations have documented the mobility of scallops less than roughly 90-100 mm shell height. These smaller scallops respond to a stimulus by swimming away from the disturbance (Caddy, 1968). As scallops grow above 90-100 mm mobility decreases, and these larger animals become sedentary, living in shallow depressions created in the substrate (Caddy, 1968).

These behavioral differences have ramifications for the capture processes in relation to the two gear types. Scallops less than 90-100 mm shell height may be able to avoid the dredge by rising in the water column and passing over the fast moving dredge (Caddy, 1968). The trawl, which is towed 50% slower than the trawl and has a higher mouth opening, may be able to capture these smaller scallops more efficiently as they elevate in the water column in response to the disturbance. In relation to larger scallops (>100mm shell height), a dredge is designed to dig into the substrate. The dredge captures larger scallops found in slight depressions in the substrate. A trawl that skims

over the substrate may not be able to capture these larger scallops as efficiently relative to the dredge.

Size selectivity

Size selection in the sea scallop fishery occurs as two separate processes: gear selectivity and crew selectivity. Gear selectivity occurs as a scallop encounters 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. Scallops that are too small to be retained by the gear pass through spaces in the meshes or rings. Crew size selection occurs when the catch is dumped on deck and the crew culls the catch for scallops to be retained for shucking. Under Amendment #4, no minimum size (i.e. meat count or shell height) restrictions exist, therefore, it is up to the discretion of the captain and crew to establish the size of scallops that are retained for harvest.

In this study, obtaining meaningful estimates of gear size selectivity proved to be difficult. 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 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.

In this study, no non-selective gear was used. The data collected represented the catch from two experimental (selective) gear configurations. With no estimate of the length frequency distribution of scallops that passed through the rings of the dredge and meshes of the trawl, 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.

Collecting catch data in a way that differentiated between scallops that were kept for shucking and those that were discarded allowed the generation of crew size selection curves. Results of the crew size selectivity analysis suggest a standard for minimum retention size. DuPaul and Kirkley (1995) reported that scallops begin to be retained by the fishery at roughly 70-75 mm shell height. Our findings corroborate this observation, as the L_{50} values over all trips ranged from 69.3-77.5 mm (Table 6). 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 marked shift in crew size selection was observed eventhough the size composition of the catch varied widely over the three trips.

Implications for the fishery and management

The establishment of age at entry is one management technique used to maximize yield per recruit and increase the spawning potential of the managed population. Serchuk *et al.* (1979) have shown that maximum scallop yield per recruit is reached at age 8, with only minor increases attained from age 6 to 8. While unrealistic under current resource conditions and fishery practices to expect a delay in the age at first capture to 8 or even 6 year old scallops, benefits in terms of yield per recruit can be realized if 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 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 scallops are allowed to grow from 73-92 mm shell height. The harvest of three year old scallops compromises the fisheries ability to maximize yield per recruit.

In addition to increasing yield per recruit, delaying age at first capture from age 3 to age 4 adds to the reproductive potential in terms of egg production. Age 3 scallops produce from 10-13.5 million eggs, while four year old scallops will produce as many as 22-34 million eggs (MacDonald and Thompson, 1985; Langton *et al.,* 1987). Exact

fecundity estimates vary, however, age 4 scallops produce 2-3 times more eggs than age 3 scallops. McGarvey *et al.,* (1993) found a statistically significant spawner-recruit relationship for sea scallops on Georges Bank. This analysis also determined age three scallops and to some extent age 4 scallops did not measurably contribute to recruitment on the Georges Bank. In terms of egg production, the harvest of age three scallops may at best represent a large reduction in spawning potential or at worst, the removal of animals before they have had a chance to reproductively contribute to the population.

Equity

The examination of equality of opportunity as created by the gear restrictions found in Amendment # 4 was an objective of this study. This examination was assessed relative to the size selectivity and harvest efficiency of the two regulated gear types. Through gear restrictions in Amendment #4, management attempted to equate the two gears in relation to size selectivity and harvest efficiency. This attempt was guided by the assumption that the size selectivity of a 5.50 diamond mesh and a 3.50" ring were equal. A similar assumption equated the harvest efficiency of 30 feet of dredge width with 144 feet of trawl width.

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. Wide selectivity patterns found in this study indicated that both gears captured a wide range of scallop shell heights. To establish the true selection properties of the two regulated gear types, the absolute size selectivity of the two gear types must be determined. Future studies that utilize a non-selective control will yield an estimate of absolute gear selectivity. These results will give a starting point and dictate the direction that future gear modifications should be focused.

Future attempts at equating dredges and trawls in relation to size selectivity could be accomplished through comparative gear research. Comparative gear studies utilizing differing diamond or square mesh sizes and ring sizes could result in the escapement of greater numbers of pre-recruit (<70 mm shell height) scallops relative to the currently regulated gear designs. Previous comparative gear studies demonstrated that modifications such as increasing ring and mesh sizes reduced the capture of smaller

scallops. These gear modifications, however, did not eliminate the capture of small scallops entirely, and often reduced the harvest efficiency of the dredge or trawl over all shell heights (DuPaul *et al.,* 1989c; DuPaul and Kirkley, 1995). Result these studies demonstrate the sloppy nature of sea scallop gear in relation to size selectivity.

While size selection properties of sea scallop gear seem to be broad, the crew culling process has been shown to be relatively knife edged. In this study, there was little observed difference in shell heights between scallops that were retained by the crew and those that were discarded. Assuming an 80-92.7% survivorship, the majority of scallops that are discarded survive the capture and culling process (Medcof and Bourne, 1964; DuPaul *et al.,* 1995; DuPaul and Kirkley, 1995). The crew culling process with knife-edge selectivity and low associated mortality rate has the potential to be an effective tool in the establishment of scallop age at entry to the fishery.

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

The reduced ability of observed trawls to capture 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 scallops but results from this and former studies suggest that current trawl designs may not be able to harvest larger 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 primarily a function of gear width.

Currently, gear width is mandated to be a maximum of 30 ft. of dredge width and 144 ft. of trawl sweep. The experimental manipulation of gear width could be performed to 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 level of analysis of how dredge and trawl vessels operate. To adequately compare the two gears, a broader view of how dredge and trawl vessels operate on the fleet level needs to be examined. Trawl vessels constitute 22% of the total permits in the fishery, and annually account for 10-15% of the landings. These 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 persecution by scallop trawl gear.

Results from this study raised many questions and problems worthy of further investigation. This study demonstrated that the assumptions that formed the basis of the gear regulations found in Amendment #4 were not entirely correct, and in doing so presented an opportunity for further research. Clearly, if a management objective is to equate sea scallop trawls and dredges in relation to size selectivity and relative efficiency, more comparative gear work is a necessity. Fishing gear is an important component of the utilization of the sea scallop resource. However, to fully understand the relationship that trawl and dredge vessels have within the fishery, results from this study should represent one factor in a complex analysis.

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