Northwest Atlantic Fisheries Organization

Serial No. N1064

NAFO SCR Doc. 85/89

SCIENTIFIC COUNCIL MEETING - SEPTEMBER 1985

SPECIAL SESSION ON BIOLOGICAL SURVEYS

Performance of an Offshore Scallop Survey Dredge Equipped with Rock Chains

by

R. J. Smolowitz, F. M. Serchuk, J. Nicolas, and S. E. Wigley

National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole Laboratory, Woods Hole, Massachusetts 02543, USA

ABSTRACT

A persistent problem in conducting fishery-independent research surveys of sea scallops in Northwest Atlantic waters is the frequency and magnitude of gear damage sustained in sampling rocky-bottom habitats. To evaluate the performance of rock chain equipped gear in ameliorating this problem, comparative alternate-haul field experiments were conducted during August 1984 with two research survey sea scallop dredges alternately equipped with and without rock chains. Eighty-eight tows were performed among nine different areas selected on the basis of bottom type (hard vs sand bottom) and scallop density (high vs low) on parts of Georges Bank and in the Gulf of Maine. Within each area, replicate 15-minute tows were accomplished using one dredge equipped with rock chains and the other without chains.

Over all areas sampled, the rock chain dredges caught 28% more scallops than the dredges without chains. On hard bottom, the rock chain dredges were 56% more efficient in capturing scallops than the standard dredges. On sand bottom, however, more scallops were taken without rock chains than with chains, although catch differences between the two dredge types were not consistent and varied with scallop density.

The rock chain dredges retained a higher proportion of smaller-sized scallops (<70 mm shell height) than the standard dredges, particularly on hard bottom substrates. Reasons for the differential performance of the two dredge types in sampling scallops are presented and discussed.

INTRODUCTION

The Woods Hole Laboratory of the Northeast Fisheries Center has conducted sea scallop, Placopecten magellanicus, research vessel surveys since 1960 to obtain fishery-independent data on resource conditions of sea scallops in the Georges Bank, Mid-Atlantic, and Gulf of Maine regions (Serchuk et al. 1979) Since 1975, annual surveys have been conducted to evaluate relative abundance, size/age composition, and recruitment patterns using a stratified random sampling design with offshore scallop areas divided into geographical zones (strata) on the basis of depth and latitude. Substrate types in these areas are variable and include soft mud, sand, gravel, cobbles, and large boulders.

Since 1979, the standard survey sampling gear has been a 2.44 m (8 ft) wide commercial sea scallop dredge equipped with 5.1 cm (2 in) rings and a 3.8 cm (1.5 in) polypropylene mesh liner. The liner is used to increase the retention of pre-recruit scallops (<70 mm shell height). However, a major problem in using the liner is that in rocky bottom areas it frequently becomes torn by rocks caught by the dredge, necessitating frequent and time-consuming repair or replacement. Shredding of the liner may also result in loss of pre-recruit catch.

Catching rocks in the dredge has other detrimental effects. Often, tows in which rocks are present have a high percentage of broken and/or unmeasurable scallops. Equally, since rock catches can range up to 30 bushels and include boulders 1.22 m (4 ft) in diameter, the task of sorting through these catches and hauling the rocks overboard can be physically demanding, dangerous, and wasteful of time. Hence, any gear modifications that would minimize the capture of rocks would be beneficial in enhancing sampling effectiveness, and safety during sampling activities. Accordingly, the use of rock chain equipped dredges was investigated.

This paper presents the results of comparative alternate-haul field experiments conducted during August 1984 to evaluate the performance of rock chain equipped survey gear. Alternate tows were made with two similar dredges, one equipped with rock chains and the other without chains. The study was performed in various areas in the Gulf of Maine and on Georges Bank using the R/V ALBATROSS IV, the vessel used in all recent sea scallop surveys.

BACKGROUND

As an introduction to the use of rock chains, a brief review of the evolution of scallop dredge design is appropriate.

Scallops were first harvested commercially using oyster dredges (Smith 1891). These dredges had a handle or "pull-bail" consisting of two iron bars that came together to form a towing eye. This eye was about 1.2 to 1.5 m (4-5 ft) from the rectangular dredge mouth which was constructed of flat iron bars, 1 m (3 ft) wide and 23 cm (9 in) high. The dredge frame had holes all around to which the "bag" was attached. The lower side of the bag consisted of iron rings (6 to 10 cm in diameter) to allow escapement of small, unmarketable scallops. Both the top and sides of the dredge were made of twine and the bag length was about 1.2 m (4 ft). Usually, the dredge was fished by two men from a small boat under oars or occasionally by sail. Another fishing technique was to "anchor dredge", similar to present anchor seining procedures. In either case, the dredge was not likely to catch a significant quantity of rocks.

Dredge size increased during the next half century when larger motorized vessels outfitted with deck equipment entered the fishery. As scallop beds became depleted, fishing effort was diverted to "harder" bottom areas where heavier and sturdier gear was required. By the 1940's, the standard New Bedford scallop dredge frame was already 3.3 m wide and 0.3 m high (11 ft by 1 ft), with the bag attached around the frame by metal links (Royce 1946). Dredges with this design did not catch large rocks since the frame opening height limited entrance into the dredge proper. An article in the Fishing Gazette (Anonymous 1952) explained: "The scallops are flat and slide through the mouth without its having to be open wide. Any amount of stone more than the size of a baseball could not be tolerated in the drag, because it would break the shells of the scallops. A few the size of a loaf of bread would be devastating."

Major modifications were made to the basic dredge design in the 1940's. A pressure plate was added to better hold the dredge to the bottom while being towed. The bag, instead of being fixed to the bottom of the frame, was attached to a chain sweep that was fastened only to the ends of the frame. This change allowed the sweep to follow ocean bottom contours resulting in a cleaner catch (Anonymous 1951). However, use of the sweep chain created a larger opening into the bag enabling the dredge to catch larger rocks. As a result, when fishing rocky areas the practice was to remove the chain sweep and bag and replace them with the older type bag attached directly to the frame.

The sweep chain equipped dredge, the norm in the present day offshore fishery, is more efficient than a dredge which has the bag affixed directly to the frame (Bourne 1966). To maintain the increased efficiency of the sweep chain equipped dredge but reduce or eliminate the capture of large rocks, rock chains were added by fishermen to their gear. By running a series of tickler chains athwart the dredge opening connected by a series of fore and aft-running "rock" chains, the size of the opening between the sweep and the frame is reduced and capture of rocks lessened. Generically, the entire chain rig is referred to as rock chains.

There is no standard arrangement for rock chains; the number, length and size of the tickler and rock chains vary from rig to rig. However, since many of the dredge frames are built by just a few manufacturers, there is some degree of standardization in the fishery. These frames have "U" shaped attachment points on the backside of the cutting bar for the rock chains to be placed about 30-46 cm (12-18 in) apart.

A diversity of opinion exists on the effects of rock chain equipped dredges on scallop catches. The majority of offshore scallopers today, however, do not use ticklers or rock chains even when fishing hard bottom. Since little scientific data were available on the performance of rock chain dredges, the present study was designed and initiated.

MATERIALS AND METHODS

Gear

Both survey scallop dredges used in August 1984 field experiments were of similar construction (Figure 1). Each was constructed of 7.9 mm (5/16 in) rings, 51 mm (2 in) in diameter. Total weight of a dredge was 646 kg (1425 lb); the frame weighed 329 kg (725 lb). The bottom or "bag" of each dredge was double linked, 32 rings wide by 15 rings deep with 12 x 12 diamonds. The top or "apron" was 32 rings by 18 rings with a 76.2 mm (3 in) mesh twine back. The chain sweep was 15.9 mm (5/8 in) case-hardened steel, 77 links long, hung to the bag with 7 link long straps of 6.4 mm (1/4 in) chain. The clubstick was 2.1 m (7 ft) long and possessed 15.2 cm (6 in) diameter rubber "cookies".

While normally the scallop survey dredge would be equipped with a 38 mm (1.5 in) mesh liner, it was removed during the series of experiments to eliminate any variability caused by tears due to rocks.

Rock-chain design and construction specifications are provided in Figure 2.

Fishing Procedure

Rock chain experiments were conducted during the last seven days of the 1984 USA sea scallop survey. Eighty-eight tows were performed among nine different areas selected on the basis of bottom type (hard vs sand) and scallop density (high vs low) observed during the earlier part of the Georges Bank and Gulf of Maine surveys (Table 1 and Figure 3). Within each area, replicate tows were performed using one dredge equipped with rock chains and the other without chains. The rock chains were variously switched from one dredge to the other to assess differences in the dredges themselves. In one area (Southeast Part of Georges Bank, Experiment 9: Figure 3), 12 sets of alternate tows were conducted using the survey dredges without the rock chains.

Standard USA sea scallop survey methods were used during all tows accomplished in the gear comparison experiments, viz. dredges were towed for 15 minutes at 6.3 km/hr (3.5 knots) with a 3:1 wire scope. Twelve experiments were performed, with each experiment comprised of at least two pairs of matched tows (a series of four tows) covering the same bottom as deduced from using a LORAN-C plotter. A rotation of tows was used to cancel out effects of tow direction and order of tow; the first and third tows were performed in one direction (one matched pair) and the second and fourth tows performed in the opposite direction (second matched pair). Substrate type was varied by shifting to different areas during the series of experiments. In all tests, tow distance and speed over bottom was recorded with a Doppler speed log.

After each tow, the catch was sorted into biological and trash components. The scallop catch was enumerated and shell height measurements taken, in 5 mm intervals, for all live individuals caught. Trash was measured by volume in bushel baskets and trash composition noted. Substrate was classified into five categories: sand, gravel, cobbles (<15 cm), rocks (15-30 cm), and boulders (>30 cm). For comparison purposes between dredges, cobbles were counted to obtain numbers per bushel. Relevant hydrographic data (water depth and temperature) were recorded as well as weather and sea state observations.

All by-catch of finfish and invertebrates was sorted by species, counted and weighed.

Scallop catch and LORAN-C location bearings are summarized by individual tow in Appendix Table 1.

Data Analysis

Relative performance of each dredge type was assessed by comparing the total scallop catch (number), scallop size frequency distributions, trash volume and composition, and finfish by-catch between the rock chain and standard dredges. Statistical comparisons of the mean difference in scallop catch between matched tows were accomplished using the t-test for paired comparisons (Sokal and Rohlf 1981:p. 356) with both linear and ln(x+1) transformed catch data. Due to the low degrees of freedom in most of the individual experiments (7 experiments had only 2 sets of matched tows or only 1 degree of freedom per experiment: Table 1), statistical testing was performed on aggregated data from experiments in which identical dredge tests were performed on the same type of bottom. In some cases, the grouped data were obtained from different locations and from different density beds of scallops, although all comparisons were based on matched pairs of tows. Hence, in assessing catch differences between the two dredge types on hard and sand bottoms some confounding of area and density effects were unavoidably introduced.

Shell height frequency data were summarized by individual experiment, by bottom type, and by type of dredge. Differences in aggregate frequency distributions between the rock chain and standard dredges on both hard and sand bottoms were evaluated using the Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981: p. 443). Selectivity differences between dredge types were assessed by examining the percentage of small (<70 mm shell height) vs large (≥70 mm shell height) scallops caught on the same bottom type from matched tows.

Comparisons of finfish by-catch between the rock chain and standard dredges in hard and sand bottom substrates were accomplished using a two-way contingency analysis employing the G-statistic and chi-square tests (Sokal and Rohlf 1981: pp. 737-743).

Differences in quantity and composition of trash taken in hard bottom areas by the two dredge types were appraised by comparing catches of gravel, cobbles, rocks, and boulders from the matched tows using paired t-tests.

RESULTS

Scallop Catches

A total of 25,160 sea scallops was obtained from the twelve experiments performed in the August 1984 gear comparison trials (Tables 1 and 2). The 20 sets of paired tows accomplished in eight experiments on hard bottom caught 16,514 scallops; the 24 sets in four smooth bottom experiments yielded 8,646 individuals.

Twelve sets of alternate tows (Experiment 9: Table 1) were performed on flat sand bottom on the Southeast Part of Georges Bank to assess fishing power differences between the two dredges (I and II) used in all of the experiments. The dredges were identical in construction and were tested without rock chains. In six of the twelve sets, Dredge I caught more scallops than Dredge II (600 vs 388), while in the other six sets Dredge II caught more scallops than Dredge I (409 vs 301) (Appendix Table 1A). No statistical difference in scallop catch (linear or transformed) was detected between the two dredges from the 12 matched sets of tows ($P = 0.44$ linear; $P = 0.46$ transformed: Table 2). Similarly, results of the Kolmogorov-Smirnov test (K-S test) indicated no significant differences ($P>0.05$) between the size distributions of scallops taken in the two dredges (Table 3 and Figure 6). These findings imply the two dredges used in the field trials exhibited equal performance. Based on this, scallop catches in subsequent experiments were pooled without respect to dredge identity (i.e., I or II).

In the hard bottom experiments (Nos. 1-5, 8, 8a and 11: Table 1), the rock chain dredge (either I* or II* where the asterisk denotes rock chains were attached) caught greater numbers of sea scallops then the standard dredge. In the 20 sets of matched tows, a total of 10,067 scallops were taken in the rock chain dredges compared to only 6,447 scallops in the standard dredges, a difference of 56% (Table 3). In all but one of the eight hard bottom experiments (No. 8a), rock chain dredge catches were higher than those in the standard dredges; in 14 of the 20 sets of matched tows, the rock chain dredge outperformed the standard dredge in catch of scallops (Appendix Table 1B).

For the composite set of hard bottom tows, the difference in scallop catch between the rock chain and standard dredges was highly significant (P=0.01) for both linear and transformed catches: Table 2). However, catch differences were non-significant (P>0.05) or only marginally significant for the pooled data from Experiments 2 and 3, 4 and 5, and 8 and 8a (Table 2). Catch data from these sets of experiments were grouped to assess differences between specific dredge types (I vs II* for Experiments 2 and 3, and 4 and 5; I* vs II for Experiments 8 and 8a). By doing this, however, density effects (i.e., differential catchability; differential catch per tow variability) between experiment sites were introduced (see Table 1), potentially confounding the statistical evaluations. As such, the lack of statistical significance from these three pooled evaluations may be more of an artifact than real. Given the consistency in which larger scallop catches were taken by the rock chain dredges (14 of 20 matched tows; 7 of 8 hard bottom experiments), this appears highly plausible.

Shell height frequency distributions of sea scallops sampled in each of the hard bottom experiments are depicted in Figures 4 and 5, and tabulated for several of the experiments (including the overall results) in Table 3. In general, both the rock chain and standard dredge frequency distributions are similar in appearance exhibiting nearly identical shell height modes within each experiment. Although the rock chain dredges caught more scallops of all sizes than the standard dredges (Table 3), pre-recruit or small scallops (<70 mm shell height) comprised a larger proportion of the rock chain catches than in the standard dredge samples. In almost all of the hard bottom experiments, the rock chain dredge caught a higher percentage of pre-recruits than the standard dredge (Figure 4). Overall, small scallops comprised 60.4% of the total rock chain catch but constituted only 48.7% of the non-chain catch (Table 3). As a consequence of this difference in selectivity between the two dredge types, the aggregate rock chain and standard dredge size frequency distributions (Figure 5) proved statistically different (P<0.01).

On sand bottom (Experiments 6, 7, and 10: Table 1), more scallops (24%) were taken without rock chains than with chains (3,841 vs 3,107: Table 3). In areas of low scallop density (Experiments 6 and 10), no apparent differences in scallop catch occurred between the two dredge types; in half of the matched tows, the standard dredge caught more scallops, while in the other half, the rock chain dredge caught more scallops (Tows 619-626, 675-682: Appendix 1C). In the high density sand bottom trials (Experiment 7), standard dredge catches were higher than those with rock chains in 3 of the 4 paired tows. For the pooled sand bottom data, no statistical difference in scallop catch was detected between the two dredge types (P=0.28 for linear catches; P=0.92 for transformed catches: Table 2).

As was true on hard bottom, the sand bottom scallop size frequency distributions from the rock chain and standard dredge catches showed similar modal patterns (Figures 6 and 7). Differences in selectivity between the two types of dredges were apparent among the experiments but were not consistent. In Experiment 6, the rock chain dredge caught a higher percentage of small scallops (<70 mm shell height) than the standard dredge (30.8% vs 16.5%: Table 3) resulting in a significant difference (P<0.01) between the two size frequency distributions (Figure 6). In Experiment 7, however, the standard dredge caught a larger proportion of small scallops than was obtained in the rock chain tows (70.7% vs 61.4%), again resulting in statistical difference (P<0.01) between the frequency distributions. In Experiment 10, no significant difference (P>0.05) was detected between the percentages of small scallops taken by the dredges (24.3%, standard; 26.9%, rock chain) or between the shell height frequency distributions (Figure 6). Although the pooled (all sand bottom tows) rock chain and standard dredge size frequency distributions (Figure 7) differed statistically (P<0.01), this finding is inordinately influenced by the results from Experiment 7 since the number of scallops collected in this experiment was on order of magnitude greater than in the other two experiments (5843 scallops vs 635 scallops for Experiment 6 and 452 scallops in Experiment 10). Hence, the aggregated results need to be interpreted with caution. The disparity in selection patterns among the individual experiments suggests that selectivity differences between the rock chain and standard gear on sand bottom are probably minor and not uniform.

Over all hard and sand bottom areas sampled in the August 1984 gear experiments, the rock chain dredges caught 28% more scallops than the dredges without chains (13,174 vs 10,288 scallops:Table 3).

Finfish Catches

A total of 594 finfish, comprising 18 different species, were taken as by-catch during the dredge comparison experiments (Table 4). No statistical difference existed (P>0.90) between the amount of finfish caught by the rock chain and standard dredges on hard and sand bottoms (Table 5). Both dredge types, however, caught more finfish on sand bottom suggesting that on sand substrate the dredges tended bottom better or that fish may be more densely aggregated on sandy substrates.

Trash Catches

During the gear experiments, a total of 812 bushels of trash were collected in the survey dredges (see Appendix Table 1 for trash catches by individual tow). Trash catches were light in sand bottom areas; only 87 bushels were caught in the twelve sets of paired tows performed in three sand bottom experiments (i.e., an average of 3.6 bushels of trash per tow). The standard dredge caught about one bushel more trash per tow than the rock chain dredge (4.16 vs 3.08 bu), a statistically significant difference (0.02<P<0.05).

In the hard bottom experiments, 725 bushels of trash were collected (Table 6) over the 20 sets of matched tows or an average of 18.1 bushels per tow. The hard bottom trash was subdivided by size (gravel, cobbles, rocks, and boulders) and enumerated for each tow (Appendix Table 2). For analytical purposes, the experimental results from Fippennies Ledge (Experiment 1) and Northern Georges Bank (Experiments 2-5, 8 and 8a) were pooled and evaluated as a unit. Separate analyses were also performed on the South Channel data (Experiment 11) (Table 6).

Comparison of rock chain and standard dredge trash catches, by trash type, revealed little difference in quantity of trash taken. For the Fippennies Ledge/Northern Georges Bank data, no significant differences (P>0.05) were detected between rock chain and standard dredge catches for any of the four trash types. However, total trash per tow was significantly greater (0.02<P<0.05) in the rock chain dredges than in the standard dredges implying that subdividing the trash into components may be an artificial construct for testing catch differences (i.e., counting numbers of rocks and boulders instead of bushels. A single boulder, for example, may account for many bushels by volume, but only a single unit by number).

In the South Channel experiment, the only statistical difference between the two dredge types occurred in the catch of cobbles (0.02<P<0.05). In five of the six matched sets of tows (Appendix Table 2), more bushels of cobbles were caught with rock chains than without. In terms of total trash caught, however, there was no difference between the dredges (P>0.40).

DISCUSSION

Commercial sea scallop fishermen have frequently added rock chains to their dredges, particularly when fishing rocky bottom, in the belief that the chains increase catch efficiency. The chains are presumed to cause the dredge to better tend bottom and/or lift scallops off the substrate making them more susceptible to capture (Bourne 1964). To date, however, most of the information supporting these contentions has been anecdotal in nature.

Results of the survey dredge comparison experiments conducted in 1984 indicate that larger scallop catches are obtained when using rock chain dredges on hard bottom. In matched tows with dredges without rock chains, rock chain dredges caught 56% more scallops than did standard dredges in rocky bottom areas. Relative to the standard dredge, the rock chain dredge was more efficient in capturing scallops of all sizes, although the largest differences in selectivity between the two dredge types occurred with small scallops (<70 mm shell height). On hard bottom, the catch of small scallops using rock chains was nearly double that taken without chains. Catch differences in marketable-size scallops, however, were not as marked; the rock chain dredge was only 21% more efficient in capturing large scallops (≥70 mm shell height) than the standard dredge.

On sand bottom, there was no significant difference in catch efficiency between dredges with and without rock chains. Scallop size selectivity patterns were similar for the two dredge types.

No consistent differences in trash accumulation were detected between the rock chain and standard dredges. On hard bottom, there was some indication that the amount of trash caught by the rock chain gear was greater than that taken by the standard gear (Fippennies Ledge and Northern Georges Bank), but this differential was not observed in all hard bottom areas. Rock chains did appear to reduce the catch of boulders larger than the spacing between chains (Table 6) although, due to sample variability, no significant difference in boulder catch could be detected between the two dredge types. Equally, although differences were not significant, the rock chain dredges caught greater quantities of gravel, cobbles, and rocks than the standard dredges. It is likely that had more paired tows been accomplished in the hard bottom experiments (i.e., increase in sample size), true underlying differences in performance of the two dredges (suggested by the amounts of trash) would have been detected due to increased statistical testing power. Unfortunately, many of the statistical tests used in comparing the rock chain and standard dredge results had small sample sizes. Thus, although test results were often not significant, the possibility that Type II statistical errors were committed (accepting the null hypothesis of no difference in performance when this is false) cannot be summarily dismissed.

Based on the 1984 field experiments, greater use of rock chain gear in the commercial sea scallop fishery would not be completely advantageous. While increased catches would ensue, a high proportion of these catches would likely be of small, immature, non-marketable scallops. These would have to be culled overboard increasing catch processing time. Moreover, if the indications that rock chain dredges accumulate more small-sized trash are true, this will also make the catch harder to sort. Indeed, the increased quantities of small scallops captured in the rock chain dredges during the 1984 field trials may have been a direct effect of the greater trash accumulations reducing small scallop escapement.

In areas where large boulders are likely to be encountered, rock chain usage may be beneficial in mitigating boulder capture. Although the 1984 test results were equivocal, fewer number of boulders were taken in the rock chain tows. Since it may take a considerable quantity of time to return a large boulder overboard, any reduction in the number of boulders caught will be advantageous. Additionally, the fewer the boulders caught, the less likely is the occurrence of major gear damage.

Both the number of rock chains and their configuration probably affect fishing performance. The more chains that lay perpendicular to the direction of tow, the deeper the substrate penetration in the center of the dredge path and, presumably, the greater catch efficiency. Only one arrangement of rock chains, however, was used in the 1984 gear comparisons. Accordingly, the the experimental findings have relevance in a generic sense to rock chain usage, but may not be representative of all possible rock chain riggings. Further work is necessary to evaluate the effect of different rock chain designs on scallop catch.

ACKNOWLEDGEMENTS

We take pleasure in thanking the officers, crew, and scientists of the R/V ALBATROSS IV for their extra and dedicated efforts during the performance of the 1984 field experiments. We especially thank Lead Fishermen Sam Reed and Bryant Silvia for their cooperation and assistance.

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Table 1. Summary of rock chain experiments conducted on Georges Bank and the Gulf of Maine during 1984 NMFS gear comparison trials using two sea scallop survey dredges (I and II).

Experiment Number	Area	Tow Numbers	Bottom Type	Scallop Density	Sets of Matched Tows	Dredges Used[1]
1	Fippennies Ledge	571-574	Hard	High	2	I vs II*
2	No. Edge (Stratum 65)	578-581	Hard	High	2	I vs II*
8	No. Edge (Stratum 65)	637-640	Hard	High	2	I* vs II
8a	No. Edge (Stratum 65)	641-644	Hard	High	2	I* vs II
3	No. Edge (Stratum 65)	582-585	Hard	Low	2	I vs II*
4	No. East Peak (Stratum 64)	586-589	Hard	High	2	I vs II*
5	No. Edge (Stratum 71)	590-594	Hard	Low	2	I vs II*
11	So. Channel (Stratum 64)	685-696	Hard	High	6	I* vs II
6	No. East Peak (Stratum 64)	619-626	Sand	Low	4	I vs II*
7	No. East Peak (Stratum 64)	629-636	Sand	High	4	I* vs II
10	So. East Part (Strata 59/60)	675-682	Sand	Low	4	I* vs II
9	So. East Part (Strata 59/60)	651-674	Sand	Low	12	I vs II
				Σ	44 (88 tows)	

[1]Rock chain equipped dredge is indicated by an asterisk (*).

Table 2. Results of t-test for paired comparisons for differences in sea scallop catches between survey dredges with and without rock chains[1]. Tests were performed on linear and ln transformed catch data from matched tows.

Comparison	Expt Nos.	Bottom Type	Linear Scallop Catch (nos) $\bar{D}$	$S_{\bar{D}}$	t_s	P	ln Scallop Catch (nos) $\bar{D}$	$S_{\bar{D}}$	t_s	P
I vs II*	2 & 3	Hard	-337.50	93.21	-3.62	0.04	-1.101	0.385	-2.86	0.06
I* vs II	8 & 8a	Hard	-250.25	270.76	-0.92	0.42	-0.902	0.855	-1.05	0.37
I vs II*	4 & 5	Hard	-163.00	131.37	-1.24	0.30	-0.783	0.413	-1.89	0.15
Chains vs No Chains	1-5,8,8a,& 11	Hard	-181.00	65.74	-2.75	0.01	-0.681	0.223	-3.06	0.01
Chains vs No Chains	6,7, & 10	Sand	61.17	54.27	1.13	0.28	-0.017	0.170	-0.10	0.92
I vs II	9	Sand	8.67	10.84	0.80	0.44	0.090	0.118	0.76	0.46

[1]$\bar{D}$ = mean difference between paired observations.

$S_{\bar{D}}$ = standard error of $\bar{D}$.

$$t_s = \frac{\bar{D} - (u_1 - u_2)}{S_{\bar{D}}}$$

P = probability of a greater absolute value of t

See Sokal and Rohlf (1981:p. 359) for computational details.

* = Rock chain equipped dredge.

Table 3. Shell height frequency distributions, by 5-mm interval, of sea scallops from alternate-haul, matched tow field experiments conducted in the Gulf of Maine and on Georges Bank during August 1984. Two sea scallop survey dredges (I and II) were used in these experiments, alternately equipped with and without rock chains (rock chain dredges are indicated by an asterisk [*]).

Shell Height (mm)	Hard Bottom Experiments: Expts 2 & 3 I	Expts 2 & 3 II*	Expts 8 & 8a I*	Expts 8 & 8a II	Expts 4 & 5 I	Expts 4 & 5 II*	All[1] No Chains	All[1] Chains	Sand Bottom Experiments: Expt 6 I	Expt 6 II*	Expts 7 & 10 I*	Expts 7 & 10 II	All[2] No Chains	All[2] Chains	Expt 9 I	Expt 9 II
2																
7																
12																
17											10	34	34	10		2
22					1		1	1			36	73	73	36		2
27	1		2	1	-		3	3		3	113	204	204	116		-
32	5	10	13	3	-	3	8	26		2	229	389	389	231		-
37	32	58	96	42	-	20	74	175		10	229	524	524	239		-
42	72	141	384	232	3	60	311	586	5	23	152	325	330	175		3
47	251	516	860	588	23	148	926	1595	23	58	96	175	198	154	25	12
52	236	599	868	572	40	192	921	1849	4	17	39	79	83	56	21	24
57	95	321	259	179	47	119	446	1041	2	1	64	51	53	65	17	11
62	18	80	56	47	17	26	181	428	4	1	158	139	143	159	5	1
67	61	89	138	124	8	15	269	373	4	8	456	442	446	464	2	1
72	164	260	396	389	15	46	717	821	20	38	484	505	525	522	10	7
77	175	344	479	446	27	52	882	1080	42	52	113	149	191	165	75	52
82	148	223	284	239	26	97	757	972	49	52	61	66	115	113	283	230
87	109	79	74	60	34	61	498	560	11	23	108	127	138	131	285	296
92	14	9	18	15	9	21	159	171	7	7	104	100	107	111	78	51
97	6	10	11	13	9	13	54	69	16	13	78	59	75	91	10	11
102	7	18	12	16	6	15	51	62	5	17	39	50	55	56	4	7
107	6	5	9	2	17	15	47	48	18	13	43	31	49	56	2	3
112	9	7	10	7	11	23	45	66	16	22	31	20	36	53	8	5
117	12	3	11	1	7	11	41	64	11	18	24	18	29	42	10	6
122	4	2	2	4	6	14	37	44	12	15	13	7	19	28	13	13
127	1	2	1	2	3	5	13	20	5	3	10	3	8	13	22	9
132					2	6	4	9		3	5	6	6	8	13	17
137					1	2	1	3			7	3	3	7	7	19
142					1	-	1	-			4	4	4	4	7	9
147						1		1			-	-	-	-	3	3
152											1	2	2	1	1	3
157											-	-	-	-		
162											1	2	2	1		
Total	1426	2776	3983	2982	313	965	6447	10067	254	399	2708	3587	3841	3107	901	797
<70 mm: #	771	1814	2676	1788	139	573	3140	6077	42	123	1582	2435	2477	1705	70	56
(%)	(54.1)	(65.3)	(67.2)	(60.0)	(44.4)	(59.4)	(48.7)	(60.4)	(16.5)	(30.8)	(58.4)	(67.9)	(64.5)	(54.9)	(7.8)	(7.0)
≥70 mm: #	655	962	1307	1194	174	392	3307	3990	212	276	1126	1152	1364	1402	831	741
(%)	(45.9)	(34.7)	(32.8)	(40.0)	(55.6)	(40.6)	(51.3)	(39.6)	(84.5)	(69.2)	(41.6)	(32.1)	(35.5)	(45.1)	(92.2)	(93.0)

[1] Combined data from experiments 1-5, 8, 8a and 11.

[2] Combined data from experiments 6, 7 and 10.

Table 4. Finfish species caught as by-catch during alternate-haul, matched tow, field experiments evaluating rock chains on survey dredges conducted in the Gulf of Maine and on Georges Bank.

Common Name	Scientific Name	Number Caught
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	172
Little skate	*Raja erinacea*	100
Silver hake	*Merluccius bilinearis*	78
Winter skate	*Raja ocellata*	60
Fourspot flounder	*Paralichthys oblongus*	53
Red hake	*Urophycis chuss*	40
Yellowtail flounder	*Limanda ferruginea*	27
Goosefish	*Lophius americanus*	21
Thorny skate	*Raja radiata*	7
Spiny dogfish	*Squalus acanthias*	6
Windowpane	*Scophthalmus aquosus*	6
Winter flounder	*Pseudopleuronectes americanus*	6
Sea raven	*Hemitripterus americanus*	6
Witch flounder	*Glyptocephalus cynoglossus*	4
Haddock	*Melanogrammus aeglefinus*	3
Atlantic cod	*Gadus morhua*	2
American plaice	*Hippoglosoides platessoides*	2
Butterfish	*Peprilus triacanthus*	1
Total		594

Table 5. Numbers of finfish caught, with and without rock chains, on sand and hard bottom during alternate-haul field experiments conducted in the Gulf of Maine and on Georges Bank during August 1984.

Bottom Type	Dredge Type: Rock Chains	Dredge Type: No Chains	Total
Hard	107	95	202
Sand	208	184	392
Total	315	279	594

$X^2 = 0.0004$ $\qquad X^2_{.05[1]} = 3.841$

$G = 0.0004$ $\qquad P > 0.90$

Chi-square and G-tests of independence performed using computational procedures provided in Sokal and Rohlf (1981: p. 737-743).

Table 6. Summary of non-living trash catch taken on hard bottom during alternate-haul field experiments using survey dredges with and without rock chains conducted in the Gulf of Maine and on Georges Bank during August 1984.

Non-Living Trash Type	Fippennies Ledge and Northern Georges Bank[2]			South Channel[3]		
	Rock Chains	No Chains	Total	Rock Chains	No Chains	Total
Gravel (bu)	78	41	119	2	0	2
Cobbles (bu)	145	93	238	88	70	158
Rocks (#)	295	281	540	332	255	587
Boulders (#)	4	13	17	22	79	101
Total Trash (bu)[1]	297	172	469	124	132	256

[1]Total trash includes fish and invertebrate by-catch as well as sand and other substrate.

[2]Experiments 1-5, 8 and 8a.

[3]Experiment 11.

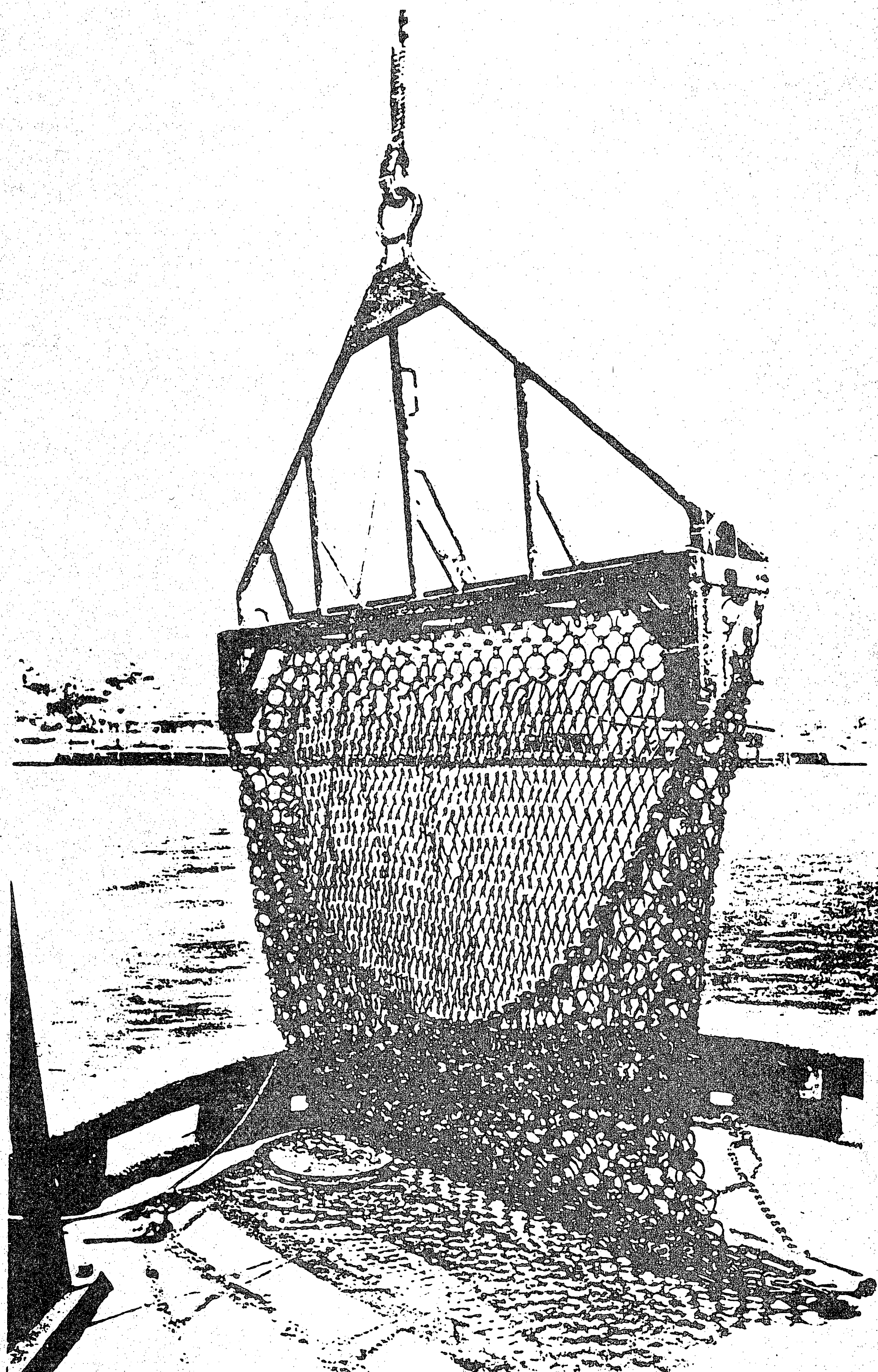
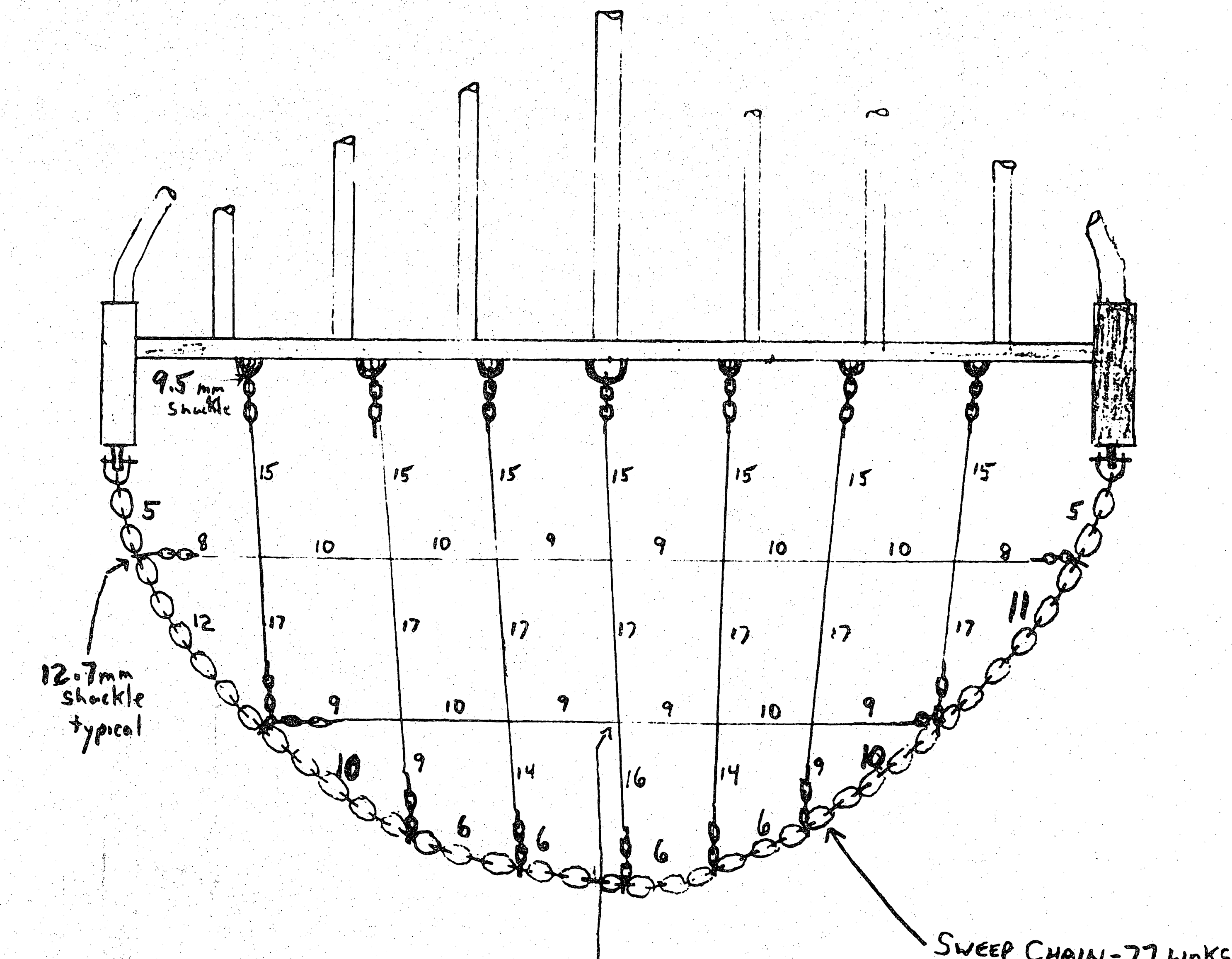


Figure 1. Photograph of the standard 2.44 m wide sea scallop dredge used in alternate-haul rock chain experiments conducted in the Gulf of Maine and on Georges Bank during August 1984.



NOTES

- Numbers indicate chain-links between connecting points.
- Rock chains cross above the tickler chains relative to the bottom. Both consist of 9.5 mm chain.

Figure 2. Schematic illustration of the relationship between sweep chain, tickler chains, rock chains, and dredge frame of the 2.44 m wide sea scallop survey dredge used in rock chain experiments conducted in the Gulf of Maine and on Georges Bank during August 1984.

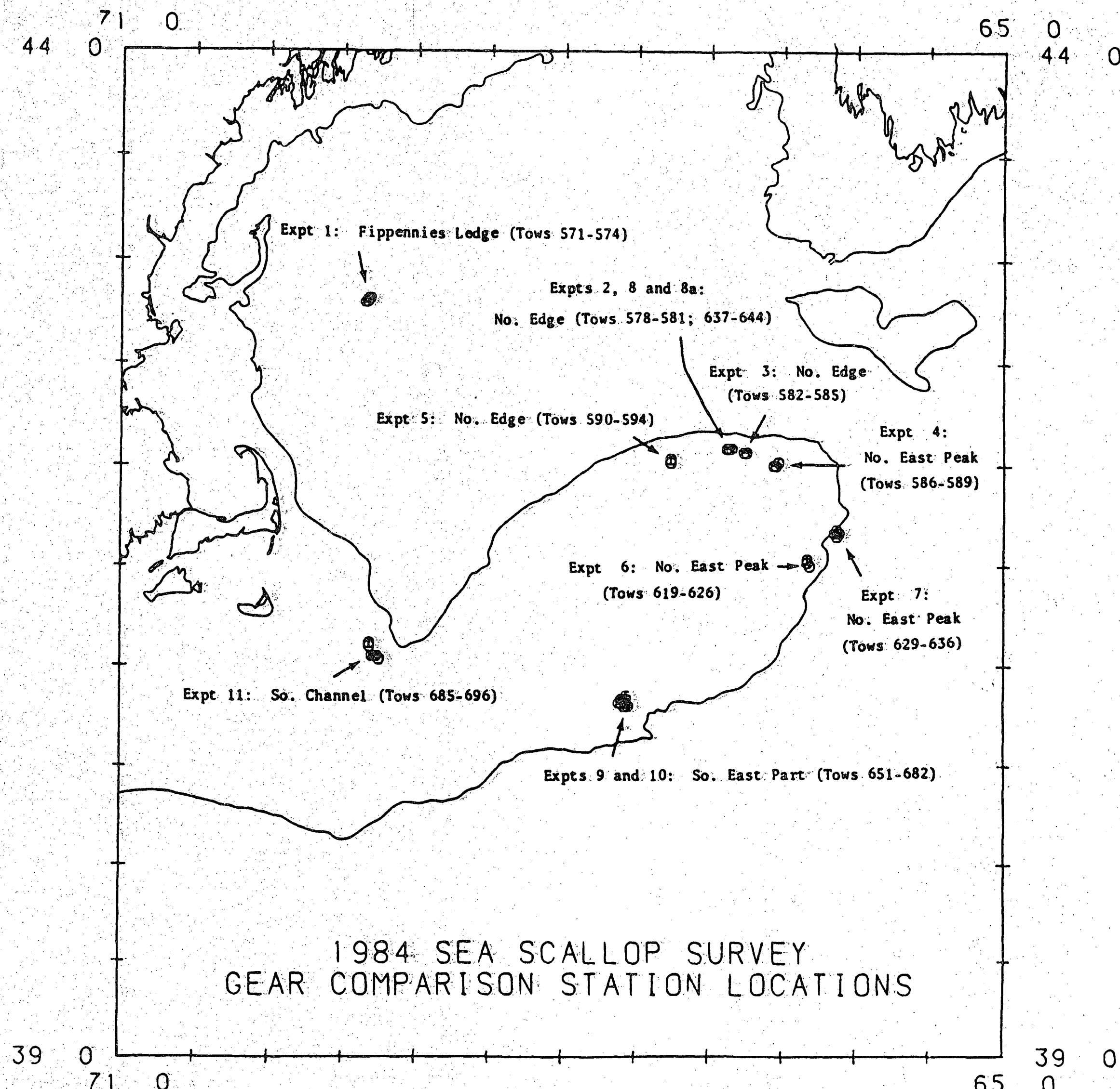


Figure 3. Station (tow) locations for rock chain experiments conducted on Georges Bank and in the Gulf of Maine during 1984 sea scallop survey dredge gear comparison trials.

USA 1984 GEAR COMPARISON EXPERIMENTS

HARD BOTTOM

TOWS WITH AND WITHOUT ROCK CHAINS

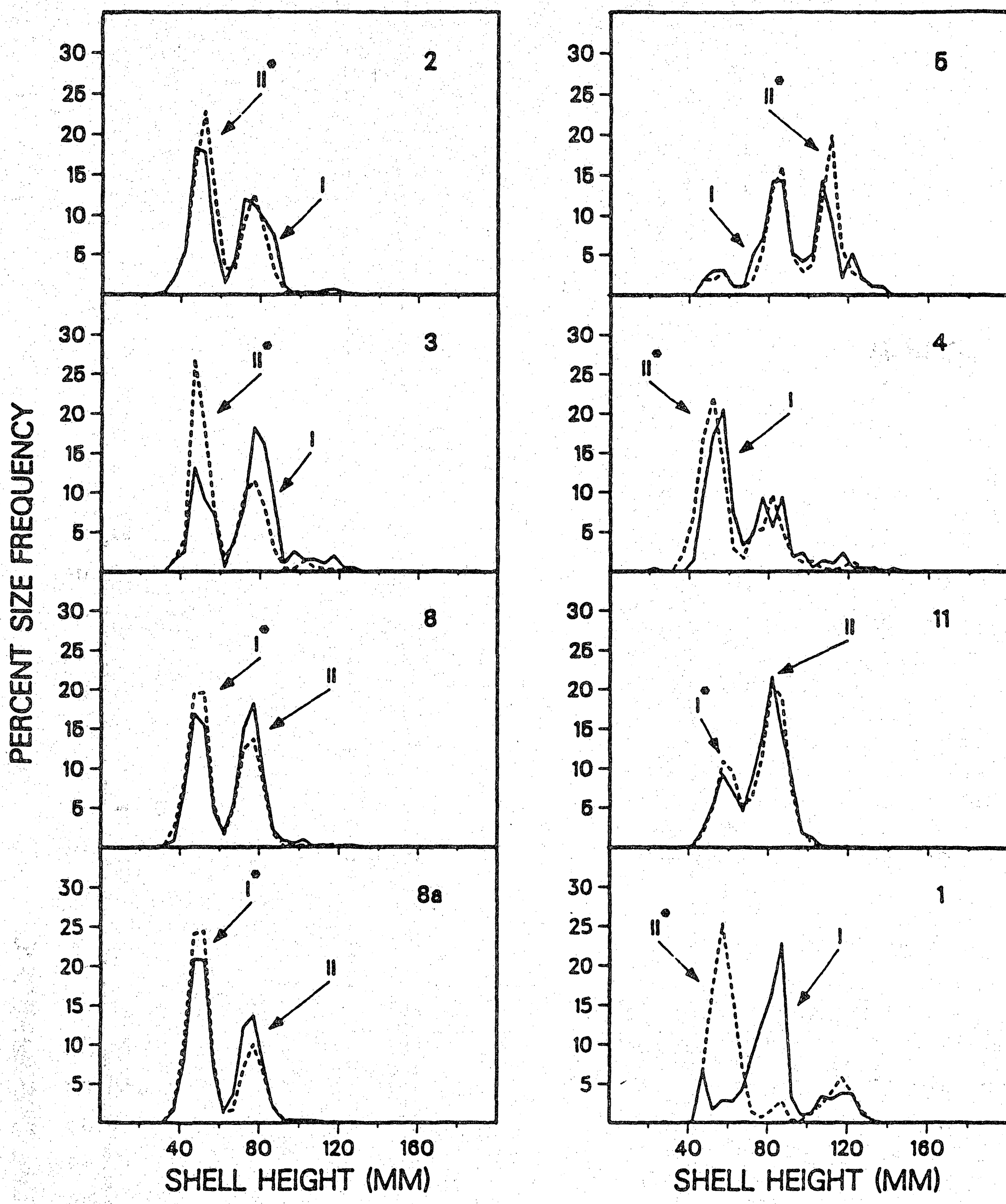


Figure 4. Comparison of sea scallop shell height frequency distributions on hard bottom substrates by two survey dredges (I and II) with and without rock chains. Dredges equipped with rock chains are indicated by an asterisk(*). All eight experiments (1-5, 8, 8a, and 11) were conducted using a paired, alternate-tow sampling design.

USA 1984 GEAR COMPARISON EXPERIMENTS

HARD BOTTOM

TOWS WITH AND WITHOUT ROCK CHAINS

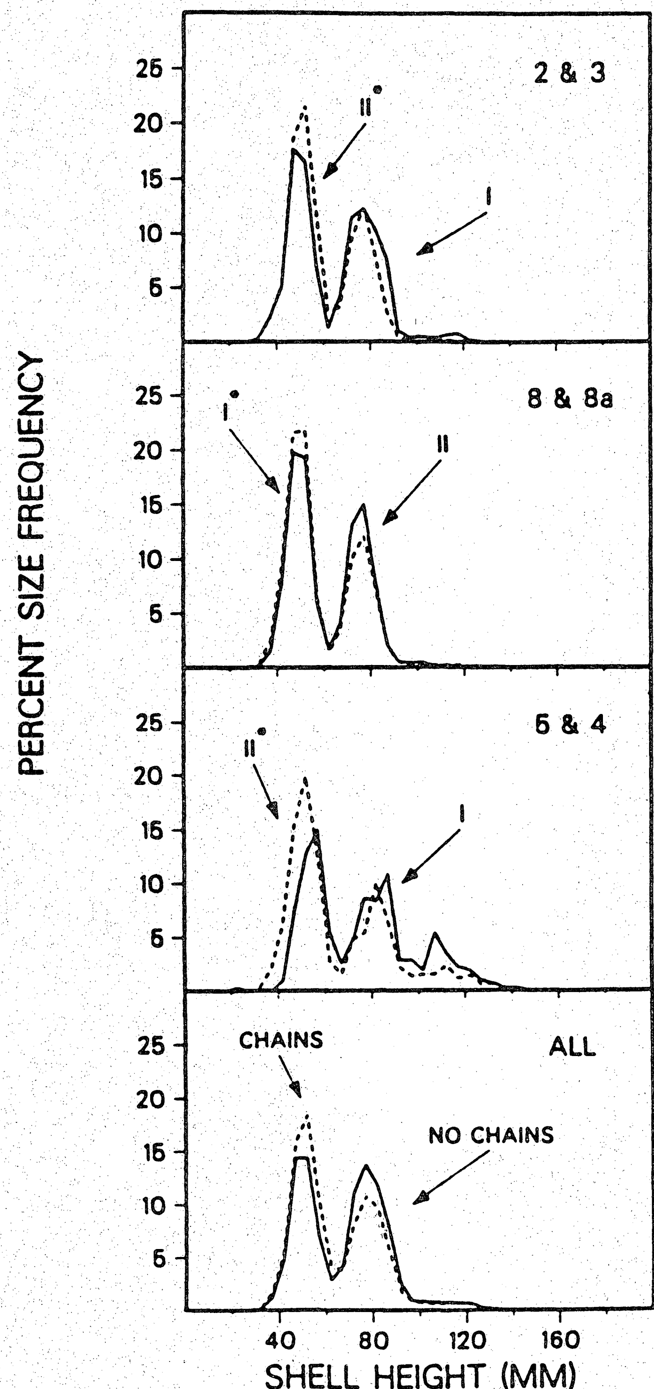


Figure 5. Aggregated sea scallop shell height frequency distributions from rock chain experiments on hard bottom. Dredges equipped with rock chains are labelled as such or indicated by an asterisk(*).

USA 1984 GEAR COMPARISON EXPERIMENTS

SAND BOTTOM

TOWS WITH AND WITHOUT ROCK CHAINS

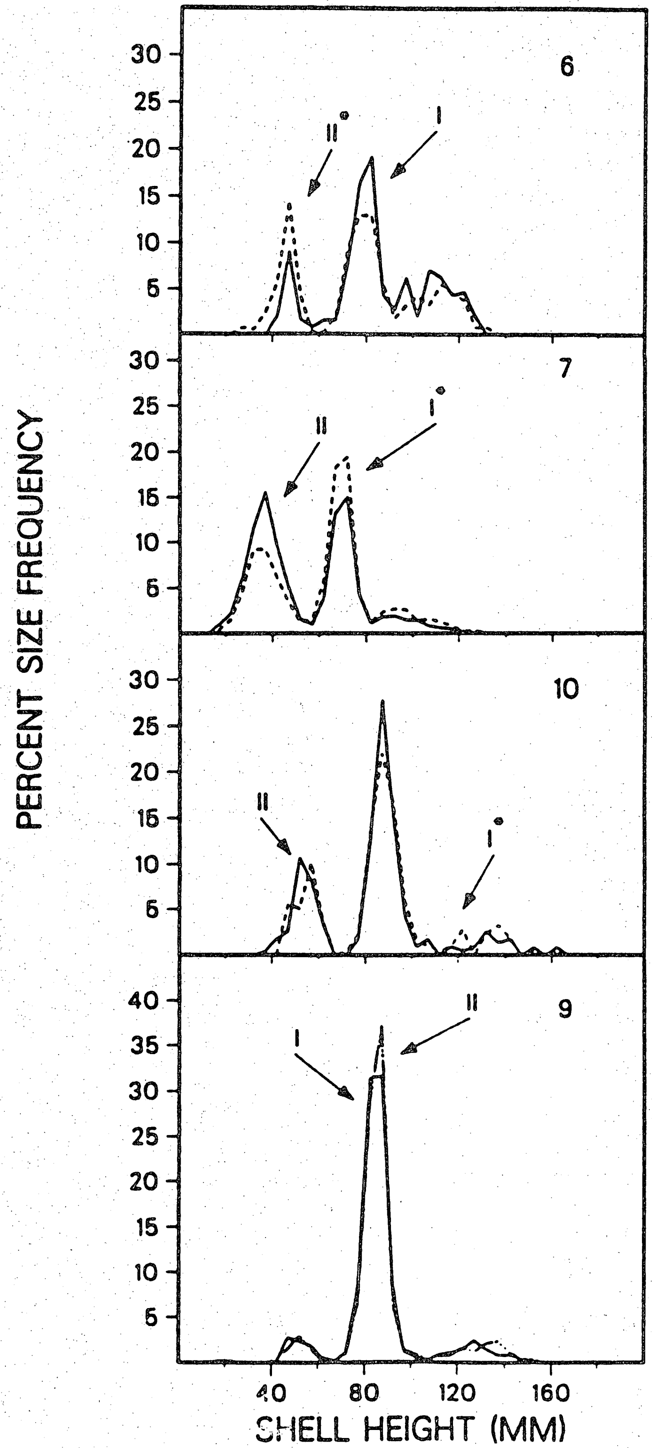


Figure 6. Comparison of sea scallop shell height frequency distributions on sand bottom substrates by two survey dredges (I and II) with and without rock chains. Dredges equipped with rock chains are indicated by an asterisk(*). Experiments 6, 7, and 10 evaluated gear performance between the two dredges with and without rock chains. Experiment 9 evaluated gear performance of the two dredges without any rock chains to assess differences in the dredges themselves. All four experiments were conducted using a paired, alternate-tow sampling design.

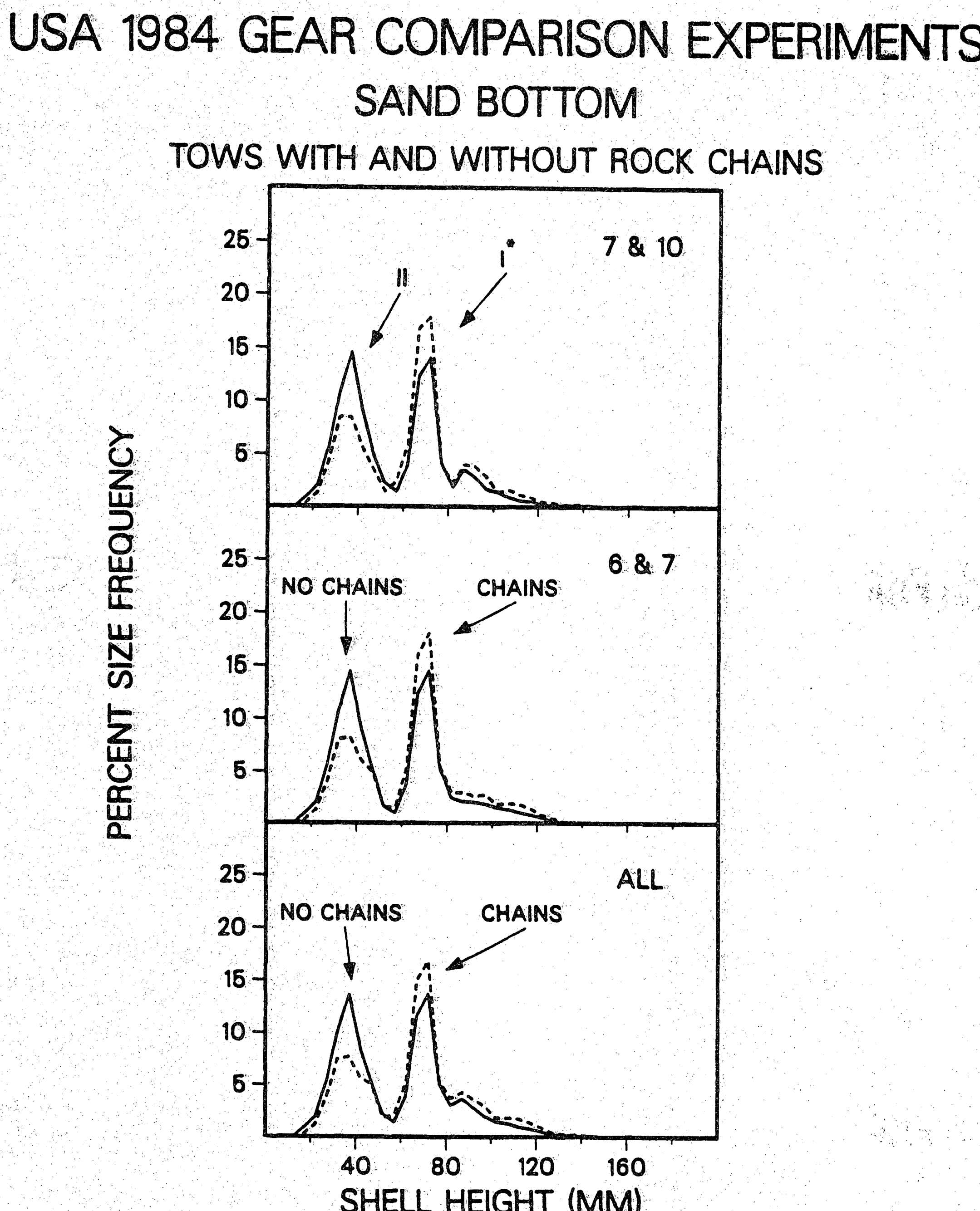


Figure 7. Aggregated sea scallop shell height frequency distributions from rock chain experiments on sand bottom. Dredges equipped with rock chains are labelled as such or indicated by an asterisk(*).

Appendix Table 1: Summary of 1984 NMFS sea scallop research vessel survey sampling data from gear comparison experiments, by individual station. Experiments evaluated performance of two survey dredges (I and II), with and without rock chains. Dredges equipped with rock chains are indicated by an asterisk(*). Dredge liners were not used in these experiments.

A. COMPARISON TOWS WITHOUT CHAINS ON SAND BOTTOM

Station Number and Dredge Type	No. of Sea Scallops Caught	Mean Shell Height (mm)	Depth (fm)	Trash (bu)	LORAN C BEARINGS Start W	Start Y	End W	End Y	DATE
Southeast Part (Border of Scallop Survey Strata 59 and 60): *Experiment 9*									
651 II	42	90	44	5	13358	43505	13364	43506	8/28
652 I	49	89	42	5	13363	43506	13358	43506	8/28
653 I	32	92	42	5	13358	43505	13364	43505	8/28
654 II	45	96	44	4	13363	43506	13358	43505	8/29
655 I	46	90	43	5	13355	43507	13355	43502	8/29
656 II	62	95	42	4	13355	43502	13355	43507	8/29
657 II	55	86	42	4	13355	43507	13355	43502	8/29
658 I	56	89	42	6	13355	43503	13355	43507	8/29
659 II	45	86	42	6	13357	43508	13351	43508	8/29
660 I	45	92	42	3	13351	43508	13357	43508	8/29
661 I	38	89	42	7	13356	43508	13351	43508	8/29
662 II	48	84	42	2	13351	43508	13357	43508	8/29
663 I	201	83	44	8	13361	43497	13363	43491	8/29
664 II	157	88	44	11	13362	43493	13361	43498	8/29
665 II	135	85	44	8	13361	43497	13362	43491	8/29
666 I	84	84	44	9	13362	43493	13362	43497	8/29
667 I	82	86	44	10	13359	43496	13358	43493	8/29
668 II	47	81	44	5	13359	43494	13360	43498	8/29
669 II	48	85	43	5	13365	43499	13362	43502	8/29
670 I	109	87	44	8	13363	43500	13367	43495	8/29
671 I	100	85	42	7	13359	43504	13365	43504	8/29
672 II	50	85	42	3	13364	43504	13359	43504	8/29
673 II	63	89	42	5	13360	43504	13366	43504	8/29
674 I	59	82	42	5	13363	43505	13358	43504	8/29

B. COMPARISON TOWS WITH AND WITHOUT CHAINS ON HARD BOTTOM

Station Number and Dredge Type	No. of Sea Scallops Caught	Mean Shell Height (mm)	Depth (fm)	Trash (bu)	LORAN C BEARINGS Start W	Start Y	End W	End Y	Date
Fippennies Ledge: *Experiment 1*									
571 I	219	84	40	6	13274	44261	13282	44261	8/24
572 II*	101	89	40	8	13282	44262	13275	44262	8/24
573 II*	496	67	45	6	13276	44262	13284	44263	8/24
574 I	329	82	40	8	13282	44262	13274	44261	8/24
Northern Edge (Scallop Survey Stratum 65): *Experiments 2, 3, 8 and 8a*									
578 I	639	63	37	15	12827	43862	12824	43862	8/25
579 II*	993	61	34	35	12824	43862	12830	43863	8/25
580 II*	1065	61	36	24	12830	43862	12824	43862	8/25
581 I	589	64	34	15	12825	43862	12830	43862	8/25
582 II*	650	61	38	34	12809	43850	12802	43849	8/25
583 I	8	64	40	5	12801	43849	12807	43849	8/25
584 I	190	72	41	10	12808	43851	12804	43848	8/25
585 II*	68	68	42	40	12802	43849	12808	43850	8/25
637 I*	965	60	37	27	12822	43862	12828	43862	8/28
638 II	812	64	38	19	12827	43862	12820	43862	8/28
639 II	31	68	37	2	12821	43862	12827	43862	8/28
640 I*	1203	61	38	11	12827	43862	12820	43862	8/28
641 II	1607	59	37	10	12825	43862	12825	43858	8/28
642 I*	532	57	37	7	12825	43857	12825	43861	8/28
643 I*	1283	58	37	24	12825	43861	12825	43857	8/28
644 II	532	64	37	11	12825	43858	12825	43862	8/28
Northern Edge (Scallop Survey Stratum 71): *Experiment 5*									
590 I	43	92	30	15	12944	43866	12949	43861	8/25
592 II*	50	105	26	21	12943	43866	12939	43871	8/25
593 II*	56	87	26	19	12937	43872	12941	43868	8/25
594 I	55	92	26	32	12942	43868	12936	43872	8/25

Appendix Table 1. Continued

B. COMPARISON TOWS WITH AND WITHOUT CHAINS ON HARD BOTTOM - CONTINUED

Station Number and Dredge Type	No. of Sea Scallops Caught	Mean Shell Height (mm)	Depth (fm)	Trash (bu)	LORAN C BEARINGS Start W	Start Y	End W	End Y	Date
Northeast Peak (Scallop Survey Stratum 64): *Experiment 4*									
586 I	23	77	44	9	12780	43820	12774	43820	8/25
587 II*	744	60	45	19	12773	43820	12778	43820	8/25
588 II*	115	78	45	22	12780	43820	12774	43820	8/25
589 I	192	67	45	15	12775	43820	12781	43820	8/25
South Channel (Scallop Survey Stratum 50) *Experiment 11*									
685 I*	236	75	31	21	13783	43669	13789	43669	8/30
686 II	113	78	32	18	13789	43669	13782	43669	8/30
687 II	391	76	32	27	13784	43668	13791	43667	8/30
688 I*	161	79	30	17	13790	43669	13783	43670	8/30
688 II	373	76	32	13	13777	43666	13779	43659	8/30
690 I*	237	73	31	14	13779	43660	13778	43665	8/30
691 I*	638	74	32	16	13777	43666	13779	43660	8/30
692 II	112	68	32	19	13778	43661	13778	43666	8/30
693 I*	317	77	28	25	13782	43687	13780	43693	8/30
694 II	94	77	30	25	13780	43691	13783	43686	8/30
695 II	95	78	28	30	13782	43687	13780	43693	8/30
696 I*	157	79	30	30	13781	43691	13783	43685	8/30

C. COMPARISON TOWS WITH AND WITHOUT CHAINS ON SAND BOTTOM

Station Number and Dredge Type	No. of Sea Scallops Caught	Mean Shell Height (mm)	Depth (fm)	Trash (bu)	LORAN C BEARINGS Start W	Start Y	End W	End Y	Date
Northeast Peak (Scallop Survey Stratum 64): *Experiments 6 and 7*									
619 II*	189	68	49	2	12875	43666	12875	43663	8/27
620 I	91	83	50	2	12875	43664	12875	43668	8/27
621 I	49	91	49	1	12874	43671	12874	43668	8/27
622 II*	63	86	50	2	12874	43671	12874	43675	8/27
623 I	79	86	48	2	12876	43668	12876	43664	8/27
624 II*	93	82	50	2	12876	43665	12876	43669	8/27
625 II*	54	94	50	2	12876	43669	12876	43665	8/27
626 I	35	79	49	2	12876	43665	12875	43669	8/27
629 I*	495	59	53	2	12791	43700	12784	43702	8/27
630 II	589	59	53	2	12786	43702	12792	43699	8/27
631 II	791	55	53	3	12792	43699	12786	43702	8/27
632 I*	607	67	53	2	12786	43701	12792	43699	8/27
633 II	1309	50	52	6	12790	43704	12785	43708	8/27
634 I*	645	61	52	4	12786	43707	12792	43703	8/27
635 I*	743	59	51	3	12791	43704	12785	43707	8/27
636 II	664	58	52	6	12787	43707	12792	43703	8/27
Southeast Part (Border of Scallop Survey Strata 59 and 60): *Experiment 10*									
675 II	56	76	41	7	13364	43505	13369	43505	8/29
676 I*	43	84	41	4	13369	43505	13363	43505	8/29
677 I*	66	80	41	5	13364	43505	13370	43505	8/29
678 II	63	81	41	6	13369	43505	13363	43505	8/29
679 I*	48	92	42	4	13366	43503	13372	43503	8/29
680 II	58	90	41	6	13371	43502	13364	43502	8/29
681 II	57	87	42	7	13366	43503	13371	43502	8/29
682 I*	61	88	41	6	13370	43503	13364	43502	8/29

Appendix Table 2: Summary of scallops and non-living trash catches by individual stations located on hard bottom.

Station Number and Dredge Type	# Scallops Caught	Total (bu)	TRASH CATCH Sand (bu)	Gravel (bu) <2"	Cobbles (bu) 2-6"	Rocks (#) 6-12"	Boulders (#) >12"
Fippennies Ledge							
571 I	219	6	0	0	3	55	1
572 II*	101	8	0	0	4	81	0
573 II*	496	6	0	0	1	34	2
574 I	329	8	0	0	1	36	2
Northern Edge							
578 I	639	15	3	0	11	4	1
579 II*	993	35	2	26	6	1	0
580 II*	1065	24	2	13	9	4	0
581 I	589	15	2	1	11	23	3
582 II*	650	35	3	1	27	15	1
583 I	8	5	0	0	4	30	1
584 I	190	10	1/2	0	16	18	0
585 II*	68	40	0	1	25	17	0
637 I*	965	27	3	3	20	20	0
638 II	812	19	2	3	12	18	0
639 II	31	2	1	0	2	4	0
640 I*	1203	11	5	1	4	0	0
641 II	1607	10	3	2	7	10	2
642 I*	532	7	2	2	3	6	0
643 I*	1283	24	8	2	12	10	0
644 II	532	11	2	0	8	11	0
590 I	43	15	8	10	0	0	0
592 II*	50	21	2	16	0	0	0
593 II*	56	19	4	13	0	0	0
594 I	55	32	5	25	0	0	0
Northeast Peak							
586 I	23	9	0	0	7	31	0
587 II*	744	19	1	0	16	34	1
588 II*	115	22	1/2	0	18	37	0
589 I	192	15	1/2	0	11	41	3
South Channel							
685 I*	236	21	1/2	0	16	12	5
686 II	113	18	0	0	10	33	7
687 II	391	27	0	0	18	32	6
688 I*	161	17	0	0	14	35	1
689 II	373	13	2	0	9	18	3
690 I*	237	14	1 1/2	0	11	39	1
691 I*	638	16	2	2	11	27	0
692 II	112	19	1/2	0	7	37	10
693 I*	317	25	1/2	0	19	112	11
694 II	94	25	0	0	13	71	13
695 II	95	30	0	0	13	64	40
696 I*	157	30	0	0	17	107	4

Average number of cobbles per bushel by area

Fippennies = 44/bu (N=4)
Northern Edge =164/bu (N=16)
Northeast Peak = 68/bu (N=4)
South Channel = 54/bu (N=1)

(N = number of samples)