BIOLOGICAL EFFECTS ON HARD CLAMS OF HAND RAKING AND POWER DREDGING

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By

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Fishery Research Biologists

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BIOLOGICAL EFFECTS ON HARD CLAMS OF HAND RAKING AND POWER DREDGING

By

John B. Glude and Warren S. Landers [1]

Narragansett Bay, Rhode Island, has supported an intensive commercial fishery for the hard-shell clam, *Venus mercenaria*, known locally as the quahaug or quahog, for many years. Hand diggers, using tongs or bull-rakes, are allowed to fish in any unpolluted waters in the State. Power dredgers have been restricted to the southern half of the Sakonnet River except for a short time during World War II when additional areas were opened to increase food production. Locations of fishing areas are shown in Figure 1.

Controversies continually arise between fishermen using power methods and those who harvest the clams by hand. Rakers and tongers claim that they are using the only methods which do not harm the bottom or destroy young clams. They claim the dredges tear up the bottom, breaking many of the clams which are caught as well as those which go through the bag of the dredge and are left to die. They also believe the dredges bury the small clams so deeply that they are smothered, and that the bottom is sometimes plowed to such an extent that current action causes scouring which prevents a new "set" from surviving.

Dredgers claim that they are merely cultivating the bottom and preventing it from becoming too compact for the clams to live. Dredging, they state, really improves the bottom, inducing new sets and increasing the growth rate of those clams which are left.

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Note.....The authors wish to acknowledge the valuable assistance of Dr. Charles J. Fish in planning the experiment, and the cooperation of the Narragansett Marine Laboratory in providing equipment and laboratory space. David W. Calhoun suggested methods for statistical analysis. Dr. Geoffrey Beall reviewed the statistical analysis involving transformations and offered many helpful suggestions. Louis D. Stringer, Fishery Research Biologist, U. S. Fish and Wildlife Service, prepared most of the illustrations for this paper. Thomas F. Kane, Fishery Aid, U. S. Fish and Wildlife Service, collected much of the field data.

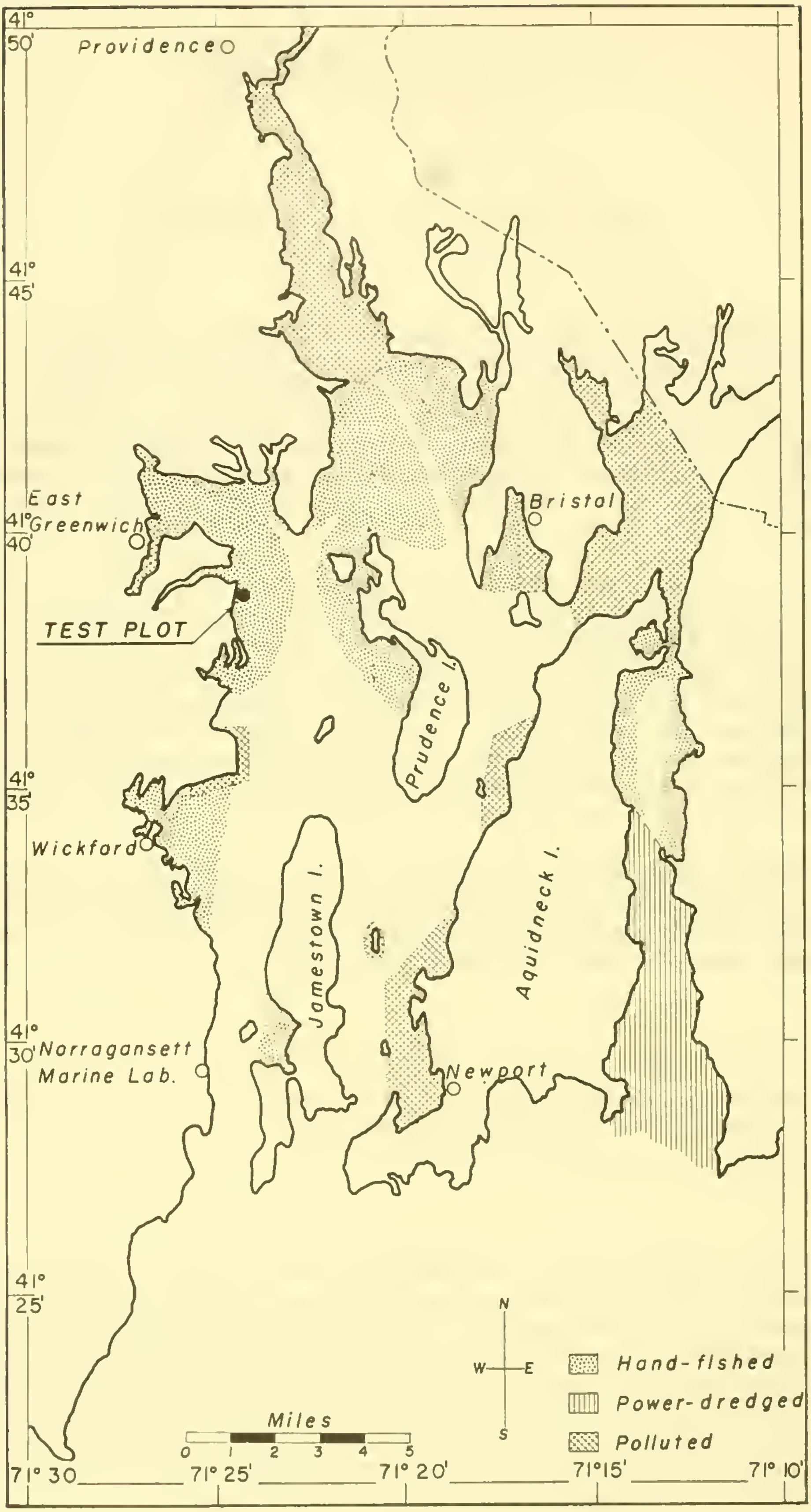

Fig. 1. Narragansett Bay, R. I. showing location of hard clam fishery and test plot.

The Division of Fish and Game of the Rhode Island Department of Agriculture and Conservation has the responsibility of enforcing laws regulating areas which may be fished by dredging as well as the dredging catch limit of 30 bushels per day. Difficulties in enforcing these laws, the dredgers' demands for additional areas, and controversies between power and hand diggers resulted in a request by the Division of Fish and Game that the Fish and Wildlife Service investigate the problem. Since this controversy has been encountered in other States, it was decided that the Service should undertake an experiment to determine the relative biological effect of power-dredging and hand-raking upon a population of hard-shell clams. The Division of Fish and Game agreed to close an experimental area and to patrol it to prevent illegal fishing. The Narragansett Marine Laboratory of the University of Rhode Island agreed to furnish office and laboratory space and to share the expenses of operating a research boat. The Fish and Wildlife Service agreed to conduct the experiment, analyze, and publish the results.

FISHING METHODS

Fishermen bullrake from flat-bottomed skiffs about 16 feet long. The rake, sometimes called a Shinnecock Rake, is about 36 inches wide and has about 30 teeth with 7/8-inch spaces between. The teeth are curved on about a 4-inch radius so the rake will dig about 8 inches deep (Fig. 2). The handle or stale is in sections and may be increased to about a 36-foot length for digging in waters 25 feet deep. Although the maximum depth for raking is about 40 feet, most is done at less than 20 feet. The fisherman pulls the rake through the bottom in a series of short jerks, occasionally bringing it to the surface to empty the catch into the boat. About 1,400 fishermen are licensed in Rhode Island to catch clams by hand-digging methods, and about half of these use bull-rakes.

The maximum catch per day for rakers is about ten 80-pound bushels, but the average is only about 4 bushels. The price depends upon the size composition of the catch. Rakers prefer to catch "little necks" which range in size from the legal minimum of 1 1/2-inch width (47-48 mm. length) to 2-inch width (60 mm. length) since the price for these averages $5.00 to $6.00 per bushel compared to $2.50 to $3.50 per bushel for larger clams. Clams over 2-inch width are known to the fishermen as "mediums", "large", or "chowders", although dealers establish additional size groups.

Fishermen tong from flat-bottomed boats similar to those used in raking. The tongs are similar to those used for oysters but are modified to dig through the bottom to remove the clams. Stales (handles) are usually no longer than 15 feet, which allows digging in water about 12 feet deep, although 18-to 20-foot stales are sometimes used in water 15 to 16 feet deep. Because this type of fishing is less strenuous than bullraking it is the method used by the older fishermen, although most fishermen use tongs where the water is shallow. The tongs catch clams of the same size range as rakes. The maximum catch per fisherman in 80-pound bushels is about 5 per day, and the average is about 3.

Fig. 2. Bullrakes are used by about half of Rhode Island's 1,400 "hand" diggers.

The dredge, sometimes called the "Fall River" or "Nantucket" dredge, consists of an iron frame with a row of teeth spaced 2 inches apart which dig the clams from the bottom. The bag which holds the catch is made of 2-inch iron rings (Fig. 3). The dredge is used primarily for catching clams of the large or chowder size.

Dredge boats which range from 30 to 45 feet in length require masts, booms, winches and powerful engines for dragging the dredge through the bottom. A crew of two is normally required. Boats dredge in water as deep as clams occur and as shallow as the draft of the boat will permit. They can operate in weather which would be too rough for hand-digging. The daily catch in Rhode Island is limited to 30 bushels per boat, but this amount can only be attained for a short time after the opening of the season in the southern part of the Sakonnet River. The dredging season is from December 1 to March 31. Rhode Island has about 24 licensed dredge boats, although at the maximum of the fishery in 1943-1945, 46 boats were engaged.

METHODS FOR CONDUCTING THE EXPERIMENT

The Highbanks area between Quonset Naval Air Station and Greenwich Bay was found to be suitable for the experiment after examination of stations throughout Narragansett Bay. The depth of the plot selected was about 20 feet and the bottom was firm sandy mud. Samples dredged with a small mesh liner inside the bag showed clams of all sizes were present (Fig. 4). We discussed the experiment with the dredgers and with the hand-diggers and both groups gave their approval.

The test plot was divided into three tracts with areas to be dredged and bullraked separated by an unfished control tract as shown in Figure 5. Each test area was divided into quarters, but a different arrangement was necessary in the two areas since dredging required a long tract, whereas a square plot was more suitable for raking. Corresponding quarters in the bullraked and dredged areas were fished simultaneously during each summer to determine the effect of digging upon the new sets of clams.

Bullraking Operations

We employed two commercial bullrakers to fish Area B. Each digger sold his catch and in addition received enough remuneration to make his wages equal to those he would have received had he fished wherever he desired. This total wage was based upon catch records from commercial bullrakers in the area. In 1949 the diggers raked in each quarter until their individual daily catch fell to a pre-established minimum value of $5.00; then they began a new quarter. In 1950 the catch of larger clams per day began at a lower level than in 1949 and termination of fishing in each quarter could not be based on the minimum catch value used in 1949. Bullraking was therefore continued in each quarter for approximately a two-week period. Digging occurred during the periods from

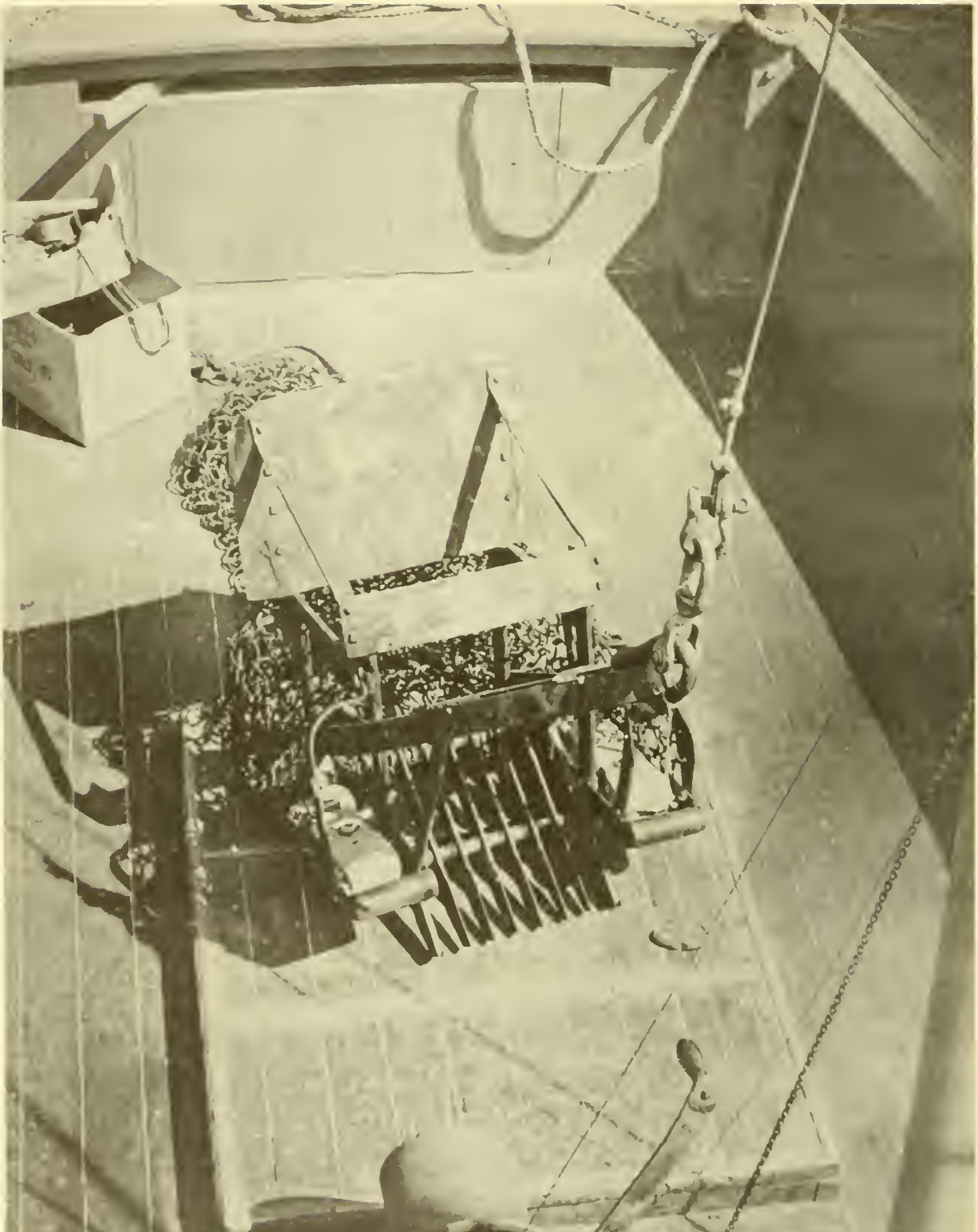

Fig. 3. Hard-shell clam dredges are operated from 30 - 45 foot power boats in the southern half of the Sakonnet River.

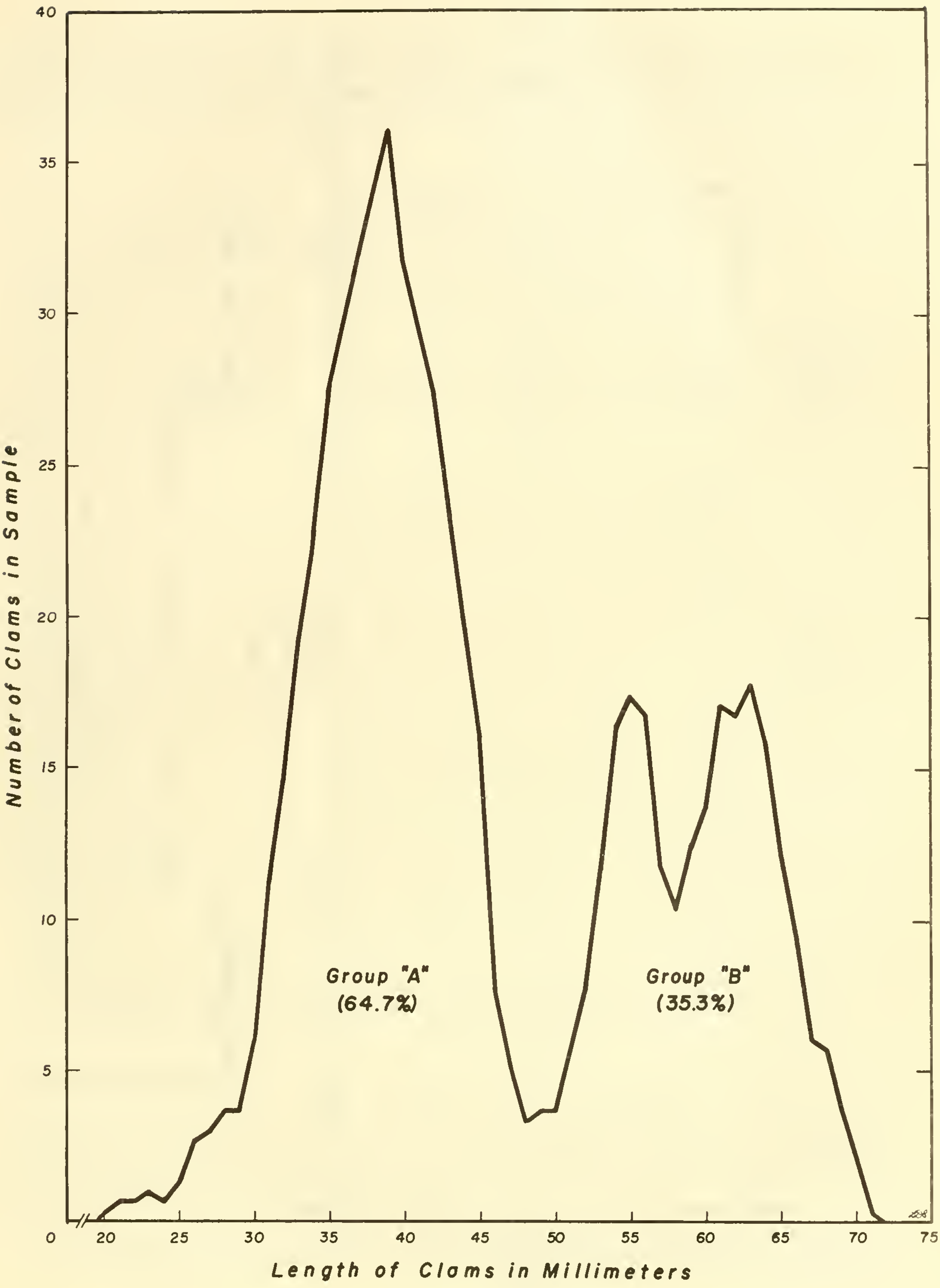

Fig. 4. Size distribution of 640 clams from test plot May 6, 1949 - before experiment. Data smoothed by moving average of 3's.

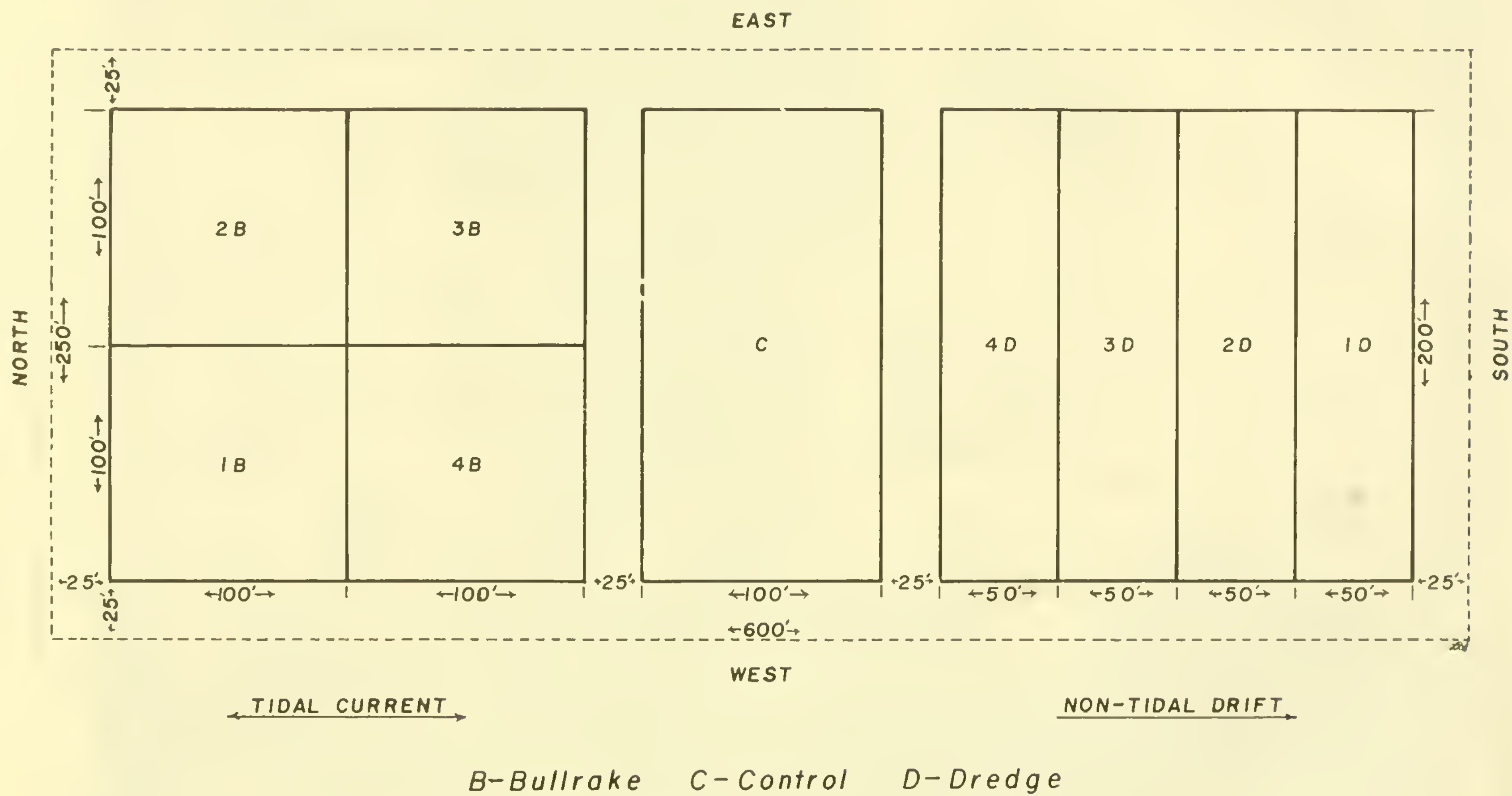

Fig. 5. Plan of dredging vs. raking test plot.

July 14 to September 30, 1949, and July 5 to September 7, 1950. A biologist was always present to obtain records of catch, size and breakage of clams. Table 1 shows the amount of clams removed from each quarter by bullraking during the experiment.

Table 1

Pecks of Clams Removed From Each Quarter 1949 and 1950 by Bullraking and Dredging

Quarter	Fishing Method *	1949 Catch in Pecks Over 60 mm.	1949 Catch in Pecks Under 60 mm.	1950 Catch in Pecks Over 60 mm.	1950 Catch in Pecks Under 60 mm.
1	B	18.0	29.75	30.5	90.5
1	D	18.0	-	27.0	-
2	B	58.75	79.0	25.0	45.5
2	D	58.0	-	28.0	-
3	B	51.0	58.0	15.25	44.25
3	D	50.5	-	15.25	-
4	B	27.5	54.5	4.75	21.0
4	D	28.5	-	7.25	-
Total	B	155.25	221.25	75.5	201.25
Total	D	155.0		77.5	

* B = Bullrake; D = Dredge

Dredging Operations

The boat "Lil-Joy" chartered by the Narragansett Marine Laboratory dredged Area D in 1949, using an 8-tooth commercial dredge. In 1950 the Fish and Wildlife Service chartered the boat "Marie" with a 12-tooth dredge to fish the experimental area.

The size and shape of the quarters of the test plot made it impossible to dredge in circles as is done commercially. In the experiment the dredge was dropped at the border of the tract, pulled the length of the quarter, and then lifted clear of the bottom. The boat then turned to make another pass across the area. After several drags the dredge was lifted aboard, the catch removed, counted, and measured, and the breakage recorded.

Dredging continued in each quarter until the same quantity of clams over 60 mm. in length had been obtained as from the corresponding quarter of the bullrake area (Fig. 5). The length of 60 mm. was chosen because it represented about the smallest size caught in any quantity by the dredge. Actually, more clams were removed from the bullraked area than from the dredged area since the rakes caught most of the clams above 45 mm.

Table 1 shows the amount of clams removed from each quarter by dredging during the experiment.

Underwater Photography

Woods Hole Oceanographic Institution took underwater photographs of the bottom after digging had been completed in 1949. Seven pictures were taken in each quarter of the two test areas and 14 in the control. The photographs included a total of 2,520 square feet of the bottom, or 2 1/2 percent of the total area of the plot. Unfortunately, due to technical difficulties, many of the pictures were unsatisfactory. Enough were usable, however, to demonstrate that this method can be a practical tool for assessing bottom surface conditions if operational difficulties are overcome.

Bottom Samples

We obtained bottom samples with a 2 1/2 cubic foot clamshell bucket each autumn after fishing had been completed (Fig. 6). This bucket sampled an area of 5 square feet to a depth sufficient to remove all of the clams. After the bucket was lifted aboard with the winch, a 6" x 6" x 2" subsample was removed and screened through a twelve-mesh-per-inch plastic screen to recover the tiny clams. The main sample was dumped into a box with a 5/8 inch screen bottom and the mud washed through with a fire pump. The quahaugs were counted and measured and returned to the water outside of the test plot.

Sampling in 1949 included 28 grabs in each of the three areas although only 24 of the samples in the control area were usable. The remaining four samples in the control area were incomplete as the bucket apparently landed on edge and came up partially filled. Seven samples were taken in each quarter of each area and were roughly spaced to cover the quarter. Difficulties in establishing exact location of stations because of tide, wind, etc., helped to randomize sampling.

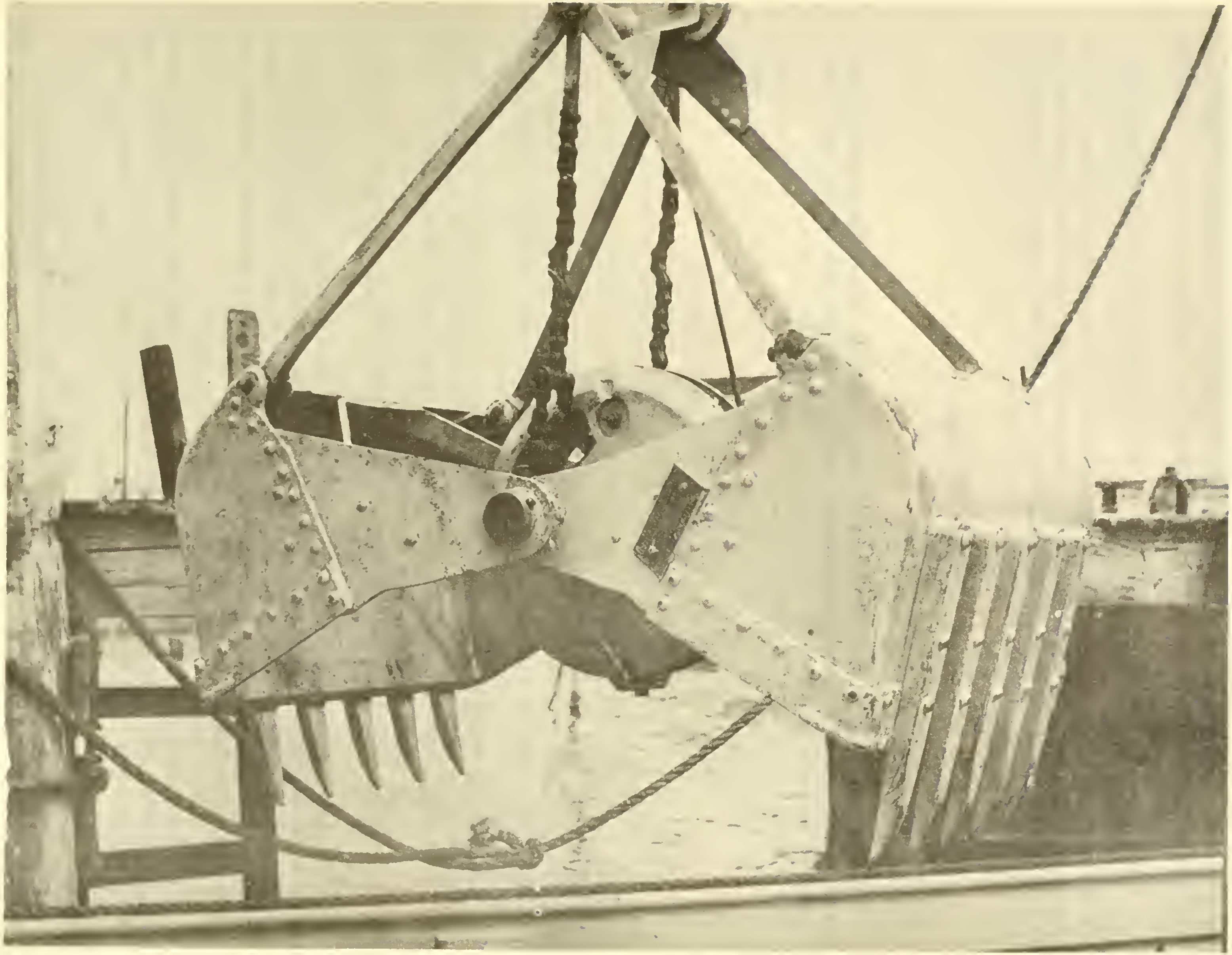

Fig. 6. Clamshell bucket samples five square feet of bottom.

The 1950 sampling included 100 grabs each in the bullraked, dredged and control areas. Sampling was randomized by allowing the boat to drift across the area with the wind or tide as samples were taken. This process was repeated until the required number of samples had been obtained.

We first planned to take only 50 samples from the control area in 1950. However, this series showed such a marked decrease in number of clams compared to the 1949 census (11.86 to 7.03 per sample) that another series of 50 samples was taken. The second series confirmed the results of the first by showing an average of 7.71 clams per sample. (Appendix C)

ANALYSIS OF RESULTS

Breakage of Commercial-Sized Clams

Breakage records for dredging shown in Table 2 are for clams above 60 mm. in length, whereas bullraking records include clams as small as 45 mm.

Table 2

Breakage of Commercial-Sized Clams by Bullraking and by Dredging in Test Plot

	1949	1950
Bullraking	0.1% 1/	0.3% 2/
Dredging	1.2%	0.7%

1/ Most of breakage caused by handling.
2/ 0.02% gear breakage; balance from handling.

The gear caused most of the breakage in the dredging operation, whereas in raking the breakage was mostly from handling the catch. The difference in size composition of the catches probably resulted in greater breakage in handling for the hand-digging operation since the smaller clams are more fragile.

Narragansett Marine Laboratory conducted a population survey of hard-shell clams in Narragansett Bay during the summers of 1949 and 1950, using an 8-tooth commercial dredge. Records of this survey show average breakage of 1.0% in bottoms without rocks and 2.9% in bottoms with rocks. The bottom in our test plot is uniformly sandy-mud without rocks; thus the breakage there agrees closely with that reported by the Narragansett Marine Laboratory. The maximum breakage reported in the survey of the Bay was 21.1% at one station where the bottom was mud with rocks and shells, although at two other stations having bottoms in the same category no breakage was observed (Pratt, 1950).

Breakage of Undersized Clams

We examined broken shells in bottom samples to determine the breakage of clams below the legal size of 47-48 mm. length. We found no evidence that this breakage was important in either test area, nor was there evidence of extensive breakage of clams below 60 mm. which had been left in the dredge area.

Smothering

Fishermen thought that one or both types of fishing might stir up the bottom to such an extent that some clams would be buried beyond the depth at which they could survive. Observations during the bottom sampling revealed very few recently dead clams in either plot, thus, in this experiment neither type of fishing caused significant smothering mortality to those clams left on the beds.

Effect of Fishing Upon Setting and Set Survival

Each experimental plot was divided into quarters which were fished successively during the summer to detect the effect of fishing at different times in relation to setting. Unfortunately, practically no setting of clams occurred in the test plot during 1949 or 1950, and therefore no results were obtained. Bottom sampling in 1949 obtained a total of seven spat in the control area, five in the bullrake area, and six in the dredge area. No spat were found in 1950.

Effect of Fishing Upon the Physical Characteristics of the Bottom

We examined bottom samples each year for evidence of silting, scouring and mixing. Surface conditions were practically identical in the test areas and in the control one to three months after fishing. This was substantiated by the underwater photographs. The top one to two inches of soil was uniformly yellow mud or silt throughout the test plot. Below this was a 5-6 inch layer of black sandy mud in which the clams live, and below that clay which supported no life. The general appearance of these layers was similar in all three areas in 1949 but in the two test areas the clay and sandy-mud layers were mixed more than in the control. No difference in extent of mixing was observed in clamshell bucket samples from the dredged and from the raked areas. In 1950 the control area showed more mixing of the clay and sandy-mud layers than it had in 1949, although mixing in the fished areas was still more pronounced than in the control.

The bullraked area seemed to be softer than the control, whereas the bottom in the dredged area varied in compactness from firm as the control, to soft as the bullraked area. The firm spots were probably places which had been missed by the dredge. The odor of decomposition was greater in the control than in either test area; probably because less mixing occurred there than in the fished areas.

Effect on Other Bottom Forms

Bottom samples in the control area contained the following species in addition to the hard-shell clam, *Venus mercenaria*:

Common name	Species	Remarks
Amphipod	*Ampelisca macrocephala*	Abundant in places; lives in mud tubes.
Tube worm	*Cistenides gouldi* (Verrill)	This Polychaete was very abundant.
Worm	*Clymenella torquata* (Leidy)	This Polychaete was very abundant in surface layer.
Clam worm	*Nereis virens* (Sars)	Infrequent.
Worm	*Amphitrite* sp.	Infrequent.
Soft-shell clam	*Mya arenaria* (Linne)	About two dozen up to 2" in length found in clam-shell bucket samples; some recently dead.
Little surf clam	*Mulinia lateralis* (Say)	Many shells, but few live specimens.
Starfish	*Asterias forbesi* (Desor)	Some shown in underwater photographs.
Borer or drill	*Eupleura caudata* (Say)	Common.
Scallop	*Pecten irradians* (Lamarck)	Some shown in underwater photographs.
Clam	*Nucula proxima*	Abundant.
Delicate tellin	*Tellina tenera* (Say)	Common.
Boring clam	*Petricola pholadiformis* (Lamarck)	Infrequent.
File yoldia	*Yoldia limatula* (Say)	Common.

Bottom samples and underwater photographs in the bullraked area indicated fewer living forms than the control. Decrease in the number of tube worms, Cistenides, was especially noted.

Bottom samples and underwater photographs in the dredged area showed a decrease in living forms similar to that observed in the bullraked area. On the basis of these observations no difference was noted in the effect of the two fishing methods on bottom forms associated with the hard clams.

Size Composition of Catch

Figure 7 presents a comparison of the size composition of the catch by raking and dredging. Maximum efficiency indicated by a catch efficiency ratio of 1.0, is reached when clams are too large to pass between the teeth of a rake or through the mesh of a dredge bag. Methods used to determine "catch efficiency ratio" are described in Appendix B.

Bullraking reaches its maximum efficiency for clams about 55 mm. long, but catches a portion of the clams between 36 and 55 mm. Some of these smaller clams represent those whose length is greater than the space between the teeth of the rake but whose width is less than this space. If these clams land on their sides they are retained, but if they land on end they pass between the teeth of the rake. A few clams which would normally pass between the teeth are retained among the larger clams or by clumps of mud brought up by the rake.

The dredge reached its full efficiency at about 70 mm. but caught some of the clams between 35 and 70 mm. The zone of partial efficiency is greater for the dredge than for the bullrake for two reasons. First, more mud, shells and debris are retained in the bag of the dredge than in a rake and these trap many small clams which otherwise would have passed through the bag. This explains the large radius of the lower part of the dredge efficiency curve in Figure 7. Second, the size at which clams are retained is determined by the size of the rings in the bag and also by the space between the rings. The space between the rings varies with the size of links used to fasten the rings together. Since a clam may often go between the rings instead of through the rings the zone of partial efficiency is extended.

Size Composition of Clams Left in Plot

Figures 8 and 9 show the size composition of the clam population left in the dredged area after each year's fishing. The dotted line in Figure 8 shows the original population in the dredged area as determined by adding those removed by 1949 fishing to the population shown by bottom samples after the dredging had been completed. Figures 10 and 11 show similar information for the bullraked area.

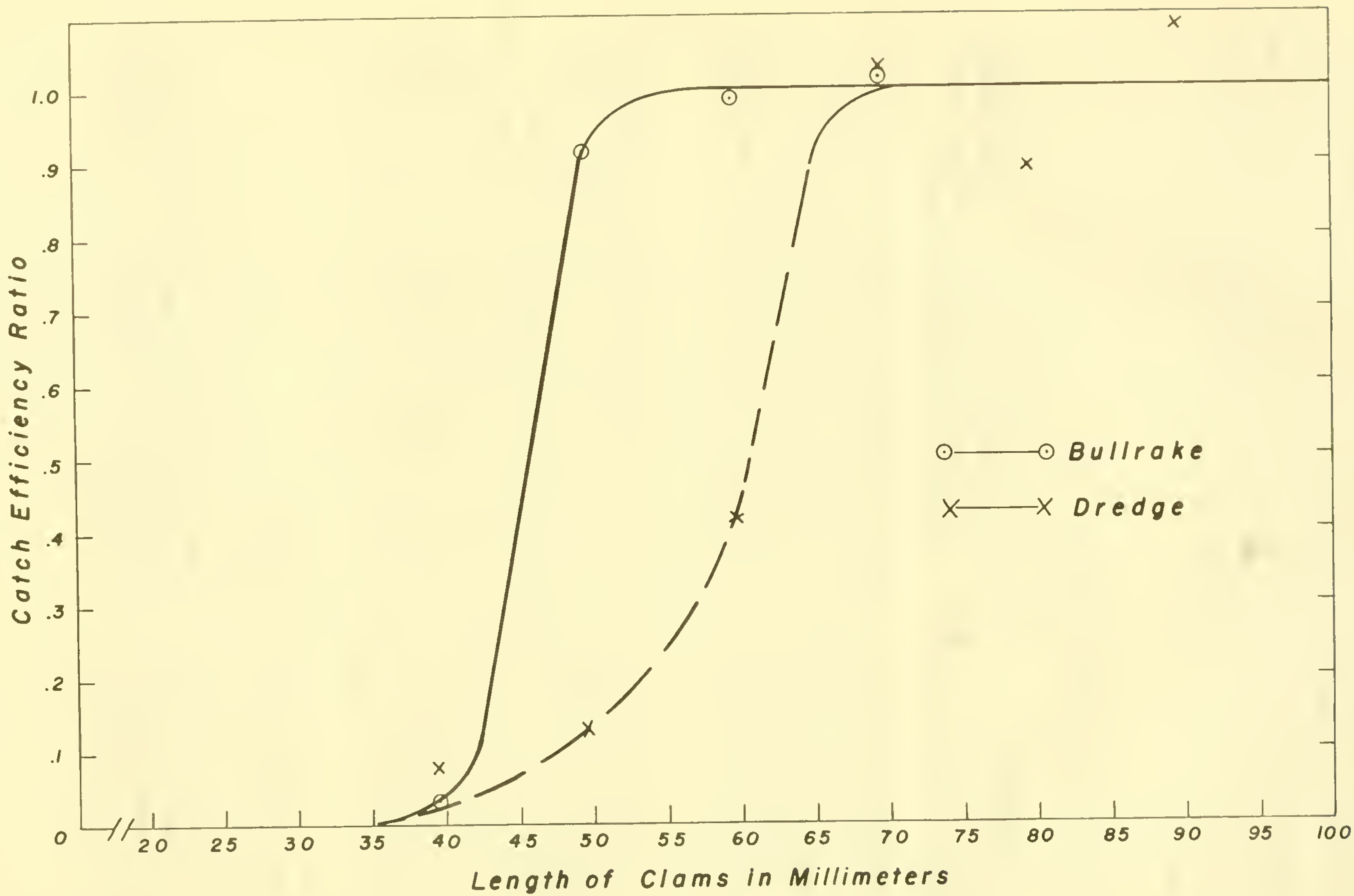

Fig. 7. Size composition of catch by bullraking and dredging in relation to available population. Catch efficiency ratio of 1.0 indicates maximum efficiency of the gear.

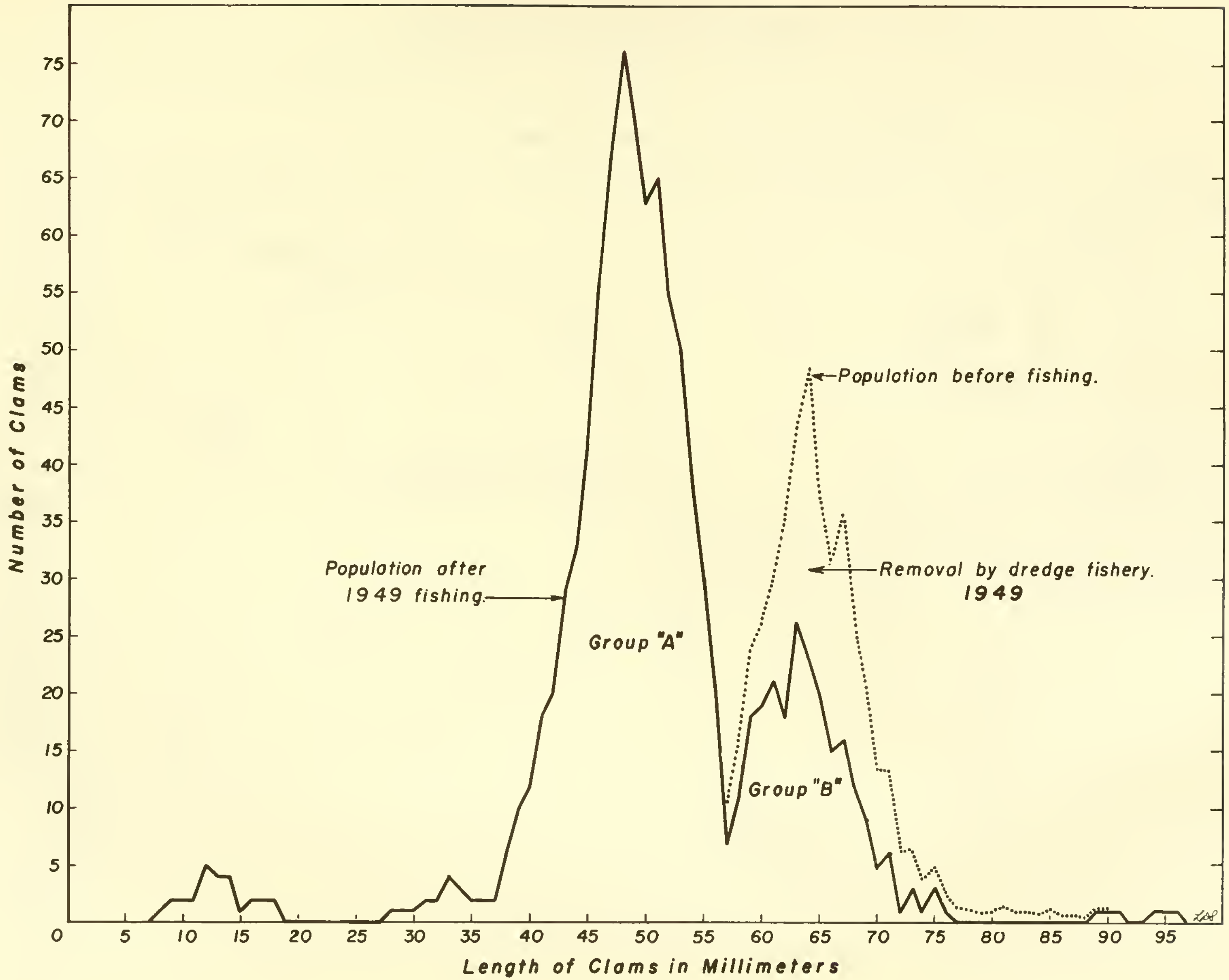

Fig. 8. Size distribution of clams in 500 square feet of bottom from dredged area before and after 1949 fishing. Difference between dotted and solid lines shows removal by dredge fishery. Population after fishing is based on 28 clamshell bucket samples taken Nov. 18, 1949, increased to 100 for comparison with Figure 9. Data smoothed by moving average of 3's.

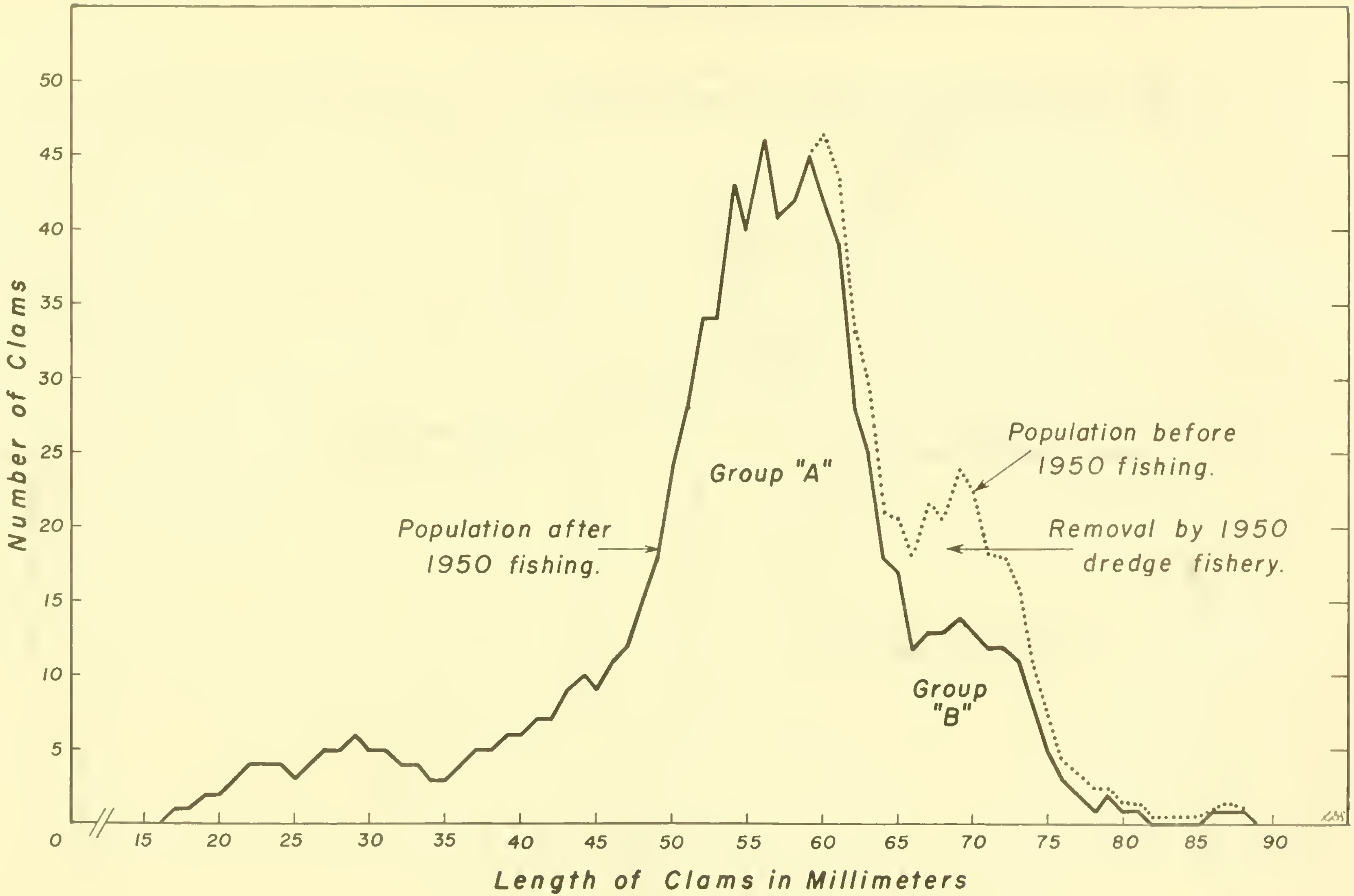

Fig. 9. Size distribution of clams in 500 square feet of bottom from dredged area before and after 1950 fishing. Difference between dotted and solid lines shows removal by dredge fishery. Population after fishing is based on 100 clamshell bucket samples taken Oct. 19 and 20, 1949. Data smoothed by moving average of 3's.

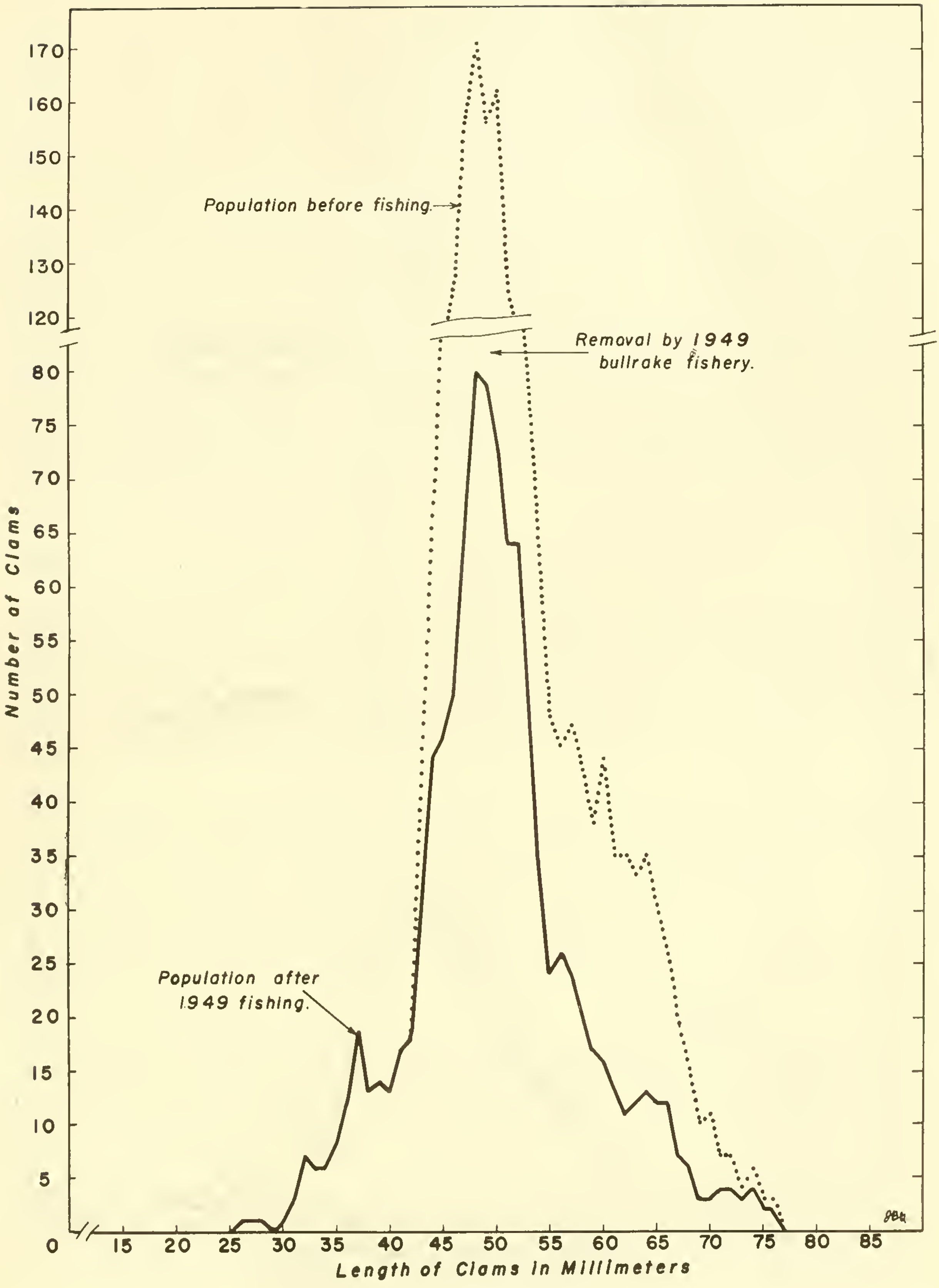

Fig. 10. Size distribution of clams in 500 square feet of bottom from bullraked area before and after 1949 fishing. Difference between dotted and solid lines shows removal by bullrake fishery. Population after fishing is based on 28 clamshell bucket samples taken Dec. 15, 1949, increased to 100 for comparison with Figure 11. Data smoothed by moving average of 3's.

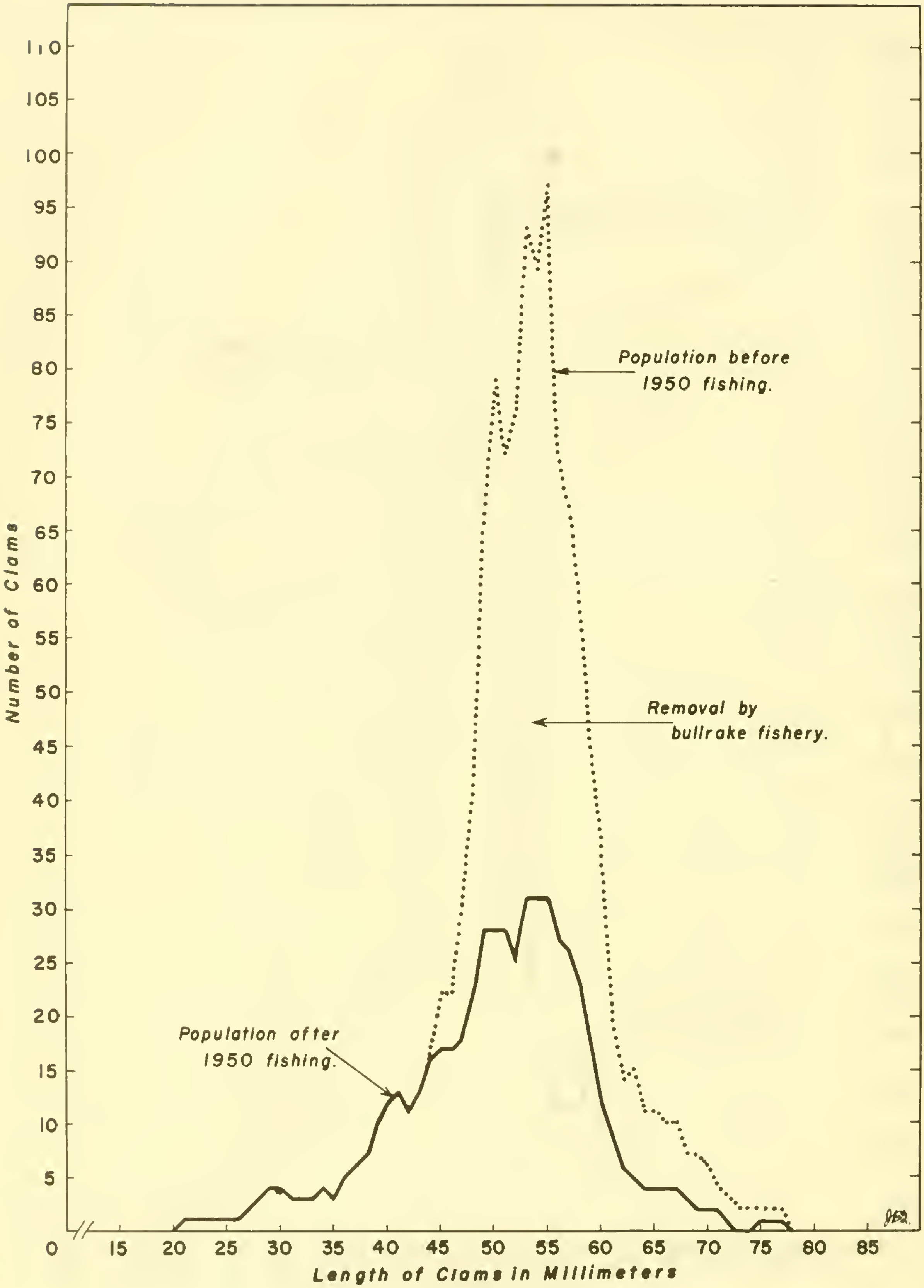

Fig. 11. Size distribution of clams in 500 square feet of bottom from bullraked area before and after 1950 fishing. Difference between dotted and solid lines shows removal by bullrake fishery. Population after fishing is based on 100 clamshell bucket samples taken Sept. 6-13, 1950. Data smoothed by moving average of 3's.

The dotted line representing those clams removed by bullraking begins slightly below 45 mm. instead of just under 60 mm. as in the dredge area which reflects the difference in the size composition of the catch by the two methods as previously shown in Figure 7. Appendices A and C give tables used in preparing Figures 8 - 11. Appendix C presents statistical analyses for estimating sampling reliability.

It would be desirable to know whether it is better to remove only large clams as dredging does, or to remove both large and small clams as raking does. The present experiment, however, does not provide an answer to this question, nor was this an original objective. We know that a spawning stock must be left, but the magnitude of this stock and its size composition has not yet been established. Further information is needed on the annual mortality from causes other than man before we can decide if growth from little neck to medium size will increase the yield sufficiently to offset mortality. Economic considerations such as the price differential between little necks and mediums would affect a decision on the best method of harvesting hard clams, but these factors are beyond the scope of the present investigations.

Disappearance of Group "B" in Control and in Bullraked Areas

Figures 12 and 13 show the size composition of the population in autumn 1949 and 1950 in the control area. A great change occurred in this area even though we removed no clams. The group of clams from 30 to 56 mm. in Figure 12, which we will designate as Group "A", decreased 19.0% by 1950 as determined from clamshell bucket samples. The larger group from 57 to 75 mm. in 1949, which will be known as Group "B", decreased 70.5% by 1950. The combined groups had a loss of 35.7%.

The original presence of Group "B" is substantiated by sampling of the test plot in May 1949 with a dredge equipped with a liner in the bag to retain small clams. At that time this group ranged from 52 to 70 mm. and comprised 35.3% of the total as shown in Figure 4. In the November 1, 1949, survey (Fig. 12), Group "B" had grown to 57-75 mm. and included 30.3% of the total. By November 8, 1950 (Fig. 13) it had grown to 64-79 mm. but contributed only 13.4% of the population. Duplicate sampling in 1950 substantiated the disappearance of Group "B" as shown in Appendix C.

Statistical analyses of the differences in mean number of clams per sample between 1949 and 1950 showed the probability of this difference occurring by chance is less than one time in 100. (Appendix C) This means there was a real difference in the population of the control area in the two years; that this difference was not due to sampling error.

During this same period Group "B" had largely disappeared from the bullraked area also. Catch measurements of clams bullraked from each of the four quarters in 1949 showed the presence of this larger group. Bullraking was completed September 30, 1949. The clamshell bucket census of

Fig. 12. Size distribution of clams in 500 square feet of bottom from control area Nov. 1, 1949. Based on 28 clamshell bucket samples increased to 100 for comparison with Figure 13. Data smoothed by moving average of 3's.

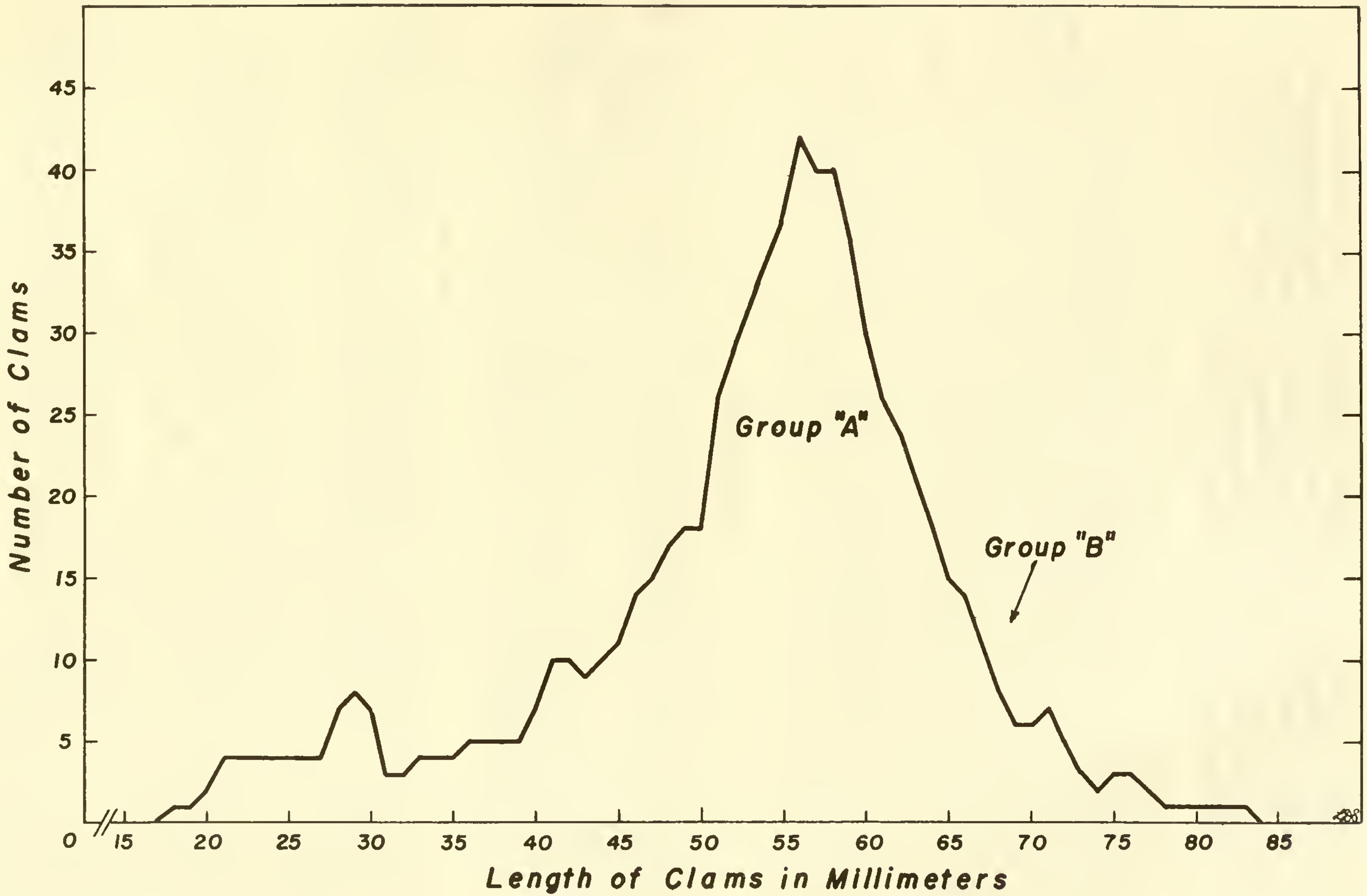

Fig. 13. Size Distribution of clams in 500 square feet of bottom from control area Oct. 20, Nov. 1 and 8, 1950. Based on 100 clamshell bucket samples. Data smoothed by moving average of 3's.

the bullraked plot was taken December 15, 1949. Group "B" was not indicated by the sampling (solid line, Fig. 10). Catch measurements of clams bullraked from each of the four quarters during 1950 also indicated the absence of Group "B" which substantiated the results of the 1949 clamshell bucket census. The 1950 clamshell bucket census taken September 6-13 also showed no peak for Group "B" (Fig. 11).

One explanation for the disappearance of Group "B" in both bullraked and control areas is illegal fishing. Catch measurements from quarter 4-B had shown that group was present as late as September 30, 1949, in the bullraked area. Clamshell bucket sampling in the control area showed Group "B" was present on November 1, 1949. Clamshell bucket samples December 15 in bullraked area showed Group "B" was absent. If illegal fishing occurred it must have been between November 1 and December 15, 1949.

Reports by shore residents confirm the theory that illegal fishing occurred in the Highbanks area during autumn 1949.

The dotted line in Figure 10 would then indicate a lower original population than actually existed. This line would be low by the amount of clams illegally fished from the sampled area.

CONCLUSIONS

1. The objective of the present experiment was to determine the relative biological effects of power-dredging as compared with hand-digging on a population of hard-shell clams. The use of the term "biological effects" should be emphasized since we made no attempt to investigate the economic, sociological, or legal phases of this problem. Therefore, the information presented in this report must not be considered as the final answer to the power vs. hand-digger controversy, but rather as information on the biological phase alone.

   Because of the time, effort and expense involved, it was possible to conduct this experiment in only one location. Care must be taken therefore, in applying the results to all areas. Likewise, the fishing methods used followed a set pattern necessitated by the size of the test area. Deviation from these fishing methods might also modify the results.

2. Fishing operations during the summers of 1949 and 1950 demonstrated the differences in size composition of the catch. Dredges removed principally those clams above 60 mm. in length, whereas bullrakes caught most of those above 45 mm. The effect of this difference on the population over a long period of time is not known.

3. Underwater photographs failed to show any difference in the surface condition of the two fished sections of the plot. Both parts appeared similar to the control area. The unsatisfactory nature of many of the pictures prevented their use as a positive criterion for comparing the two fishing methods.

4. Bottom samples confirmed the indications of the underwater photographs that surface appearance of the three areas was similar. Mixing of the sandy-mud layer and the underlying clay was more pronounced in both fished areas than in the control. Fished areas were also softer and had less odor of decomposition than the control. No difference in the above physical characteristics was observed between dredged and bull-raked sections.

5. Breakage of commercial-sized clams was recorded during the experimental fishing. Bullraking operations broke about 0.1% of the clams above 45 mm. but most of this breakage was from handling. Dredging broke about 1.0% of the clams above 60 mm. in length. Even though dredging breakage was 10 times that of raking, it is still extremely low in this sandy-mud bottom, and is not considered to be important. The observations of Narragansett Marine Laboratory agree with our records for this type of bottom, but list dredge breakage of 2.9% in rocky bottoms. In one instance, 21.1% breakage was observed in a rocky-shelly bottom.

6. Breakage of undersized clams by raking and dredging was found to be negligible in the sandy-mud of the test plot, but this might not be true in rocky or shelly ground.

7. Observations of recently dead clams made during bottom sampling showed no evidence of significant mortality in either fished area.

8. No setting occurred on the test plot during the summers of 1949 and 1950. Therefore, no observations could be made on the effect of fishing upon setting and set survival.

9. Bottom samples and underwater photographs indicated fewer living bottom forms in the test areas than in the control. Decrease in number of tube worms, Cistenides, was especially noted. No difference was shown in the effect of dredging and raking on bottom forms associated with the clams.

10. The disappearance of 35.7% of clams in the control area from 1949 to 1950 has been demonstrated by statistical analyses. A similar disappearance of the larger group of clams occurred in the bullraked section between September 30 and December 15, 1949. Natural mortality could not have caused this loss or shells would have been found in bottom samples. It is therefore concluded that these clams were removed by illegal fishing.

11. This experiment shows no biological basis for restricting either method of fishing.

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APPENDIX "A"

Size Composition of Population Before and After Fishing

Table 3 shows the length frequencies of clams in 500 square feet of bottom in each area in autumn 1949 and 1950 as determined from five-square-foot bottom samples taken with a clamshell bucket.

Frequencies for 1949, which were based on 28 samples, have been multiplied by 3.57 to make them comparable with frequencies for 1950 when 100 samples were taken. Frequencies in Table 3 smoothed by a moving average of 3's are plotted as solid lines in Figures 8, 9, 10, 11, 12 and 13.

Table 3

Length Frequencies of Clams remaining in 500 square feet of Bottom after Raking and Dredging 1949 and 1950; Control was Unfished.

Length	Bullraked Area		Control		Dredged Area	
in mm.	1949	1950	1949	1950	1949	1950
9			4			
10						
1			4		7	
2						
3					7	
4			4		4	
5			4			
6						
7				1	7	1
8						2
9			4	2		1
20		1		2		3
1				3		2
2		1		6		4
3		1	4	4		6
4		2	4	3		3
5				6		2
6		2		3		4
7	4	2	7	4		5
8		2	4	4		6
9		6	4	13	4	4
30		3		6		8
1	4	3		1		3
2	4	3	7	2	7	5
3	14	4		5		3
4		2	4	4	4	4
5	4	5	4	3	4	3
6	21	2		4		2

Table 3 (Continued)

Length in mm.	Bullraked Area		Control		Dredged Area	
	1949	1950	1949	1950	1949	1950
37	11	8		7	4	7
8	14	7	4	3	4	5
9	14	7		5	11	3
40	14	16	7	6	14	9
1	11	12	11	11	11	7
2	25	10	25	12	29	6
3	39	12	25	8	21	8
4	32	17	39	7	36	12
5	61	18	43	15	43	10
6	46	17	39	10	46	6
7	64	15	46	18	79	17
8	93	23	61	18	75	12
9	82	29	57	16	75	16
50	61	32	46	21	61	25
1	75	22	89	18	54	30
2	57	29	75	38	79	28
3	61	24	50	30	32	43
4	21	39	43	30	39	31
5	21	29	43	44	43	55
6	29	26	7	37	7	35
7	29	27	11	44	11	48
8	14	25	11	40	7	39
9	18	17	29	35	14	40
60	18	13	29	32	32	55
1	11	7	21	23	11	32
2	14	6	21	24	21	31
3	7	6	21	25	21	20
4	14	4	25	14	36	24
5	18	3	32	16	11	10
6	4	4	18	14	14	16
7	14	5	25	11	21	11
8	4	2	29	9	14	13
9		3	11	3		15
70	4	2	11	7	14	14
1	4	2	18	7		9
2	4	1	14	6	4	13
3	4		11	1		13
4			4	2	4	7
5	7		4	4		5
6		2		2	4	4
7				2		1
8			4	1		2
9			4	1		1
80			4			2
1				2		
2						1

Table 3 (Continued)

Length in mm.	Bullraked Area 1949	Bullraked Area 1950	Control 1949	Control 1950	Dredged Area 1949	Dredged Area 1950
83				1		
4	4		4			
5						1
6						
7						1
8		1				1
9						
90					4	
1						
2						
3			4			
4			4			
5					4	
6						1
Total	1,074	561	1,137	756	1,045	866

Table 4 shows length frequencies of clams removed from 500 square feet of bottom by bullraking and dredging 1949 and 1950. These frequencies were computed by the following procedure and are shown as the difference between dotted and solid lines in Figures 8, 9, 10 and 11:

1. Determine percentage of catch at each length from length measurements of clams removed from each quarter of each area by experimental fishery.

2. From fishing records determine total bushels removed from each quarter of each area by each fishing method.

3. By proportion compute bushels which were removed from an area equal to that which was later sampled by clamshell bucket.

$$\frac{\text{Bushels removed from quarter by fishery}}{\text{Total area of quarter}} = \frac{\text{Bushels removed from area sampled by bucket}}{\text{Area in quarter sampled by bucket}}$$

4. Multiply bushels removed from sampled area in each quarter (as determined in Step 3) by percentage of clams at each length (as determined in Step 1) to determine bushels of clams of each length removed by fishery from an area equal to that sampled in each quarter.

5. Convert bushels at each length (as determined in Step 4) to numbers at each length using Belding's (1931) Table III.

6. Total frequencies for four quarters of each area for 1949 and 1950.

7. Add totals to frequencies representing population remaining after fishing (solid lines Figures 8, 9, 10 and 11) and plot as dotted line to show population before each year's fishing.

Table 4

Length Frequencies of Clams Removed by Raking and Dredging from 500 square feet of Bottom 1949 and 1950

Length in mm.	Bullraked Area 1949	Bullraked Area 1950	Dredged Area 1949	Dredged Area 1950
41			1	
2	2		1	
3	10		1	
4	23	1		
5	55	5	1	
6	77	5	2	
7	88	13	2	
8	91	19	1	
9	77	37	1	
50	89	51	3	
1	61	44	1	
2	54	50	2	
3	45	62		
4	26	58	1	
5	24	66	1	
6	19	45	2	
7	23	40	2	
8	23	35	5	
9	21	27	6	*
60	28	23	7	4
1	20	10	10	4
2	24	8	17	4
3	21	10	18	5
4	22	7	21	6
5	18	7	18	6
6	14	6	17	6
7	12	6	20	9
8	9	4	13	7
9	7	5	12	10
70	8	4	9	9
1	3	2	7	6
2	3	2	5	6
3	1	2	3	4
4	2	2	3	3

Table 4 (Continued)

Length in mm.	Bullraked Area 1949	Bullraked Area 1950	Dredged Area 1949	Dredged Area 1950
5	1	1	2	2
6		1	1	1
7		1	1	1
8			1	1
9			1	1
80			1	
1			1	
2			1	
3			1	
4			1	
85			1	
6			1	
7			1	
Total	1,001	659	227	95

APPENDIX "B"

Method for Determining Size Composition of the Catch in Relation to Available Population for Bullraking and Dredging (Figure 7):

1. Data for 1950 were used since the clamshell bucket sampling for that year was more intensive than for 1949.

2. Size composition of the catch was taken from Table 4.

3. Size composition of the available population before fishing was estimated by adding catch from Table 4 and population remaining after fishing from Table 3.

4. Ratios of catch to available population were computed by 10 mm. intervals of length and adjusted to 1.0 for that part of the size range where the gear was at maximum efficiency.

5. Since different multipliers were necessary to adjust raking and dredging efficiencies to 1.0 the two curves are comparable only in regards to the lengths at which various efficiency ratios are reached.

APPENDIX "C"

Population Census Using Clamshell Bucket

Table 5 shows the number of clams per bottom sample obtained by the 2 1/2 cubic foot clamshell bucket autumn 1949 and 1950 after experimental digging had been completed.

Table 5

Number of Clams per Bottom Sample From All Series 1949 and 1950

No. Clams per Sample	Bullraked Area			Control			Dredged Area			Total B. and D.	
	1949	1950 1st 50	1950 2nd 50	1949	1950 1st 50	1950 2nd 50	1949	1950 1st 50	1950 2nd 50	1949	1950
0		6	1		3	4		2		0	9
1	2	4	5		7	4		3	2	2	14
2	1	4	6		3	4	1	3	5	2	18
3	1	6	6	1	4	6	1	3	4	2	19
4	2	7	3	2	5	1	2	9	6	4	25
5		3	9	2	6	2	2	1		2	13
6	1	5	3			3	2	4	4	3	16
7	3	5	6	2	3	1	2	4	5	5	20
8	2	1	5		2	2	3	1	3	5	10
9	2	2	3	2	1	5	1	3	2	3	10
10				3	4	3	1	1	3	1	4
11	3	2		2	1	3	4	1	2	7	5
12	2		1	1	1		4	1	1	6	3
13	1	1		1	3	4		3	3	1	7
14	1			2				1	1	1	2
15					1	1			3	0	3
16	2	1			1	3	1	2		3	3
17	1				1	1	1	1	1	2	2
18			2	2	1	1	1	2	1	1	5
19	2	1			1			1	1	2	3
20				1	1				1	0	1
21									1	0	1
22		1		1		2				0	1
23				1				1		0	1
24				1			1		1	1	1
25	1	1								1	1
26								1		0	1
27					1					0	0
28								1		0	1
29	1						1	1		2	1
30										0	0
Total	28	50	50	24	50	50	28	50	50	56	200

Figure 14 shows variance plotted against arithmetic mean for frequency of number of clams per bottom sample grouped in classes of two for each sampling series shown in Table 5. Slope of trend line indicates need for transformation to make variances independent of the means in order that methods for analysis of variance become applicable (Beall, 1942 and Barnes, 1952; Barlett, 1936 and 1947 and Snedecor, 1940).

Table 6 shows transformation of data from Table 5 by grouping number of clams per sample into classes of two, adding 3/8 to midpoint of each class as per Anscombe (1948) and Quenouille (1950), and taking the square root.

Arithmetic means and variances for untransformed and for transformed values which are plotted in Figures 14 and 15 are shown at the bottom of Table 6. Also shown are derived arithmetic means, standard deviations and standard error in number of clams computed from the transformed values.

Derived arithmetic means were determined by squaring the transformed mean, subtracting 3/8 and adding the Variance as per Quenouille (1950).

Derived standard deviations were determined by the following formula:

$$\text{Derived } s = [\text{Trans } \bar{x} + \text{trans } s)^2 - 3/8] - \text{derived } \bar{x}.$$

Derived standard errors were computed by the following formula:

$$\text{Derived } s\,\bar{x} = \frac{\text{Derived } s}{\sqrt{N}}$$

Figure 15 shows variance plotted against arithmetic means for counts transformed by $\sqrt{x + 3/8}$

Figures 16 and 17 show untransformed and transformed frequencies of number of clams per sample for all series 1949 and 1950. The square root transformation has changed the distribution to approximate normality and has made the variance independent of the mean as shown by the fact that the trend line in Figure 15 has practically no slope.

Therefore statistical methods designed for normal distributions can be applied to these transformed values. The mean number of clams, standard deviation and standard error computed from transformed values and shown in the last three lines of Table 6 can then be considered reliable.

Sampling reliability was estimated by computing standard error of the difference of means and normal deviates for each pair of series in 1950. Results are shown in Table 7.

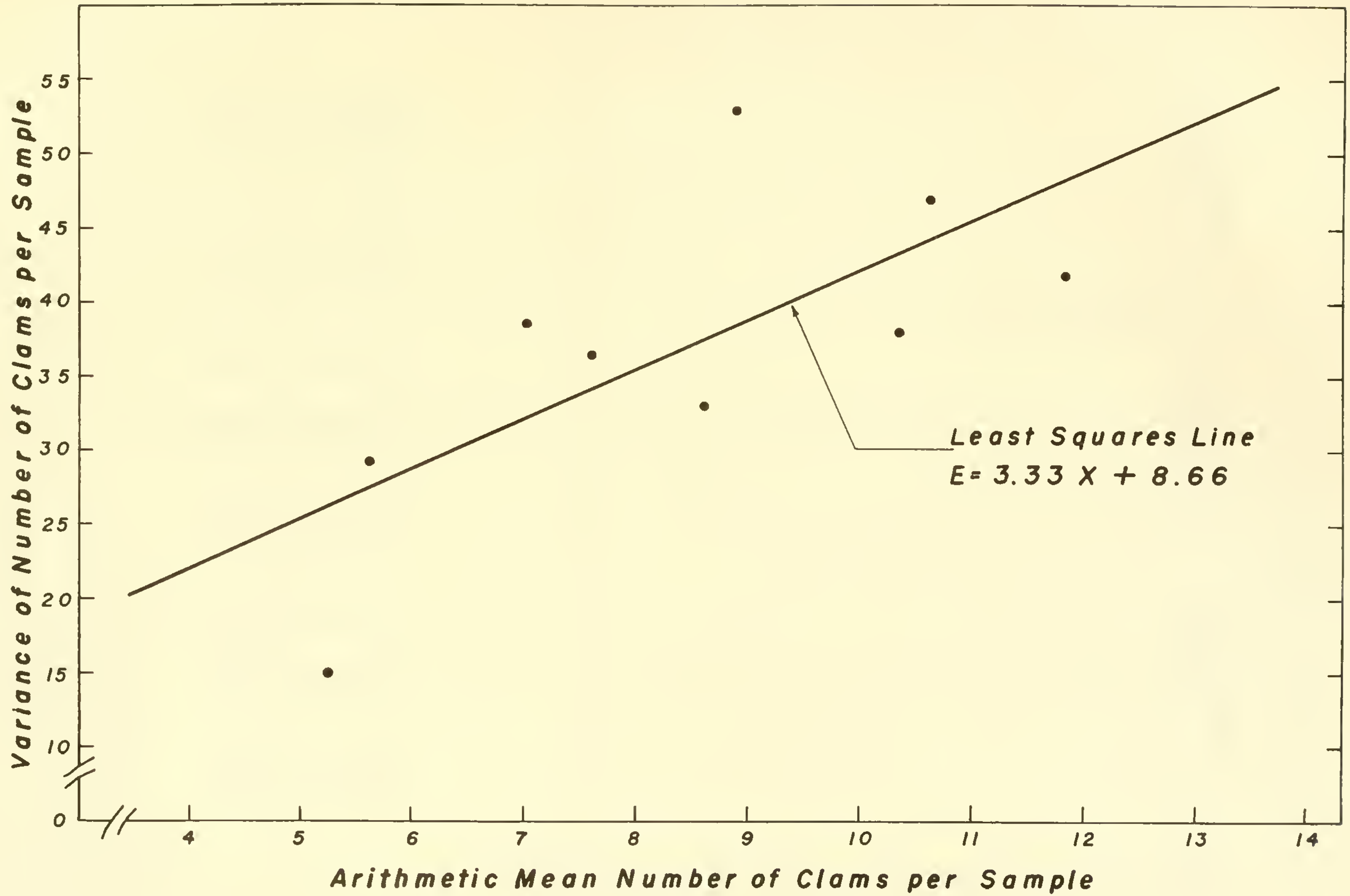

Fig. 14. Variance plotted against arithmetic mean for nine sampling series listed in Table 6. Slope of trend line fitted by least squares method indicates need for transformation to make analysis of variance applicable.

TABLE 6

Transformation of Number of Clams par Bottom Sample grouped in Classes of 2 by $\sqrt{\text{midpoint of class} + 3/8}$.

Midpoint of class	Midpoint transformed by $\sqrt{x + 3/8}$	Bullraked Area 1949	Bullraked Area 1950 1st 50	Bullraked Area 1950 2nd 50	Control Area 1949	Control Area 1950 1st 50	Control Area 1950 2nd 50	Dredged Area 1949	Dredged Area 1950 1st 50	Dredged Area 1950 2nd 50	Total
0.5	0.935	2	10	6	0	10	8		5	2	43
2.5	1.696	2	10	12	1	7	10	2	6	9	59
4.5	2.208	2	10	12	4	11	3	4	10	6	62
6.5	2.622	4	10	9	2	3	4	4	8	9	53
8.5	2.979	4	3	8	2	3	7	4	4	5	40
10.5	3.298	3	2		5	5	6	5	2	5	33
12.5	3.588	3	1	1	2	4	4	4	4	4	27
14.5	3.857	1			2	1	1		1	4	10
16.5	4.108	3	1			2	4	2	3	1	16
18.5	4.345	2	1	2	2	2	1	1	3	2	16
20.5	4.569				1	1				2	4
22.5	4.783		1		2		2		1		6
24.5	4.988	1	1		1			1		1	5
26.5	5.184					1			1		2
28.5	5.374	1						1	2		4

	Bullraked 1949	Bullraked 1950 1st 50	Bullraked 1950 2nd 50	Control 1949	Control 1950 1st 50	Control 1950 2nd 50	Dredged 1949	Dredged 1950 1st 50	Dredged 1950 2nd 50
A	10.64	5.62	5.26	11.83	7.02	7.70	10.36	8.90	8.62
B	46.77	29.09	15.00	41.62	38.50	36.24	37.90	52.80	33.05
C	6.84	5.39	3.87	6.45	6.21	6.02	6.16	7.27	5.75
D	3.14	2.24	2.24	3.37	2.47	2.61	3.16	2.81	2.84
E	1.19	1.00	0.61	0.88	1.30	1.27	0.76	1.38	0.94
F	1.09	1.00	0.78	0.94	1.14	1.13	0.87	1.18	0.97
G	10.67	5.64	5.25	11.86	7.03	7.71	10.37	8.90	8.63
H	6.85	4.48	3.51	6.32	5.66	5.90	5.50	6.61	5.51
J	1.29	0.63	0.50	1.29	0.80	0.83	1.04	0.93	0.78

A = Arithmetic Mean of untransformed grouped data.
B = Variance of untransformed grouped data.
C = Standard Deviation of untransformed grouped data.
D = Arithmetic Mean of transformed grouped data.
E = Variance of transformed grouped data.
F = Standard Deviation of transformed grouped data.
G = Derived Mean number of clams computed from transformed data.
H = Derived Standard Deviation in number of clams computed from transformed data.
J = Derived Standard Error of the mean in number of clams computed from transformed data.

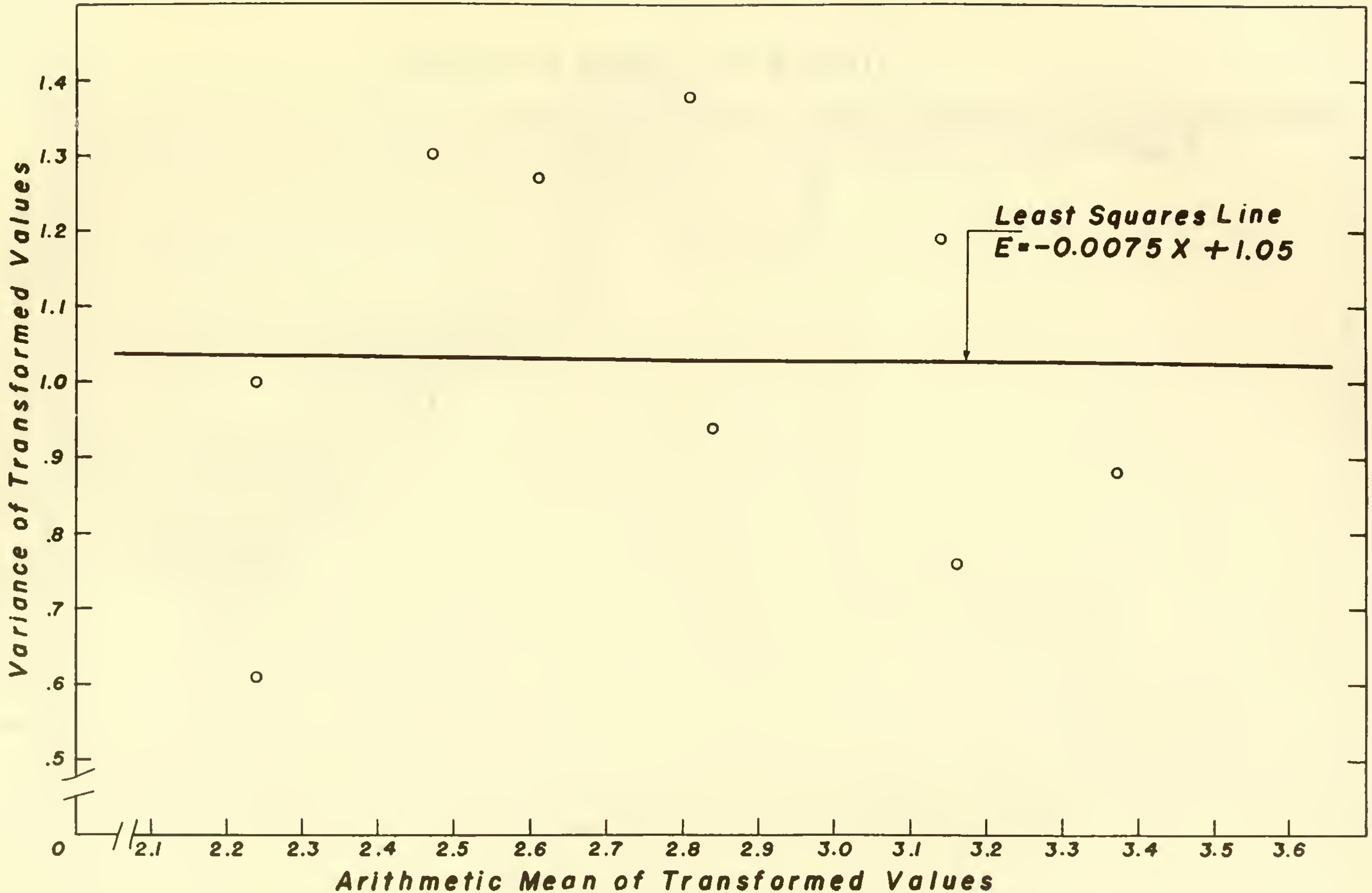

Fig. 15. Variance plotted against arithmetic mean for nine sampling series listed in table 6 after number of clams per sample were grouped in classes of two and transformed by $\sqrt{\text{class midpoint} + 3/8}$. Extremely slight slope of trend line indicates this transformation has made variance independent of the mean.

Fig. 16. Number of clams per clamshell bucket sample showing skewed distribution. Date for all areas and all samples, 1949 and 1950 grouped in classes of two.

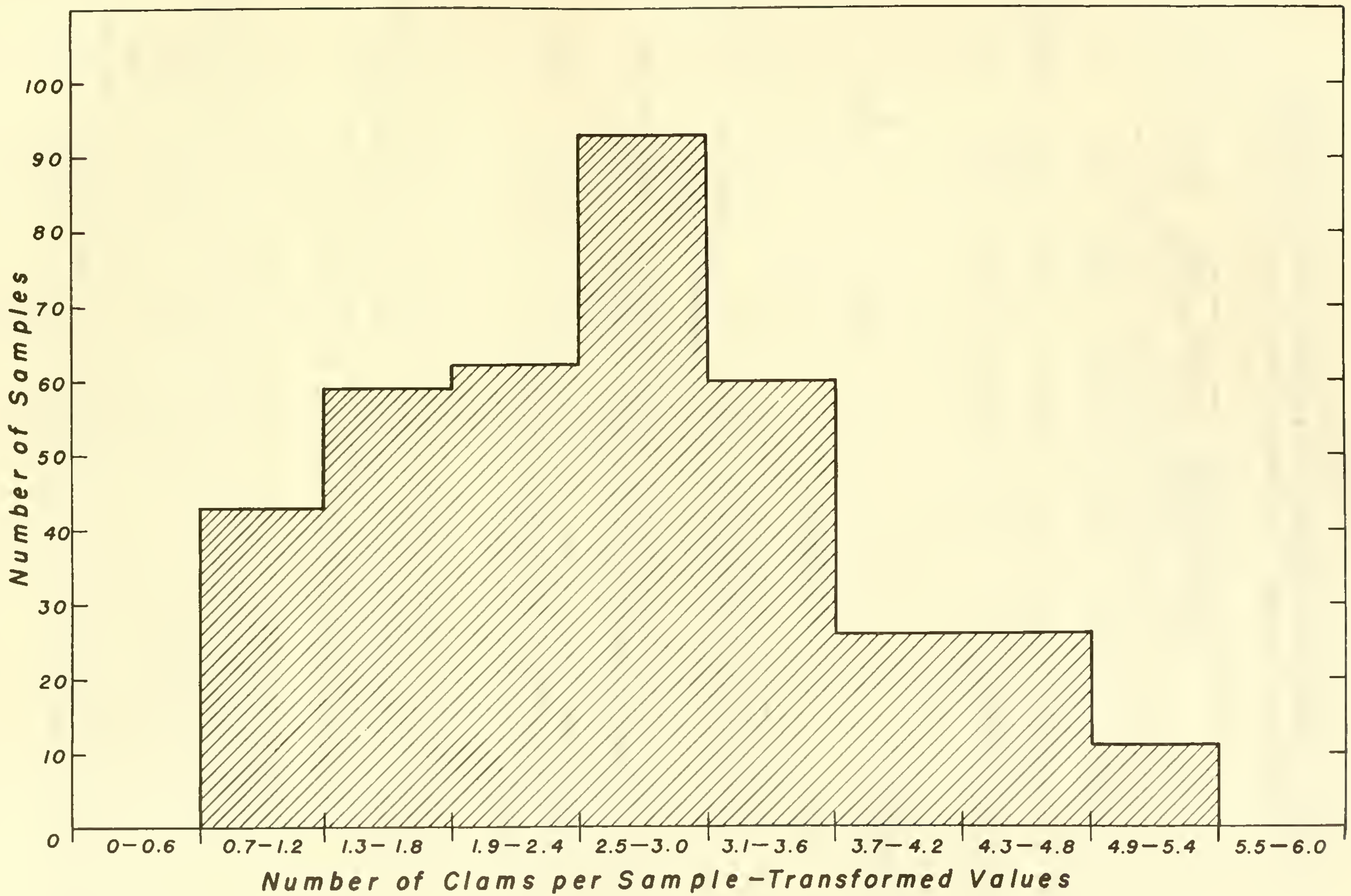

Fig. 17. Number of clams per clamshell bucket sample after applying square root transformation as shown in Table 6. Date for all areas and all samples, 1949 and 1950 grouped in classes of two.

Table 7

Tests for Estimating Sampling Reliability of 1950 Clamshell Bucket Samples Computed Using Values Transformed by $\sqrt{x + 3/8}$

Statistics	Bullraked Area		Control Area		Dredged Area	
	1st 50	2nd 50	1st 50	2nd 50	1st 50	2nd 50
Arithmetic Mean	2.24	2.24	2.47	2.61	2.81	2.84
Standard Deviation	1.00	0.78	1.14	1.13	1.18	0.97
Standard error of mean	0.14	0.11	0.16	0.16	0.17	0.14
Standard error of difference between means	0.179		0.228		0.217	
Normal deviate	0.000 1/		0.614 2/		0.138 3/	

1/ This deviate would be exceeded by 100% of trials. Therefore difference is due to chance and sampling is considered reliable.

2/ This deviate would be exceeded by 50-55% of trials. Therefore difference is due to chance and sampling is considered reliable.

3/ This deviate would be exceeded by 90% of trials. Therefore difference is due to chance and sampling is considered reliable.

In each case the normal deviates are so small that variations of this magnitude would be expected in repeated sampling of a single population. Since we already know that each pair of series were taken from one plot with a single population these tests show that series of 50 samples each provided reliable estimates of the population.

The difference between the mean of the 1949 survey in the control area was compared with the means of the two 1950 series in this unfished plot. This decrease from 11.86 to 7.03 clams per sample as indicated by the first sampling series of 1950 would be expected to occur by chance only one time in one thousand. If the value of 7.71 clams per sample indicated by the second series in 1950 is used, the probability becomes once in one hundred. Therefore this decrease in abundance of clams was real, and was not attributable to sampling error. Reasons for the disappearance of clams in the control area are given in the text.

A further indication of sampling reliability is provided by a comparison of length frequencies of clams taken in the two series of 50 samples each from the control area in 1950. These frequencies are listed in Table 8 and plotted in Figure 18.

Table 8

Length Frequencies of All Clams in Two Series of 50 Clamshell Bucket Samples Each in the Control Area October and November, 1, 1950, and November 8, 1950

Length in mm.	1st Series 10/20 - 11/1/50	2nd Series 11/8/50	Mean of 2 Series	Length in mm.	1st Series 10/20 - 11/1/50	2nd Series 11/8/50	Mean of 2 Series
17		1	0.5	60	15	17	16.0
18				1	15	8	11.5
19	2		1.0	2	14	10	12.0
20		2	1.0	3	11	14	12.5
1		3	1.5	4	6	8	7.0
2	2	4	3.0	5	8	8	8.0
3	3	1	2.0	6	9	5	7.0
4	1	2	1.5	7	6	5	5.5
5	2	4	3.0	8	6	3	4.5
6		3	1.5	9	1	2	1.5
7		4	2.0	70	3	4	3.5
8	2	2	2.0	1	3	4	3.5
9	6	7	6.5	2	4	2	3.0
30		6	3.0	3		1	0.5
1		1	0.5	4	1	1	1.0
2	1	1	1.0	5	2	2	2.0
3	2	3	2.5	6		2	1.0
4	3	1	2.0	7	1	1	1.0
5	1	2	1.5	8		1	0.5
6		4	2.0	9		1	0.5
7	4	3	3.5	80			.0
8	1	2	1.5	1	1	1	1.0
9	4	2	3.6	2			.0
40	5	1	3.0	3		1	0.5
1	6	5	5.5	4			
2	5	7	6.0	5	——	——	
3	2	6	4.0	6	373	383	
4	2	5	3.5	7			
5	9	6	7.5	8			
6	5	5	5.0	9			
7	12	6	9.0	90			
8	7	11	9.0	1			
9	6	10	8.0	2			
50	6	15	10.5	3			
1	5	13	9.0	4			
2	27	11	19.0	5			
3	16	14	15.0	6			
4	14	16	15.0	7			
5	25	19	22.0	8			
6	19	18	18.5	9			
7	27	17	22.0	100			
8	21	19	20.0				
9	15	20	17.5				

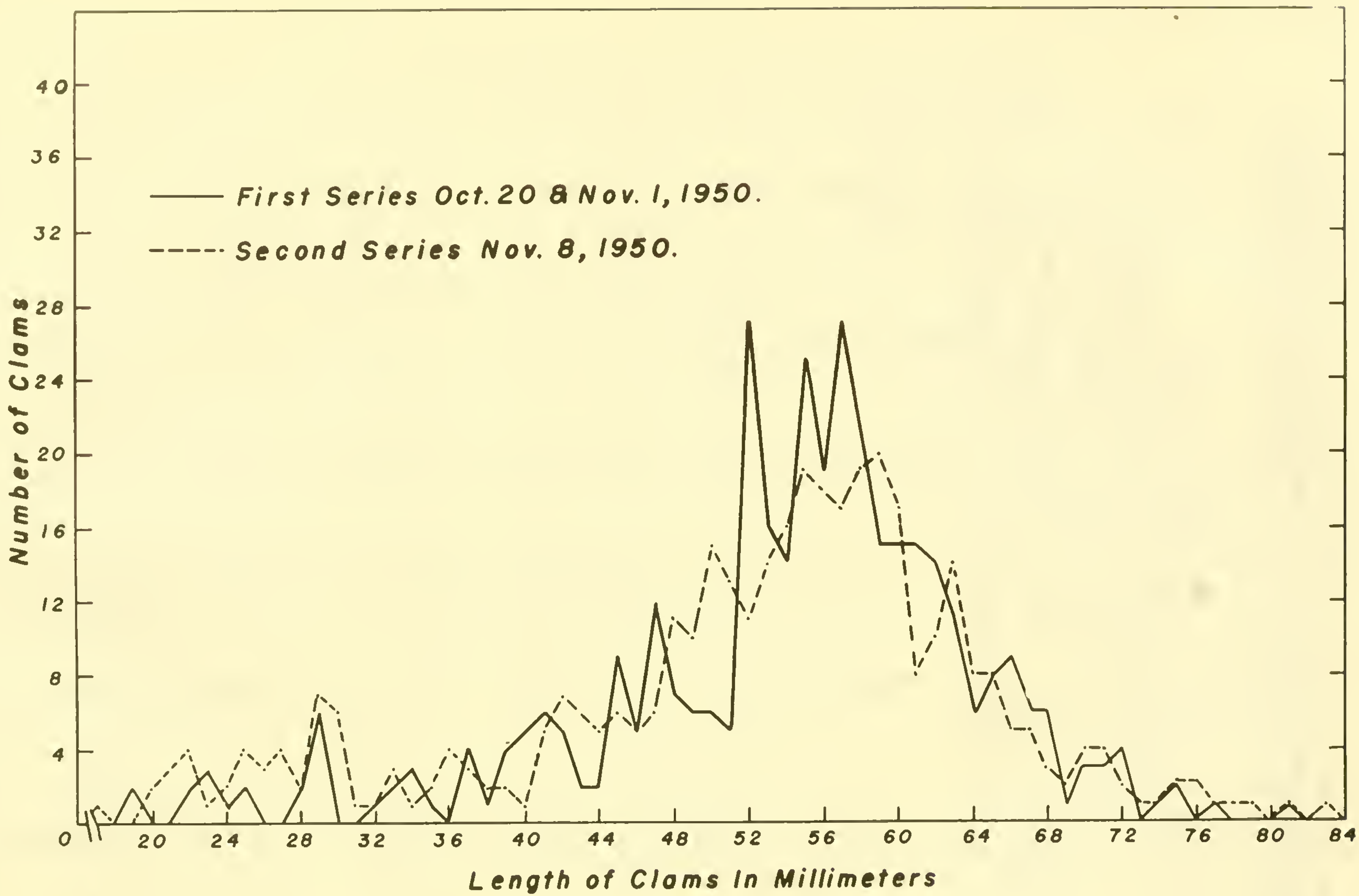

Fig. 18. Length frequencies of clams taken in two series of 50 clamshell bucket samples each in control area Oct. 20 and Nov. 1, 1950, and Nov. 8, 1950.

The chi-square test was applied to the length frequencies shown in Table 8 grouped into classes and using the mean of the two series as the expected frequency. The resulting chi square of 6.62 indicated the difference between expected frequency and that observed in each of the series would be exceeded 76 times out of one hundred in a homogeneous population. Excluding those clams below 31 mm. in length changes chi square to 2.75, and the resulting probability to 97%. Exclusion of these small clams is justified on the basis that their enumeration is subject to greater error because of their size and because counts were based on 1/4 square foot subsamples taken from the regular five-square-foot bottom samples.

The size composition of the population in the control area can therefore be reliably estimated from series of 50 clamshell bucket samples.

Length frequencies for the bullraked and dredged areas were not separated into series of 50 samples each and therefore cannot be analyzed by the chi-square test. If these areas can be considered analagous to the control, the same limits of accuracy can be applied. The length frequencies in Figures 9, 11 and 13 were based on 100 samples, so it is likely that they are reliable estimates of the size composition of the population on the test plot in 1950. Length frequencies shown by the solid line in Figures 8, 10 and 12 are based on 28 clamshell bucket samples, so it is likely that these provide less accurate estimates of the size composition of the clam population.