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DEPARTMENT OF THE INTERIOR
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BUREAU OF COMMERCIAL FISHERIES

COMMERCIAL FISHERIES RESEARCH AND DEVELOPMENT ACT

FINAL CONTRACT REPORT

State Maryland

Contract Nos. 3-93-R-1, 3-93-R-2, 3-93-R-3.

Project Title " The effects of the Maryland Hydraulic Clam Dredge on Populations of the Soft-shell Clam, *Mya arenaria*.

Period Covered January 1, 1969-December 31, 1971

Prepared By H. T. Pfitzenmeyer Date 24 April 1972

Approved By [signature] Date 25 April 1972

ABSTRACT

This is the final report on a three-year study designed to investigate the effects of the Maryland hydraulic escalator clam dredge on populations and recruitment of the soft-shell clam, *Mya arenaria*. Experimental plots were established in the Potomac River, Maryland, and were dredged in a commercial manner by removing only legal size clams. Quarterly samples were taken in the experimental and control plots by means of a van Veen grab for juvenile clams and the hydraulic dredge for older, deeper burrowing clams. Sediment samples were taken at selected periods for organic carbon and grain size analysis. Clam samples were separated into two size-groups; those

smaller than 36 mm in shell length and those larger than 35 mm in shell length. Population densities of these two groups were analyzed by the analysis of variance. Smaller size-groups could not be treated separately because of the heavy mortalities throughout the Chesapeake Bay during the study period.

All data on effects and differences were tested statistically. There was no significant effect on the submarket clams by the removal of marketable clams. The smaller the clams, the greater their ability to overcome disturbances created by the dredging activity. Densities of clams larger than 35 mm in plots which were dredged in March and June were not statistically different from the control plots 4 months later. Plots dredged in August were significantly different from the control plots until 8-12 months after dredging. Initial clam sets were not greater in dredged areas, however, survival of juvenile clams was better in areas where the population densities were reduced. Because of the low number of specimens obtained in the samples, as the result of heavy unexplained mortalities, no comparison on growth rates was attempted.

A uniformity of medium-to fine-sand sediment grain size, at least up to 12 inches in depth in the experimental areas, resulted in no major changes in sediment structure after dredging. Compaction tests indicated a softness in dredged bottoms at least 1 year after dredging. Organic carbon measurements showed comparatively little loss of organic matter from the dredged areas but remains trapped in the dredged sediments and redeposited in various concentrations on the bottoms.

INTRODUCTION

This study was initiated in January 1969 to investigate the effects of the Maryland hydraulic soft-shell clam dredge on populations and recruitment of the soft-shell clam, Mya arenaria. Concurrent with the biological studies, observations were made also on physical alterations to the substrates.

The objectives as stated in the proposal were: (1) to determine the effects of seasonal hydraulic clam dredging upon survival and growth of the remaining populations and annual recruitment of juvenile soft-shell clams, (2) to determine the effects of intermittent dredging upon growth, survival, and recruitment of soft-shell clams, and (3) to follow the physical and chemical changes which take place in substrate which has been altered by the hydraulic clam dredge.

Large mortalities in the clam populations of the Chesapeake Bay reduced the densities to the extent that it was not possible to make any comparison on growth rates in dredged and undredged areas. We were able to fulfill the objectives on setting, survival, and recruitment of the remaining populations as well as the studies on the physical and chemical changes to the substrate.

MATERIALS AND METHODS

The Potomac River was chosen as the area to conduct these field studies since it possessed bottoms of heavy clam densities which were prohibited to commercial dredging (Chart 1).

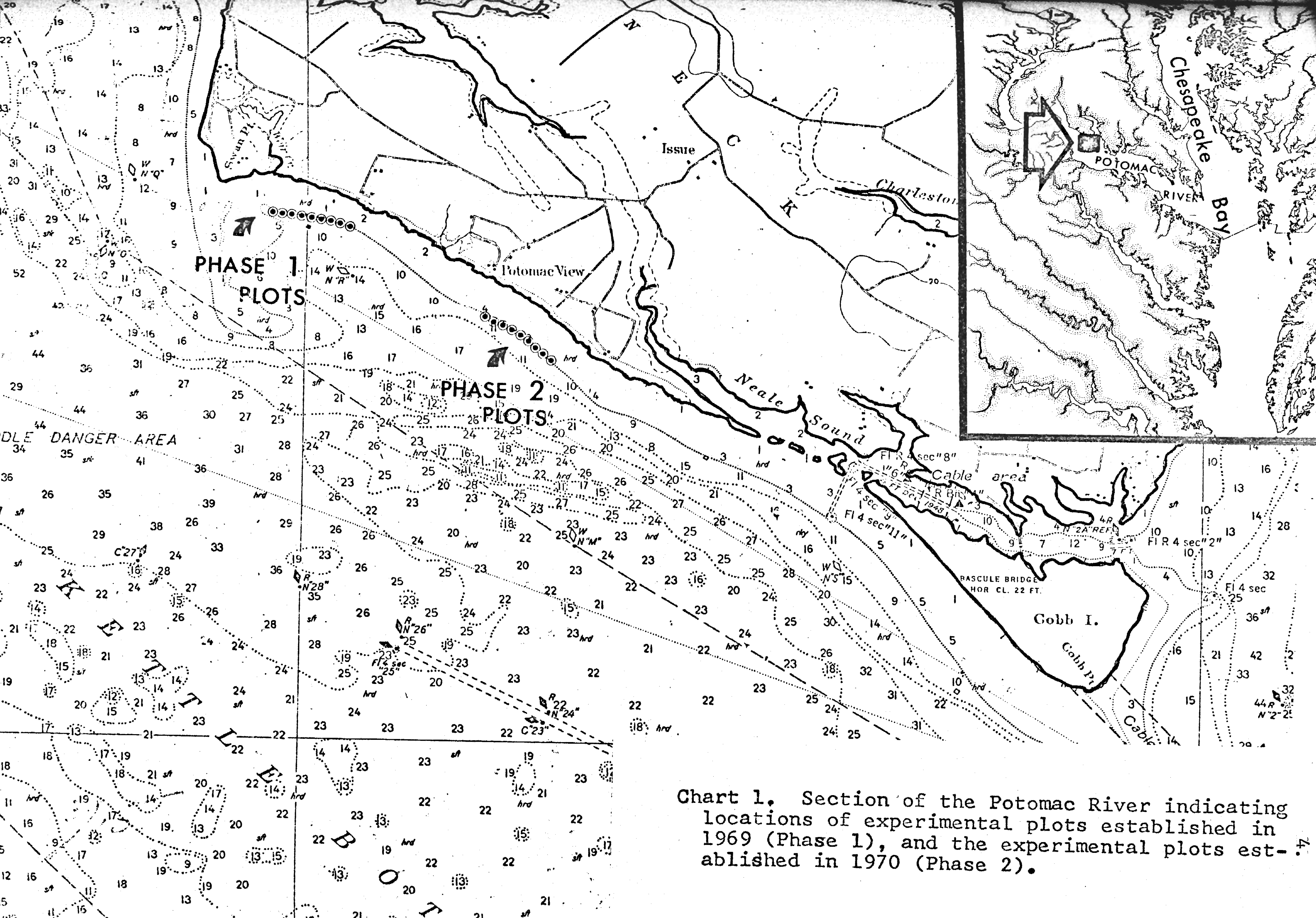

Chart 1. Section of the Potomac River indicating locations of experimental plots established in 1969 (Phase 1), and the experimental plots established in 1970 (Phase 2).

A linear pattern of nine experimental plots was established in about 6 ft of water. This series of plots (Phase 1) was for testing the effects of seasonal dredging on clam populations. A second series of nine plots (Phase 2) was set up a year later approximately 1-mile downriver from the first series for the purpose of testing intermittent dredging effects on the populations. The total area of each circular plot was 10,000 ft^2 with a 50-ft buffer zone separating adjacent plots. A piling with a submerged marker at its base was located in the center of each plot. Temporary floats were established to mark the perimeter of each plot while it was being dredged.

Samples of recently set and small clams were taken by means of the van Veen grab, which samples a surface area of .1 m^2 approximately 5 cm in depth. The deeper burrowing adult clam population was sampled by means of the hydraulic clam dredge using a 3/8-inch mesh conveyor belt. The hydraulic dredge digs in the bottom 18-inches deep and 24-inches wide. This sampling covered a bottom surface area of 10 ft^2. Pre- and post-treatment samples were taken in triplicate in each plot and at each quarterly sampling period.

Sediment samples were taken to a depth of 12 inches in the bottom by means of a piston corer. These samples were divided into 3-inch segments and analyzed separately for grain size determinations. They were wet-sieved through the U. S. Standard Sieve Series corresponding to the following sizes. Greater than 2 mm, gravel; 2 - 1 mm, very coarse sand; 1 mm - 500 microns, coarse sand; 500 - 250 microns, medium sand; 250 - 125 microns, fine sand; 125 - 63 microns, very fine sand; 62 - 4 microns, silt; and less than 4 microns, clay.

<u>Phase 1.</u> This series of plots was established to determine the effects of seasonal dredging on the clam populations. Prior to any dredging, population densities were determined from hydraulic dredge samples taken in all of the plots in June 1969 (Table 1). The average densities per 30 ft^2 (total size of three hydraulic dredge samples) were converted to number of bushels per acre. Three plots (Nos. 3, 6, 8) selected at random, then were dredged in a commercial manner by using a 1½-inch mesh belt on the conveyor. All legal, market-size, 2-inch (52 mm) clams collected were removed from the plots and the remaining sizes were permitted to fall back overboard near where they were dredged. All soft-shell clams in pre- and post-treatment samples were counted and measured to the nearest mm.

Three other plots (Nos. 1, 2, 9) in the same series were dredged in March 1970 using the same procedures. The number of bushels removed from these plots, while simulating a commercial dredging operation, is also given in Table 1. Post-treatment samples also were taken on a quarterly basis. Control plots (Nos. 7, 5, 4) were sampled before and after dredging the treatment plots and thereafter on a quarterly schedule.

Sediment cores were also taken before and after dredging to determine any structural changes in the sediment profile.

<u>Phase 2.</u> A second series of plots was established about a mile downriver from the first series for the purpose of studying the effects of intermittent dredging on the populations of clams. Population densities of marketable clams were determined in each plot by means of taking samples with the hydraulic dredge. Three randomly selected plots (Nos. 1,3,8) were dredged in a commercial manner for a period of 1 hour or ½ an hour each day for 5 consecutive days.

Table 1. Estimated population density in each plot prior to treatment in June 1969 and March 1970, and the number of bushels removed. Actual data was from 1/4-acre size plots and converted to 1 acre.

Plot No.	Treatment	Calculated Av. Bu/Acre 6/69	Calculated Bu/Acre Removed	Calculated Av. Bu/Acre 3/70	Calculated Bu/Acre Removed
7	Control	131		87	
3	Dredge 6/69	131	64	217	
5	Control	87		87	
1	Dredge 3/70	174		87	12
8	Dredge 6/69	131	72	87	
2	Dredge 3/70	87		87	36
6	Dredge 6/69	131	72	217	
9	Dredge 3/70	261		87	12
4	Control	217		174	

Three other plots (Nos. 2, 4, 7) were each dredged 2 days at approximately weekly intervals for a period of 1½ to 2 hours each day. The total number of hours dredged in both groups of plots were the same. The total number of bushels of clams removed from each plot was determined. An attempt was made to dredge all areas of each treatment plot as evenly as possible, whether clams were present in commercial quantities or not. The three remaining plots in the series of nine plots served as controls and were not dredged.

Samples of the juvenile clam populations were taken with the van Veen grab prior to any dredging also in this series of plots. Sediment cores and bottom samples for organic carbon content were also taken in selected plots.

The results from both phases were analyzed by a multivariate analysis of variance program run on the 1108 computer at the University of Maryland. The number of clams from each sample for these analyses were divided into two size-groups; 1 - 35 mm and 36+ mm. None of the individuals of the 0 age-class exceeded 35 mm in shell length during the August sampling period, and by the next sampling period (November), all individuals had exceeded this length. These two large groups were chosen because of the lack of sufficient numbers of clams if smaller groups were chosen, especially in 1970 and 1971.

RESULTS AND DISCUSSION

Phase 1. The experimental plots for this phase of the project, to determine the effects of seasonal dredging on the clam population, were established in June 1969. Three of the 9 plots were chosen at random as the first set of treatment plots. They were dredged to remove the large clams, but the smaller, sublegal size clams were permitted to return to the water, thus simulating a commercial dredging operation. Based on pre-treatment sampling, population densities of market-size clams (52 mm) averaged 2.9 clams per ft^2 in these three plots (Nos. 3, 6, and 8 - Table 3). As a result of treatment dredging, 52 bushels of clams were harvested from these three areas and the population density was reduced to an average of 1.1 clams per ft^2, as determined a month later. When compared with the control plots, this decrease was highly significant at .001 level of probability (Table 5). This statistical determination was based on clams > 35 mm shell length.

Submarket-size clams with a mode of 22 mm, which averaged 25.2 clams per ft^2 prior to dredging, were reduced to 1.1 clams per ft^2 after dredging (Table 2). This is a 96% reduction in those dredged plots, as compared with a 45% reduction during the same period in the control plots. This difference is significant only at the 9.6% probability level (Table 6). Not all of the decrease in the dredged plots, a difference of about 50% more than in the control plots, may be attributed to dredging mortality. Small clams are very active and subject to movement either of their own volition or by external forces and as they increase in size, they become progressively less active. A natural loss of this size-group of clams, which occurred between sampling periods in the control plots and dredged plots, may be due to growth, mortality, and emigration. Besides some mortality due to dredging, an additional mechanical loss in the dredged plots was probably due to propellor wash from the boat in shallow water.

Table 2. Results of samples taken in Phase 1 experimental plots. Sub-market-size clams.

Plot No.	Treatment	No. of Clams per Sample[1/] Sub-market-size (<52 mm)								
		Jun 1969	Jul 1969	Oct 1969	Mar 1970	Apr 1970	Aug 1970	Nov 1970	Apr 1971	Aug 1971
7	Control	17.9	2.0	.5	18.3	8.6	.3	217	44	14.3
3	Dredge Jul 1969	31.6	.6	2.3	25.6	----	.4	118	88	12.9
5	Control	36.6	24.4	2.2	14.3	8.0	.4	145	104	28.9
1	Dredge Mar 1970	47.2	15.0	5.7	31.3	7.3	.4	116	125	13.0
8	Dredge Jul 1969	29.2	2.4	4.6	24.6	----	3.6	128	122	14.2
2	Dredge Mar 1970	37.8	26.2	5.6	28.0	6.6	1.3	152	143	14.3
6	Dredge Jul 1969	14.8	.2	.3	29.0	----	.8	125	134	12.9
9	Dredge Mar 1970	15.2	5.3	2.3	37.6	8.6	.6	92	78	12.6
4	Control	5.7	7.0	.4	16.3	16.0	.4	74	95	13.5

1/ Jun 1969, Jul 1969, and Apr 1971 are averages obtained with 3 van Been grabs and 3 hydraulic dredge samples.
Mar 1970, Apr 1970, Nov 1970 are averages obtained with van Veen grab ($.1m^2$) only.
Oct 1969, Aug 1970, and Aug 1971 are averages obtained with hydraulic dredge ($1ft^2$) only.

Table 3. Results of samples taken in Phase 1 experimental plots. Market-size clams.

Plot No.	Treatment	No. of Clams per 1 ft^2 Market-size (51 mm)									
		Jun 1969	Jul 1969	Oct 1969	Mar 1970	Apr 1970	Aug 1970	Nov 1970	Apr 1971	Aug 1971	Dec 1971
7	Control	5.5	7.8	.5	.4	.3	.4	.7	.8	.4	.05
3	Dredge Jul 1969	2.6	1.1	2.6	3.1	---	2.4	.2	.9	.2	.2
5	Control	5.7	8.4	2.7	.5	.5	1.4	.1	.1	.6	.05
1	Dredge Mar 1970	5.9	3.8	4.6	1.4	1.0	2.1	.9	.3	.1	.05
8	Dredge Jul 1969	2.9	1.7	3.8	2.7	---	5.5	.6	1.0	.3	.3
2	Dredge Mar 1970	5.4	4.4	4.2	2.1	1.7	2.9	1.7	1.4	.6	.2
6	Dredge Jul 1969	3.3	.5	.7	2.3	---	3.7	1.0	1.0	1.3	.11
9	Dredge Mar 1970	3.3	4.1	2.0	1.3	1.9	1.9	.6	.9	1.6	.2
4	Control	5.3	6.3	.7	1.4	1.2	2.2	.6	.9	.5	.04

Table 4. The new series of plots (Phase 2) showing the time in minutes of hydraulic dredging each received and the number of bushels of clams removed. Also shown is the estimated clam density before dredging.

Plot	Estimated Bu/Acre	10 Aug.		11 Aug.		12 Aug.		13 Aug.		14 Aug.		18 Aug.		19 Aug.		Total Hours Dredged	Total Bushels Removed
		Min.	Bu.	Min.	Bu.	Min.	Bu.	Min.	Bu.	Min.	Bu.	Min.	Bu.	Min.	Bu.		
1	48	60	.5	60	.5	30	.25	30	.25	30	.25					3.5	1.75
2	72					90	1					120	2			3.5	3
3	144	60	1	60	1	30	.5	30	.5	30	.5					3.5	3.5
4	84					90	1							120	3	3.5	4
5*	84																
6*	144																
7								90	1.25					120	3	3.5	4.25
8	104	60	2	60	1	30	.5	30	.75	30	1					3.5	5.25
9*	160																

* Control plot.

Table 5. Analysis of variance of the data for number of clams 36 mm and larger in shell length. Phase 1 experiment.

Source of Variance	SS	df	MS	F	P
Jun 1969					
Within Cells	75.77	6	12.63		
Treatment	5.29	2	2.64	.209	.817
Jul 1969					
Within Cells	9.75	6	1.63		
Treatment	143.14	2	7157	44.046	.001
Oct 1969					
Within Cells	84.45	6	14.08		
Treatment	69.27	2	34.64	2.461	.166
Mar 1970					
Within Cells	11.15	6	1.86		
Treatment	47.48	2	23.74	12.780	.007
Apr 1970					
Within Cells	9.05	4	2.26		
Treatment	13.46	1	13.46	5.952	.071
Aug 1970					
Within Cells	36.56	6	6.09		
Treatment	44.88	2	22.44	3.683	.090
Nov 1970					
Within Cells	12.84	6	2.14		
Treatment	3.09	2	1.54	.722	.524
Apr 1971					
Within Cells	13.78	6	2.30		
Treatment	1.82	2	.91	.396	.689
Aug 1971					
Within Cells	9.46	6	1.58		
Treatment	.21	2	.10	.066	.937
Dec 1971					
Within Cells	24.41	6	4.07		
Treatment	12.77	2	6.38	1.569	.283

Table 6. Analysis of variance of the data for number of clams 1-35 mm in shell length. Phase 1 experiment.

Source of Variance	SS	df	MS	F	P
Jun 1969					
Within Cells	40.12	6	67.19		
Treatment	90.78	2	45.39	.676	.544
Jul 1969					
Within Cells	353.77	6	58.96		
Treatment	417.82	2	208.91	3.543	.096
Oct. 1969					
Within Cells	23.16	6	3.86		
Treatment	25.93	2	12.96	3.359	.105
Mar 1970					
Within Cells	.93	6	.16		
Treatment	15.08	2	7.54	48.404	.001
Apr 1970					
Within Cells	8.33	4	2.08		
Treatment	1.19	1	1.19	.573	.491
Aug 1970					
Within Cells	1.94	6	.32		
Treatment	2.62	2	1.31	4.041	.077
Nov 1970					
Within Cells	41.37	6	6.90		
Treatment	1.91	2	.96	.139	.873
Apr 1971					
Within Cells	45.50	6	7.58		
Treatment	20.33	2	10.17	1.341	.330
Aug 1971					
Within Cells	57.53	6	9.59		
Treatment	23.08	2	11.54	1.204	.364

The second series of three plots (Nos. 1, 2, 9) were dredged in March 1970 in a similar manner as the first series which were dredged in June 1969. A lower population of legal clams, 1.6 per ft^2, necessitated the reduction of the dredging intensity so that only a total of 16 bushels of clams were removed from 3 plots (Table 1). An effort was made to dredge all areas of the plots as evenly as possible. Post-treatment sampling indicated the population of marketable clams was reduced only .1 clam per ft^2 (Table 3).

Prior to dredging, juvenile clams averaged 16.3 per .1 m^2 in the control plots and 32.3 per .1 m^2 in the treatment plots (Table 2). After dredging, the number of juvenile clams in the control plots was 10.9 per .1 m^2 or a 33% reduction compared to 7.5 per .1 m^2 or a 77% reduction in the treatment plots. While there was about a 44% greater reduction in the treatment plots, the density in the control and treatment plots were not significantly different after dredging (49% level),as shown in Table 6. When the results obtained at this season of the year, March - April, are compared with the results obtained during the June - July treatment period, the immediate effects of dredging on juvenile clams are less during the March - April period. This may be explained by the greater dredging effort which took place in June - July. The presence of younger clams during March - April, which are more active and capable of counteracting the turbulence created by dredging, may also explain the difference. The modal size during March - April is 9 - 13 mm as opposed to 20 - 24 mm during June - July.

After April 1970, all plots were sampled at approximately quarterly intervals to detect any future trends in the population levels of both juvenile and adult clam populations. Tables 7 and 8 list the means and

Table 7. Mean (M) and standard deviation (SD) of numbers of clams sampled in Phase 1 experimental plots. Clam size 1-35 mm shell length.

Plot		Jun 1969	Jul 1969	Oct 1969	Mar 1970	Apr 1970	Aug 1970	Nov 1970	Apr 1971	Aug 1971
Control	M	608	358	15	51	88	7	289	250	556
	SD	471	386	17	7	18	4	138	98	262
Dredge Jun 1969	M	771	37	15	82	---	2	249	355	391
	SD	280	44	16	5	---	1	12	69	24
Dredge Mar 1970	M	1011	505	53	106	73	2	245	356	392
	SD	496	328	23	9	31	1	54	102	21

Table 8. Mean (M) and standard deviation (SD) of number of clams per 30 ft^2 sample taken in Phase 1 experimental plots. Clam size 36 mm and larger in shell length.

Plot		Jun 1969	Jul 1969	Oct 1969	Mar 1970	Apr 1970	Aug 1970	Nov 1970	Apr 1971	Aug 1971
Control	M	329	247	54	30	22	46	20	22	24
	SD	176	40	49	16	17	27	11	17	4
Dredge Jun 1969	M	254	38	128	121	---	151	24	31	28
	SD	23	20	96	30	---	89	14	2	14
Dredge Mar 1970	M	310	143	192	73	57	79	35	27	29
	SD	135	11	74	20	18	17	18	16	18

standard deviations for numbers of clams collected each sampling period in the dredged and control plots. The results of the analysis of variance at each sampling period is shown in Tables 5 and 6.

Spawning and setting of the soft-shell clam in Maryland waters occurs during October and November. Growth during the first year is comparatively rapid, reaching a mode of 35 - 40 mm by the following October. Sampling indicates that both the young and older clams were not spatially distributed evenly in the bottom but occur in patches of varying densities. It was indicated earlier that post-treatment sampling showed a decrease in numbers of all clams just after dredging. Because of recruitment, movement, and rapid growth, the effects of dredging were not long-lasting and, by 4 months after treatment, no significant difference was detected in clams greater than 35 mm (Table 5). Pre-treatment sampling in March 1970 indicated a highly significant difference in the juvenile populations (.1% - Table 6). An examination of the means in Table 7 shows that the plots to be dredged had twice the number as the control plots. Dredging reduced the populations in the treatment plots so that the significant difference was then at the 49% probability level (Table 6). The most recent age-class outgrew the 1 - 35 mm group, chosen for statistical analysis of the juvenile clam group, by the end of the first year. No significant difference in setting or survival of juvenile clams could be discerned in succeeding age groups. The major mortality, which occurred in the clam populations just after the August 1970 sampling period, did not have an effect on spawning intensity. Set were just as dense throughout 1971 as in the preceding years (Table 2).

Early in the experiment (June 1969), when clams were more dense, market-size clams were removed from the dredged plots in pre-determined quantities until it was not commercially profitable to continue harvesting (less than 100 bushels per acre). Post-treatment samples were taken in July 1969 after the June treatment period and the statistical results in Table 5 show a highly significant decrease in the population (.1% level). Three months later in October another series of samples indicated no significant difference between the control and dredged plots. Within this three-month period, however, the density of clams decreased in the control plots and increased in the dredged plots. This same general trend continued to the March 1970 sampling period. In August 1970, recruitment increased the density in the control and all dredged plots (Table 8).

The next sampling period in November 1970 indicated a large mortality had taken place since the preceding sampling period in August (Table 8). Large clam density was reduced to less than 1 clam per ft^2 in most plots and no significant difference in plot densities was observed in the analysis of data in the following sampling periods (Table 5).

<u>Sediment Analysis</u>

Prior to dredging and taking samples of the clam population in each plot, sediment cores were taken to a depth of twelve inches for grain size analysis. Earlier work by Saunders (1958)[1/] on sediment-animal relationships has shown that two sediment criteria, a median grain size in fine sands and a well-sorted sand sample, might be correlated with large populations of infaunal filter feeders such as clams. These criteria

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1/ Saunders, H. L. 1958. Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnol. & Oceanog. 3(3):245-258.

are present in the area of this study, as may be seen in the results of the core analysis in Figs. 1 - 6. These figures show the cumulative percentages of various sands, silt, and clay in the four segments of each core. To a depth of twelve inches, there is very little variability in the percentages of each category in either the dredged plots or control plots. Most of the bottom consists of about 90% medium and fine sands, at least up to the measured depth of twelve inches. Because of this uniformity, no major changes in sediment structure could be detected after dredging.

Compactness.

One physical characteristic not shown in these figures, but noticeably different when wading across the bottom, was the compactness of the sediments. Random tests on compactness were taken in selected plots by the method described earlier. The depth the probe penetrated into the bottom sediments was measured after being struck 10 times. In Phase 1 experimental plots, the probe penetrated an average of 6 inches in all treatment plots as well as the control plots. These tests were made 1½ and 2 years after dredging. In Phase 2 experimental plots, the probe penetrated 6 inches in the plots dredged weekly, 7 inches in the plots dredged daily, while only 5 inches in the control plots. These tests were made 1 year after dredging and indicate that a difference in compactness of the bottom sediments does exist at least 1 year after dredging.

Organic Carbon.

Animals such as soft-shell clams, which burrow in the sediments, require some stability of the bottom sediments in which they live. Shifting sand granules interfere with their normal feeding habits at

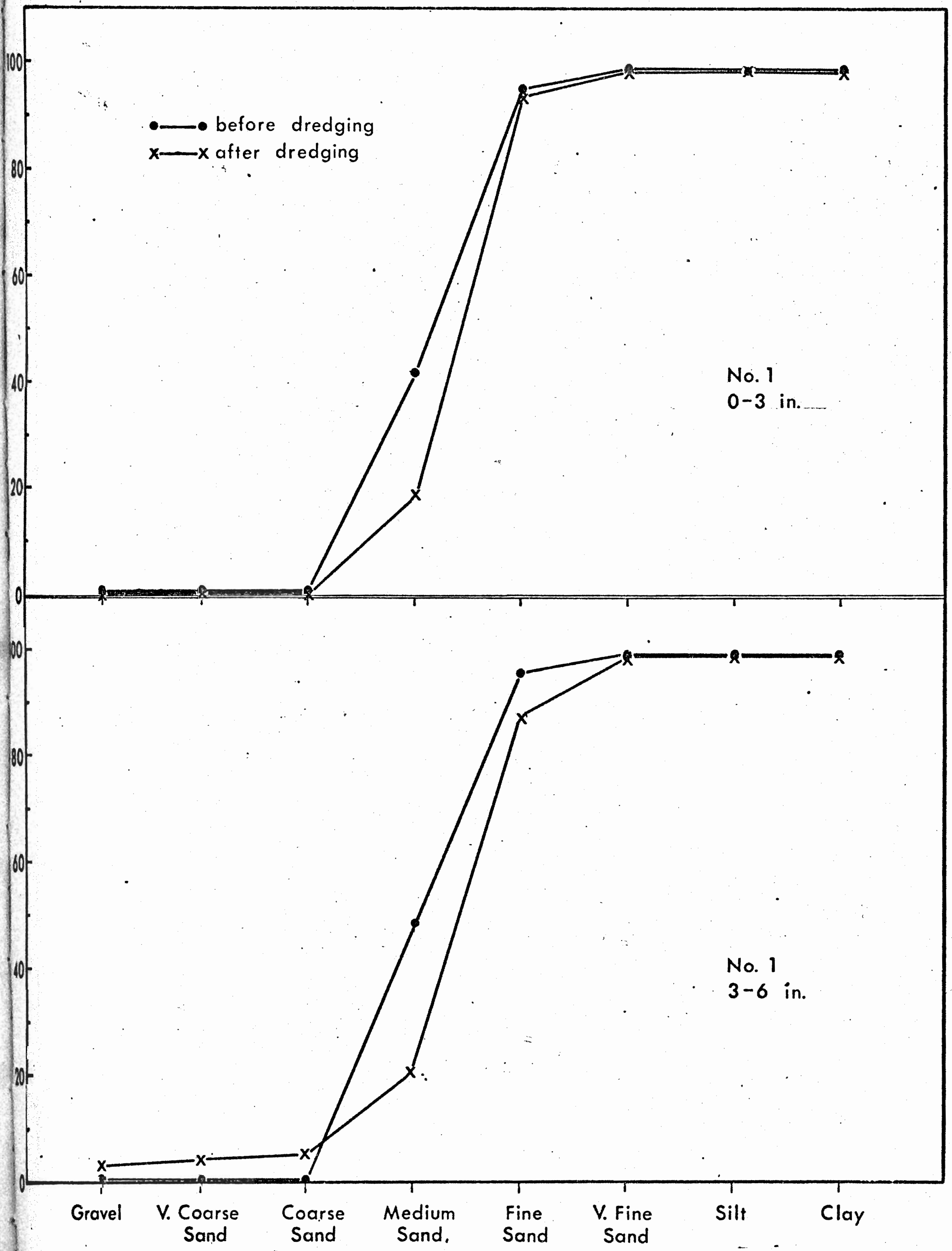

Fig. 1. Sediment grain size distribution in plot before treatment and after daily dredging.

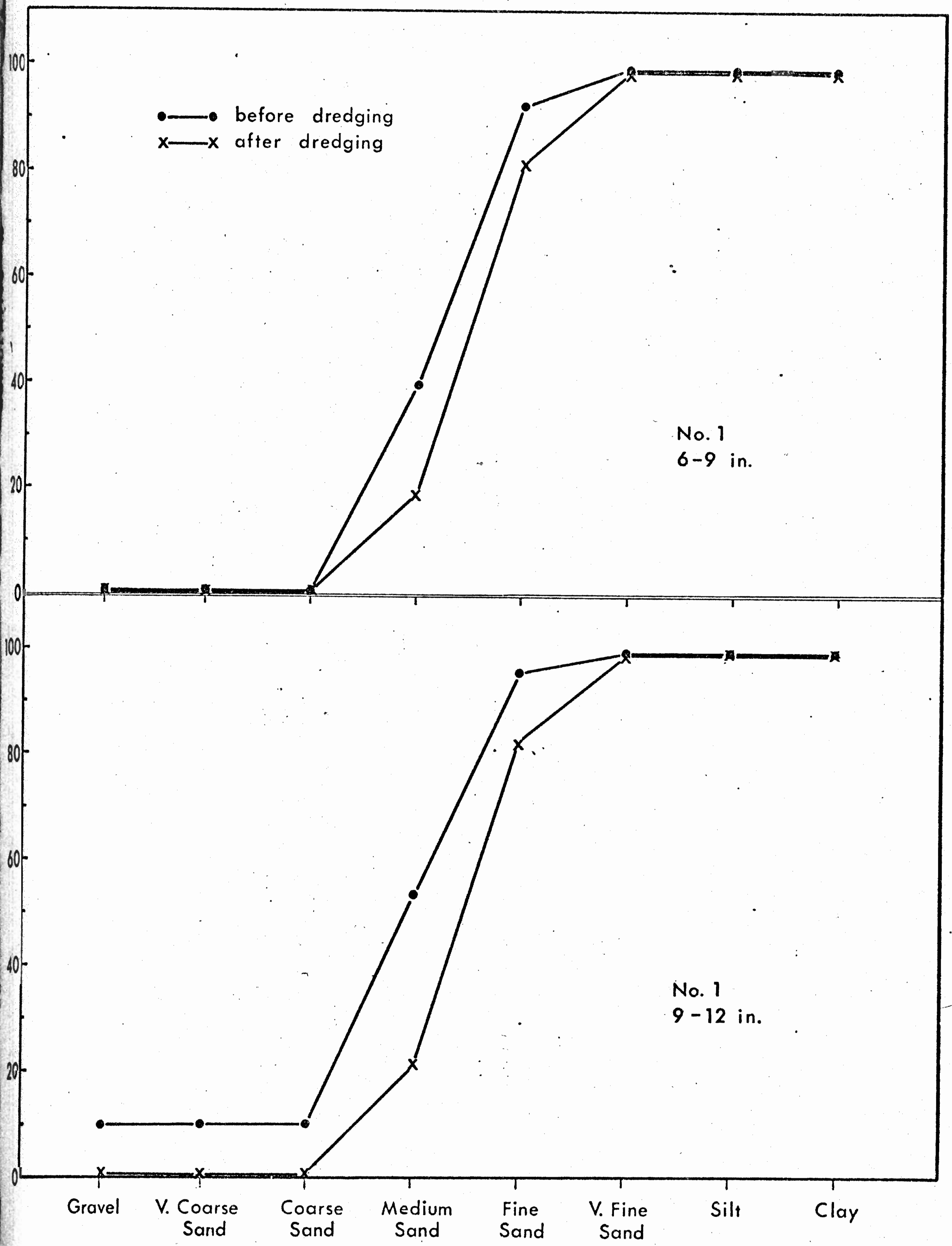

Fig. 2. Sediment grain size distribution in plot before treatment and after daily dredging.

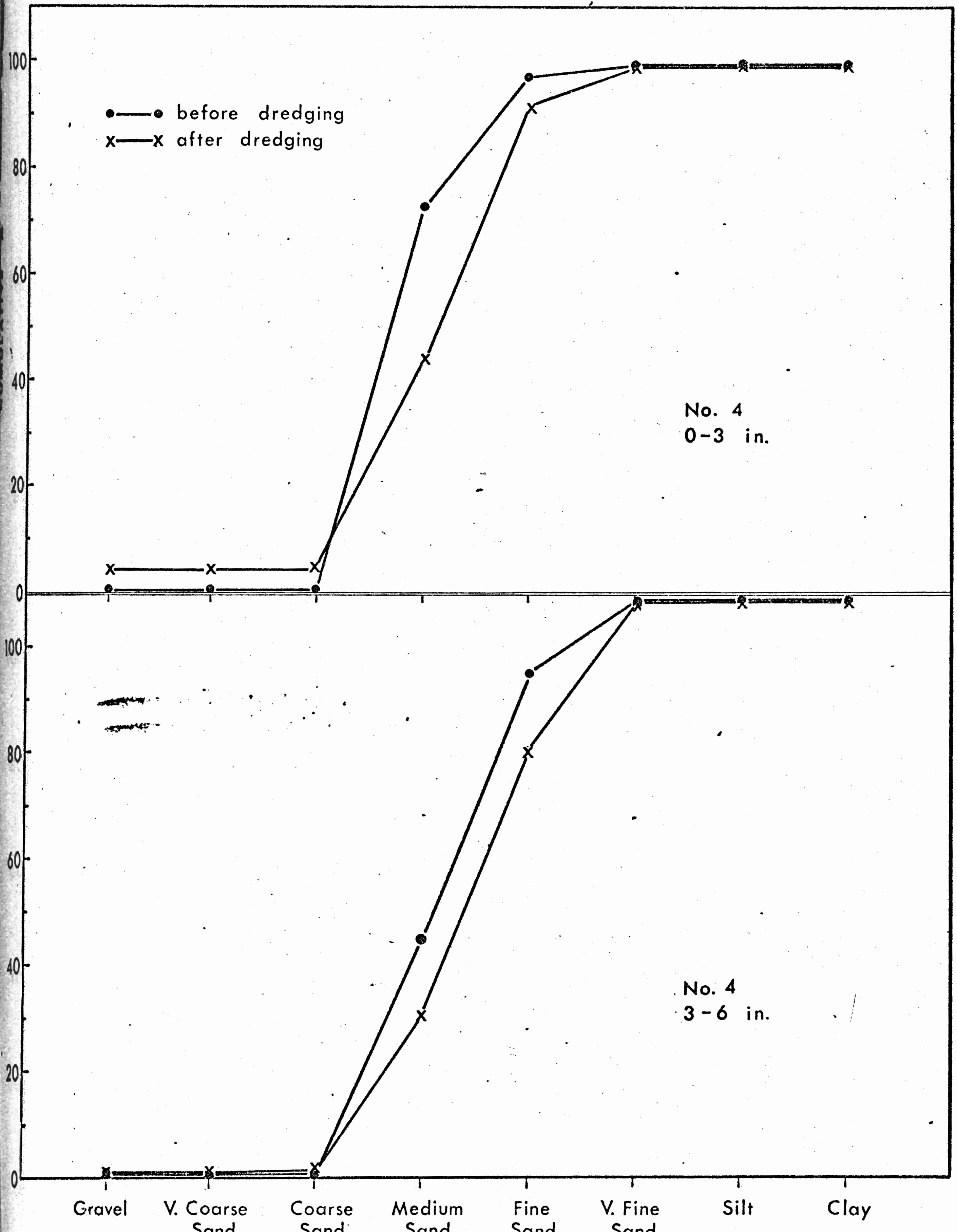

Fig. 3. Sediment grain size distribution in plot before treatment and after weekly dredging.

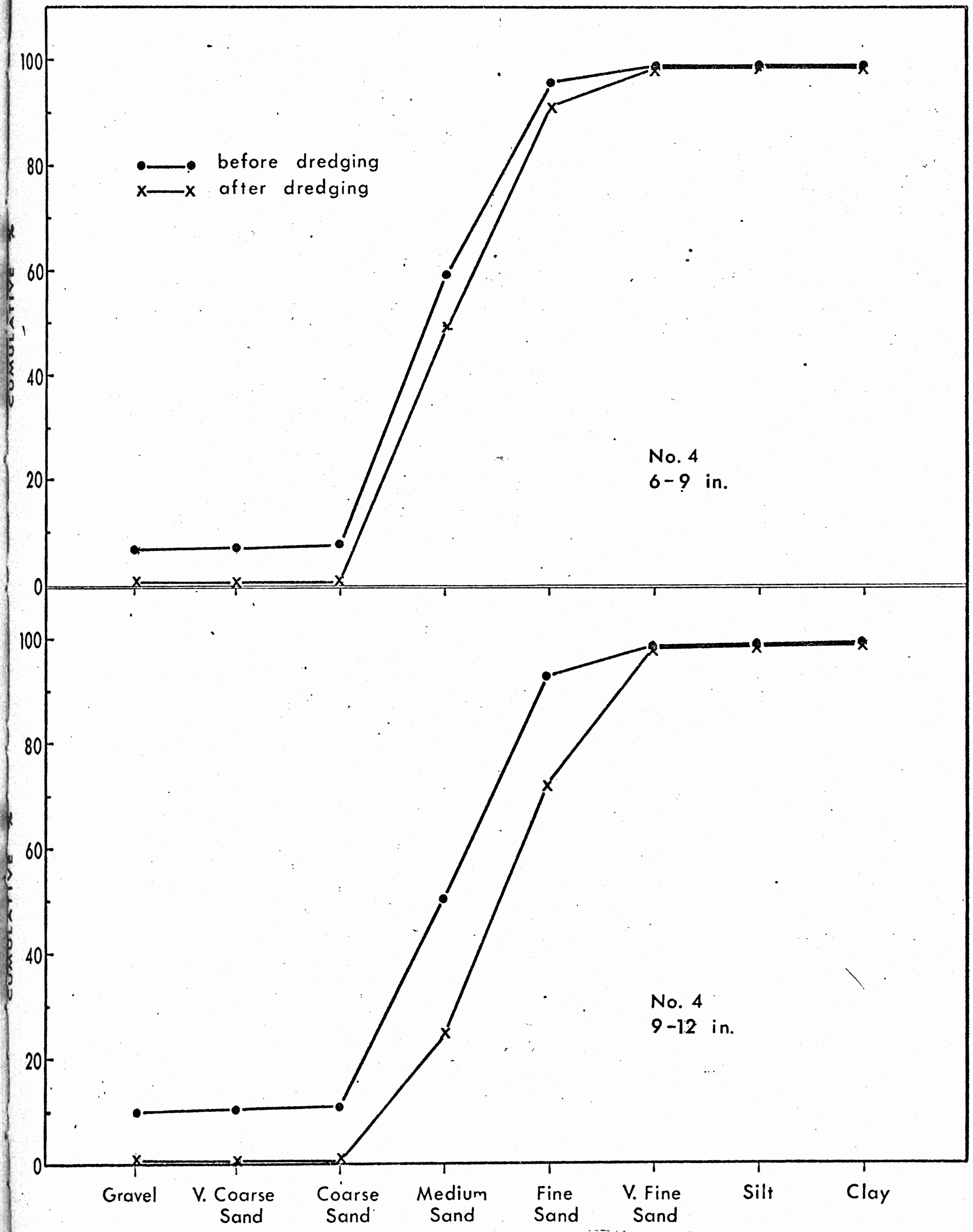

Fig. 4. Sediment grain size distribution in plot before treatment and after weekly dredging.

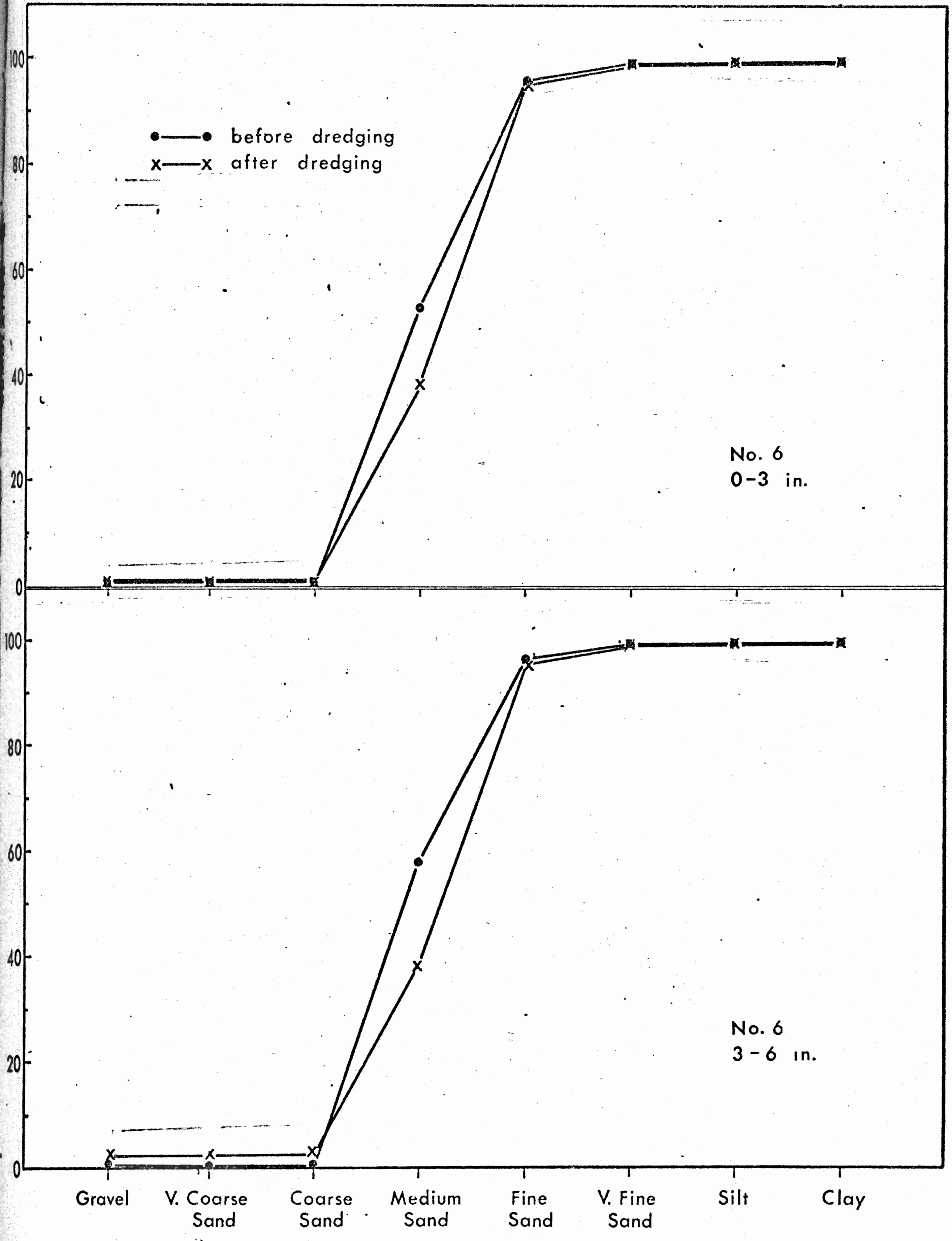

Fig. 5. Sediment grain size distribution in control plot before and after treatment to nearby plots.

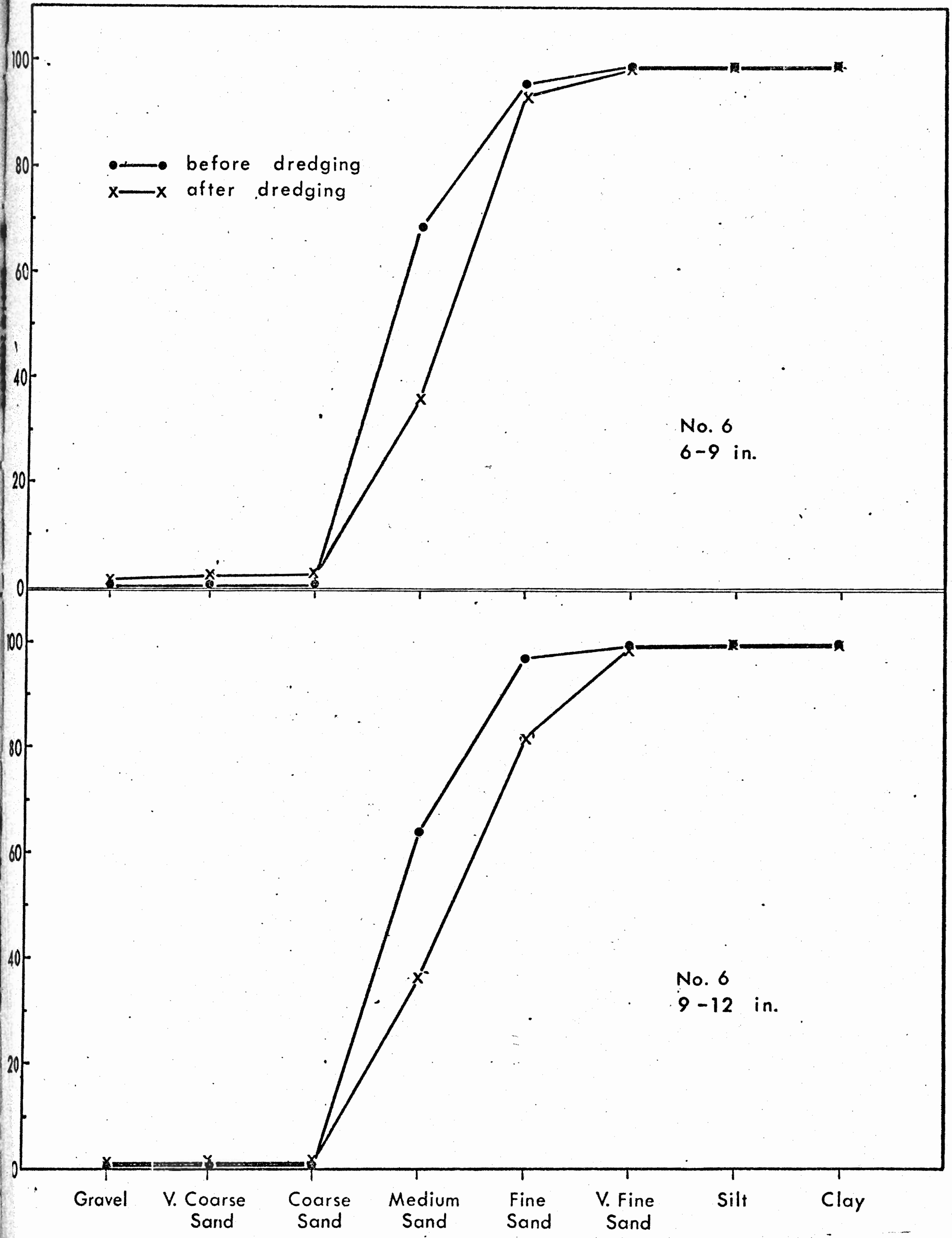

Fig. 6. Sediment grain size distribution in control plot before and after treatment to nearby plots.

the sediment-water interface. Bottom consisting of sand with no clay-silt fraction is usually an indication of instability. Since the hydraulic dredge disrupts the sediment profile of the bottom, it was thought that the organic matter may be washed away with the finer sediments. Samples were taken from all nine plots from the top 1 inch of sediment before treatment to any of the plots. After dredging, triplicate samples were taken in three plots; one plot which received daily dredging, one plot which received weekly dredging, and one control plot. The organic carbon of these samples was measured with a Coleman Carbon and Hydrogen Analyzer. These results are given in Table 9.

Before the sediments were disturbed , one sample was taken in each plot and the values were relatively uniform among all the plots, varying from .11 to .15% organic carbon. These values are comparatively low and characteristic of a substrate predominantly made up of sands with low silt-clay content. The values after dredging were not as close as before dredging. In the plots after dredging, they varied from .09 to .51% (this high value may be an analytical error), indicating a disturbance of the substrate. More uniformity was found in the samples from the control plot. It appears that not much of the organic matter was lost from the dredged areas, but was redistributed and, in some instances, concentrated in large amounts. It is therefore apparently not lost to the immediate area and the sediments do not become clean, sterile sands, but some silts, clays, and resulting organic matter are trapped in the dredged sediments and redeposited on the bottoms.

Phase 2. The second series of plots was dredged in August 1970 for the purpose of determining the effects of intermittent dredging on the populations of clams. Three plots (1, 3, 8) were dredged 30 or 60

Table 9. Percentage of organic carbon in each plot before dredging (July 31), and after dredging (August 24).

Plot and Treatment		July 31	August 24
1	Daily	.15	.51* .10, .10
2	Weekly	.12	
3	Daily	.13	
4	Weekly	.12	.18, .09, .12
5	Control	.14	
6	Control	.13	.12, .18, .12
7	Weekly	.15	
8	Daily	.13	
9	Control	.11	

* May be analytical error.

minutes each day for five consecutive days. Three other plots (2,4,7) were dredged 90 or 120 minutes each day for 2 days at about a weekly interval. The total amount of time dredged in all plots was the same (3.5 hours). The total number of bushels removed from each plot was different, however, due to a different population density. Three plots served as controls and were not treated in any manner except for obtaining samples (Table 4).

Post-treatment samples were first taken in November 1970. The effects of the removal of market-size clams was still evident and the difference between the dredged and control plots was significant at the 1.8% level (Table 10). Population density of marketable clams decreased in the control plots since the August sampling period (Table 11), indicating heavy mortalities occurred in this area as well as in the populations of Phase 1 experiment. No difference could be detected between the plots dredged daily or weekly, however, the significant difference (3.6%) between the control and dredged plots was still measured in April 1971 (Table 10). The following sampling period in August 1971 indicated a recruitment in the dredged plots and a decrease in the control plots (Table 12), so the densities were significantly the same (57% - Table 10). The recruitment, larger than 35 mm, resulted from the October-November 1970 set. A major decline in density took place after the August 1971 sampling period and so few individual clams were sampled in December that no further data were useable (Table 12). The survival of newly recruited clams in the dredged plots in August 1971 and the corresponding decrease in the control plot suggests the attainment of an optimum

Table 10. Analysis of variance results of the data for number of clams 36 mm and larger in shell length. Phase 2 experiments.

Source of Variance	SS	DF	MS	F	P
Aug 1970					
Within cells	10.83	6	1.80		
Treatment	2.40	2	1.20	.666	.548
Nov 1970					
Within cells	3.53	6	.59		
Treatment	9.95	2	4.98	8.445	.018
Apr 1971					
Within cells	10.74	6	1.79		
Treatment	21.89	2	10.94	6.114	.036
Aug 1971					
Within cells	9.29	6	1.55		
Treatment	1.91	2	.96	.618	.570
Dec 1971					
Within cells					
Treatment					

Table 11. Results of samples taken in Phase 2 experimental plots.

Plot	No. of clams per 1 ft^2 sample - Legal Size (52 mm and larger)				
	Aug 1970	Nov 1970	Apr 1971	Aug 1971	Dec 1971
1	.6	.2	.3	.1	.03
2	.8	.5	.7	.1	.01
3	2.0	.3	.4	.2	.01
4	1.2	.3	.1	.1	.06
5	1.1	.8	1.6	.5	.07
6	2.0	.8	.9	.5	..07
7	1.7	.4	.1	.2	.3
8	.9	.3	.3	.1	.08
9	2.2	.4	1.1	.6	.06

Table 12. Mean (M) and standard deviation (SD) of numbers of clams per 1 ft^2 sample taken in Phase 1 experimental plots. Clam size 36 mm and larger in shell length.

Plot		Aug 1970	Nov 1970	Apr 1971	Aug 1971	Dec 1971
Control	M	53	39	41	35	1
	SD	16	14	14	11	1
Dredge	M	39	13	11	30	2
Daily	SD	22	2	4	10	2
Dredge	M	40	20	11	25	2
Weekly	SD	14	6	13	18	3

density of population level per unit space. This also appeared to be taking place in the Phase 1 plots where the populations were reduced by dredging. A period of one year elapsed between dredging and the time when the densities became significantly the same in all plots of Phase 2.

Clams in the 1 - 35 mm category showed less effects of dredging, as might be expected, since they were returned to the water. In November 1970, when the first post-dredging samples were taken, setting of clams as a result of the autumn spawning had not been completed (Table 13). In April 1971, the density of juvenile clams was not significantly greater in the dredged plots (Table 14). These results were also noted in the August 1971 samples when the mode of that age-class was about 30 mm. Considerably more sub-legal clams per unit area were found in August 1971 than in August 1970, indicating a better survival of juvenile clams in 1971 (Table 15). The major die-off of large clams after August 1970 apparently did not have a detrimental effect on the brood stock because of the large set and survival of juvenile clams. The lack of spatial competition among age-classes may have resulted in a better survival of the 1970 age-class of clams, at least to 30 mm modal shell length. Severe mortality in the 1970 age-class was evident in December 1971 samples, with densities averaging only about 2 clams per ft^2 (Table 12). Recruitment of this age-class did not advance into the marketable-size category since a significant decrease was also observed in this group (Table 8).

The only effect of the hydraulic clam dredge on clam populations determined in the present work was on density of clams per unit area. There was not sufficient data to determine effects of dredging on the growth rate of the remaining populations. This was due to increasing

Table 13. Results of samples taken in Phase 2 experimental plots.

Plot No.	Treatment	No. of clams per sample[1/] sub-market-size (<52 mm)				
		Aug 1970	Nov 1970	Apr 1971	Aug 1971	Dec 1971
1	Dredge Daily	.9	63	9.5	9.5	2.0
2	Dredge Weekly	.8	41	11.0	10.9	1.3
3	Dredge Daily	.5	65	19.0	9.1	1.3
4	Dredge Weekly	.7	37	18.5	10.8	0
5	Control	1.2	71	7.9	8.7	1.0
6	Control	1.0	59	12.1	9.6	.3
7	Dredge Weekly	.9	49	12.5	5.2	.3
8	Dredge Daily	.6	47	4.8	11.1	4.3
9	Control	.5	76	7.2	4.1	4.0

1/ Aug 1970, Aug 1971, and Dec 1971 are averages obtained with hydraulic dredge (1 ft^2). Nov 1970 and Apr 1971 are averages obtained with van Veen grab (.1 m^2).

Table 14. Analysis of variance of the data for number of clams 1-35 mm in shell length. Phase 2 experiment.

Source of Variance	SS	DF	MS	F	P
Aug 1970					
Within cells	3.28	6	.55		
Treatment	.48	2	.24	.435	.666
Nov 1970					
Within cells	8.96	6	1.49		
Treatment	8.63	2	4.32	2.889	.132
Apr 1971					
Within cells	27.27	6	4.54		
Treatment	8.57	2	4.28	.943	.441
Aug 1971					
Within cells	41.56	6	6.93		
Treatment	8.40	2	4.20	.607	.575

Table 15. Mean (M) and standard deviation (SD) of numbers of clam samples in Phase 2 experimental plots. Clam size 1-35 mm shell length.

Plot		Aug 1970	Nov 1970	Apr 1971	Aug 1971
Control	M	30	137	77	205
	SD	11	27	22	89
Dredge	M	24	123	102	268
Daily	SD	4	32	63	27
Dredge	M	28	88	125	251
Weekly	SD	5	19	37	87

natural mortalities on the populations in the Potomac River and other areas of the Chesapeake Bay, which reduced the populations to such a low level that it was impossible to obtain an adequate sample size for analysis.

CONCLUSIONS

1. Population densities of sub-legal (<35 mm shell length) soft-shell clams were not significantly reduced by dredging and harvesting legal-sized clams.

2. Population densities of legal-sized clams sampled 4 months after March or June dredging were not significantly different from densities in undredged areas. August dredging resulted in significantly different population densities until 8-12 months after dredging activity.

3. Initial setting was not greater in dredged areas, but recruitment (and/or survival) of young clams increased in plots where adult populations were reduced by harvesting.

4. No differences in survival or recruitment were observed in plots dredged at daily and weekly intervals.

5. Growth rates did not appear to be different in dredged and undredged plots, but no direct measurements could be made because of heavy, unexplained mortalities that occurred throughout the study area.

6. No major changes in sediment grain size were detected after dredging, possibly because of the presence of predominately medium and fine sands in the experimental areas.

7. Dredged bottoms exhibited less compaction of the sediments that was still detectable 1 year after dredging activity.

8. Organic carbon in the first inch of undisturbed sediment was redistributed within the substrate by dredging activity.

9. The marketable population of soft-shell clams in the dredged plots averaged 5 clams per ft^2 at the beginning of the experiment in June 1969. A progressive decrease in numbers occurred throughout the investigation. At the termination of the investigation in December 1971, average density was .05 clams per ft^2.