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Reinaldo Morales-Alamo
Virginia Institute of Marine Science

Roger L. Mann
Virginia Institute of Marine Science

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By
Reinaldo Morales-Alamo
and Roger Mann

Special Report No. 304 in
Applied Marine Science and Ocean Engineering

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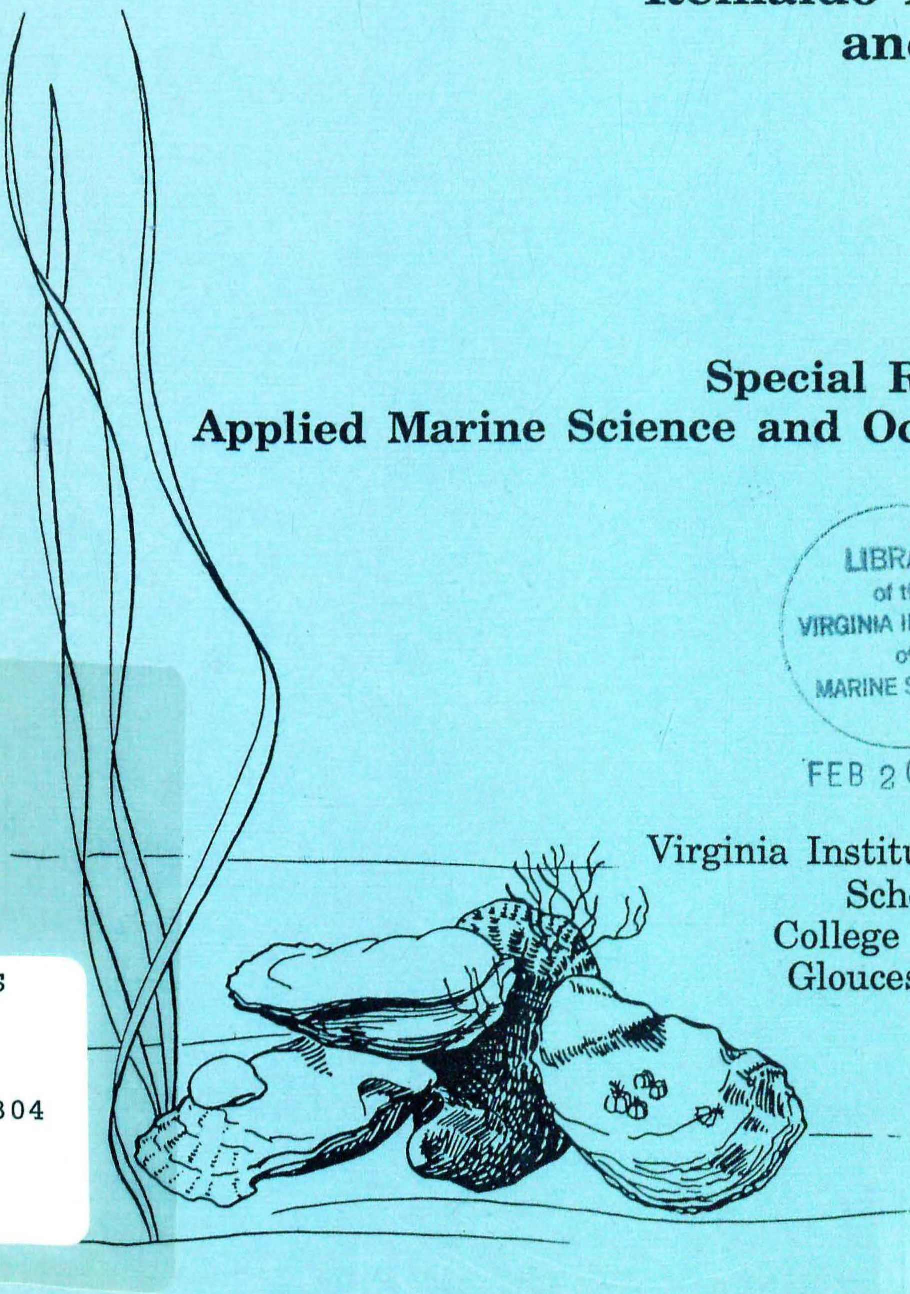

Virginia Institute of Marine Science
School of Marine Science
College of William and Mary
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RECRUITMENT AND GROWTH OF OYSTERS ON SHELL CULTCH PLANTED AT MONTHLY INTERVALS (MAY-AUGUST 1986) AT JONES SHORE BAR IN THE LOWER POTOMAC RIVER, MARYLAND

By

Reinaldo Morales-Alamo

and

Roger Mann

SPECIAL REPORT NO. 304 IN APPLIED MARINE SCIENCE AND OCEAN ENGINEERING

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SUMMARY

Oyster shells were planted on four successive months (May to August 1986) in contiguous plots at Jones Shore Bar in the Potomac River, Maryland, to study the effect of differences in time of cultch planting on settlement and survival of oyster spat. The plots were usually sampled at two-week intervals from time of planting through November, 1986, and once in June, 1987.

A massive concentration of the tunicate *Molgula manhattensis* (the common sea squirt) covered the bottom in all plots within four to six or eight weeks following shell planting. A high percentage of the shell surface areas, however, were found to be clean throughout the 1986 collections. Sloughing off of the tunicate clusters during sampling and handling was believed to have contributed significantly to the amount of clean shell areas.

A commercially acceptable survival of between 1.8 and 2.2 spat $shell^{-1}$ (approximately equivalent to 900-1200 spat bu^{-1}) was recorded at three of the plots on June 26, 1987, in spite of the heavy tunicate fouling of 1986. Recruitment of oyster spat was lower in the plot on which cultch was planted earliest, on May 13, than in the other three plots on which cultch was planted 1-3 months later. Number of spat was highest in the plot on which shells were planted on July 14; accidental planting of cultch into two elongated mounds on that plot may have contributed to the high recruitment of spat observed.

Mean spat size was lowest in the plot on which cultch was planted on August 12 and highest in the plots on which shell was planted on May 13 and June 16. Mean size was intermediate in the plot on which shell was planted on July 14. On most dates, there was no significant difference in spat size between the plots on which cultch was planted on May 13 and June 16.

Based on the low recruitment on cultch planted on May 13 and the smaller size of spat at the end of the study on cultch planted on August 12, it appears advisable to plant shell cultch between late June and mid-July at Jones Shore, although plantings as early as mid-June and as late as early August may be acceptable, especially in view of annual variations in spatfall timing.

INTRODUCTION

Oyster shells from shucking houses are planted on public and private estuarine bottoms in Virginia and Maryland to provide new clean substrate on which larvae of the oyster *Crassostrea virginica* (Gmelin 1791) can set. The time selected for planting shell cultch, in reference to oyster spatfall, has always been considered critical to successful recruitment of oyster spat because of reduction of the space available for settlement of oyster larvae by fouling organisms and sedimentation (Manning, 1952; Shaw, 1967; Abbe, 1988). Shells planted too early in the year may become heavily fouled prior to the beginning of oyster spatfall. On the other hand, if shell cultch is planted too late in the season, the peak spatfall period could be missed.

The objective of this study was to investigate the effect of cultch planting time on recruitment and growth of oysters, and its relationship to fouling, at one location in the lower Potomac River under conditions that simulated the usual cultch planting practices of the oyster industry in that region.

Jones Shore Bar was selected as the experimental site because oyster settlement in the maryland shore of the lower Potomac River has usually been higher than on bars further upriver or on the virginia shore (Davis et al., 1976; Krantz and Davis, 1983; Whitcomb, 1985).

This study was sponsored jointly by the Virginia Institute of Marine Science and the Potomac River Fisheries Commission.

MATERIALS AND METHODS

The station at Jones Shore was located on the north side of the Potomac River, approximately 3.5 nautical miles upriver from Point Lookout and one km from the shoreline (Figure 1). Water depth at the station is approximately 3.6 m at mean low water. The river bottom at the station had a muddy sand texture with scattered clumps of oysters and shells.

The experimental area was a square approximately 20 m on each side with one side parallel to the shoreline. The area was divided into four square plots (labelled A, B, C and D), each approximately 100 m^2. The central juncture of the four plots was defined by an existing cylindrical steel marker. A shellstring was also suspended from this marker as part of a separate spatfall monitoring program by the Virginia Institute of Marine Science. The boundary between adjoining plots was marked on the outside edge by a wooden pole. Oyster shells were broadcast from a barge over each plot by a private contractor in the manner employed by commercial oyster growers. Plantings were made at monthly intervals in 1986: plot A on May 13 (361 bu), plot B on June 16 (380 bu), plot C on July 14 (418 bu) and plot D on August 12 (361 bu).

Divers' observations of the bottom in each of the plots following planting of cultch indicated that shell distribution over plots A and B was uneven and that many of the shells in some places were buried in the muddy sand. Shell distribution over plot D was more even than in plots A and B. Shells in plot C were concentrated into two elongated mounds approximately 5 m long, 2-3 m wide and 1.5 m high; the mounds resulted when inclement weather over the area on July 14 forced the barge operator to throw the shell overboard hurriedly without trying to broadcast it evenly over the bottom. The mounds were joined at one end forming a V with an angle of approximately 45 degrees and the apex pointing in a N-NE direction toward the central cylindrical marker.

Shell samples were collected at 2-week intervals between June 3 and November 4, 1986; except that no collections were made on August 12 and on October 7 and 21 because of inclement weather or other unavoidable circumstances. No sample collections were made between November 1986 and June 1987. Sampling dates are numbered in sequence from 1 (June 3, 1986) to 10 (June 26, 1987) in some of the tables and figures to simplify their format.

Samples were collected into plastic bags by SCUBA-equipped divers from three randomly-selected 0.25 m^2 quadrats in each plot on each date. Shell samples were transferred to large plastic buckets filled with river water for transportation to the laboratory where they were placed in a 4% solution of ethanol in river water for 2 hrs prior to preservation in a 70% solution of ethanol. Temperature measurements were made at the station and water samples collected for salinity determinations.

Fouling on the shells was quantified using a modified point-sampling technique (Rheinhardt and Mann, in press). It consisted of placing shells in water in a small rectangular container that held 3-4 shells without overlap and recording the type of fouling found at randomnly selected points on the shells; both sides of each shell were examined and the data combined. Shells in the box were treated as a unit, as if they were a single shell.

Four shell-box units were examined from each plot on each sampling date. Fouling coverage was computed as the percentage of the total number of points examined that lay over fouling agents or over a clean area on the shell.

Spat on the shells examined for fouling were counted and measured after they were air-dried. Size of each spat was measured as its height (the distance from the umbo to the farthest point on the opposite edge of the shell). Measurements were grouped into height class intervals of 4 mm.

Analysis of variance and Scheffe's multiple contrast test (Zar, 1984) were used to compare means when variances were homogeneous. In cases where the variances were heterogeneous, the nonparametric Mann-Whitney test (Olson, 1988) was applied for mean comparisons. A significance probability level of 0.15 was used for rejection of the null hypothesis in comparisons of mean number of spat and mean spat height between plots and dates to enhance visualization of the probable relationship among means while maintaining a low probability of committing a Type I error. The coefficient of variation (the standard deviation as a percentage of the mean; Sokal and Rohlf, 1981) was computed as a measure of the relative variability of the data on number of spat $shell^{-1}$.

RESULTS

Fouling.

Visual observation of the bottom by our divers indicated that the tunicate Molgula manhattensis (the common sea squirt) appeared to cover completely, or almost completely, all shell substrate within 4-6 weeks after the shells were planted (8 weeks in plot A). This cover persisted through the last sampling date in 1986 (November 4). Tunicate clusters were lost often during collection and handling of shells and those losses prevented accurate quantification of fouling by tunicates. Therefore, the values given in Figure 2 underestimate coverage by tunicates.

The percentage of clean shell area in samples from all plots was generally much greater than the percent coverage of any of the other fouling categories (Figure 2; Tables 1-4). Clean shell areas constituted an estimated 60 to 85% of the total surface area on the first sampling date at each plot and ranged between 40 and 60% on most of the other dates. In contrast, percent coverage for each of the other fouling categories was, in most cases, well under 20% throughout 1986. Only tunicates and encrusting bryozoa ever exceeded 20% but without any consistency.

Three of the four times when a fouling species exceeded the percent occurrence of clean shell areas were recorded on June 26, 1987. On that date, coverage by encrusting bryozoa was slightly higher than clean shell area percentage in plot A, but it was considerably higher in plots B and C;

percent coverage by most of the other fouling species also exceeded percent occurrence of clean shell areas in plots B and C.

Spat Settlement, Survival and Growth.

Spat were first found in plot A on June 17, 1986, approximately one month after shells were planted (Figure 3, Table 5). At the other plots, spat were first found on the first sampling date, two weeks after shell planting (Figure 3, Tables 6-8). The first substantial number of spat (15 or more) was not found in plots A and B until July 15, eight and four weeks after planting, respectively; substantial numbers, however, were found in plots C and D only two weeks after planting.

Spat ≤ 8.0 mm were presumed to have set in the two weeks preceding the sampling date because almost all spat in samples collected two weeks after shells were planted were 8.0 mm or smaller. This assumption was supported by the bimodal size frequency distribution of spat in later samples, which could be separated into two distinct size groups, one composed of spat ≤ 8.0 mm and the other one made up of spat > 8.0 mm (Figure 3).

Spat ≤ 8.0 mm were found at all plots in substantial numbers between July 15 and September 23 in plots A and B and in plots C and D from the first sampling date through November 4 (Figures 3 and 4). Spat ≤ 8.0 mm were still present in plots C and D on June 26, 1987, but in very reduced numbers. According to data collected by the Virginia Institute of Marine Science, using shellstrings suspended over the bottom and exposed for one-week intervals, oyster spatfall at Jones Shore in 1986 extended from the week of July 7-14 to the week of September 1-8 (Whitcomb, 1986). Thus, the number of spat $\leq$ 8.0 mm found on September 23 probably represent recruitment of spat after September 8 which was not observed in the suspended shellstrings. The presence of spat $\leq$ 8.0 mm on November 4 was probably the result of lag in growth of the spat, rather than new recruitment. The low numbers recorded on June 26, 1987, most likely represent early spat set on that summer.

There was no significant difference ($P \leq 0.15$) in mean number of spat $\leq$ 8.0 mm between plots A and B on any of the sampling dates except on July 15 when the highest number of spat in that size group recorded during the study was found in plot A (Table 9). Mean number of spat $\leq$8.0 mm in plot C was significantly higher than in plots A and B on every sampling date but one (August 26), suggesting that recruitment of spat was greater in plot C than in A and B. No difference was evident, however, between plots C and D, probably because the cultch in those two plots was planted during peak spatfall periods. Mean number of spat in the same size group was significantly higher ($P \leq 0.15$) in plots C and D than in A and B on September 23.

Mean number of spat > 8.0 mm increased significantly ($P \leq 0.15$) with time in all plots as a result of the continuous recruitment through the spatfall season (Figure 4). The highest number of spat occurred on the last two sampling dates, dates 9 and 10 (November 4, 1986, and June 26, 1987). Mean number of spat $shell^{-1}$ was significantly higher in plot C than in the other plots on most dates (Table 9). Likewise, on most dates, mean number of spat was significantly lower in plot A than in the other plots. On

September 23, however, there was no evidence of a difference in mean number of spat > 8.0 mm between plot A and plots B and D, the probable result of better than usual recruitment in plot A during the two weeks preceding September 9.

Size frequency distribution in all four plots was approximately bell-shaped on June 26, 1987, although numbers were low in plot A (Figure 3). In plot B the frequency distribution was slightly skewed towards the larger sizes and in plots C and D it was slightly skewed towards the smaller sizes, which reflects the presence of older (thus, larger) spat in plot B .

The coefficient of variation (CV) for mean number of spat $\leq$ 8.0 mm shell^{-1} was considerably lower in plot C than in the other plots on all sampling dates, with the exception of September 23 indicating less variability in samples from plot C (Table 10). On September 23, CV was lower in plots A, B and D than on any of the other sampling dates with the exception of July 15 in plot A; this indicated a reduction in variability among samples, for which we cannot suggest an explanation. CV for mean number of spat > 8.0 mm was relatively high on all sampling dates.

There was no evidence of a significant difference ($P \leq 0.15$) in mean size of spat $\leq$ 8.0 mm between plots A and B on six of the seven sampling dates (Tables 11 and 12). Mean size of spat $\leq$ 8.0 mm was, however, lower in plot A than in plots C and D on each of the first three dates that samples were collected from plots C and D, because of a lower proportion of spat 4.1-8.0 mm in plot A on those dates. No discernible pattern was evident in size differences among spat $\leq$ 8.0 mm between plots B, C and D. Mean size in plot D, however, was significantly higher than in plots B and C on September

23 because there were more spat in the size class 4.1-8.0 mm in plot D than in B and C.

Size differences between plots among spat > 8.0 mm were closely related to the time of shell planting except that no difference was evident between spat in plots A and B on most dates (Figure 5, Tables 12 and 13). Mean size was significantly higher ($P \leq 0.15$) in plots A and B than in plots C and D on most dates and on all dates mean height was significantly lower in plot D than in the other three plots. Although differences in mean height could not be detected between plots A and B on most dates, the upper end of the size range was higher in B than in A on all but one of the sampling dates (Table 12). The largest mean height and the largest individual height among all plots were also recorded in plot B.

Bottom water temperature ranged between 15.5°C and 28.6°C during the 1986 sampling period and was 25.8°C on June 26, 1987. Bottom water salinity ranged between 14.1 o/oo and 18.6 o/oo in 1986 and was 14.0 o/oo on June 26, 1987 (Table 14).

DISCUSSION

The complete or nearly complete cover of the bottom substrate observed by divers early in our study indicated a dominance of fouling in the experimental plots at Jones Shore in 1986 by the tunicate Molgula manhattensis. Coverage of shell surfaces by tunicates, however, could not be accurately quantified because of loss of clusters during collection and handling. Had the tunicates remained attached to shells in our samples, percent coverage by that species would most likely have been close to 100% after individuals attained adult size.

Abundance of other fouling species on shell cultch in our experimental plots was probably affected by the high density of tunicates, as indicated by the low coverage of those other species and the lack of a consistent increase in shell coverage with time by any individual species. Those species, however, as well as oyster spat, were still able to settle and survive under the tunicate cover throughout the study.

Loss of tunicate clusters during sampling may have contributed substantially to the high percentages of clean shell areas recorded throughout the study. Large areas of shell surface remained relatively free of macroscopic fouling during the first 2-3 weeks following planting because it took that long for fouling organisms to colonize the new surfaces. Clean areas found subsequent to that period must have resulted from coverage by sedimentation, partial burial in the bottom, or coverage by other shells, but a large portion of the clean areas found after the initial 4-6 weeks following planting must represent areas covered by tunicate clusters before they fell off during collection. It would be otherwise difficult to reconcile those high percentages of clean shell areas with the nearly-complete tunicate cover observed over the bottom by divers.

The relationship between the presence of clean shell areas and the loss of tunicate clusters is partially supported by the fouling coverage percentages recorded on June 26, 1987. At that time, reduced numbers of

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tunicate clusters (associated with fewer subsequent losses in handling) permitted barnacles and encrusting bryozoa to occupy larger areas on the shell surfaces. The apparent result of those changes in the composition of the fouling community was a near absence, or reduced amounts of clean areas on the shells.

Higher recruitment of spat $\leq$ 8.0 mm in plots C and D than in plots A and B may be attributed primarily to planting of shells in C and D having coincided in time with the most intense periods of spatfall at Jones Shore Bar, thus giving oyster larvae the opportunity to settle and grow before fouling became a negative factor affecting those two processes. Higher numbers of spat as well as smaller variances among samples in plot C may have been associated with a greater uniformity in distribution of spat over the cultch on that plot. Aggregation of shells into mounds in plot C may have contributed to uniformity in spat distribution because there was a thicker layer of shells beneath the surface cover of tunicates and sedimentation and burial may have been reduced by the inclined sides of the mounds and height of the mounds above the bottom.

The effect of time of cultch planting on oyster recruitment could not be separated from the effect of the unquantified massive fouling by tunicates and aggregation of cultch into mounds in plot C for analysis of the data; consequently, definitive conclusions about the relationship between time of cultch planting, fouling, and oyster recruitment cannot be advanced. Nevertheless, based on the low number of spat recorded in the plot on which shell were planted on the earliest date (plot A), which was considerably lower than in the other three plots, it would appear inadvisable to plant shell cultch as early as mid-May in the Jones Shore area of the Potomac River. The lag in growth of spat on cultch planted in August (plot D) should be taken into account when consideration is given to planting cultch later than mid-July. Therefore, it seems advisable to plant shell cultch between late June and mid-July in that area. Plantings as early as mid-June and as late as early August may, however, be acceptable, especially in view of recorded annual variations in spatfall peaks (Kennedy, 1980). These suggestions would apply to most of the oyster-producing areas of the Chesapeake Bay because timing of spatfall is similar throughout the bay, as is shown by the data in Shaw (1967), Kennedy (1980) and Whitcomb (1986).

The number of spat found in plots B, C and D on June 1987, between 1.8 and 2.3 spat shell^{-1}, which translate into approximately between 900 and 1200 spat bushel^{-1} (based on an estimated 500 shells in one bushel) represent a good survival of spat through the previous summer and winter, especially in the presence of the massive tunicate cover over the bottom. MacKenzie (1981) reported that 2.5 spat shell^{-1} was a good criterion for a commercially successful oyster set on shells planted by oyster growers in Long Island Sound.

ACKNOWLEDGEMENTS

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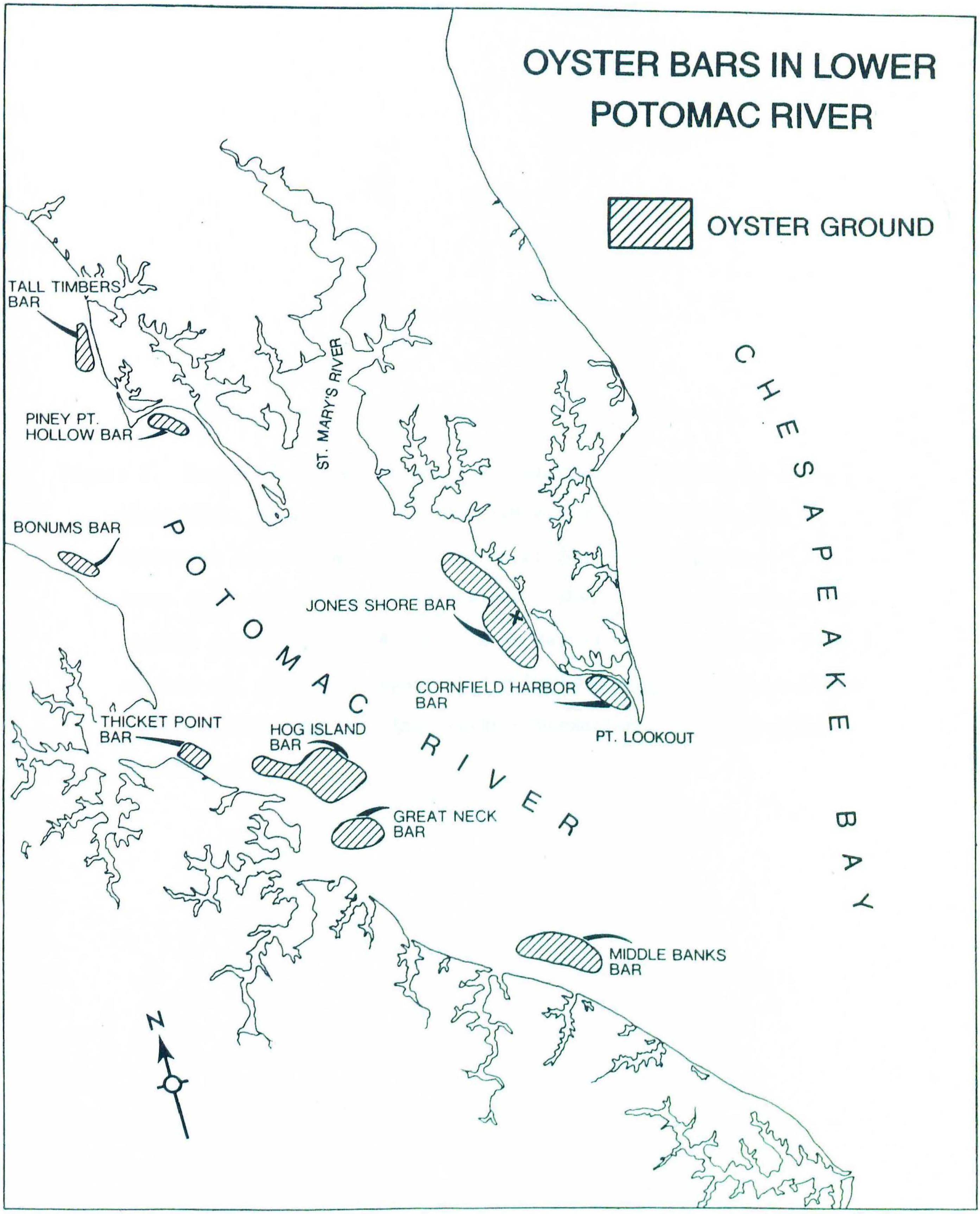
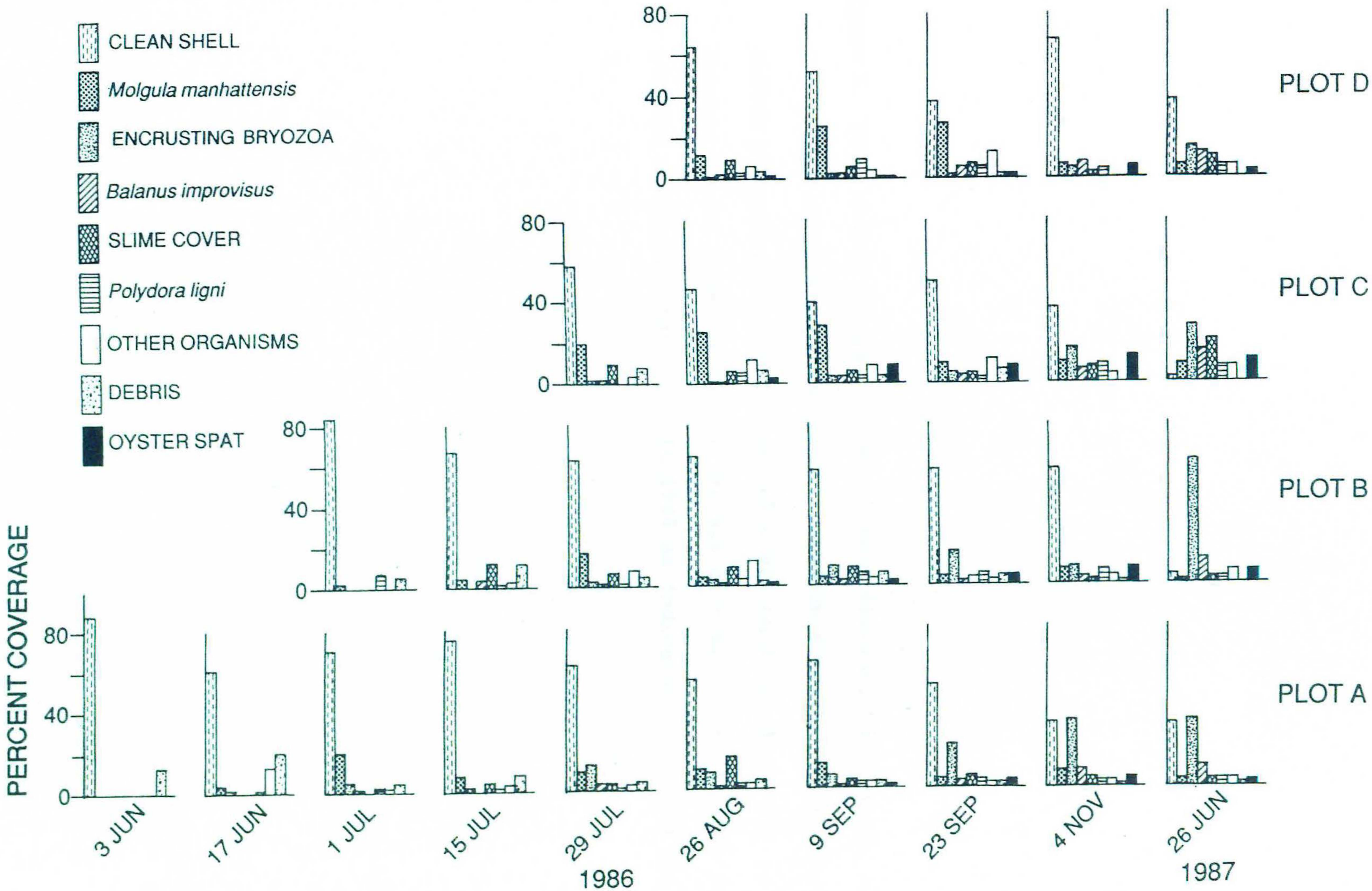
Figure 1. Chart of the lower Potomac River showing location of Jones Shore oyster bar. Location of experimental station on Jones Shore Bar marked by an X. Modified from Haven (1976).



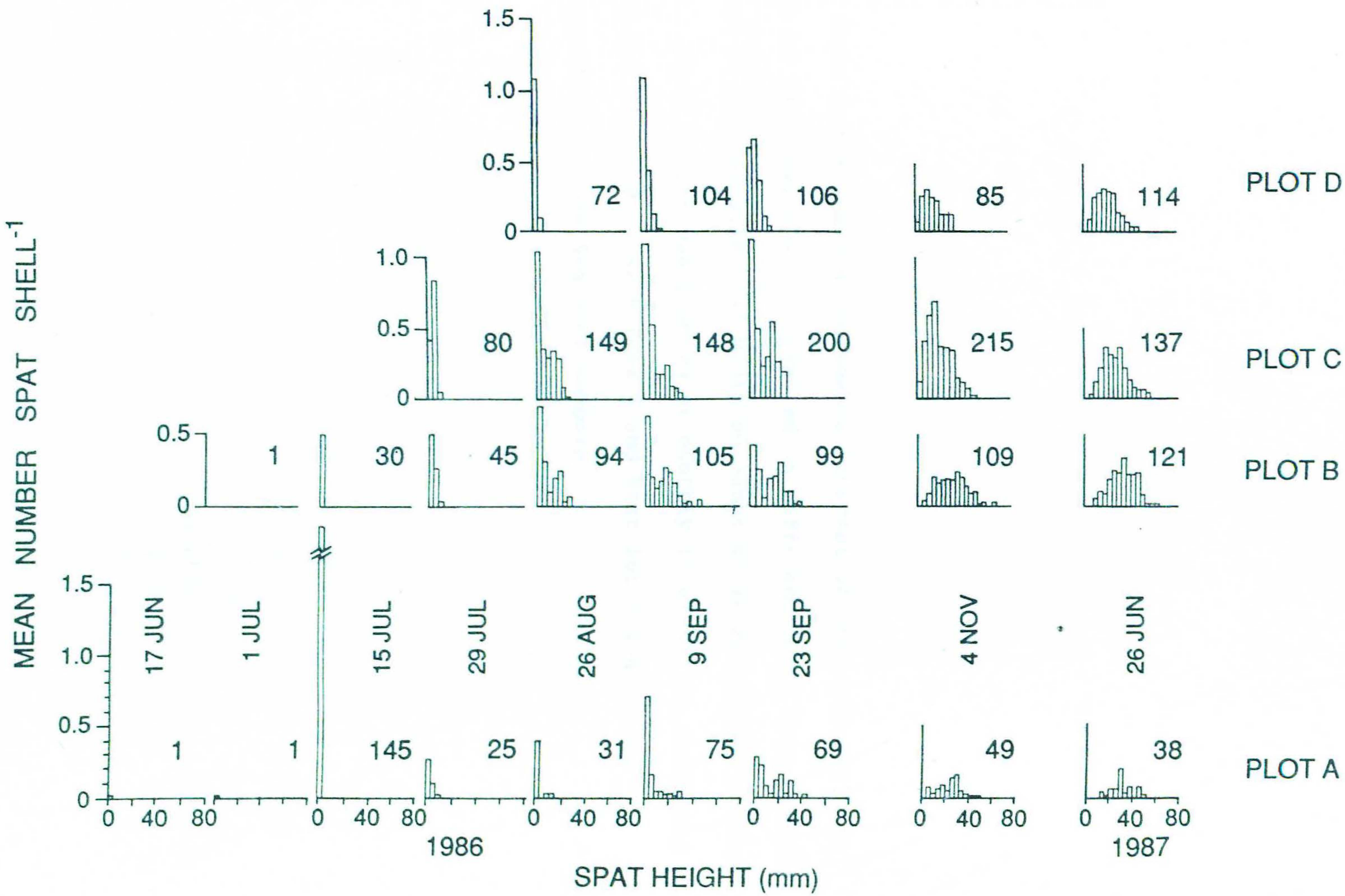
OYSTER BARS IN LOWER POTOMAC RIVER
OYSTER GROUND
TALL TIMBERS BAR
PINEY PT. HOLLOW BAR
ST. MARY'S RIVER
BONUMS BAR
POTOMAC RIVER
JONES SHORE BAR
CORNFIELD HARBOR BAR
PT. LOOKOUT
THICKET POINT BAR
HOG ISLAND BAR
GREAT NECK BAR
MIDDLE BANKS BAR
CHESAPEAKE BAY
N

Figure 2. Percent coverage of fouling organisms and debris and percent of clean shell areas on groups of 13-19 oyster shells collected on different dates from cultch planted at four experimental plots on Jones Shore bar in the Potomac River. Shell cultch was planted at monthly intervals in 1986: plot A on May 13; plot B on June 16; plot C on July 14; plot D on August 12. Molgula manhattensis = tunicates (sea squirts), Balanus improvisus = barnacles, Polydora ligni = mud-blister worms



CLEAN SHELL
Molgula manhattensis
ENCRUSTING BRYOZOA
Balanus improvisus
SLIME COVER
Polydora ligni
OTHER ORGANISMS
DEBRIS
OYSTER SPAT
PERCENT COVERAGE
0
40
80
PLOT D
PLOT C
PLOT B
PLOT A
3 JUN
17 JUN
1 JUL
15 JUL
29 JUL
26 AUG
9 SEP
23 SEP
4 NOV
26 JUN
1986
1987

Figure 3. Mean number of spat per shell in different shell height classes for groups of 60 oyster shells collected on different dates from cultch planted at four experimental plots on Jones Shore bar in the Potomac River. Shell height intervals of 4 mm. Shell cultch was planted at monthly intervals in 1986 as indicated in legend for Figure 2.



MEAN NUMBER SPAT SHELL^{-1}
SPAT HEIGHT (mm)
PLOT A
PLOT B
PLOT C
PLOT D
17 JUN
1 JUL
15 JUL
29 JUL
26 AUG
9 SEP
23 SEP
4 NOV
26 JUN
1986
1987

Figure 4. Mean number and 95% confidence interval of spat per shell in groups of 60 oyster shells collected on different dates from cultch planted at four experimental plots on Jones Shore Bar in the Potomac River. Shell cultch was planted at monthly intervals as indicated in legend for Figure 2. See Figure 6 and text for actual dates corresponding to Date Sequence numbers.

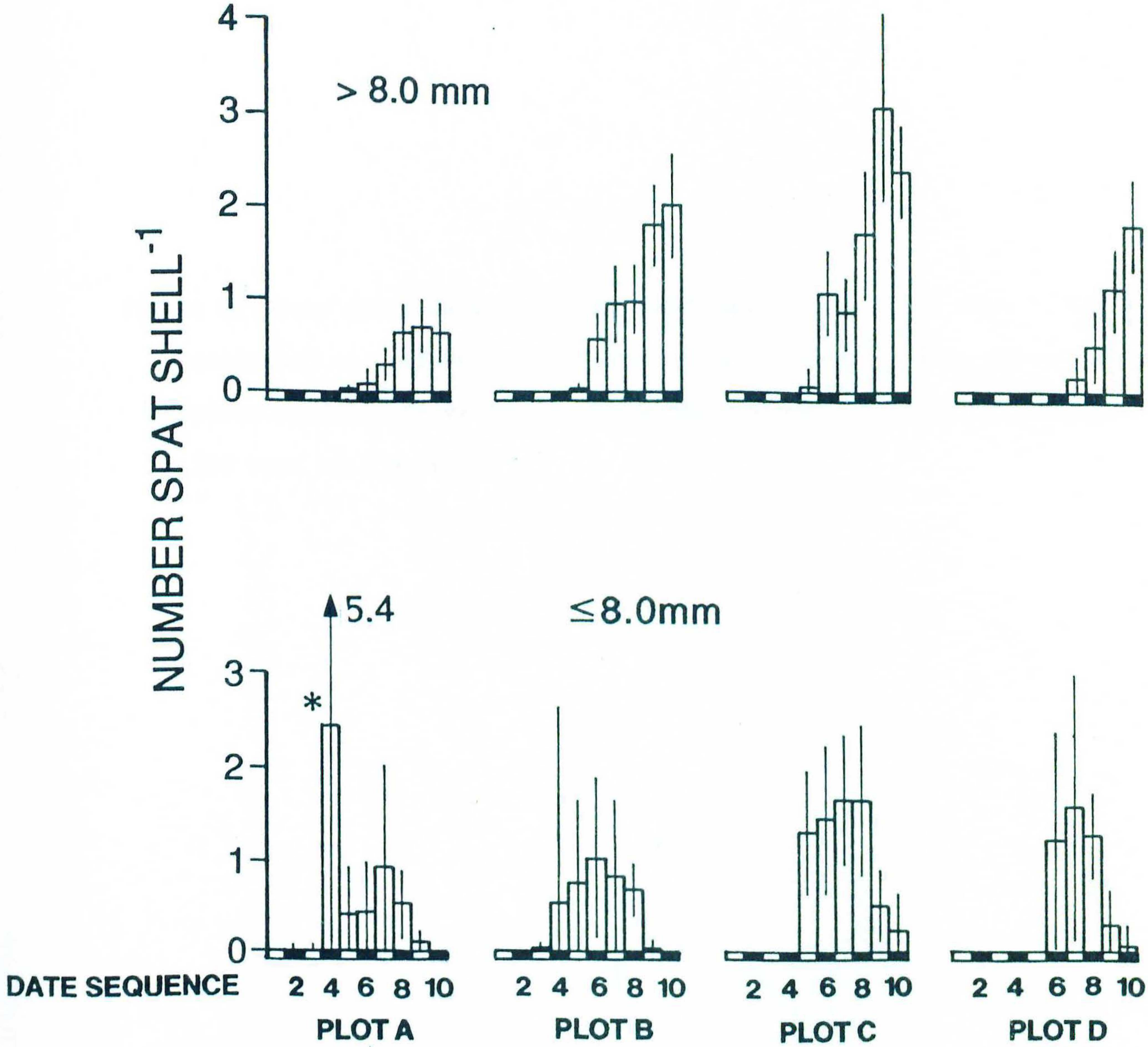

NUMBER SPAT SHELL-1
> 8.0 mm
≤8.0mm
5.4
*
DATE SEQUENCE
PLOT A
PLOT B
PLOT C
PLOT D

Figure 5. Mean shell height and 95% confidence interval of spat on shells collected on different dates from cultch planted at four experimental plots on Jones Shore Bar in the Potomac River. Mean height computed for spat >8.0 mm only.

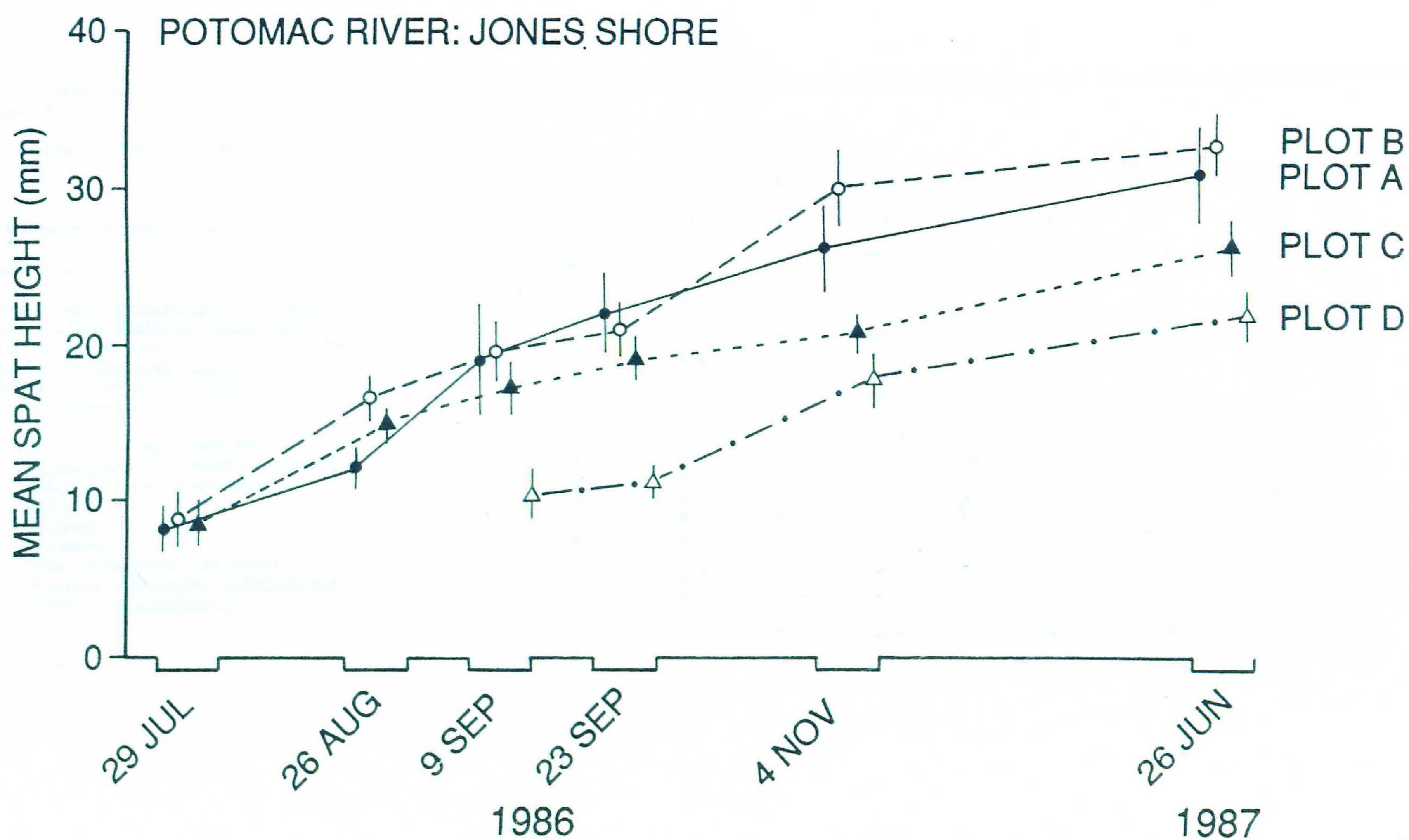

POTOMAC RIVER: JONES SHORE
MEAN SPAT HEIGHT (mm)
40
30
20
10
0
PLOT B
PLOT A
PLOT C
PLOT D
29 JUL
26 AUG
9 SEP
23 SEP
4 NOV
26 JUN
1986
1987

TABLE 1. Percent coverage of shell surfaces by attached organisms and other fouling agents on oyster shells planted on the public oyster ground at Jones Shore in the Potomac River.

PLOT A: shells planted on 13 May 1986

	Sampling Dates									
	3 June 86	17 June	1 July	15 July	29 July	26 Aug.	9 Sept.	23 Sept.	4 Nov.	26 June 87
Number of Points Counted	231	241	267	269	273	269	296	250	273	567
Clean shell	88.3	60.6	68.2	74.3	62.3	54.6	63.5	51.6	32.2	31.7
Oyster spat (<u>Crassostrea virginica</u>)	0	0	0	0	0	0	1.4	4.4	4.8	3.0
Sea squirts (<u>Molgula manhattensis</u>)	0	3.7	18.7	7.4	9.5	10.0	11.8	4.0	7.7	3.4
Encrusting bryozoans	0	2.1	4.1	0.4	12.5	9.7	6.4	21.6	33.7	37.7
Barnacles (<u>Balanus improvisus</u>)	0	0.4	1.1	0	3.7	0.7	1.0	4.0	8.4	10.8
Mudblister worms (<u>Polydora ligni</u>) and tubes	0	0.8	2.2	2.2	0.7	2.6	4.4	4.8	4.4	3.9
Other organisms:	0	12.8	1.5	3.0	3.3	1.9	3.0	2.4	3.7	3.8
Non-encrusting bryozoans	0	1.7	0	1.9	0	0.4	0	0	0	0
<u>Folliculina</u> (Ciliated protozoan)	0	0.4	0	0	1.1	0.7	3.0	1.2	0	0
Other ciliated protozoans	0	4.1	0	0	0	0	0	0	0	0
Hydroids	0	0	0	0	0.4	0.4	0	0.4	0.4	0.2
Sponges	0	0	0	0	0.7	0	0	0	0.7	0.4
Anemones	0	0	0	0	0	0	0	0	0.4	0
Other tube-worms and tubes	0	0	0	1.1	1.1	0	0	0	0	0
Seaweeds (<u>Ceramium</u>, <u>Polysiphonia</u>)	0	6.6	1.5	0	0	0.4	0	0.8	2.2	2.1
Mussels (<u>Brachidontes</u>)	0	0	0	0	0	0	0	0	0	1.1
Debris	11.7	19.5	4.1	8.9	4.4	5.0	3.8	1.6	0.4	0.9
Slime cover	0	0	0	3.7	3.7	15.6	4.7	5.6	4.8	4.6

TABLE 2. Percent coverage of shell surfaces by attached organisms and other fouling agents on oyster shells planted on the public oyster ground at Jones Shore in the Potomac River.

PLOT B: shells planted on 16 June 1986

	Sampling Dates									
	3 June 86	17 June	1 July	15 July	29 July	26 Aug.	9 Sept.	23 Sept.	4 Nov.	26 June 87
Number of Points Counted			238	201	287	291	289	265	205	482
Clean shell			83.6	67.2	61.7	64.6	57.1	57.0	57.0	4.4
Oyster spat (*Crassostrea virginica*)			0	0	0	1.1	2.1	4.6	8.0	6.4
Sea squirts (*Molgula manhattensis*)			1.7	4.5	16.7	4.8	4.2	4.9	8.3	1.7
Encrusting bryozoans			0	0	1.7	3.4	9.3	16.6	8.7	61.8
Barnacles (*Balanus improvisus*)			0	3.0	0.7	0.7	2.4	1.9	4.4	12.4
Mudblister worms (*Polydora ligni*) and tubes			7.1	0.5	0.3	2.7	5.9	5.7	6.3	2.9
Other organisms:			2.1	2.0	7.9	11.7	4.5	1.9	4.9	6.8
Non-encrusting bryozoans			0	0.5	0.3	1.4	0	0	0	0
Folliculina (Ciliated protozoan)			0	0.5	5.2	8.6	0	0	0	0
Other ciliated protozoans			0	0	0	0	0	0	0	0
Hydroids			0	0	0.7	0	0.7	0	1.4	0
Sponges			0	0	0	0.7	0	0	0.5	0.4
Anemones			0	0	0	0	0	0	0	0.4
Other tube-worms and tubes			0	1.0	1.4	0.3	2.4	1.9	0	0
Seaweeds (*Ceramium*, *Polysiphonia*)			2.1	0	0.3	0	0.7	0	1.5	1.9
Mussels (*Brachidontes*)			0	0	0	0.7	0.7	0	1.5	4.1
Debris			5.5	11.6	4.5	1.7	6.2	4.5	0.5	0
Slime cover			0	11.0	6.3	9.3	8.3	3.0	2.0	3.5

TABLE 3. Percent coverage of shell surfaces by attached organisms and other fouling agents on oyster shells planted on the public oyster ground at Jones Shore in the Potomac River.

PLOT C: shells planted on 14 July 1986

	Sampling Dates									
	3 June 86	17 June	1 July	15 July	29 July	26 Aug.	9 Sept.	23 Sept.	4 Nov.	26 June 87
Number of Points Counted					303	307	318	227	626	331
Clean shell					58.4	45.3	39.3	48.9	36.3	1.5
Oyster spat (Crassostrea virginica)					0	2.3	8.8	7.5	12.8	10.9
Sea squirts (Molgula manhattensis)					19.5	24.8	27.7	9.7	8.1	9.1
Encrusting bryozoans					0.7	0	1.9	4.8	16.5	28.1
Barnacles (Balanus improvisus)					0.7	0.3	1.9	3.5	5.8	15.4
Mudblister worms (Polydora ligni) and tubes					0	4.9	3.8	2.6	8.5	7.0
Other organisms:					3.0	11.1	7.9	11.9	4.6	7.8
Non-encrusting bryozoans					0	0	0	0	0	0
Folliculina (Ciliated protozoan)					1.7	7.5	3.5	0	0	0
Other ciliated protozoans					0	0	0	0	0	0
Hydroids					0	0.3	0	0.9	0.5	0
Sponges					0	1.0	0	0.9	3.2	5.1
Anemones					0	0	0	0	0	0
Other tube-worms and tubes					1.3	2.3	1.6	2.2	0	0
Seaweeds (Ceramium, Polysiphonia)					0	0	2.8	7.5	0.3	1.5
Mussels (Brachidontes)					0	0	0	0.4	0.6	1.2
Debris					8.3	5.9	3.1	6.2	0	0
Slime cover					9.6	5.5	5.7	4.8	7.5	20.2

TABLE 4. Percent coverage of shell surfaces by attached organisms and other fouling agents on oyster shells planted on the public oyster ground at Jones Shore in the Potomac River.

PLOT D: shells planted on 12 August 1986

	Sampling Dates									
	3 June 86	17 June	1 July	15 July	29 July	26 Aug.	9 Sept.	23 Sept.	4 Nov.	26 June 87
Number of Points Counted						261	727	312	594	251
Clean shell						64.0	51.7	37.2	66.2	38.7
Oyster spat (*Crassostrea virginica*)						0.8	0.3	2.6	5.9	4.0
Sea squirts (*Molgula manhattensis*)						11.5	25.0	26.0	6.1	7.2
Encrusting bryozoans						0.4	1.8	1.9	5.7	17.5
Barnacles (*Balanus improvisus*)						1.5	1.1	5.1	7.4	14.3
Mudblister worms (*Polydora ligni*) and tubes						2.7	9.9	5.8	4.7	8.0
Other organisms:						5.7	4.7	13.1	0.7	7.2
Non-encrusting bryozoans						1.9	0	0	0	0
Folliculina (Ciliated protozoan)						1.9	0	0	0	0
Other ciliated protozoans						0	0	0	0	0
Hydroids						0.4	0.1	0	0	0
Sponges						0	1.0	0	0.5	0
Anemones						0	0	0	0	0
Other tube-worms and tubes						1.5	0.1	0	0	0
Seaweeds (*Ceramium*, *Polysiphonia*)						0	3.4	12.8	0	6.0
Mussels (*Brachidontes*)						0	0.1	0.3	0.2	1.2
Debris						3.8	0.1	2.2	0.3	0.8
Slime cover						9.5	5.2	6.1	3.0	12.4

TABLE 5. Number of oyster spat of different sizes in three samples of 20 oyster shells collected at different time intervals in 1986 and 1987 from the bottom of Plot A in Jones Shore public oyster ground, Potomac River. Shells planted on May 13, 1986.

Size Class (mm)	1986 Jun 3 (1)	Jun 17 (2)	Jul 1 (3)	Jul 15 (4)	Jul 29 (5)	Aug 26 (6)	Sep 9 (7)	Sep 23 (8)	Nov 4 (9)	1987 Jun 6 (10)
0.0-4.0		1	1	145	17	25	44	17	1	0
4.1-8.0					7	0	11	14	5	0
8.1-12.0					1	3	4	5	2	0
12.1-16.0						3	4	2	4	3
16.1-20.0							3	8	6	1
20.1-24.0							3	10	3	4
24.1-28.0							2	2	9	4
28.1-32.0							4	8	11	13
32.1-36.0								2	3	2
36.1-40.0								0	2	5
40.1-44.0								1	1	0
44.1-48.0									1	5
48.1-52.0									1	1
52.1-56.0										
56.1-60.0										
60.1-64.0										
64.1-68.0										
Total		1	1	145	25	31	75	69	49	38

TABLE 6. Number of oyster spat of different sizes in three samples of 20 oyster shells collected at different time intervals in 1986 and 1987 from the bottom of Plot B in Jones Shore public oyster ground, Potomac River. Shells planted on June 16, 1986.

Size Class (mm)	1986 Jun 3 (1)	Jun 17 (2)	Jul 1 (3)	Jul 15 (4)	Jul 29 (5)	Aug 26 (6)	Sep 9 (7)	Sep 23 (8)	Nov 4 (9)	1987 Jun 6 (10)
0.0-4.0			1	30	29	42	37	25	0	0
4.1-8.0					15	18	11	15	2	0
8.1-12.0					1	5	7	3	5	3
12.1-16.0						11	9	11	12	6
16.1-20.0						14	15	12	9	5
20.1-24.0						1	13	18	11	11
24.1-28.0						3	8	6	11	15
28.1-32.0							3	6	11	14
32.1-36.0							0	1	14	20
36.1-40.0							1	2	12	12
40.1-44.0							0		8	13
44.1-48.0							1		5	14
48.1-52.0									6	5
52.1-56.0									1	1
56.1-60.0									1	1
60.1-64.0									0	1
64.1-68.0									1	
Total			1	30	45	94	105	99	109	121

TABLE 7. Number of oyster spat of different sizes in three samples of 20 oyster shells collected at different time intervals in 1986 and 1987 from the bottom of Plot C in Jones Shore public oyster ground, Potomac River. Shells planted on July 14, 1986.

Size Class (mm)	1986 Jun 3 (1)	Jun 17 (2)	Jul 1 (3)	Jul 15 (4)	Jul 29 (5)	Aug 26 (6)	Sep 9 (7)	Sep 23 (8)	Nov 4 (9)	1987 Jun 6 (10)
0.0-4.0					26	63	66	67	7	0
4.1-8.0					51	22	31	30	25	2
8.1-12.0					3	18	11	14	35	7
12.1-16.0						21	11	18	41	13
16.1-20.0						18	15	33	22	22
20.1-24.0						6	6	16	20	19
24.1-28.0						1	5	9	22	17
28.1-32.0							3	12	21	22
32.1-36.0								0	9	13
36.1-40.0								1	7	8
40.1-44.0									4	5
44.1-48.0									1	4
48.1-52.0									1	4
52.1-56.0										1
56.1-60.0										
60.1-64.0										
64.1-68.0										
Total					80	149	148	200	215	137

TABLE 8. Number of oyster spat of different sizes in three samples of 20 oyster shells collected at different time intervals in 1986 and 1987 from the bottom of Plot D in Jones Shore public oyster ground, Potomac River. Shells planted on August 12, 1986.

Size Class (mm)	1986 Jun 3 (1)	Jun 17 (2)	Jul 1 (3)	Jul 15 (4)	Jul 29 (5)	Aug 26 (6)	Sep 9 (7)	Sep 23 (8)	Nov 4 (9)	1987 Jun 6 (10)
0.0-4.0						66	66	36	3	0
4.1-8.0						6	27	40	15	5
8.1-12.0							9	22	18	15
12.1-16.0							1	6	14	17
16.1-20.0							1	2	13	19
20.1-24.0									7	18
24.1-28.0									7	17
28.1-32.0									7	8
32.1-36.0									0	7
36.1-40.0									1	4
40.1-44.0										2
44.1-48.0										2
48.1-52.0										
52.1-56.0										
56.1-60.0										
60.1-64.0										
64.1-68.0										
Total						72	104	106	85	114

Table 9. Probability values for Mann-Whitney tests between mean number of spat shell^{-1} in paired experimental plots at Jones Shore, Potomac River, Maryland, on sampling dates following planting of clean shell cultch. Cultch planted on staggered dates in 1986 at four plots: plot A on May 13, plot B on June 16, plot C on July 14 and plot D on August 12. Probabilities ≤ 0.15 underlined. Superscripts identify plot with higher mean.

		1986							1987
Date		JULY 1	JULY 15	JULY 29	AUG 26	SEPT 9	SEPT 23	NOV 4	JUNE 26
Date Sequence		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SIZE GROUP : ≤ 8.0 mm									
Plot A	vs. Plot B	1.00	$\underline{0.05}^{A}$	0.70	0.18	0.70	0.39	0.39	
	vs. Plot C			$\underline{0.04}^{C}$	$\underline{0.06}^{C}$	$\underline{0.06}^{C}$	$\underline{0.01}^{C}$	$\underline{0.07}^{C}$	
	vs. Plot D				0.18	0.39	$\underline{0.02}^{D}$	0.59	
Plot B	vs. Plot C			$\underline{0.13}^{C}$	0.31	$\underline{0.09}^{C}$	$\underline{0.00}^{C}$	$\underline{0.03}^{C}$	
	vs. Plot D				0.69	0.39	$\underline{0.03}^{D}$	0.24	
Plot C	vs. Plot D				0.69	0.82	0.70	0.48	0.59
SIZE GROUP : > 8.0 mm									
Plot A	vs. Plot B			1.00	$\underline{0.05}^{B}$	$\underline{0.15}^{B}$	0.22	$\underline{0.00}^{B}$	$\underline{0.00}^{B}$
	vs. Plot C			0.80	$\underline{0.01}^{C}$	$\underline{0.01}^{C}$	$\underline{0.01}^{C}$	$\underline{0.00}^{C}$	$\underline{0.00}^{C}$
	vs. Plot D					0.32	0.98	$\underline{0.10}^{D}$	$\underline{0.00}^{D}$
Plot B	vs. Plot C			1.00	$\underline{0.08}^{C}$	0.50	$\underline{0.08}^{C}$	$\underline{0.08}^{C}$	0.64
	vs. Plot D					$\underline{0.13}^{B}$	$\underline{0.13}^{B}$	$\underline{0.11}^{B}$	0.89
Plot C	vs. Plot D					$\underline{0.01}^{C}$	$\underline{0.03}^{C}$	$\underline{0.01}^{C}$	0.43

Table 10. Coefficient of variation (Std. Dev./Mean x 100) for number of spat shell^{-1} on sampling dates at four experimental plots planted with clean shell cultch at Jones Shore, Potomac River, Maryland. Values < 75 underlined.

		SHELL HEIGHT ≤ 8.0 mm				SHELL HEIGHT > 8.0 mm			
Date	Date Sequence	Plot A	Plot B	Plot C	Plot D	Plot A	Plot B	Plot C	Plot D
1986									
June 3	(1)								
June 17	(2)	173							
July 1	(3)	173	73						
15	(4)	49	65						
29	(5)	122	114	49		173	173	173	
Aug 26	(6)	126	81	54	92	127	86	77	
Sept 9	(7)	114	98	41	86	119	118	89	159
23	(8)	66	40	47	34	117	87	95	100
Nov 4	(9)	127	245	72	123	112	81	93	88
1987									
June 26	(10)			155	245	146	91	82	73

Table 11. Mean height, 95% confidence interval, and range of oyster spat collected from four experimental plots at Jones Shore, Potomac River, Maryland, between July 1986 and June 1987. Spat ≤ 8.0 mm.

		Spat Height (mm)		
Date	n	Mean	95% Confid. Intvl.	Range
Plot A				
1986 July 15	145	0.65	0.59 - 0.71	0.24 - 2.17
July 29	24	3.10	2.35 _ 3.85	0.35 - 6.51
Aug 26	25	1.29	0.99 - 1.50	0.28 - 2.94
Sept 9	55	2.47	2.02 - 2.91	0.32 - 7.00
Sept 23	31	3.58	2.88 - 4.28	0.80 - 7.68
Nov 4	6	5.60	4.09 - 7.11	2.90 - 6.80
1987 June 26	0			
Plot B				
1986 July 15	30	0.64	0.52 - 0.76	0.24 - 1.68
July 29	44	3.12	2.51 - 3.73	0.28 - 6.65
Aug 26	60	2.85	2.26 - 3.44	0.28 - 7.84
Sept 9	48	2.74	2.19 - 3.29	0.50 - 7.70
Sept 23	40	3.31	2.64 - 3.97	0.48 - 7.36
Nov 4	2	5.70		5.80 - 7.60
1987 June 26	0			
Plot C				
1986 July 29	77	4.63	4.19 - 5.07	0.42 - 8.00
Aug 26	85	2.61	2.17 - 3.04	0.32 - 7.20
Sept 9	99	3.24	2.83 - 3.65	0.28 - 8.00
Sept 23	97	3.23	2.88 - 3.59	0.84 - 7.14
Nov 4	32	5.53	4.98 - 6.07	2.20 - 7.80
1987 June 26	2	6.85		6.20 - 7.50
Plot D				
1986 Aug 26	72	1.84	1.56 - 2.12	0.21 - 5.04
Sept 9	93	3.06	2.65 - 3.46	0.42 - 7.70
Sept 23	76	4.23	3.75 - 4.71	0.64 - 8.00
Nov 4	18	5.44	4.77 - 6.11	2.40 - 7.10
1987 June 26	5	5.91	4.25 - 7.57	4.50 - 7.95

Table 12. Probability values for Mann-Whitney tests between mean spat height in paired experimental plots at Jones Shore, Potomac River, Maryland, on sampling dates following planting of clean shell cultch. Probabilities ≤ 0.15 underlined. Superscripts identify plot with higher mean.

	1986							1987
Date	JULY 1	JULY 15	JULY 29	AUG 26	SEPT 9	SEPT 23	NOV 4	JUNE 26
Date Sequence	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
SIZE GROUP : ≤ 8.0 mm								
Plot A vs. Plot B	1.00	0.95	0.93	$\underline{0.01}^{B}$	0.55	0.55	0.43	
vs. Plot C			$\underline{0.00}^{C}$	$\underline{0.01}^{C}$	$\underline{0.04}^{C}$	0.42	0.84	
vs. Plot D				$\underline{0.07}^{D}$	$\underline{0.09}^{D}$	$\underline{0.15}^{D}$	0.66	
Plot B vs. Plot C			$\underline{0.00}^{C}$	0.72	0.23	0.80	0.24	
vs. Plot D				$\underline{0.05}^{B}$	0.35	$\underline{0.02}^{D}$	0.21	
Plot C vs. Plot D				$\underline{0.06}^{C}$	0.70	$\underline{0.00}^{D}$	0.87	
SIZE GROUP : > 8.0 mm								
Plot A vs. Plot B			1.00	$\underline{0.01}^{B}$	0.94	0.37	$\underline{0.12}^{B}$	0.36
vs. Plot C			0.50	$\underline{0.06}^{C}$	0.31	$\underline{0.02}^{A}$	$\underline{0.00}^{A}$	$\underline{0.01}^{A}$
vs. Plot D					$\underline{0.00}^{A}$	$\underline{0.00}^{A}$	$\underline{0.00}^{A}$	$\underline{0.00}^{A}$
Plot B vs. Plot C			0.50	$\underline{0.06}^{B}$	$\underline{0.11}^{B}$	$\underline{0.06}^{B}$	$\underline{0.00}^{B}$	$\underline{0.00}^{B}$
vs. Plot D					$\underline{0.00}^{B}$	$\underline{0.00}^{B}$	$\underline{0.00}^{B}$	$\underline{0.00}^{B}$
Plot C vs. Plot D					$\underline{0.00}^{C}$	$\underline{0.00}^{C}$	$\underline{0.04}^{C}$	$\underline{0.00}^{C}$

Table 13. Mean height, 95% confidence internal and range of oyster spat collected from four experimental plots at Jones Shore, Potomac River, between July 1986 and June 1987. Spat >8.0mm.

		Spat Height (mm)		
Date	n	Mean	95% Confid. Intvl.	Range
Plot A				
1986 July 29	1	8.3		
Aug 26	6	12.1	10.7 - 13.4	10.4 - 13.5
Sept 9	20	19.2	15.6 - 31.9	8.3 - 31.9
Sept 23	38	22.1	19.6 - 24.7	9.0 - 42.8
Nov 4	43	26.4	23.6 - 29.1	10.2 - 48.5
1987 June 26	38	31.1	28.1 - 34.1	14.6 - 51.4
Plot B				
1986 July 29	1	8.8		
Aug 26	34	16.6	15.2 - 18.0	9.5 - 26.4
Sept 9	57	19.6	17.8 - 21.5	8.2 - 47.0
Sept 23	59	21.0	19.3 - 22.6	8.3 - 39.4
Nov 4	107	30.1	27.8 - 32.5	8.5 - 64.6
1987 June 26	121	33.1	31.1 - 35.0	8.8 - 60.9
Plot C				
1986 July 29	3	8.5	8.3 - 8.8	8.5 - 8.6
Aug 26	64	14.9	13.9 - 15.9	8.2 - 24.2
Sept 9	51	17.3	15.6 - 19.0	8.0 - 31.0
Sept 23	103	19.1	17.9 - 20.4	8.5 - 40.0
Nov 4	183	20.7	19.4 - 22.0	8.3 - 51.1
1987 June 26	135	26.4	24.8 - 28.1	9.1 - 53.8
Plot D				
1986 Sept 9	11	10.4	8.4 - 12.5	8.2 - 18.6
Sept 23	30	11.1	10.2 - 12.1	8.1 - 17.9
Nov 4	67	17.7	16.0 - 19.4	8.3 - 37.1
1987 June 26	109	22.0	20.4 - 23.6	8.9 - 44.5

Table 14. Water temperature and salinity at Jones Shore, Potomac River, Maryland, on sampling dates at experimental area on which shell cultch was planted.

Date		Temperature (°C)		Salinity (o/oo)	
		Surface	Bottom	Surface	Bottom
1986	June 3	21.5	20.0	13.98	14.12
	17	26.5	25.5	13.64	14.57
	July 1	24.5	24.0	15.51	15.06
	15	28.0	27.4	14.82	14.87
	29	30.0	28.6	14.87	16.02
	Aug 26	24.8	24.5	16.87	17.00
	Sept 9	22.5	23.0	17.02	17.14
	23	23.5	24.0	17.93	18.14
	Nov 4	15.9	15.5	18.55	18.64
1987	June 26	26.0	25.8	14.10	13.97