1990

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Journal of Shellfish Research, Vol. 9, No. 1, 165–172, 1990.

RECRUITMENT AND GROWTH OF OYSTERS ON SHELL PLANTED AT FOUR MONTHLY INTERVALS IN THE LOWER POTOMAC RIVER, MARYLAND[1]

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ABSTRACT 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* covered the bottom in all plots within four to six or eight weeks following shell planting. A commercially acceptable number of spat per shell, between 1.8 and 2.2 (approximately equivalent to 900–1200 spat per bu), 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 height 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. The lower number of spat found on shells planted on May 13 was probably associated with the early planting date. The data suggest that combined maximum recruitment and growth of oyster spat is most likely to occur at Jones Shore on cultch planted between late June and mid-July, although plantings as early as mid-June and as late as early August may also produce commercially-acceptable results.

KEY WORDS: *Crassostrea virginica*, oysters, fouling, recruitment, growth

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 has always been considered critical to successful recruitment of oyster spat because fouling by organisms and sedimentation reduce the amount of space readily available for settlement of oyster larvae (Manning 1952; Shaw 1967; Abbe 1988). Shells planted too early in the year may become heavily fouled prior to the beginning of the oyster settlement season; however, if shell cultch is planted too late in the season, the peak oyster settlement period could be missed.

The objective of this study was to investigate the effect of cultch planting time on recruitment and growth of oysters at Jones Shore Bar, in the lower Potomac River, under conditions similar to 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).

MATERIALS AND METHODS

The study site at Jones Shore was located on the north side of the Potomac River, approximately 6.5 km upriver from Point Lookout and 1 km from the shoreline (Fig. 1); water depth at that location is approximately 3.6 m at mean low water. The river bottom at the site had a muddy sand texture with scattered clumps of oysters and shells prior to introduction of the experimental shell cultch.

The experimental area was a square approximately 20 m on each side aligned 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; this marker was also the structure from which shellstrings were suspended in spatfall-monitoring studies of 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, with scattered areas in which no new cultch was found. Shell distribution over plot D was more even than in plots A and B. Shells in plot C were accidentally concentrated into two elongated mounds approximately 5 m long, 2–3 m wide and 1.5 m high, joined at one end to form 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 collec-

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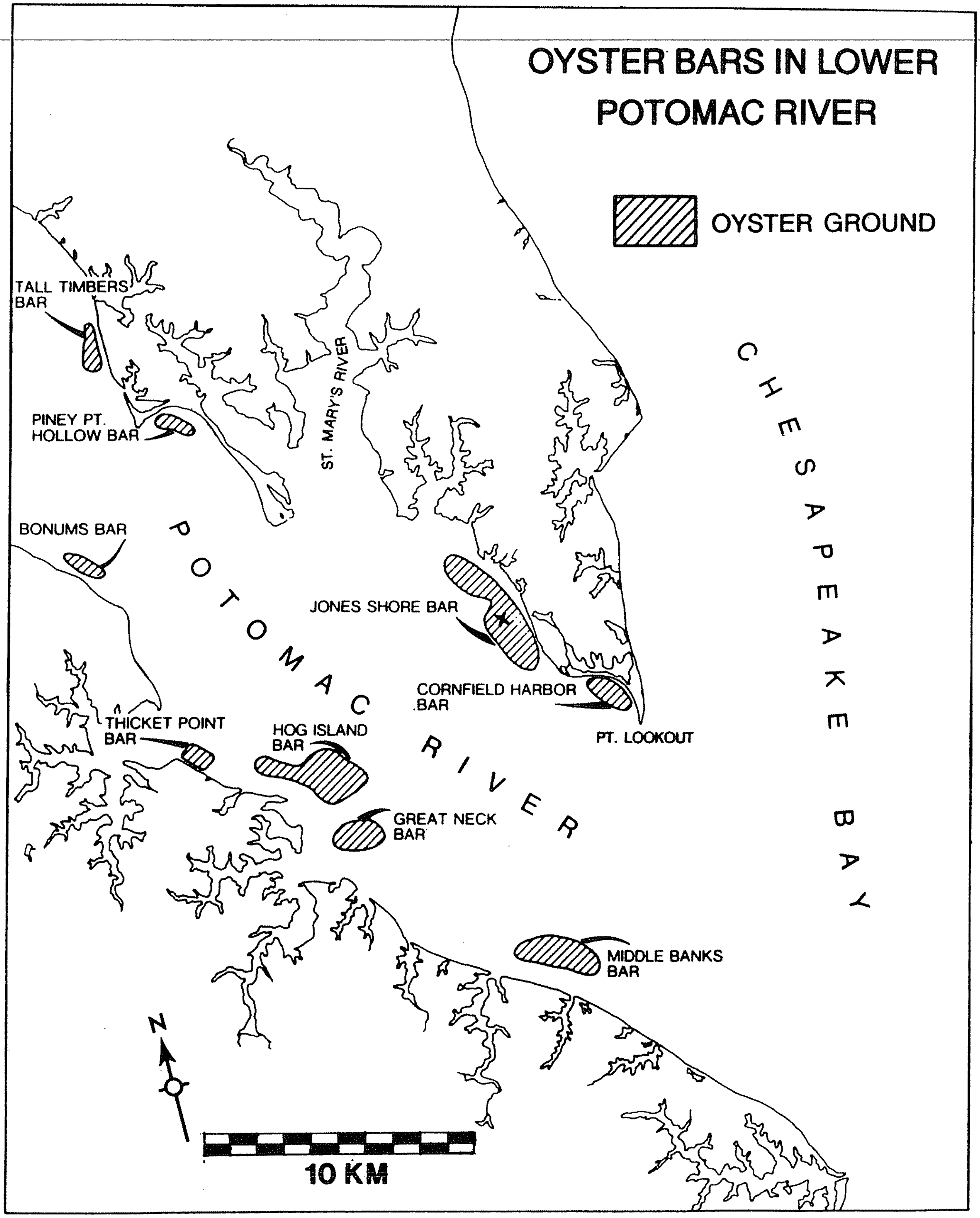

Figure 1. Chart of the lower Potomac River showing location of Jones Shore oyster bar. Approximate location of experimental station is marked by an X. Modified from Haven (1976).

tions 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.

Samples were collected by SCUBA-equipped divers. Marked floating lines guided the divers to the approximate location of three randomly-selected quadrats in each plot. A 0.25-m^2 square frame was dropped over the bottom at each of the selected quadrats and two plastic 4-liter bags were filled with shells from the area within the frame. In instances when the frame landed in an area devoid of new cultch, it was moved to the nearest shell concentration. Locations sampled on plot C were selected differently because of the aggregation of shells into two mounds; there, the square frame was placed on the side of the mound closest to the location of the selected quadrat. The height on the mound from which shells were collected was arbitrarily chosen by the divers. Shell samples were transported to the laboratory in large plastic buckets filled with river water where they were placed in a 4% solution of ethanol in river water for 2 hr prior to preservation in a 70% solution of ethanol. Temperature measurements were made at the station and water samples collected for salinity determinations.

Oyster spat on the shells were counted and measured after the shells were air-dried. An oyster spat is defined here as the attached post-larval form that shows evidence of shell growth beyond the margin of the larval shell. Spat were also counted and measured on other shells selected at random from the three subsamples when needed to increase the number of shells examined to 20. Height of each spat was measured as 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 per-

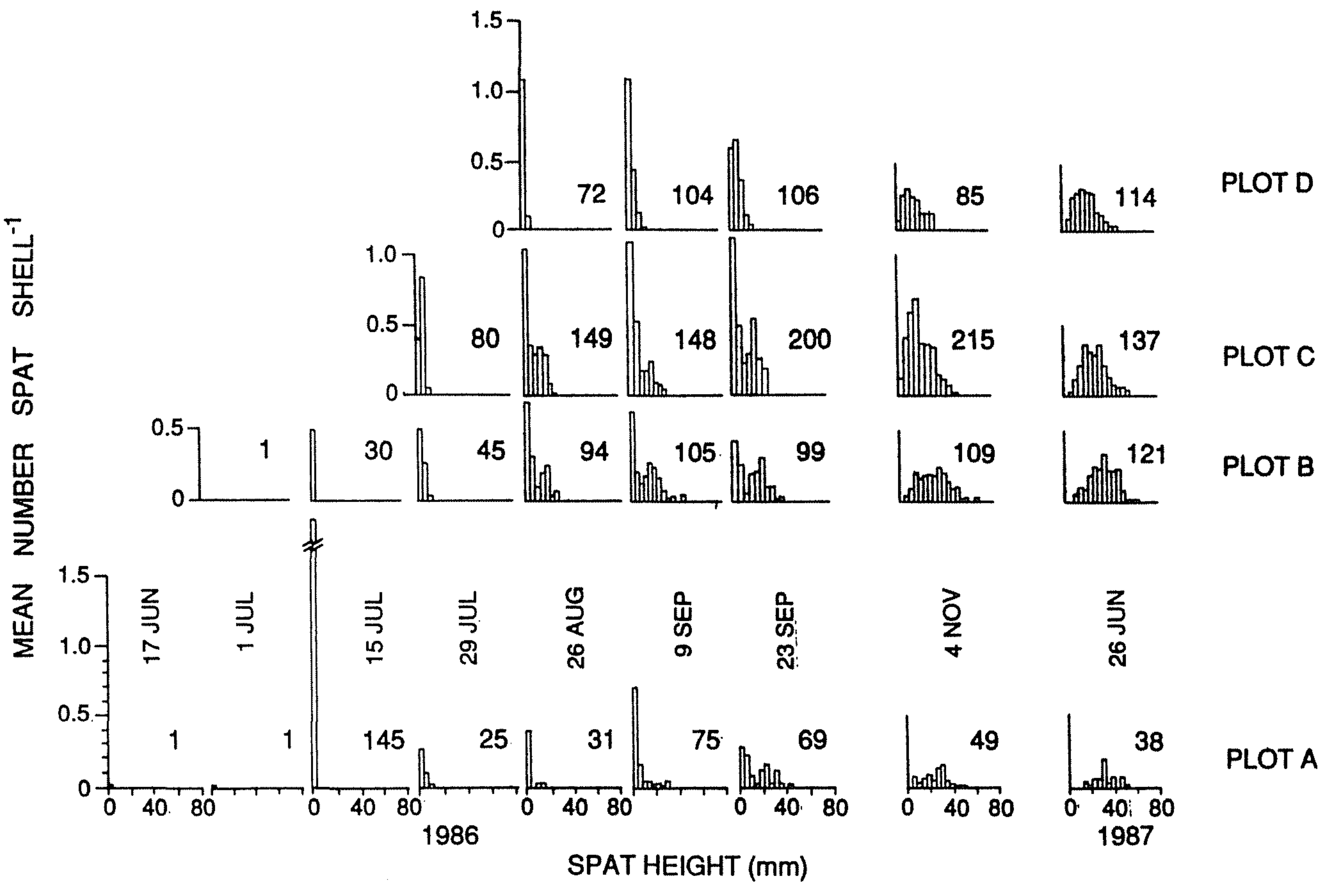

Figure 2. Mean number of spat per shell in different shell height classes for groups of 60 oyster shells collected on different dates from cultch planted at four experimental plots on Jones Shore Bar in the Potomac River. Shell height intervals of 4 mm. Value for single bar on July 15 in plot A was 2.4. 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. Total number of spat given by each histogram.

ception of the probable relationship among means while maintaining a low probability of committing a Type I error. The coefficient of variation (Sokal and Rohlf 1981) was computed as a measure of the relative variability of the data on number of spat per shell.

RESULTS

Visual observation of the bottom by divers indicated that the tunicate *Molgula manhattensis* appeared to cover completely, or almost completely, the experimental shell substrate within 4–6 weeks after the shells were planted (8 weeks in plot A). A heavy tunicate cover persisted through the last sampling date in 1986 (November 4). Diver observations indicated that tunicate coverage was considerably lower on June 26, 1987, than was found during most of the summer in 1986. Many tunicate clusters were lost during collection and handling of shells because the strength of their attachment to the shells was easily overcome by the weight of the clusters. Those losses prevented accurate quantification of fouling; however, the presence of other fouling organisms, predominantly barnacles and encrusting bryozoa, was evident on most of the shells.

Spat were first found in plot A on June 17, 1986, approximately one month after shells were planted (Fig. 2). At the other plots, spat were first found on the first sampling date, two weeks after shell planting. 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 (Fig. 2).

After July 15, spat ≤ 8.0 mm were found at all plots in substantial numbers on every sampling date through September 23 and in reduced numbers on November 4 (Figs. 2 and 3). They were also present in plots C and D on June 26, 1987, but in very low 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 settlement at the experimental site in Jones Shore extended from the week of July 7–14 to the week of September 1–8 in 1986 (Whitcomb 1986). Thus, the number of spat ≤ 8.0 mm on September 23 may represent settlement after September 8 that was not observed on the suspended shellstrings. Water temperature was 24°C on September 23 (Table 1); this was sufficiently high to permit continued spawning by oysters. The presence of spat ≤ 8.0 mm on November 4 was probably the

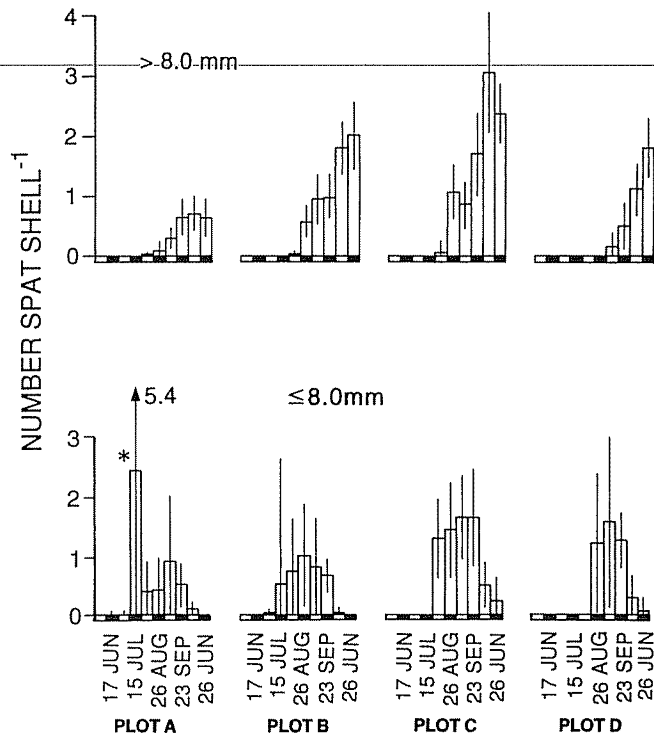

Figure 3. Mean number and 95% confidence interval of spat per shell in groups of 60 oyster shells collected on different dates from cultch planted at four experimental plots on Jones Shore Bar in the Potomac River. Shell cultch was planted at monthly intervals in 1986 as indicated in legend for Figure 2.

result of lag in growth of the spat, rather than of new recruitment, because water temperature had declined to 15.5°C between September 23 and November 4. The low numbers recorded on June 26, 1987, most likely represent early spat set on that summer.

No significant difference (P ≤ 0.15) could be detected in mean number of spat ≤ 8.0 mm between plots A and B

TABLE 1.

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 (‰)	
		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

on any of the sampling dates except one, primarily because of the high variation among samples in each plot; the exception was found on July 15 when the highest number of spat in that size group recorded during the study occurred in plot A (Fig. 3, Table 2). Mean number was significantly higher in plot C than in plots A and B on every sampling date but one (August 26), suggesting that recruitment of newly-set spat was greater in plot C than in A and B. No difference was evident, however, between plots C and D, probably because cultch was planted during peak spatfall periods in those two plots.

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 settlement season (Figure 3). Mean number of spat per shell was significantly higher in plot C than in the other plots on most dates (Fig. 3, Table 2). 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 preceding weeks.

The coefficient of variation (CV) for mean number of spat ≤ 8.0 mm shell was considerably lower in plot C than in the other plots on all but one of the sampling dates, (Table 3); the exception was September 23, when CV was also lower in plots A, B and D than on any of the other sampling dates (with the exception of July 15 in plot A) indicating a reduction in variability among samples collected on that date. We cannot suggest an explanation for the lower CV values on September 23. CV for mean number of spat > 8.0 mm was relatively high on all sampling dates.

Size frequency distribution in all four plots was approximately bell-shaped on June 26, 1987, although numbers were low in plot A (Figure 2). 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.

Height differences between plots among spat > 8.0 mm were closely related to the time of shell planting except that mean height of spat > 8.0 mm was similar in plots A and B on most dates (Fig. 4, Table 4). On most dates, mean height was significantly higher ($P \leq 0.15$) in plots A and B than in plots C and D and on all dates mean height was significantly lower in plot D than in the other three plots. Differences in mean height could not be detected between plots A and B on most dates, probably due to a scattered distribution of spat over the size range in plot A (Figure 2). There were, however, more spat in the larger size classes in plot B than in plot A on all sampling dates (Figure 2) indicating better survival and growth in B than in A.

DISCUSSION

The complete or nearly complete cover of the bottom substrate by the tunicate *Molgula manhattensis* observed by divers early in our study indicated a dominance of fouling

TABLE 2.

Probability values for Mann-Whitney tests between mean number of spat per shell 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 plots with higher mean.

	1986							1987
Date	July 1	July 15	July 29	Aug 26	Sept 9	Sept 23	Nov 4	June 26
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 3.

Coefficient of variation (Std. Dev./Mean × 100) for number of spat per shell 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	Plot A	Plot B	Plot C	Plot D	Plot A	Plot B	Plot C	Plot D
1986								
June 3								
June 17	173							
July 1	173	73						
15	49	65						
29	122	114	49		173	173	173	
Aug 26	126	81	54	92	127	86	77	
Sept 9	114	98	41	86	119	118	89	159
23	66	40	47	34	117	87	95	100
Nov 4	127	245	72	123	112	81	93	88
1987								
June 26			155	245	146	91	82	73

by that species in the experimental plots at Jones Shore in 1986. *M. manhattensis* can cover cultch surfaces completely in a very short time and can reach maximum size in lower Chesapeake Bay in less than two weeks, quickly dominating new or established fouling communities (Andrews 1953 and Otsuka and Dauer 1982).

Distribution and abundance of other fouling species on shell cultch in our experimental plots was probably affected by the high density of tunicates. Those species, however, as well as oyster spat, were still able to settle and survive under the tunicate cover throughout the study. This is in agreement with Sutherland and Karlson (1977) who interpreted results presented by Boyd (1972) as indicating that resident adults inhibit subsequent larval recruitment into a

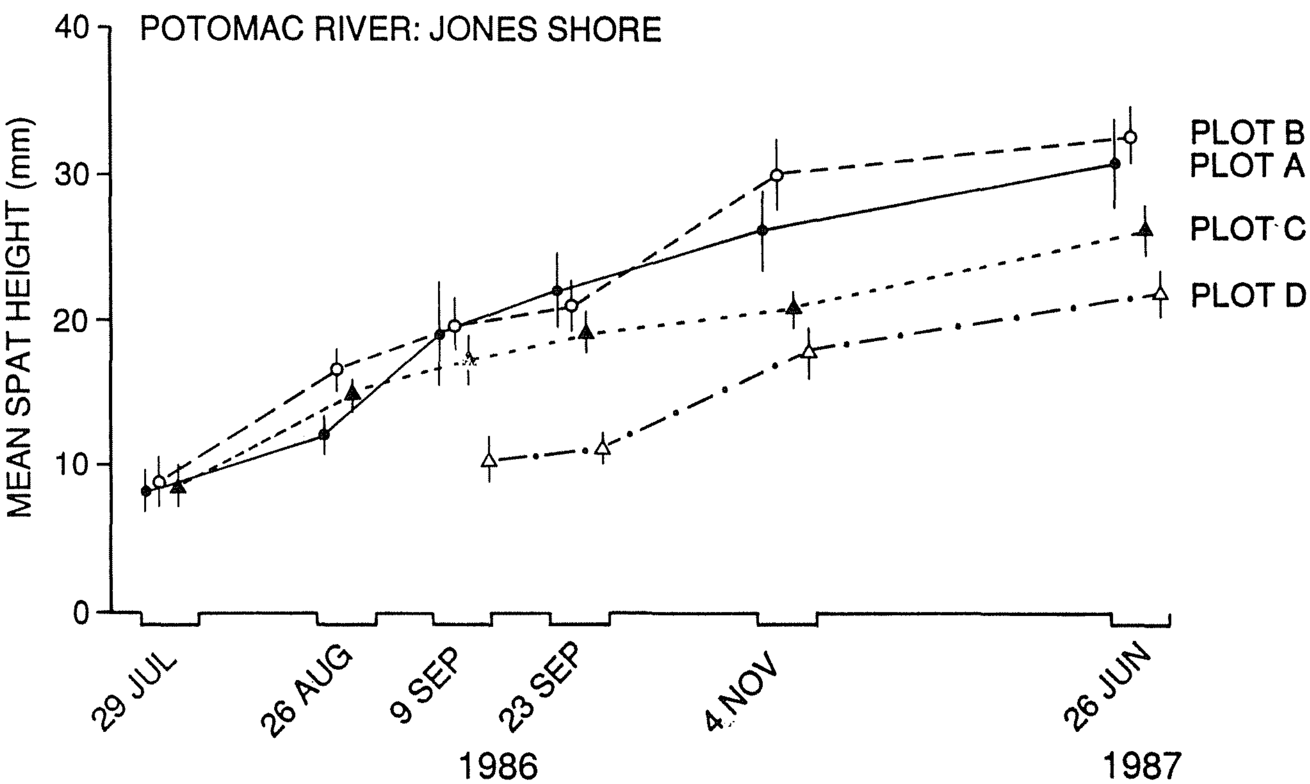

Figure 4. Mean shell height and 95% confidence interval of spat on shells collected on different dates from cultch planted at four experimental plots on Jones Shore Bar in the Potomac River. Mean height computed for spat > 8.0 mm only.

TABLE 4.

Probability values for Mann-Whitney tests between mean spat height of spat >8.0 mm 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 plots with higher mean.

	1986							1987
Date	July 1	July 15	July 29	Aug 26	Sept 9	Sept 23	Nov 4	June 26
Size Group: >8.0 mm								
PLot A vs. Plot B			1.00	0.01^{B}	0.94	0.37	0.12^{B}	0.36
vs. Plot C			0.50	0.06^{C}	0.31	0.02^{A}	0.00^{A}	0.01^{A}
vs. Plot D					0.00^{A}	0.00^{A}	0.00^{A}	0.00^{A}
Plot B vs. Plot C			0.50	0.06^{B}	0.11^{B}	0.06^{B}	0.00^{B}	0.00^{B}
vs. Plot D					0.00^{B}	0.00^{B}	0.00^{B}	0.00^{B}
Plot C vs. Plot D					0.00^{C}	0.00^{C}	0.04^{C}	0.00^{C}

fouling assemblage but do not stop it entirely. It is also partially in agreement with Young (1989), whose experiments with the tunicate *Molgula occidentalis* in Florida suggested that larval predation by tunicates may not be important in determining community composition or settlement density of fouling assemblages.

Higher recruitment of spat ≤ 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 period of spat settlement at Jones Shore, thus giving oyster larvae the opportunity to settle and grow before fouling could become the potentially negative factor it is presumed to be in oyster settlement. Higher numbers of newly-set 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, as evidenced by the lower coefficients of variation (CV) computed for those data. This is a significant departure from what appears to be the norm; Sutherland and Karlson (1977) concluded that recruitment into fouling communities appears to be a universally variable process after examining data from four different studies in which CV values for all species were extremely high, usually exceeding 100. Greater uniformity in distribution of newly-set spat in plot C may have resulted from concentration of the volume of shells planted in that plot over a smaller area of bottom than in the other plots. The higher numbers of spat found in plot C may have also been related to the high elevation of the mounds and the concomitant increase in quantity of exposed surface shells and of interstitial spaces, factors which are characteristic of highly productive oyster bottoms (Haven and Whitcomb 1983, and DeAlteris 1988).

The effect of time of cultch planting on oyster recruitment could not be correlated clearly with fouling coverage because of the massive unquantified coverage by tunicates; aggregation of cultch into mounds in plot C also interfered with interpretation of the results obtained. Consequently, definitive conclusions about the relationship between time of cultch planting, fouling, and oyster recruitment and growth cannot be advanced. Nevertheless, the lower number of spat recorded in plot A suggests that the reduced recruitment observed in that plot was most likely associated with the early planting date (mid-May) because, except for the aggregation of cultch into mounds in plot C, time of planting was the most outstanding difference between plots.

Combined maximum recruitment and growth of oyster spat appears most likely to be attained at Jones Shore on cultch planted between late June and mid-July, as indicated by the absence of substantial numbers of spat before July 1 and the lag in growth of spat on shell planted in mid-August (plot D). Shell plantings as early as mid-June and as late as early August, however, may also produce commercially acceptable recruitment, especially in view of recorded annual variations in spatfall peaks (Kennedy 1980). The number of spat found in plots B, C and D in June 1987, between 1.8 and 2.3 spat per shell, which translates into between 900 and 1200 spat per bushel (based on an estimated 500 shells in one bushel), support that conclusion. MacKenzie (1981) used a criterion of 2.5 spat per shell to define a commercially successful oyster set on shells in Long Island Sound. These suggestions may apply to most of the oyster-producing areas of the Chesapeake Bay because onset of spatfall does not vary greatly throughout the bay, as is shown by the data in Shaw (1967), Kennedy (1980) and Whitcomb (1986).

ACKNOWLEDGMENTS

This study was sponsored jointly by the Potomac River Fisheries Commission and the Virginia Institute of Marine Science. We are grateful to K. A. Carpenter, PRFC executive secretary, for his cooperation in development and conduct of this study; to the Maryland Department of Natural Resources and the Virginia Marine Resources Commission and their respective marine patrols and personnel for providing the boats used as work platforms during sample collections; to Rick Rheinhardt for assistance in planning and implementation of the study procedures; to Bernardita Campos, Lyn Cox, David Eggleston, Kevin McCarthy, Rick Rheinhardt, Curtis Roegner, Ya-Ke Shu and Kenneth Walker for their assistance in collection and examination of the shell samples; to Joseph T. DeAlteris, Robert A. Blaylock, Rick Rheinhardt and Curtis Roegner for valuable comments and suggestions in reviews of the manuscript; to Diane Bowers for the art work; and to Valise Jackson for transcription of the manuscript and tables.

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