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CULTURE OF *MERCENARIA MERCENARIA* (LINNAEUS): EFFECTS OF DENSITY, PREDATOR EXCLUSION DEVICE, AND BAG INVERSION

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ABSTRACT Growth, survival, and condition index (CI) of the northern quahog, *Mercenaria mercenaria* (Linnaeus, 1758), cultured in nylon mesh bags (1.2 × 1.2 m) were assessed against density and predator exclusion device (PED: Vexar net with 2.5-cm openings) in the northern Indian River Lagoon at Oak Hill, Florida. Nursery seed [mean ± SD: 6.0 ± 0.8 mm shell length (SL)] were stocked in February 1997 at densities of 7,500 (5,210), 10,000 (6,944), and 12,500 (8,680) clams/bag (clams/m^2) (n = 4) and monitored until the end of May 1997. Two replicates of each treatment were inverted 5 weeks before harvesting to smother fouling organisms and examine their influence on growth. Growout seed (mean ± SD: 21.1 ± 1.7 mm SL) were stocked in October 1996 at densities of 750 (521), 1,000 (694), and 1,250 (868) clams/bag (clams/m^2) (n = 4) and monitored until early June 1997. At the end of the nursery seed experiment, the average final SL of clams was significantly different among the density treatments (p = .03) and not significantly different between the PED (p = .31) treatments. Nursery seed in the inverted bags were significantly larger (p = .03), and a higher percentage of them reached growout seed size (12 mm in SL). Density (p = .60) did not have a significant effect on survival; whereas, the bags with PED had significantly (p = .005) lower survivorship than that of the bags without PED. Density (p = .15) and PED (p = .79) did not significantly affect mean CI at the end of the study, but inversion significantly (p = .002) increased CI. At the end of the growout seed experiment, SL was not significantly different among the treatments (density, p = .40; PED, p = .17). There was a significant (p = .04) effect of density on percentage of the seed that reached legal harvest size (16 mm in shell thickness). In general, percentage of seed that reached harvest size decreased with increasing density. The effects of density (p = .04) and PED (p = .0009) on survival were significant, but there was no apparent pattern. Density (p = .29) and PED (p = .88) did not affect mean final CI. Chlorophyll *a* concentration and water current speed measured in April and May, 1997 indicated that food was not a limiting factor on growth of the northern quahog at the study site. Our recommendations for northern quahog culture in the Oak Hill area are: (1) use a planting density of 7,500 clams/bag for nursery seed and 750 clams/bag for growout seed; (2) could use PED to reduce fouling on the culture bags, although PED may not improve clam survivorship; and (3) invert culture bags periodically.

KEY WORDS: *Mercenaria mercenaria,* density, Florida, fouling

INTRODUCTION

The northern quahog, *Mercenaria mercenaria* (Linnaeus, 1758), is a commercially important shallow-water species that has been harvested by subsistence fishermen since pre-Columbian times and today supports an important commercial and recreational fishery (Crawford 1992). Since the early 1950s, the feasibility of artificially enhancing the commercial crop of cultured northern quahog has been studied intensively (MacKenzie 1979). Some of the factors affecting the growth and survival of commercial northern quahog are planting density and predation (Flagg and Malouf 1983). Most studies dealing with densities found that high planting density resulted in slower growth of clams (Eldridge et al. 1976, Eldridge et al. 1979, Hadley and Manzi 1984, Walker 1984), although others indicated no significant difference in final size (Godwin 1968, Summerson et al. 1995).

A major inhibition to commercially viable northern quahog culture has been predation (Carriker 1959, Menzel and Sims 1964, Haven and Loesch 1973, Menzel et al. 1976, MacKenzie 1977, Whetstone and Eversole 1978, Steinberg 1980, Castagna and Kraeuter 1981, McHugh 1981, Peterson et al. 1995), with crabs representing the most serious problem from Massachusetts to Texas (MacKenzie 1977, Virnstein 1977, Boulding and Hay 1984, Jory et al. 1984, Hines et al. 1990, Eggleston et al. 1992, Summerson et al. 1995, Kraeuter et al. 1998). Several techniques have been developed to minimize predation, including rafts, trays, cages, nets (Manzi et al. 1980), addition of gravel to inhibit foraging effectiveness (Castagna and Kraeuter 1977), introduction of organisms that consume clam predators (Castagna and Kraeuter 1981, Castagna 1984, Jory et al. 1984, Bisker and Castagna 1989) and combinations of the various methods (Kraeuter and Castagna 1985). Despite the partial effectiveness of these control measures, predation remains a critical factor in northern quahog aquaculture.

The field culture of bivalve mollusks is also dependent on the production and supply of phytoplankton and other food sources. Seston depletion is a major influence on cultured suspension feeders whose growth can be limited by both food quality and quantity (Fegley et al. 1992).

It has proved most economical to grow quahogs in the natural environment at controlled densities, because space and food requirements increase exponentially as clams grow (Castagna and Kraeuter 1977). Although field nursery and growout offer a low-cost production system for the shellfish, one of the disadvantages is fouling. Fouling can affect production in various ways. The most obvious is a reduction of water flow through the enclosure, which, in turn, decreases food availability (Paul and Davies 1986, Wildish and Kristmanson 1984). In addition, fouling organisms are often themselves filter feeders, so they compete with the cultured species for food resources. Finally, fouling may reduce oxygen supply (Wallace and Reinsnes 1985). Several solutions have been used to remove fouling: addition of animals that prey upon the biofoulers (Flimlin and Mathis 1993), cleaning and changing structures often (Claereboudt et al. 1994), and inversion of bags (Mojica and Nelson 1993).

In Florida, growth of northern quahogs is more rapid than that observed for northern populations (Jones et al. 1990, Arnold et al. 1991) because of the warmer temperature and longer growing

season. The best growth occurs in fall and spring (Eldridge et al. 1976, Eldridge et al. 1979, Menzel 1961). Fouling of culture bags and heavy predation force modifications in culture techniques, such as different mesh size of bags and predator excluding devices (Vaughan et al. 1988), as well as maintenance and cleaning of the system. In Florida, cultured clams reach legal harvest size (16 mm in ST) in approximately 9 to 10 months, and the commercial "littleneck" size (25.4 mm in ST, legal harvest size of wild clams) in approximately 12 to 18 months (Vaughan et al. 1988).

Clam farming is an important industry in the Indian River Lagoon (IRL) of east central Florida. During the early to middle 1980s, a successful fishery for naturally occurring northern quahogs developed in the IRL. Landings from this fishery peaked in 1985 at more than 1.5 million pounds with an estimated value of more than US $8 million (Florida Department of Natural Resources 1986). Landings decreased substantially since then. The magnitude and success of this fishery influenced the development of a culture-based fishery in the IRL. The IRL possesses the necessary components of a suitable growout site for northern quahog aquaculture (Arnold et al. 1990): area of the lagoon is considerable, water quality is generally good, and extensive shoreline is available from which to monitor and maintain aquaculture operations. The present study was designed to determine how clam growth, survival, and CI was affected by planting density, predator exclusion device (in addition to the culture bag), and bag inversion at Oak Hill, Florida.

MATERIALS AND METHODS

Experimental Design

This study took place in the IRL at Oak Hill, Florida (Fig. 1). In the IRL, water depth generally does not exceed 1–1.5 m, except near the Atlantic Intracoastal Waterway, and tidal range does not exceed 0.5 m (Sheng et al. 1990).

Hatchery-reared northern quahog seed used in this study were produced by Harbor Branch Oceanographic Institution, Inc. in Fort Pierce, Florida. The seed were stocked in bags made of a flexible nylon mesh material. The experiment consisted of two different growing periods. Nursery seed clams were planted on February 27, 1997 and monitored until May 29, 1997 (13 weeks), and growout seed clams were planted on October 10, 1996 and monitored until June 6, 1997 (34 weeks). The experimental densities utilized for the nursery seed were 7,500/bag (5,210/m^2), 10,000/bag (6,944/m^2), and 12,500/bag (8,680/m^2), with four replicates for each density. Growout seed densities were 750/bag (521/m^2), 1,000/bag (694/m^2), and 1,250/bag (868/m^2), with four replicates for each density. For both nursery and growout seed experiments, an additional four replicates were planted and covered with PED for each density treatment. The PED was a 1.6 × 1.5 m Vexar cover net of 2.5-cm mesh size laid over the bags to exclude predators. Water temperature (to the nearest 0.1°C with a thermometer), salinity (to the nearest 1 ppt with a hand-held temperature-compensated refractometer (Atago S/Mill), dissolved oxygen (to the nearest 0.01 ppm with a temperature-compensated dissolved oxygen meter (YSI Model 57), current speed (to the nearest 0.01 cm/second) and direction (with a mechanical flowmeter (Model 2030R, General Oceanics Inc.), and Secchi disc depth (to the nearest 1 cm with a 15-cm diameter Secchi disc) were measured weekly.

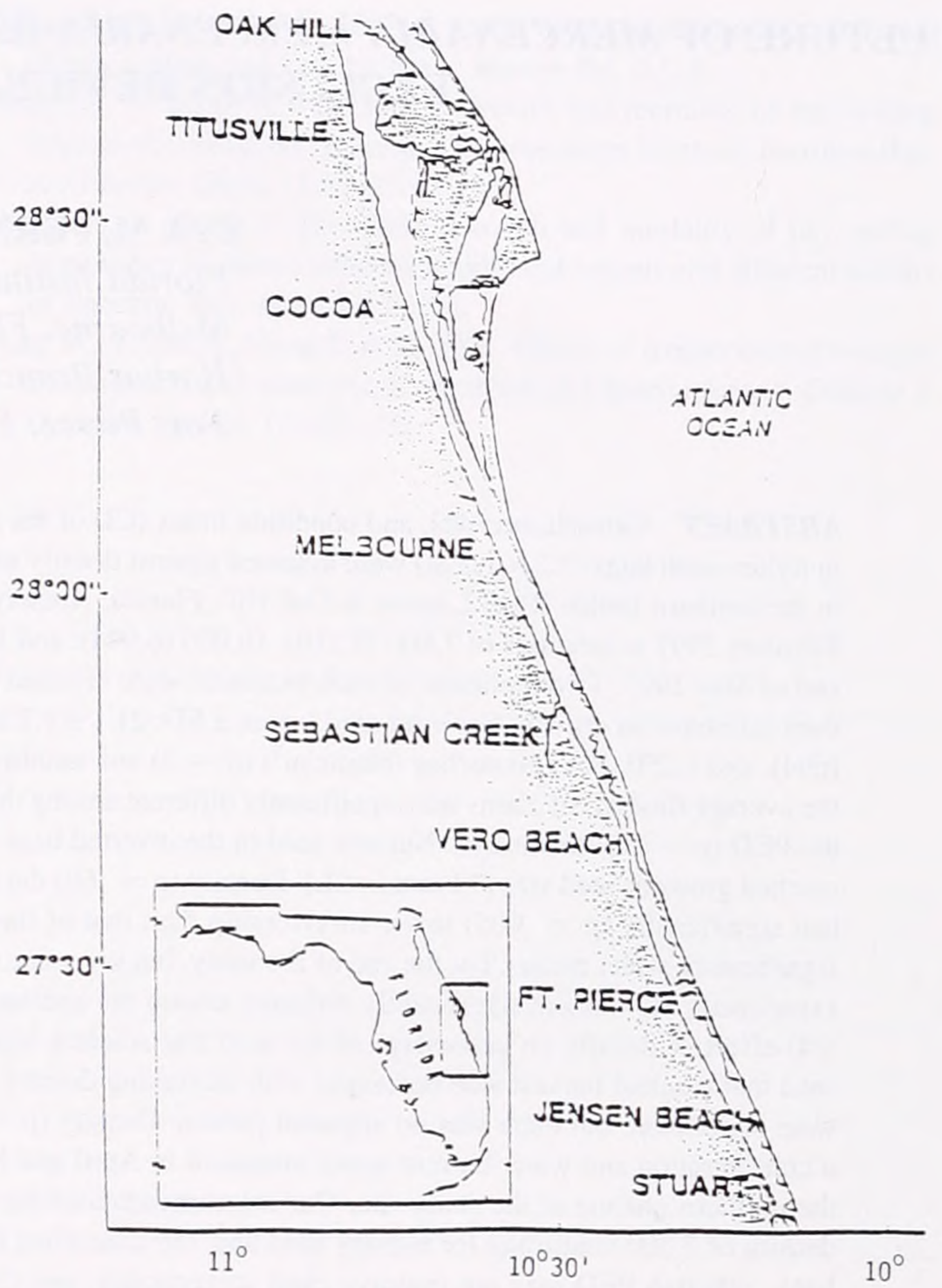

Figure 1. Map of the Indian River Lagoon, including the study area (Oak Hill).

Nursery Seed

Nursery seed [mean ± SD shell length (SL): 6.0 ± 0.8 mm; n = 100] were stocked in 24 3-mm mesh size bags (1.2 × 1.2 m) on February 27, 1997. The number of seed placed in each bag was determined volumetrically. The bags and cover nets were kept in place on the bottom with metal stakes. PVC pipes were placed underneath the PED at the corners to maintain tension and prevent predators from entering the bags.

Growth was assessed by measuring 100 clams per bag for SL, shell height (SH), and ST to the nearest 0.01 mm with Vernier calipers every 4 weeks. Only SL was used in further analysis because of the high correlations between the measurements (r^2 = 0.97 for SL and SH; r^2 = 0.80 for SL and ST). The measured clams were then returned to the bags. At the beginning of the study, 100 clams were sacrificed and dried in an oven at 65°C for 48 hours to determine shell and soft tissue dry weight (Walne and Mann 1975). At the end of the 13-week trial, another sample of 100 animals per bag was similarly sacrificed and measured. During weekly monitoring, any dead clams found were removed and recorded, but not replaced. Bags and cover nets were inspected weekly and cleaned biweekly to assure proper water flow. Cleaning consisted of manually removing fouling organisms that grew on the bags. Two replicates from each density and PED treatment combination were inverted on April 27, 1997, 5 weeks before harvesting to smother fouling organisms further and to examine their influence on growth. The 24 bags containing nursery seed clams were harvested on May 29, 1997. Surviving clams were counted, and the percentage of seed reaching the growout size was determined by sieving (10 to 11-mm mesh screen) clams from each bag. Clams that were retained on the screen were large enough for the growout phase, whereas, seed that passed through

the sieve were not. The percentage of growout seed from each bag was calculated based on the total number of seed harvested.

Growout Seed

Growout seed (mean ± SD SL: 21.1 ± 1.7 mm; n = 100) were stocked in 10.5-mm mesh size bags (1.2 × 1.2 m, n = 24) and planted on October 10, 1996 following the same method described for nursery seed. One hundred clams per bag were sampled every 4 to 5 weeks. Growth was assessed by measuring SL, SH, and ST, but only analysis on SL was conducted, because that shell measurement was highly correlated (r^2 = 0.94 for SL and SH; r^2 = 0.83 for SL and ST). One hundred clams were sacrificed to measure shell and tissue dry weight, as described earlier, at the beginning and again at the end of the study. Inversion of bags to smother fouling organisms was not performed on the growout seed. The 24 bags containing growout seed clams were harvested on June 5, 1997. Surviving clams were counted and the percentage of seed reaching legal harvest size was determined by grading (16 mm width on bar grader) clams from each bag. Clams that were retained on the bar grader had reached legal harvest size for cultured clams in Florida. The percentage of harvestable clams from each bag was calculated based on the total number of clams harvested.

Food Availability

Chlorophyll *a* concentration and current speed were estimated at five locations in the study site to assess food availability along the prevailing flow gradient. Over a period of several days, floating objects were placed in the water during incoming and outgoing tides and followed to establish the prevailing current pattern in the area. Once the prevailing current pattern was established, five locations (two before, one inside, and two after the clam bed) were chosen to estimate food availability. Three 1-Liter water samples were taken at each location, on 3 days during incoming tide (April 10, May 8, and May 22, 1997) and 3 days during outgoing tide (April 18, May 15, and May 29, 1997). Water samples were taken to the laboratory and kept cool and dark until analyzed within a few hours. An appropriate volume (500 to 1000 mL) of seawater was vacuum filtered onto a synthetic filter (Millipore AA 47-cm diameter). Chlorophyll *a* was measured by spectrophotometric analysis (Strickland and Parsons 1976). Pigments were extracted from the filter with 90% acetone, and pigment absorbance was estimated spectrophotometrically at 750, 660, 647, and 630 nm wavelengths. A standard concentration curve was produced using a commercial chlorophyll *a* extract (SIGMA Chemical Company, St. Louis, MO).

Data Analysis

All data were examined for variance heteroscedascity using F max test (Sokal and Rohlf 1995), and no data transformation was necessary. Final SL of the clams was analyzed by a two-way (density and PED) ANOVA for growout seed and a three-way ANOVA (density, PED, and inversion) for nursery seed. Bonferroni's multiple comparison test was used to compare the means if there was a significant difference in the ANOVA (Sokal and Rohlf 1995). Survival of nursery seed was analyzed by a three-way ANOVA (density, PED, and inversion), and survival of growout seed was analyzed by a two-way (density and PED) ANOVA. Condition index was calculated using the formula: dry soft tissue wt. (g)* 1000/ dry shell wt. (g) (Walne and Mann 1975) and was analyzed by a three-way ANOVA (density, PED, and inversion) for the nursery seed and a two-way (density and PED) ANOVA for the growout seed. Percentage of clams that reached growout size was analyzed by a three-way (density, PED, and inversion) ANOVA, and percentage of clams that reached legal harvest size was analyzed by a two-way (density and PED) ANOVA. Pearson product moment correlation was used to correlate growth with temperature, salinity, and Secchi disc depth (Sokal and Rohlf 1995). The significance level (α) for all statistical tests was 0.05.

RESULTS

Environmental Parameters

Water temperature ranged from 8.8 to 28.8°C during the study period, with a mean (± SD) of 21.7 (±4.1)°C (n = 32). Mean (± SD) salinity was 32 (±1.7) ppt (n = 32) with a range of 29 to 34 ppt. Mean (± SD) dissolved oxygen concentration (D.O.) was 11.6 (±4.7) ppm (n = 32) at the surface (range: 4.8–20.0 ppm) and 11.3 (±4.8) ppm (n = 32) at the bottom (range: 5.0–19.0 ppm). Water depth was between 1 and 1.5 m. Mean (± SD) Secchi disc depth was 0.86 (±0.14) m (range: 0.57–1.00 m, n = 32). Mean (± SD) current speed was 6.8 (±4.2, n = 32) cm/s at the surface (range: 2.0–15.0 cm/s, n = 32) and 6.6 (±3.3, n = 32) cm/s at the bottom (range: 3.0–13.8 cm/s). Water temperature, salinity, D.O., Secchi disc depth, and current speed did not show significant ($p > .05$) correlation with SL.

Nursery Seed

Nursery seed clams of all treatments grew at almost perfect linear rates over time, from an average initial SL of 6.0 mm to a mean final SL of 14.6 mm in the 13-week study. Density (p = .03) and inversion (p = .03) had a significant effect on the final SL; whereas, PED did not (p = .31). Low density clams tended to be larger than those of medium and high density treatments; and clams from inverted bags tended to be larger than those from the noninverted bags (Table 1). Mean percentage of nursery seed that reached growout size ranged from 25.5 to 91.8% (Table 1). There was a significant effect of density (p = .02) and inversion ($p < .001$) on percentage of clams attaining growout size. A higher percentage of clams in the low-density treatment reached growout size than that of clams in the medium- and high-density treatments (Table 1); inversion resulted in a higher percentage of nursery seed that reached the growout size (Table 1).

Survival at the end of the study ranged from 59.0 to 94.5% (Table 1). PED (p = .005), and inversion (p = .002) effects were significant, but density effect was not (p = .60). Surprisingly, survival of clams in bags with PED was lower than that of clams in bags without PED ($p < .05$, Bonferroni's test) (Table 1); inversion resulted in higher survivorship ($p < .05$, Bonferroni's test) (Table 1).

Mean (± SD) initial condition index (CI) of nursery seed was 49.6 (±28.3) (n = 100), and it changed little after the 13-week trial period (Table 1). The density (p = .15) or PED (p = .79) had no significant effect; whereas, the inversion (p = .002) did. The CI of the clams in the inverted bags was larger than that of the clams in the noninverted bags ($p < .05$, Bonferroni's test) (Table 1).

Growout Seed

Growout seed clams grew from an initial SL of 21.1 mm to a mean final SL of 33.3 mm. There was no significant difference (density: p = .40, PED: p = .17) in the final SL among the

TABLE 1.

Mean (± SD) of shell length, percentage reached growout size, survival, and CI of nursery seed grown for 13 weeks.

Inversion (I, NI)	Density (Clams/Bag)	PED (N, C)	Shell Length (mm)	% Reached Growout Size	Survival (%)	Condition Index
I	7,500	N	17.1 ± 0.0^{a}	91.8 ± 9.8^{a}	94.5 ± 6.4^{a}	55.2 ± 0.1^{abc}
I	10,000	N	14.1 ± 0.5^{ab}	62.5 ± 13.4^{abc}	76.0 ± 11.3^{abc}	65.3 ± 3.2^{a}
I	12,500	N	14.2 ± 0.8^{ab}	45.5 ± 6.4^{cd}	81.0 ± 5.7^{ab}	52.9 ± 6.1^{abc}
I	7,500	C	15.1 ± 0.2^{ab}	67.5 ± 7.8^{ab}	82.0 ± 5.7^{ab}	56.5 ± 2.6^{ab}
I	10,000	C	14.4 ± 0.3^{ab}	56.0 ± 7.1^{bcd}	83.5 ± 7.8^{ab}	52.3 ± 4.1^{abc}
I	12,500	C	13.7 ± 0.7^{b}	57.5 ± 0.7^{abcd}	75.5 ± 3.5^{abc}	42.9 ± 2.0^{bc}
NI	7,500	N	14.2 ± 2.0^{ab}	40.5 ± 3.5^{bcd}	78.0 ± 2.8^{abc}	45.9 ± 9.0^{bc}
NI	10,000	N	13.1 ± 1.0^{b}	29.5 ± 6.4^{cd}	77.0 ± 1.4^{abc}	36.5 ± 8.0^{c}
NI	12,500	N	14.3 ± 1.1^{ab}	37.0 ± 1.4^{bcd}	81.0 ± 1.4^{ab}	43.2 ± 4.5^{bc}
NI	7,500	C	14.1 ± 1.4^{ab}	35.5 ± 28.9^{bcd}	59.0 ± 8.5^{c}	52.8 ± 10.0^{bc}
NI	10,000	C	13.3 ± 0.8^{b}	29.5 ± 10.6^{cd}	69.5 ± 9.2^{c}	43.5 ± 5.7^{bc}
NI	12,500	C	13.9 ± 0.6^{b}	25.5 ± 4.9^{d}	62.5 ± 6.4^{c}	47.1 ± 4.9^{abc}

Values within a column with different superscripts were significantly different.
Under inversion, "I" means inverted, "NI" means noninverted; under PED, "N" means not cover, and "C" means cover.

treatments (Table 2, Fig. 2). Mean percentage of growout seed that reached 16 mm in ST (legal harvest size for cultured northern quahog) at the end of the study ranged from 30.1 to 66.8% (Table 2). The density effect was significant ($p = .04$); whereas, the PED effect was not ($p = .25$). In general, the percentage decreased with increasing density (Table 2).

Survival at the end of the study ranged from 75.0 to 87.0% (Table 2). The effects of density ($p = .04$) and PED ($p = .0009$) were significant, but there was no apparent pattern (Table 2).

Mean (± SD) initial CI of growout northern quahog seed was 65.4 (±28.3). The CI decreased after the 34-week trial period to an average of 36.3, with no significant difference among the treatments (Table 2).

Food Availability

Generally, chlorophyll *a* concentration was similar among the stations and between incoming and outgoing tides at a given date. Average chlorophyll *a* concentration in the April 1997 samples was 0.0642 µg/L. Mean surface current during the April sample days was 11.3 cm/s, and mean bottom current was 9.5 cm/s. May 8 and May 15 samples showed an order of magnitude increase in chlorophyll *a* concentration to 0.96 µg/L. Average late-May measurements of chlorophyll *a* was 0.81 µg/L. In May, mean surface current speed was 6.7 cm/s and mean bottom current speed was 6.1 cm/s.

DISCUSSION

Ansell (1968) reviewed the growth of northern quahog in various locations along the eastern coast of the United States and concluded that the optimum temperature for growth was approximately 20°C and that shell growth ceased below 9°C or above 31°C. In the present study, the mean water temperature over the 34-week period ranged from 15.1 to 26.3°C. Small changes in salinity do not have a major influence on growth rates, unless the salinity goes below 20 ppt (Castagna and Kraeuter 1981). The optimal salinity for the growth of northern quahog is reported to be about 26 and 27 ppt (Rice and Pechenik 1992). In the present study, salinity ranged from 29 to 36 ppt. In the Oak Hill area, D.O. was high (mean = 13 ppm) during the 34-week period. High D.O. has been found to be common in the southern IRL as well (Arnold et al. 1990, Dierberg et al. 1986).

Manzi et al. (1981) recommended that intensive field culture is best initiated with seed size larger than 10 mm in SL. However, larger seed are more expensive, and their cost may be >60% of the total cost of producing the final product in northern quahog aquaculture (Adams et al. 1991). In a study conducted in New Jersey

TABLE 2.

Mean (± SD) of shell length, percentage reached legal harvest size, survival and CI of growout seed grown for 34 weeks.

Density (Clams/Bag)	PED (N, C)	Shell Length (mm)	% Reached Legal Harvest Size	Survival (%)	Condition Index
750	N	33.5 ± 2.1	53.7 ± 4.3^{a}	75.0 ± 3.4^{b}	37.2 ± 6.0
1,000	N	32.9 ± 2.1	49.1 ± 11.2^{ab}	87.0 ± 1.3^{a}	34.8 ± 4.9
1,250	N	32.8 ± 2.5	30.1 ± 4.8^{b}	75.0 ± 3.1^{b}	35.5 ± 5.7
750	C	34.0 ± 2.2	66.8 ± 8.2^{a}	81.0 ± 3.4^{ab}	35.3 ± 5.8
1,000	C	33.0 ± 2.2	38.9 ± 10.0^{b}	81.0 ± 2.3^{ab}	34.1 ± 5.5
1,250	C	33.8 ± 2.5	49.5 ± 3.8^{ab}	82.0 ± 1.8^{ab}	38.6 ± 6.4

Values within a column with different superscripts were significantly different.
Under PED, "N" means not cover and "C" means cover.

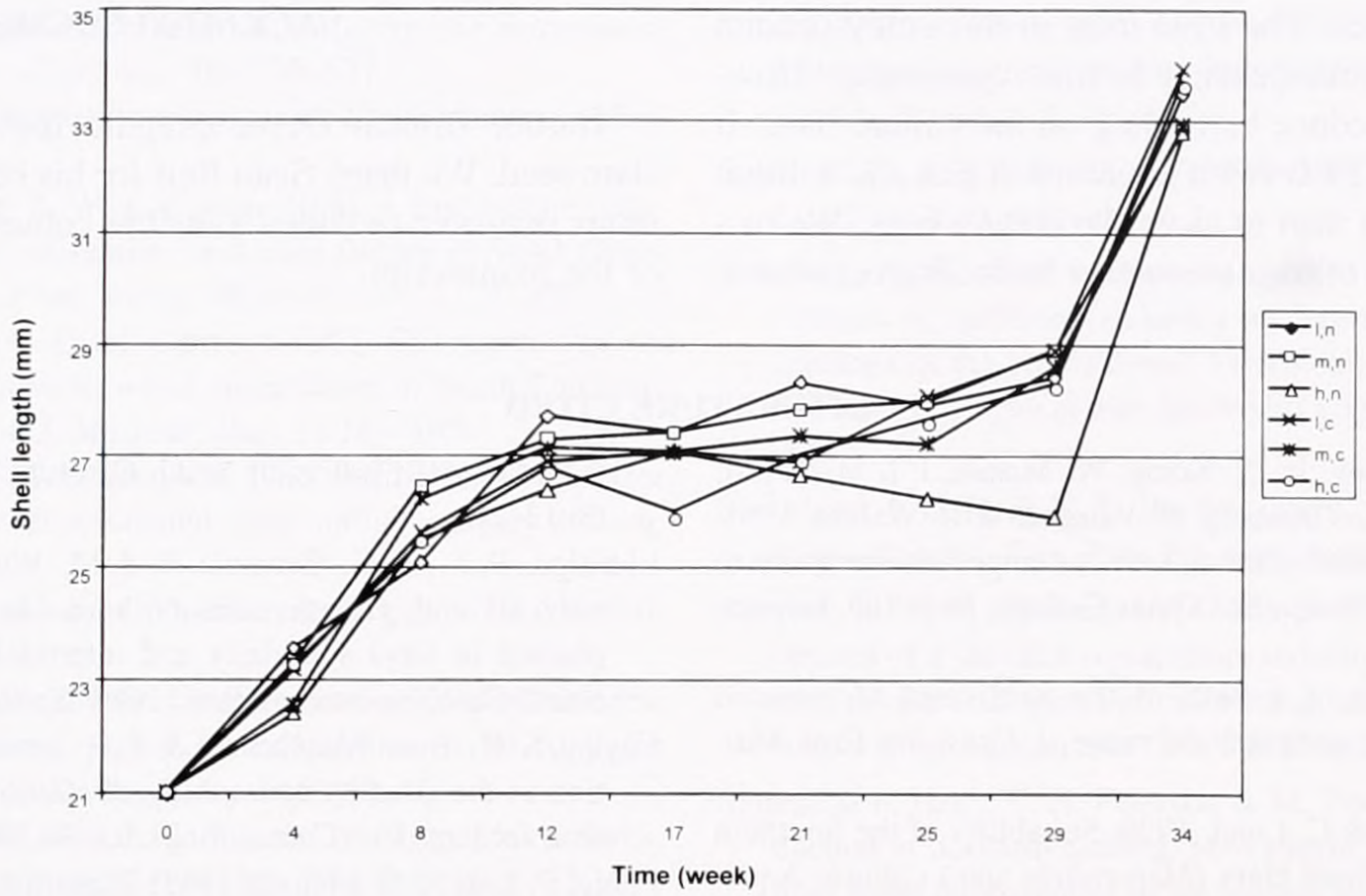

Figure 2. Mean (n = 4) shell length of growout seed over time at the different density and PED treatment combinations. (l,n: low-density bags without PED; m,n: medium density without PED; h,n: high density without PED; l,c: low with PED; m,c: medium with PED; h,c: high with PED).

(Kraeuter et al. 1998) and the present study, successful culture was achieved with nursery seed of 5 and 6 mm SL, respectively. Our nursery seed grew on average 2.76 mm/month in SL, similar to that found by Kraeuter et al. (1998) in New Jersey in the summer and by Sturmer et al. (1995) on the west coast of Florida, and higher than that found by Summerson et al. (1995) in North Carolina. The growth rates of nursery seed were similar among the months. The winter months had much smaller effects in reducing grow rates on the nursery seed, as it did on the growout seed (Fig. 2).

Growout clams in high density bags showed retarded growth during the winter months (Fig. 2), when environmental conditions were not optimal for clam growth. As soon as environmental conditions became optimal, clams in the high-density bags grew rapidly to reach similar SL as the clams of the other treatments (Fig. 2). However, a lower percentage of clams in high-density bags reached the legal harvest size (Table 2).

Menzel et al. (1976) and Kraeuter et al. (1998) suggested that survival of planted clams should be more than 40 to 50% for the commercial culture to be profitable. In the present study, average survival of nursery clams ranged from 59.0 to 94.5%. This survival is similar to the 87% found by Summerson et al. (1995) for the nursery seed grown in raceways in North Carolina and to the 58 to 88% found by Sturmer et al. (1995) in a 3-month field study on the west coast of Florida.

Densely packed seed clams without PED in southeastern states have demonstrated massive losses to predation in very short periods of time (e.g., Menzel et al. 1976, Gibbons and Castagna 1985, Peterson 1990, Kraeuter et al. 1998). Predators did not seem to be a significant problem in the present study. Although crabs and sheepshead were observed in the area, and sometimes small crabs were found inside the bags. Also, some of the dead clams found showed signs of crab predation: chipped margins or crushed shells (Vaughan et al. 1988). The PED used in the present study did not improve clam survival, and the maintenance of the PED was time consuming. However, biofouling on the culture bags without the PED was heavier than those with the PED. Some PEDs were found floating or folded over the bags during the study and were re-installed.

The use of PED may affect such biological processes as growth (Virnstein 1977, Dayton and Oliver 1980, Riese 1985). In the present study, survival was slightly higher in bags with PED in the growout period, and clams in bags with PED were found to grow slightly, but not significantly, faster than those in the bags without PED. Water flow in bags without PED seemed to be retarded because of fouling (by drift algae and sea squirts) of the bags. Fouling was found to be higher in bags without PED than in bags with PED where fouling was mainly observed on the PED itself. Fouling organisms diminish the water flow that passes through a bag, preventing clams from getting food necessary for optimal growth (Flimlin and Mathis 1993, Mojica and Nelson 1993). Drift algae (*Gracilaria* sp.) and tunicates were the most abundant fouling organisms in the present study. They grew rapidly if left unchecked. Inversion of the bags to smother fouling organisms was found to increase the growth of clams in the area. Inversion increased the percentage of nursery clams that reached the growout size and resulted in higher CI. Inversion also increased survival of the clams.

A large increase in chlorophyll *a* concentration was observed from late April to late May. This increase in food supply in conjunction with increasing temperature may explain the rapid growth of the clams during this period. Since the pioneering work of Kellog (1903), it has been recognized that current speed has a major effect on the growth of northern quahog (Kerswill 1949, Haskins 1952, Hadley and Manzi 1984, Manzi et al. 1986). Grizzle and Morin (1989) and Grizzle and Lutz (1989) suggest that northern quahog growth is primarily determined by horizontal seston flux past the animals and that intermediate seston flux rates produce the highest growth rates in *Mercenaria mercenaria* in sandy sediments. In the present study, mean current velocity was 6.7 cm/s for the 34-week period, and mean chlorophyll *a* concentration was 0.61 μg/L in April and May. Cahalan et al. (1989) indicated that growth rate of scallops peaked at 6.5 cm/s at 6,000 algal cells/mL.

In conclusion, a planting density of 7,500 and 750 clams/bag for nursery seed and growout seed, respectively, should be used in the Oak Hill, Florida area, because the highest percentage of seed that reached growout seed or legal harvest size, respectively, was

found at these low densities. The PED used in this study did not improve survival, and its maintenance is time consuming. However, it could be used to reduce biofouling on the culture bags. It is much easier to clean the PED (with larger mesh size and without clams and sediment inside) than to clean the culture bags. We recommend periodic inversion of bags to smother biofouling organisms.

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