BIOLOGICAL FEASIBILITY OF MESH BAG CULTURE OF THE NORTHERN
QUAHOG
MERCENARIA MERCENARIA (L) IN SOFT-BOTTOM SEDIMENTS IN COASTAL WATERS OF GEORGIA

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Biological feasibility of mesh bag culture of the northern quahog, *Mercenaria mercenaria* (L.), in soft-bottom sediments in coastal waters of Georgia

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Growth and survival of the northern quahog, Mercenaria mercenaria (L.), were tested against stocking density, seed size, grow-out bag mesh diameter, and benthic environment in a maricultural application in cooperation with the Satilla Sea Farms, Inc., Colonel's Island, Georgia. Quahog seed were stocked in commercial oyster-growing bags, 1.0 X 0.5 m. Bags with different mesh sizes, 3 and 6 mm in diameter, were used initially. In year two, quahogs were moved into 6- and 12-mm mesh bags, respectively. Five bags were attached to a single line. Factorial experiments were established to test: 1) effects of low stocking densities (250, 325, 500, 675, and 750 quahogs per bag) on growth and survival; 2) effects of high stocking densities (750, 975, 1500, 2025, and 2250 quahogs per bag) on growth and survival with density reduction to 750 clams per bag, after one year's growth; 3) effects of mesh size on growth and survival; 4) effects of initial quahog stocking size (4.7 mm, 6.1 mm, and 8.9 mm), stocking density and mesh size (3 mm and 6 mm) for 8.9-mm seed on growth and survival; and 5) effects of five planting locations on growth and survival. Ten replicate bags were used per treatment. All bags, excluding one set planted in Christmas Creek, were placed within the commercially leased areas of Jointer Creek on October 26, 1991. All bags were sampled in August 1992, and the high density bags were re-sampled and thinned to 750 clams per bag in December. All experiments were terminated in October 1993.

The results show that the mesh bag line system of clam culture is a biologically feasible means of culturing quahogs in the soft-bottom areas of coastal Georgia. Seed greater than 6 mm should be utilized, and the size of the mesh bag needs to be small enough to retain seed. Overall, mesh size had little effect on growth or survival of clams. High stocking densities (3000) should be used initially, thinned to 1500 clams per bag after six months, thinned to 750 clams per bag after year one, and finally to 500 clams per bag for growth-to-market size in 1.5 years.

Keywords:
aquaculture, bivalve, clams, culture, fishery, mollusc, growth, stock, survival

INTRODUCTION

The potential for a northern quahog, *Mercenaria mercenaria* (Linnaeus, 1758), aquaculture industry in the State of Georgia has been demonstrated in experimental grow-out trials in Georgia by The University of Georgia's Shellfish Research Laboratory (Walker 1983; Walker and Humphrey 1984; Walker 1984, 1985; Walker and Heffernan 1990 a,b). In 1990, Satilla Sea Farms, Inc., began the first commercial-scale clam farming enterprise in Georiga. Previously developed methods for quahog grow-out involved either off-bottom box or bottom-cage culture of clams. Both methods require sandy, sandy/mud, or shell bottoms to support the boxes or for partial burial of the cages into sediment. Unfortunately, neither method works in the soft, mud-bottom habitats which predominate throughout most of the marsh system in coastal Georgia. The area leased by Satilla Sea Farms was unsuitable for existing grow-out techniques, which necessitated that a new method be developed for culturing quahogs on the site.

In the Indian River Lagoon, Florida, a method of cultivating oysters in mesh bags (1.0 X 0.5 m) has been developed at the Harbor Branch Oceanographic Institute and adapted for growing quahogs (Vaughan *et al.*, 1988). The method involves placing oysters within mesh bags, attached in series to a long line, in a conveyor-belt configuration. In the field, one end of the belt is brought aboard a fishing vessel, and one bag at a time is harvested, checked or cleaned, and passed off the other side of the vessel while the next bag is processed. An entire line consisting of up to 140 bags is harvested, cleaned, or checked in this manner. The oyster belt is placed on the bottom of the river with a buoy attached to one end to mark its location. A simplified version of this system was tested by the Shellfish Research Laboratory in co-operation with Satilla Sea Farms personnel to determine if it could be utilized for northern quahog culture in soft-bottom areas of coastal Georgia.

The modified belt system utilized in this pilot project was designed to study the effects of:

1) low stocking densities (no thinning);
2) high stocking densities with a density reduction (thinning), after year one;
3) bag mesh size on growth and survival of clams;
4) seed stocking size and stocking densities; and
5) location on growth of quahogs at four sites within the Satilla Sea Farms lease area in the Jointer Creek area of Colonel's Island, compared to a control site at Christmas Creek, Little Cumberland Island, Georgia.

METHODS AND MATERIALS

Clam bags with mesh sizes of 6 mm and 12 mm were purchased from ADPI Enterprises, Inc., and 3-mm mesh bags were purchased from Internet Corporation. All bags were 1.0 X 0.5 m in size. A 1.2-m piece of polypropylene rope, 8 mm in diameter (dia) and knotted at both ends, was laid on each end of the short end of the bag (Fig. 1). The end of the bag was folded over the rope. A piece of schedule 40 PVC pipe, 0.5 m in length and 19 mm in diameter, was slit longitudinally on one side and pulled over each end containing the rope to serve as a simple closing device for the bag. Each end of a 20-m piece of polypropylene rope (8-mm dia) was threaded through an 11-mm hole drilled into one end of a 0.6-m piece of 19-mm dia PVC pipe. The two ends of the rope were then clamped together by hog rings. Individual bags (five per line) were attached to the rope by threading the knots through the rope (Fig. 1). Five bags were placed on each line at 0.5-m intervals. Knotted ends were hog-ringed to prevent the knots from unraveling. Bags were stocked by pulling one of the PVC pipes partially off the bag; one corner of the bag was opened and clams were poured in; a tag was inserted which designated stocking density, clam size, mesh size and experiment number; and the pipe was replaced. After all five bags were stocked, the line was moved to its field growing site. The line was pulled tight and placed on the bottom parallel to the current. Then two PVC end pipes were pushed down into the sediment to secure the line.

Quahogs were purchased from Aquaculture Research Corporation of Dennis, Massachusetts. Bags were stocked (number of clams was determined by volumetric displacement) and placed in the field on October 26, 1991. Bags were positioned so that eventually they would be covered with a thin layer of silt after deployment.

Bags were sampled on August 12, 13, 14, and 17, 1992, by returning the lines to the dock, where they were washed with a high-pressure hose. To assess growth, thirty clams per bag were measured for shell length with a Vernier caliper. A total live count per bag was obtained to assess survival. Notes were taken on the presence of predators. All 3-mm mesh bags were replaced with 6-mm mesh bags, because a few Internet bags exhibited tears on the seams. All 6-mm mesh bags were replaced with 12-mm mesh bags. Experiments were terminated in October 1993, with growth and survival of quahogs assessed as above.

Stocking Density

The relationship between stocking densities and mesh size (3-mm and 6-mm mesh) was determined by stocking densities of 250, 325, 500, 675, and 750 clams (11.5 ± 0.1 S.E. mm initial shell length). Ten bags per density, per mesh size were stocked, for a total of 100 bags. Clams stocked at the above densities and meshes were randomly attached, five bags per line, for a total of 10 lines per mesh treatment. All 20 lines were deployed in the subtidal area at Site D (Fig. 2). After year one, clams held in bags with 3-mm and 6-mm mesh were moved into bags with 6-mm and 12-mm mesh, respectively. Growth and survival were assessed as above.

High Stocking Density

The relationship between high initial stocking densities and growth and survival of clams, was tested by placing clams in 6-mm mesh bags at densities of 750, 975, 1500, 2025, and 2250 clams (11.5 ± 0.1 mm initial shell length) per bag. Ten bags were stocked per density with all bags randomly assigned to a five-bag line. Ten lines were deployed subtidally at the Satilla Sea Farms dock (Site A; Fig. 2) to test the effects of stocking density.

In August 1992, clams in all bags were sampled as above. Clams held in 6-mm mesh bags were moved into bags with 12-mm mesh and redeployed. In December 1992, after year-one data were analyzed, all 750- and 975-count bags were returned to the bottom. Bags stocked at 1500 to 2250 clams were restocked at 750 clams per bag. Additional lines were assembled to accommodate the increase in bag numbers resulting from the density reduction process.

Bag Mesh Size

The relationship between mesh size and growth and survival of quahogs was determined at stocking densities of 250, 325, 500, 675, and 750 per bag. Two mesh sizes were used, 3 mm and 6 mm. In addition, two clam stocking sizes were tested, 11.5 ± 0.1 mm and 8.9 ± 0.07 mm. The 11.5-mm size clam test is the test situation stated for the stocking density experiment. A replicate of that experiment was set up using 8.9-mm seed. These clams were planted at the Slough area (Site D; Fig. 2). In August 1992, all 3-mm and 6-mm mesh bags were replaced with bags of 6-mm and 12-mm mesh. Growth and survival were assessed as above.

Quahog Stocking Size

The relationship between optimum clam stocking size (4.7 ± 0.03 mm, 6.1 ± 0.06 mm, and 8.9 mm) and density (250, 325, 500, 675, and 750 clams per bag) was tested in 3-mm mesh bags. Ten bags per clam size, per density were prepared, with a total of 30 lines and 150 bags. All bags per clam size were assigned randomly to their respective 10 lines. All lines were placed subtidally in Clam Creek (Site C). In August, all 3-mm mesh bags were replaced with 6-mm bags. Growth and survival were assessed as above.

Location

Two lines of five bags each per area were established to determine which areas of the lease (Fig. 2) might provide optimum growth. Bags were stocked with

11.5-mm seed at 500 clams per bag. They were deployed at the mean low-water mark at the dock of the Satilla Sea Farms (Site A), in Roland's Creek (Site B), in Clam Creek (Site C), in a slough in Jointer Creek (Site D), (areas all within the Satilla Sea Farms lease; Fig. 2) and in Christmas Creek, Little Cumberland Island, as a control. Christmas Creek was selected to serve as a control site because of its previous documentation as an excellent clam-growing area (Walker 1987; Walker and Stevens 1988 a,b).

Grow-out lines from Roland Creek were inadvertently left out of water for two days after sampling in August 1992, resulting in heavy mortalities. This treatment was subsequently terminated. Due to poor growth after year one, clams from Christmas Creek were redeployed at the Satilla Sea Farms dock. Growth and survival of clams were assessed as above.

Statistics

Clam growth and survival data per experiment were analyzed by Analysis of Variance (ANOVA) ($\alpha = 0.05$) and a Tukey's Studentized Range Test (SRT) ($\alpha = 0.05$) utilizing SAS for PC computer (SAS Inst. Inc., 1989). Survival data were arcsine transformed before analysis.

Stocking Density

The results of the ANOVA and Tukey's SRT for growth and survival data of the 11.5-mm clams planted at densities from 250 to 750 clams per bag in two mesh sizes are given in Table 1. No significant differences in survival occurred between stocking densities for clams planted in either mesh size or in either year. In 1992, significantly lower growth occurred only in the 6-mm mesh bags with a stocking density of 750 clams. By August 1993 and afterwards, significant differences in growth occurred between stocking densities for each mesh treatment. In general, lower growth occurred at the higher stocking densities. For pooled survival data per mesh treatment, survival was 42.1% and 40.3% for the treatments with 3-mm and 6-mm mesh bags. Overall, pooled survival for the 11.5-mm seed clams was 41.2%. However, these survival data are low due to the fact that 24 bags were unaccounted for at the end of the experiment (October 1993). Table 2 compares the survival results listed above with results obtained by eliminating the missing bags. Not including mortalities due to missing bags, pooled survival data for each mesh bag treatment are 59.0% and 54.0% for the 3-mm and 6-mm mesh bag treatments, respectively. Overall, pooled survival for 11.5-mm seed clams in this experiment was 56.5%.

High Stocking Density

No significant differences in percent survival (Table 3) were determined for the clams grown at high stocking densities in August 1992 (P=0.1913), December 1992 (P=0.0537), or October 1993 (P=0.1423). Overall survival ranged from 55% for the 1500 stocking density to 73% for the 750 stocking density. Pooled survival for the 11.5-mm clams used in this experiment was 59%.

Significant differences in mean shell length, as determined by ANOVA and Tukey's SRT, occurred in August and December 1992, and October 1993 (all P<0.0001) (Table 3). Prior to thinning in December, density effects were evident; greater growth in clams occurred at the two lowest stocking densities. After thinning, no significant differences in growth occurred for the four higher stocking densities in October 1993; however, clams were significantly larger at the lowest stocking size of 750 (actual mean density of 550 clams per bag after two years).

Bag Mesh Size

Growth and survival data for 11.5-mm seed planted in bags with 3-mm and 6-mm mesh at stocking densities of 250 to 750 clams per bag are given in Table 4. Significantly higher survival (P=0.0062) occurred for clams planted in the bags with larger mesh after year one, but no difference in survival occurred after two years of growth (P=0.6331). In terms of growth, significantly larger clams occurred in the bags with smaller mesh after two years' growth; however, the difference in mean size between mesh treatments was 2.4 mm.

Data for growth and survival of 8.9-mm seed planted at stocking densities from 250 to 750 clams per bag in bags of 3-mm and 6-mm mesh are given in Table 5. No significant differences in survival occurred for 8.9-mm seed planted at various stocking densities for each mesh treatment per year with the exception of October 1993, where ANOVA (P=0.0417) revealed a significant difference in survival of clams from 12-mm mesh bags; however, Tukey's SRT failed to separate the means. Significant differences in growth between stocking densities within mesh treatments and within years did occur. In general, larger clams were obtained at lower stocking densities.

Pooled data for comparison of growth and survival of 8.9-mm seed planted in stocking densities of 250 to 750 clams per bag are given in Table 6. Significantly greater survival ($P=0.0087$) of 8.9-mm seed occurred in the 3-mm mesh bags after year one, but no significant difference in survival ($P=0.1285$) occurred between the two mesh treatments after year two. Again, survival data are low due to the fact that 15 bags were unaccounted for at the end of the experiment (October 1993). Table 7 compares survival results with and without missing bags included in the data set. Twice as many bags from the initial 3-mm treatment were missing compared to the 6-mm treatment. In terms of growth, clams were significantly larger ($P<0.0001$) when cultured in bags with 6-mm mesh after year one, but no significant differences in size ($P=0.5124$) occurred between the two mesh sizes after year two.

Stocking Size Experiment

The results of the ANOVA and Tukey's SRT for growth and survival data of the 4.7-mm, 6.1-mm, and 8.9-mm seed sizes stocked at densities from 250 to 750 clams per bag are given in Table 8. At the end of year two, there was no significant difference in survival among stocking densities for any of the three sizes of seed. Overall, survival for the pooled stocking density bags per seed size treatment was 9.6% for 4.7 mm, 48.5% for 6.1 mm, and 47.6% for the 8.9-mm seed (Table 9). There was significantly lower survival of 4.7-mm seed compared to the larger stocking sizes (Table 9). Significant differences occurred in growth between stocking densities for the 4.7-mm seed clams; however, the differences in growth between smallest (250 stocking density) and largest group (all others) was only 1.8 mm. This low overall growth difference, coupled with high overall mortality for all stocking densities, makes the growth results of little value. Clams initially stocked at the lowest density (250 clams per bag) were significantly smaller than clams from other treatments primarily because, by the experiment's termination, they were actually the second highest density (Table 8). For the 6.1-mm and 8.9-mm stocking sizes, clam size differences between the slowest and fastest growing stocking densities were only 2.2 mm and 3.6 mm, respectively (Table 8).

Location

After year one, the results of ANOVA and a Tukey's SRT (Table 10) revealed that no significant differences in quahog survival occurred at four of the five sites. Survival percentages ranged from 70% at Christmas Creek to 79% at the Dock site; however, significantly ($P<0.0001$) fewer clams survived at the Slough site (49%). One line (not included in statistical analysis) was completely lost at the Slough site. Overall, 71% survival was experienced. It was noted that few mud crabs were observed in bags at the Roland's Creek site compared to other sites, which generally had several crabs per bag. After year two, Tukey's SRT (Table 10) revealed that no significant differences in survival occurred between the Clam Creek and Dock sites nor were there significant differences between the Christmas Creek and Slough sites. Clam survival rates at the Dock and Clam Creek sites were significantly higher than at the Slough and Christmas Creek sites. No clams survived at Roland's Creek due to 100% mortalities occurring in August 1993, when clams inadvertently were left out of water for several days after sampling.

After year one, mean size of the clams varied significantly ($P<0.0001$) among all sites (as determined by ANOVA and Tukey's SRT). The mean sizes ranged from 18.4 mm at the Christmas Creek site to 25.5 mm at the Slough site. After year two, shell length growth ranged from 24.2 mm to 33.4 mm, with clams at Clam Creek growing significantly larger than animals at other sites. Clams transplanted from Christmas Creek were significantly smaller (Table 10).

Predators

Numerous clam predators were found within the bags. Most bags, regardless of experiment or location (excluding Roland's Creek), contained anywhere from one to ten mud crabs, *Panopeus herbstii*. Clamshell fragments characteristic of crab predation were present in most bags. Only bags at the Roland's Creek site were devoid of crabs. In August 1992, each of two bags from the Dock site contained a large blue crab, *Callinectes sapidus*. In October 1993, six bags contained a single large blue crab. All crabs were over 100 mm in width, yet no holes were observed in the bags. It is unlikely that the crabs entered as larvae and grew to this size, since clam survival was average in these bags and it would require more food than the entire bag of clams to produce such large crabs. It is possible that, during deployment, bags were not properly closed. Numerous snapping shrimp, *Alpheus heterochaelis,* were found in most bags. Two small oyster drills, *Urosalpinx cinerea,* were collected from two bags, but no clamshells with drill holes were observed. Although it is not a predator, the parasitic boring sponge, *Cliona,* was observed on some clams. The sponges were attached to clams that had not been buried in silt, generally those in one or both of the bags at the end of each line.

Other Benthic Organisms

Other benthos commonly observed within bags included the razor clam, *Tagelus plebeius*, the mud snail, *Ilyanassa obsoleta*, toadfish, *Opsanus* sp. and blennies. A large set of *Tagelus* was found in bags (up to 10 clams per bag) in August 1992, while few clams occurred in bags in October 1993. Large populations of the snail, *Ilyanassa*, are common in coastal tidal areas. In general, most bags contained either a toadfish and/or blenny. In general, all the toadfish were small, 5 to 7 cm in length.

DISCUSSION

The results to date suggest that this modified (i.e., simplified) oyster belt system can be applied successfully to culture quahogs in soft-bottom areas of coastal Georgia. The original plan called for 10 bags per line, but deploying lines of this size proved cumbersome and inefficient by comparison to the five-bag system. Two people can easily deploy a five-bag line. It also was found that it is important to place lines in areas where they will be covered by a thin layer of silt. If clams are placed on firmer bottoms, growth is reduced because they are disturbed continually by wave and tidal action. Furthermore, siltation, or shallow burial of the clams, prevents the sponge, *Cliona*, from settling on the clams. *Cliona* will not kill the clam, but they do bore extensively into the shell matrix of the clam, which makes it more susceptible to crab predation. Also, *Cliona* boring marks make the shell unsightly to the consumer. Fouling of bags by sea squirts, *Molgula*, also may occur if bags and clams are not covered with silt, but *Molgula* fouling can be controlled by periodic bag rotation.

Mean sizes of clams from the Christmas Creek site were low compared to those of the other four sites. Initially the Christmas Creek site was chosen as a "control," since the greatest growth rates were expected to occur there. Growth studies of naturally occurring clam beds throughout the Christmas Creek area provided the basis for this belief (Walker 1987; Walker and Stevens 1989 a,b). Upon collecting the two lines from Christmas Creek for sampling, the lines were found to be twisted. Clams within the bags were white and their shells smooth, indicating that they were loose in the bags and out of the sediment. Originally the bags were placed at a bend in the creek, but strong currents precluded them from settling down into the sediment. Consequently, they twisted and turned with the change of each tide. It is reasonable to assume such constant agitation would result in poor clam growth.

At all sites, growth was generally poorest in the two end bags of each five-bag line system. Unfortunately, data were insufficient to verify this observation. For the most part, clams in the two end bags had cleaner (white) shells compared to clams from the middle bags, which were generally black (i.e., obviously having been in the mud). A possible explanation of this growth differential is that when a line is deployed, the two ends are pulled apart in order to straighten the line. Then the line is placed on the bottom with the middle bag settling first. Tension on the line is kept on the two end bags as the stakes are driven down into the sediment to anchor the line. Thus, the tension on the two end bags may have prevented them from being covered by silt. In the future, this can be corrected by allowing a little slack in the rope when staking down the lines.

Previous studies (Walker 1984) have shown that the optimum density required for clams to grow to market size in bottom cages is about 750 clams per m2. Eldridge et al. (1979) found that clams grew significantly faster at densities of 290 clams per m2 compared to clams at 869 and 1160 per m2. Clams at 1160 per m2 required an additional 12 months of growth to achieve market size. Bags in this study were stocked at 250, 325, 500, 675, and 750 clams per bag (0.5 m2) or at densities of 500, 650, 1000, 1350, and 1500 per m2, respectively. At these low densities after year one, no density effects on clam growth were observed; however, density effects occurred at the higher stocking densities (750, 975, 1500, 2025, and 2250 clams per 0.5 m2 bag). Thus, the optimal initial stocking density appears to be 1500 clams per bag (3000 per m2) for the first year before reduction in numbers is necessary to insure continued optimal growth. Final optimal grow-out densities utilizing this bag system appear to be less than 750 clams per bag (Table 1 and Table 5). Starting with a high stocking density of 1500 clams per bag and thinning down after one year results in a considerable reduction in the number of bags deployed, as well as time spent handling, cleaning, and monitoring the bags.

For the three larger sizes of stocking seed, overall survival was approximately 50%. In this experiment, bags, excluding those in the high density bag experiment, were checked and cleaned of predators only once, in August 1992. High density experimental bags were rechecked, cleaned, and thinned in December 1992, at which time mud crabs had already repopulated the bags. Thus, experiments in which bags were checked and cleaned of predators only once in two years represent a worst-case scenario. Checking the bags more frequently probably would have resulted in increased survival rates, but the additional cost of labor to check the bags could negate any potential profits. In this study, bags which were stocked at low densities (250 to 750 clams per bag) represent wasted manpower, since low stocking densities had no effect on survival and little effect on growth.

Initial planting size also was shown to be important in this type of grow-out system, with smaller planting sizes resulting in a lower survival rate. Overall (all experimental data combined), 4.7-mm clams had only 9.6% survival compared to 48.5%, 47.6% and 59% for 6.1-mm, 8.9-mm and 11.5-mm seed, respectively. Previous field grow-out studies utilizing cages or box-culture techniques employing seed less than 6 mm have yielded low survival rates (Walker 1983). Thus, a minimal field planting size of 6 mm is required for this type of bag grow-out system. An 8- to 10- mm field planting size is preferred.

Apparently the mesh size of the bag is important only as long as the mesh size of the bag is small enough to retain the smallest seed. No appreciable size difference occurred for either 8.9-mm or 11.5-mm seed grown in bags of different mesh sizes.

The optimum quahog grow-out site within the Satilla Sea Farms lease area was found to be at the Dock site. For the location experiment, the highest survival rate for quahogs occurred at the Dock site where quahogs grew to the second largest size (Table 10). Quahogs were significantly larger at the Clam Creek site than at the Dock site, but the mean difference in size was only 1.3 mm. Survival, although not statistically different between the two sites, was 16% higher at the Dock site (Table 10). In addition, the Dock site has the added advantage that a boat is not needed to deploy or harvest bags. Finally, the Dock site is the most secure site, since grow-out lines can be monitored directly, thereby reducing the risk of loss due to vandalism or poaching.

The results of this work indicate that this bag method of culturing hard clams is feasible for the environmental conditions of coastal Georgia. More importantly, this system worked well on soft bottoms which predominate in the marsh system of coastal Georgia. Clams can be grown with this method anywhere within approved shellfishing grounds in coastal Georgia. Prior clam grow-out methods required hard bottoms, which do not always exist within a leased area, as is the case with the Satilla Sea Farms lease.

Based upon the results of these experiments, this mesh-bag line system is recommended for use by the Georgia clam aquaculturist. Initial stocking size of clams should be at least 6-mm seed planted in 3-mm mesh bags or preferably 9-mm seed planted in 6-mm mesh bags. Initial stocking densities should be 3000 clams per bag, reduced to 1500 clams per bag after six months, reduced to 750 clams after an additional six months, and to 500 clams for growth-to-market-size. By starting at high initial densities and thinning every six months, the aquaculturist can utilize his time and effort more efficiently by starting with fewer bags and checking more often to remove predators.

The mesh-bag line system for culturing clams works well for growing seed clams up to approximately 30-35 mm in length, but growth-to-market size appears to be retarded. In this study, clams failed to reach a mean marketable size (44.4 mm) within two years as observed in previous studies (Walker 1983, 1984, 1985). It may be that the mesh bag line system somehow retards the final growth phase and that 30 to 35 mm clams may have to be planted in a different manner to achieve market size. Experiments are underway to test differences in clam growth between boxes, cages, and mesh bags.

Finally, preliminary estimates suggest that this method is much more cost-efficient than other methods. Cage culture requires the purchase of vinyl-coated wire which costs about $375.00 per roll. One roll makes only ten 1 m2 cages. One cage, which holds 1000 clams, would cost approximately $38.00 in materials. It is very labor-intensive to partially bury these cages into the sediment and the cages last only two to three years. Boxes made out of wood with vinyl-coated wire tops are also expensive and labor-intensive to construct and deploy. One box (2.9 m2 in area) with gravel and top costs $84.44. Thus, you can plant three times as many clams in boxes at a 122% increase in cost of materials. Boxes generally last two years. Bags (the ADPI ones) should last many years. The cost of one line of five bags is approximately $22.25. Thus, the cost in materials for planting 1000 seed per m2, per method, is $38.00 for cages, $28.00 for boxes, and $9.00 for bags. The material cost of setting up and deploying bags is significantly less than that for either boxes or bottom cages. Bags are reusable year-after-year, whereas boxes and cages have a maximum life span of three years. Finally, setting up and harvesting clams using the bag system is relatively simple compared to the labor-intensive measures required for cage and box culture.

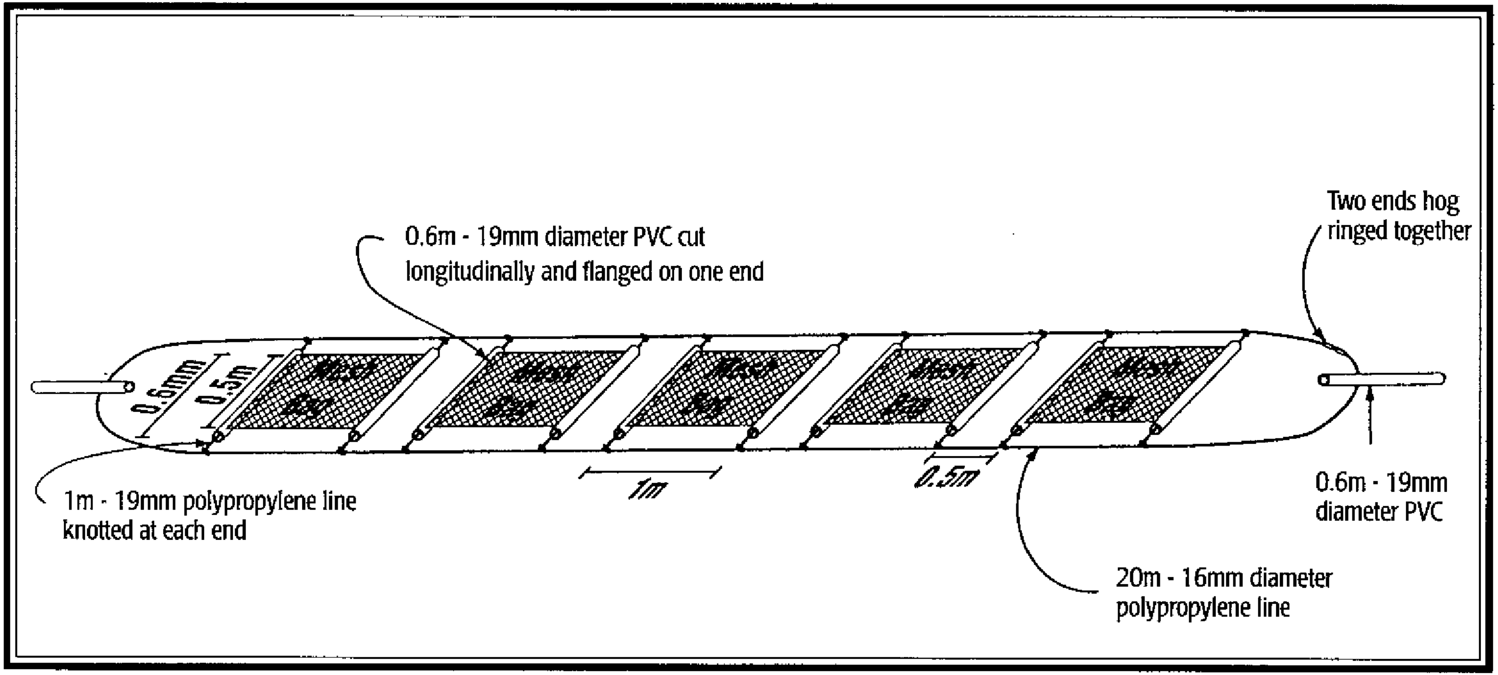

Figure 1. Schematic of the mesh bag line system for culturing northern quahogs in soft-bottom areas

Figure 2. Maps of the Satilla Sea Farm lease area of Jointer Creek, Colonel's Island, Georgia. Grow-out sites are indicated as: a) Dock Site, b) Roland Creek, c) Clam Creek, and d) Slough

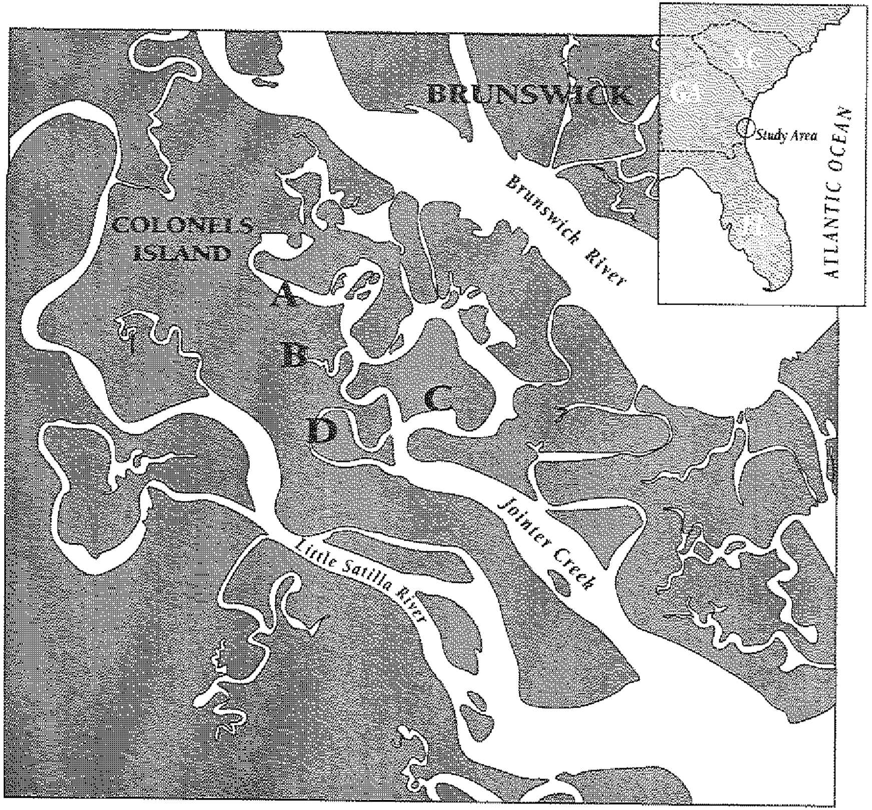

Table 1. Results of the Tukey's Studentized Range Test for growth and survival data for 11.5-mm quahog, *Mercenaria mercenaria*, seed cultured in bags of two different mesh sizes at low stocking densities. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL

3-mm mesh - August 1992 (P=0.6037)

Stocking Density	325	250	500	765	750
Percent Survival	68.0 ± 3.7	68.1 ± 3.0	71.6 ± 1.5	72.4 ± 2.3	73.3 ± 3.3

6-mm mesh - August 1992 (P=0.6672)

Stocking Density	675	750	500	325	250
Percent Survival	71.2 ± 6.2	74.5 ± 1.4	76.9 ± 1.5	77.5 ± 4.5	78.8 ± 2.7

3-mm (6-mm)* mesh - October 1993 (P=0.8132)

Stocking Density	325	750	250	675	500
Percent Survival	33.0 ± 11.2	38.6 ± 8.8	40.7 ± 7.4	45.8 ± 8.1	52.6 ± 6.9

6-mm (12-mm)* mesh - October 1993 (P=0.3904)

Stocking Density	325	750	250	500	675
Percent Survival	31.7 ± 8.5	34.6 ± 7.3	36.4 ± 9.3	48.4 ± 7.1	50.4 ± 7.7

Table 1 continued.....

GROWTH

3-mm mesh - August 1992 (P=0.0876)

Stocking Density	750	500	675	250	325
Mean SL	22.3 ± 0.22	22.7 ± 0.21	22.8 ± 0.15	23.1 ± 0.23	23.1 ± 0.23

6-mm mesh - October 1992 (P<0.0001)

Stocking Density	750	675	500	250	325
Mean SL	20.7 ± 0.21	22.6 ± 0.18	22.6 ± 0.19	23.0 ± 0.2	23.2 ± 0.21

3-mm (6-mm)* mesh - August 1993 (P<0.0001)

Stocking Density	750	675	500	250	325
Mean SL	29.4 ± 0.29	31.3 ± 0.33	31.9 ± 0.33	33.0 ± 0.36	34.4 ± 0.45

6-mm (12-mm)* mesh - October 1993 (P<0.0001)

Stocking Density	750	500	250	675	325
Mean SL	26.8 ± 0.27	28.4 ± 0.23	29.2 ± 0.25	30.5 ± 0.31	32.8 ± 0.37

* 3-mm and 6-mm bags were exchanged for 6-mm and 12-mm mesh bags, respectively, after year one.

Table 2. Comparison of survival of 11.5-mm *Mercenaria mercenaria* seed between data calculated with and without missing bags

6-mm (3-mm) mesh

Stocking Density	325	750	250	675	500
No. of Missing Bags	5	2	2	2	1
Percent Survival	39.3	40.5	42.0	47.3	54.0

6-mm (3-mm) mesh

Stocking Density	325	500	675	250	750
Percent Survival	49.9	51.5	57.8	59.2	72.2

12-mm (6-mm) mesh

Stocking Density	325	750	250	500	675
No. of Missing Bags	4	3	3	1	1
Percent Survival	33.0	35.4	38.6	49.9	52.1

12-mm (6-mm) mesh

Stocking Density	750	325	250	500	675
Percent Survival	49.4	53.2	53.6	54.7	57.2

Table 3. Results of the Tukey's Studentized Range Test for growth and survival data for 11.5-mm quahog, *Mercenaria mercenaria*, seed cultured in mesh bags at high stocking densities. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL

August 1992 (P=0.1913)

Stocking Density	2250	1500	750	2025	975
Mean Survival	67.3 ± 6.8	70.1 ± 3.5	75.3 ± 3.8	76.7 ± 5.9	83.0 ± 9.0

December 1992 (P=0.0537)

Stocking Density	2250	1500	975	750	2025
Mean Survival	64.8 ± 8.7	70.4 ± 4.5	73.4 ± 8.0	76.6 ± 5.5	76.8 ± 2.1

October 1993 (P=0.1423)

Stocking Density	1500	2250	2025	975	750
Mean Survival	54.6 ± 5.6	55.3 ± 2.5	57.9 ± 4.5	64.0 ± 4.4	73.2 ± 2.6

Table 3 continued.....

GROWTH

August 1992 (P<0.0001)

Stocking Density	2250	2025	1500	975	750
Mean SL	22.7 ± 0.19	23.1 ± 0.19	24.1 ± 0.19	25.3 ± 0.20	25.9 ± 0.21

December 1992 (P<0.0001)

Stocking Density	2025	2250	1500	975	750
Mean SL	24.3 ± 0.20	24.6 ± 0.18	25.7 ± 0.21	28.1 ± 0.19	28.6 ± 0.18

October 1993 (P<0.0001)

Stocking Density	975	2025	1500	2250	750
Mean SL	33.5 ± 0.21	33.6 ± 0.22	33.8 ± 0.25	34.1 ± 0.24	35.7 ± 0.25

Table 4. Comparison of pooled stocking data for growth and survival of 11.5-mm quahog, *Mercenaria mercenaria,* seed cultured in bags of two different mesh sizes. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL of 11.5-mm seed

August 1992 ($P=0.0062$)

Mesh Size	3 mm	6 mm
Percent Survival	70.5 ± 1.3	75.8 ± 1.6

October 1993 ($P=0.6331$)

Mesh Size	6 mm (12 mm)*	3 mm (6 mm)*
Percent Survival	40. 3 ± 3.7	42.1 ± 4.0

GROWTH of 11.5-mm seed

August 1992 ($P=0.0031$)

Mesh Size	6 mm	3 mm
Mean SL	21.4 ± 0.19	22.8 ± 0.20

October 1993 ($P<0.0001$)

Mesh Size	6 mm (12 mm)	3 mm (6 mm)
Mean SL	29.5 ± 0.15	31.9 ± 0.18

* 3-mm and 6-mm mesh bags exchanged for 6-mm and 12-mm mesh bags, respectively, after one year.

Table 5. Results of the Tukey's Studentized Range Test for growth and survival for 8.9-mm quahog, *Mercenaria mercenaria*, seed cultured initially in both 3-mm and 6-mm mesh bags, but meshes increased to 6 mm and 12 mm, respectively, after year one. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL

3-mm mesh - August 1992 (P=0.6512)

Stocking Density	750	500	250	675	325
Percent Survival	66.2 ± 4.9	75.9 ± 2.9	76.2 ± 2.7	77.1 ± 0.9	82.0 ± 3.6

6-mm mesh - August 1992 (P=0.5878)

Stocking Density	250	675	500	325	750
Percent Survival	63.6 ± 7.3	68.3 ± 4.4	71.7 ± 4.5	71.8 ± 2.9	77.5 ± 2.9

3-mm (6-mm)* mesh - October 1993 (P=0.7586)

Stocking Density	250	325	675	500	750
Percent Survival	39.5 ± 10.9	44.0 ± 9.9	46.0 ± 8.5	51.0 ± 7.7	57.5 ± 4.8

6-mm (12-mm)* mesh - October 1993 (P=0.0417)

Stocking Density	500	250	675	750	325
Percent Survival	46.3 ± 8.1	49.3 ± 9.4	53.9 ± 7.1	63.5 ± 4.4	64.2 ± 5.5

Table 5 continued.....

GROWTH

3-mm mesh - August 1992 ($P<0.0001$)

Stocking Density	675	750	500	325	250
Mean SL	19.6 ± 0.22	20.2 ± 0.44	20.2 ± 0.20	21.6 ± 0.19	22.1 ± 0.20

6-mm mesh - August 1992 ($P<0.0001$)

Stocking Density	750	675	325	500	250
Mean SL	21.3 ± 0.27	21.3 ± 0.20	21.4 ± 0.22	22.1 ± 0.22	23.9 ± 0.19

3-mm (6-mm)* mesh - October 1993 ($P<0.0001$)

Stocking Density	675	500	750	250	325
Mean SL	28.9 ± 0.28	30.0 ± 0.32	30.6 ± 0.29	31.5 ± 0.38	32.5 ± 0.39

6-mm (12-mm)* mesh - October 1993 ($P<0.0001$)

Stocking Density	750	325	675	500	250
Mean SL	29.0 ± 0.28	30.2 ± 0.28	30.9 ± 0.20	31.4 ± 0.32	33.1 ± 0.31

* 3-mm and 6-mm mesh bags exchanged for 6-mm and 12-mm mesh bags, respectively, after year one.

Table 6. Results of pooled stocking data for growth and survival of 8.9-mm quahog, *Mercenaria mercenaria*, seed cultured in bags of two different mesh sizes. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL of 8.9-mm seed

August 1992 (P=0.0087)

Mesh Size	6 mm	3 mm
Percent Survival	70.5 ± 2.0	75.4 ± 2.0

October 1993 (P=0.1285)

Mesh Size	3 mm(6mm)*	6 mm(12mm)*
Percent Survival	47.6 ± 4.0	55.4 ± 3.3

GROWTH of 8.9-mm seed

August 1992 (P<0.0001)

Mesh Size	3 mm	6 mm
Mean SL	20.7 ± 0.09	22.0 ± 0.11

October 1993 (P=0.5124)

Mesh Size	3 mm(6mm)*	6 mm(12mm)*
Mean SL	30.6 ± 0.15	30.7 ± 0.13

* 3-mm and 6-mm mesh bags exchanged for 6-mm and 12-mm mesh bags, respectively, after year one.

Table 7. Comparison of survival of 8.9-mm *Mercenaria mercenaria* seed between data calculated with and without missing bags.

6-mm (3-mm) mesh					
Stocking Density	250	325	675	500	750
Percent Survival with Missing Bags	39.5 ± 10.9	44.0 ± 9.9	46.0 ± 8.5	51.0 ± 7.7	57.5 ± 4.8
No. of Missing Bags	4	2	2	1	0
Percent Survival Excluding Missing Bags	65.9 ± 7.2	62.9 ± 5.9	57.5 ± 5.9	56.7 ± 6.5	57.5 ± 4.8
12-mm (6-mm) mesh					
Stocking Density	500	250	675	750	325
Percent Survival with Missing Bags	46.3 ± 8.1	49.3 ± 9.4	53.9 ± 7.1	63.5 ± 4.4	64.2 ± 5.5
No. of Missing Bags	2	2	1	0	0
Percent Survival Excluding Missing Bags	57.8 ± 4.6	61.7 ± 6.9	59.9 ± 5.0	63.5 ± 4.4	64.2 ± 5.5

Table 8. Results of the Tukey's Studentized Range Test for growth and survival data for 4.7-mm, 6.1-mm and 8.9-mm quahog, *Mercenaria mercenaria*, seed cultured initially in 3-mm mesh bags, but mesh bags were exchanged for bags of 6-mm mesh after year one. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL of 4.7-mm seed

August 1992 (P=0.0386)

Stocking Density	675	500	750	250	325
Percent Survival	8.3 ± 3.0	10.9 ± 2.3	11.0 ± 1.9	16.0 ± 2.0	18.9 ± 3.1

October 1993 (P=0.0172)

Stocking Density	500	675	750	250	325
Percent Survival	5.8 ± 1.8	6.3 ± 2.5	7.6 ± 1.7	13.2 ± 2.2	14.9 ± 2.6

SURVIVAL of 6.1-mm seed

August 1992 (P=0.7119)

Stocking Density	675	325	250	750	500
Percent Survival	49.6 ± 5.1	58.5 ± 3.8	61.1 ± 5.3	65.8 ± 2.0	66.7 ± 2.8

October 1993 (P=0.4354)

Stocking Density	675	750	250	500	325
Percent Survival	42.0 ± 6.8	46.0 ± 7.0	46.6 ± 3.2	53.0 ± 2.9	55.0 ± 3.2

Table 8 continued.....

SURVIVAL of 8.9-mm seed					
August 1992 (P=0.0355)					
Stocking Density	750	500	250	675	325
Percent Survival	66.2 ± 4.9	75.9 ± 2.9	76.2 ± 2.7	77.1 ± 0.9	82.0 ± 3.6
October 1993 (P=0.7586)					
Stocking Density	250	325	675	500	750
Percent Survival	39.5 ± 10.9	44.0 ± 9.9	46.0 ± 8.5	51.0 ± 7.7	57.5 ± 4.8
GROWTH of 4.7-mm seed					
August 1992 (P<0.0001)					
Stocking Density	675	325	500	250	750
Mean SL	17.4 ± 0.22	18.2 ± 0.19	18.5 ± 0.20	18.8 ± 0.20	18.9 ± 0.18
October 1993 (P<0.0005)					
Stocking Density	250	675	325	500	750
Mean SL	28.4 ± 0.35	30.0 ± 0.40	30.0 ± 0.32	30.0 ± 0.35	30.2 ± 0.28

Table 8 continued.....

GROWTH of 6.1-mm seed

August 1992 (P<0.0001)

Stocking Density	325	675	500	750	250
Mean SL	18.2 ± 0.18	18.4 ± 0.20	19.2 ± 0.21	19.2 ± 0.20	20.1 ± 0.18

October 1993 (P<0.0001)

Stocking Density	750	325	675	250	500
Mean SL	27.9 ± 0.33	28.8 ± 0.27	29.8 ± 0.26	29.9 ± 0.33	30.1 ± 0.28

GROWTH of 8.9-mm seed

August 1992 (P<0.0001)

Stocking Density	675	750	500	325	250
Mean SL	19.6 ± 0.22	20.2 ± 0.44	20.2 ± 0.20	21.6 ± 0.19	22.1 ± 0.20

October 1993 (P<0.0001)

Stocking Density	675	500	750	250	325
Mean SL	28.9 ± 0.28	30.0 ± 0.32	30.6 ± 0.29	31.5 ± 0.38	32.5 ± 0.39

Table 9. Comparison of pooled stocking density data for survival of 4.7- mm, 6.1-mm, and 8.9-mm quahog, *Mercenaria mercenaria*, seed cultured initially in 3-mm mesh bags, but mesh bags were exchanged for 6-mm mesh bags after year one. Treatments connected by the same line are not significantly different.

SURVIVAL

August 1992 (P<0.0001)

Stocking Size	4.7 mm	6.1 mm	8.9 mm
Percent Survival ± SE	13.1± 1.2	61.8 ± 2.0	76.8 ± 1.6

October 1993 (P<0.0001)

Stocking Size	4.7 mm	6.1 mm	8.9 mm
Percent Survival ± SE	9.6 ± 1.1	48.5 ± 2.4	47.6 ± 4.0

Table 10. Results of the Tukey's Studentized Multiple Range Test for growth and survival data for 8.9-mm quahog, *Mercenaria mercenaria*, seed cultured in mesh bags at five sites. Treatments connected by the same line are not significantly different. Shell length (SL) is given in mm ± SE and survival in percent ± SE.

SURVIVAL

August 1992 ($P<0.0001$)

Location	Slough	Christmas C.	Roland C.	Clam C.	Dock
Percent Survival	49.0 ± 0.44	70.0 ± 0.26	78.0 ± 0.84	78.0 ± 0.07	79.0 ± 0.2

October 1993 ($P<0.0001$)

Location	Christmas C.	Slough	Clam C.	Dock
Percent Survival	8.4 ± 3.4	24.8 ± 8.8	55.4 ± 9.1	71.6 ± 3.3

GROWTH

August 1992 ($P<0.0001$)

Location	Christmas C.	Roland C.	Clam C.	Dock	Slough
Mean SL	18.4 ± 0.36	21.3 ± 0.69	22.6 ± 0.59	24.5 ± 0.59	25.5 ± 1.51

October 1993 ($P<0.0001$)

Location	Christmas C.	Slough	Dock	Clam C.
Mean SL	24.2 ± 1.5	31.7 ± 1.7	32.1 ± 1.7	33.4 ± 1.6

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