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GROWTH AND MORTALITY OF TRANSPLANTED JUVENILE HARD CLAMS, *MERCENARIA MERCENARIA*, IN THE NORTHERN INDIAN RIVER LAGOON, FLORIDA

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ABSTRACT Growth and mortality were examined in hatchery-produced, early-juvenile *Mercenaria mercenaria* transplanted to protected and unprotected plots at a site in the northern Indian River lagoon, FL. Clam density and size were examined in both treatments five times in the year after transplantation. The growth of clams in both treatments was rapid and comparable to that of clams from other areas within the lagoon. Growth in the protected treatment was initially depressed, but after 363 days, clams from both treatments did not differ significantly in shell height (SH). The mortality of clams in both treatments was high, although significantly greater in the open treatment. Clams in the protected treatment died at a high rate until 80 days into the experiment (SH about 8 mm), beyond which no significant mortality occurred. This experiment suggests that (1) growth rates in the northern Indian River lagoon may favor future aquaculture ventures; (2) clams can be grown out in the lagoon (if protected from epibenthic predators) when they are 8 mm SH, much smaller than current aquaculture practice suggests; and (3) placing unprotected juvenile clams in situ at high densities is not an efficient stock-enhancement technique.

KEY WORDS: Growth, mortality, *Mercenaria*, hard clam, aquaculture, Indian River lagoon

INTRODUCTION

Growth and mortality in early life stages are important aspects of bivalve population dynamics. The abundance of early-juvenile bivalves is a critical determinant of the abundance of the adult bivalve population (Muus 1973, Marelli 1990) and is negatively affected by mortality. There is also generally an inverse relationship between size and mortality that is expressed as a prey size refuge (Carriker 1959, Menzel and Sims 1962, MacKenzie 1977, Whetstone and Eversole 1977, Kraeuter and Castagna 1980, Arnold 1984, Peterson et al. 1995). Finally, the livelihood of harvesters and culturists of commercially important clams depends on the availability or production of adequate numbers of legal-sized clams.

The success of bivalve populations is heavily dependent on the survival of postsettlement juveniles, which are the most vulnerable benthic stage (Carriker 1959, Menzel and Sims 1962, Muus 1973, Eldridge et al. 1976, Kraeuter and Castagna 1985). Predation on juvenile clams is often relieved by growth into sizes that offer refuge from predation or by their occupation of a spatial refuge. Spatial refugia occur where physical or biologic structures or physiological regimes interfere with predator efficiency (Gainey and Greenberg 1977, Menge 1978, Pohle et al. 1991, Peterson 1982, Summerson and Peterson 1984, Riese 1985, Bertness 1989). Clam culturists construct artificial refugia with predator-exclusion devices (Eldridge et al. 1976, Menzel et al. 1976, Flagg and Malouf 1983, Kraeuter and Castagna 1985, Vaughan 1989).

We examined three premises regarding the growth and mortality of transplanted juvenile *Mercenaria mercenaria* (Linnaeus 1758) in Florida's Indian River lagoon: (1) Clam growth rate in an area historically depauperate of clams is similar to those in areas that support large clam populations; (2) It is economically feasible for clam culturists to begin the field growout phase of their operation with smaller, less expensive clams than those traditionally used; (3) Broadcasting unprotected juvenile clams (1- to 3-mm shell height [SH]) as a stock-enhancement technique is not effective.

MATERIALS AND METHODS

Approximately 56,000 hatchery-spawned and hatchery-reared early juveniles, or "seed," of *M. mercenaria* were held for 1 wk in a 1,600-L conical tank at the Harbor Branch Oceanographic Institution. The tank contained a 62.5 mg/L solution of tetracycline hydrochloride, and clams were fed from cultured algae. Water was not changed for the first 2 days, and subsequently, the water and food supply were changed daily, but no additional tetracycline was added.

Clams were then concentrated on a 750-μm-pore-size screen, and the entire sample population was measured volumetrically. Thirty-two 6-mL subsamples were removed from the sample population, and each was placed dry in a glass jar. Jars were transported to the field site in a chilled cooler. A portion of the sample population (approximately 8 mL) was preserved and used to estimate the mean size (maximum SH: the maximum measurement from the umbo to the ventral margin) and density of the juvenile clams.

The experimental site was located in Shellfish Harvesting Area B ("body B") in the northern Indian River lagoon, just north of State Road 405 on the east side of the Intracoastal Waterway (Fig. 1). This area had a depauperate *Mercenaria* population during 1986 and 1987 (Arnold and Marelli pers. obs.). Hard clam growth rates in body B have been estimated to equal or exceed growth rates from other areas of the lagoon (Arnold et al. 1991). The study site had a sandy bottom, was approximately 2 m deep, and was vegetated with attached and drift algae (*Gracilaria* sp.). Water temperatures reach a maximum near 30°C in midsummer and decline to 10–15°C in early winter (Arnold and Marelli pers. obs.). Mean salinity is stable, high (30–36‰; McCall et al. 1970), and similar to that of body C, an area with a large clam population (Arnold et al. 1996).

We defined a 2.5- by 2.5-m area on the bottom by laying down a polyvinyl chloride (PVC) template (3/4″ schedule 40 pipe) and marking the corners with stainless steel stakes. The template was subdivided with net-mending twine into 16 equal squares (0.39 m^2

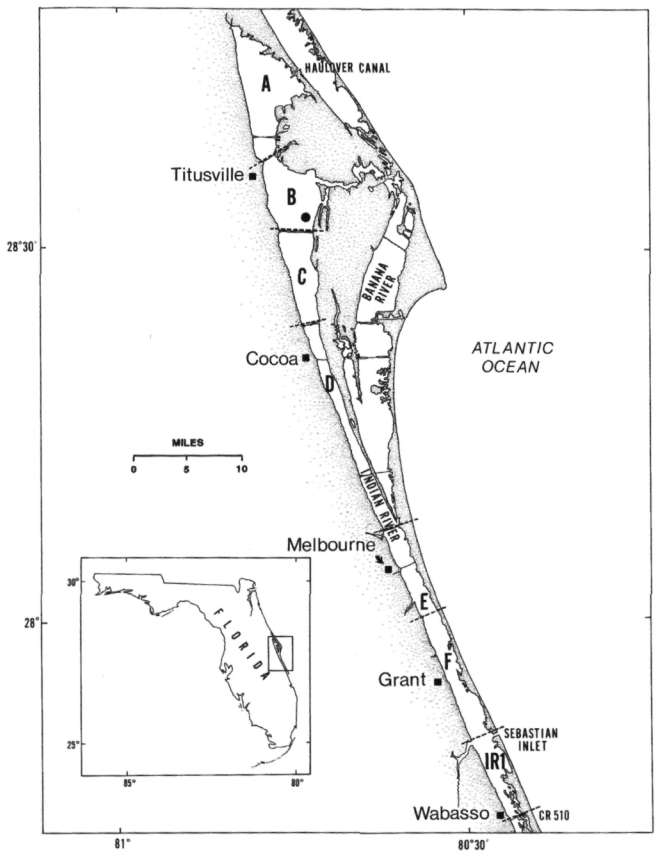

Figure 1. Indian River lagoon, FL, indicating shellfish-harvesting bodies and approximate position of experimental site (●).

each) and was anchored to the substrate during transplanting by four steel rebar pins (9.5-mm [3/8″]). On September 14, 1989, a diver haphazardly poured the clams from one 120-mL jar onto the surface of each of the 16 subplots. The template was then removed. A second plot was prepared with a second PVC template and covered on the lower side with polypropylene mesh (open areas, 10 by 10 mm), approximately 4 m away from the first plot. The cage template was also subdivided into 16 0.39-m^2 squares and was anchored to the substrate by eight rebar pins. The diver planted the clams by pouring the contents of one jar per subplot directly through the mesh onto the substrate. On both treatments, the diver observed that juvenile clams rapidly burrowed into the substrate.

Fifteen days after transplantation, three of the subplots from each treatment were sampled. Samplings were also conducted 80, 183, 273, and 363 days after transplanting. The selection of sampled subplots was random, but no subplot was sampled more than once during the experiment. Subplots were located by laying a subdivided template over the plot. Three cores with surface areas of 0.032 m^2 and depths of 5 cm were removed with a suction dredge from each randomly selected subplot. Material removed was collected in a 303-μm-pore-size mesh bag and preserved in buffered 10% seawater formalin. After the 80-day sampling, six cores were taken from each subplot because declining densities in the open plots might make statistical analysis difficult. All live *M. mercenaria* that displayed a tetracycline band under ultraviolet illumination were counted, and the SH of each was measured. Most authors report clam size as shell length (SL). The relationship between SL and SH was calculated from clams recovered during the early postplanting stages. During each sampling of the caged subplot, the mesh template was cleared of all fouling growth, which was always minimal. Before transplantation and also after the 363-day sampling, three cylindrical cores (37 mm in diameter, 5 cm in length) were taken haphazardly from within both the open and the caged plots. These were analyzed separately for major sedimentary characteristics (% gravel, % sand, % silt-clay, and % organic matter by ignition [Folk 1974]) as a measure of the influence of the treatments on the sediment profile.

We analyzed survivorship using a two-way analysis of variance (ANOVA) with days after transplantation and plot condition (open or caged) as factors. Lack of treatment replication may make interpreting the meaning of between-treatment effects difficult, but highly significant differences would suggest real main effects. Because the experimental design was unbalanced, data were analyzed with the SAS GLM procedure (SAS Version 5; SAS Institute, Inc., Cary, NC). Where F ratios were significant ($p < 0.05$), Hochberg's GT2 method for comparing means was applied (Hochberg 1974) because it is useful when variances are equal but sample sizes are unequal (Day and Quinn 1989). We used ANOVA to analyze shell data and developed a growth model by fitting (via Table Curve 2D software, Version 3.0; Jandel Scientific, Corte Madera, CA) a nonlinear growth function to the SH data. Separate functions were fit to the data from each treatment because prior ANOVA results demonstrated significant growth differences between treatments. Five functions that have been demonstrated to be useful in modeling bivalve growth (von Bertalanffy, Gompertz, power curve, logistic curve, and exponential curve) (Kennish and Loveland 1980, Kaufmann 1981, Walker and Humphrey 1984, Jones et al. 1990, Arnold et al. 1991, Allison 1994, Lefort 1994) were fit to the SH data. The most appropriate function for each of the data sets was selected on the basis of best fit (highest r^2 value) among the five functions.

RESULTS

The mean clam density at planting was 5,221.2/m^2, and the mean SH of these clams was 1.63 ± 0.01 mm (range, 0.7–3.7 mm SH). The relationship between SH and SL was determined to be $SH = -0.209 + (0.967)(SL) + (-9.127 \times 10^{-5})(SL)$. Clams in both treatments experienced high mortality almost immediately (Fig. 2): mortality approached 90% within 15 days in the open plot and exceeded 40% in the caged plot. Mortality in both treatments exceeded 95% within 80 days after planting, but clam densities did not decline appreciably for the remainder of the experiment. Because of the drastic early mortality in both treatments, the clam-density data for the 15-day sampling was eliminated from the analysis and the two-way ANOVA was conducted on the remaining data. Within-treatment densities on sample dates from 80 to 363 days did not differ significantly from each other; however, clam densities in the caged plot were significantly higher than those in the open plot on all sample dates ($p < 0.0001$).

Sample date had a significant effect on clam height ($p \approx 0$), and mean sizes on all dates were significantly different from each other. Treatment also had a significant main effect on clam height ($p < 0.0001$), although there was a significant interaction between date and treatment ($p < 0.0001$). Clam growth initially appeared to be more rapid in the open plot (Fig. 3). For both treatments, a power curve provided the best fit for clam height over time. The open-treatment data yielded a power curve of the form $SH_t = 0.021(t + 78.99)^{1.603}$, where t = days after planting and SH_t =

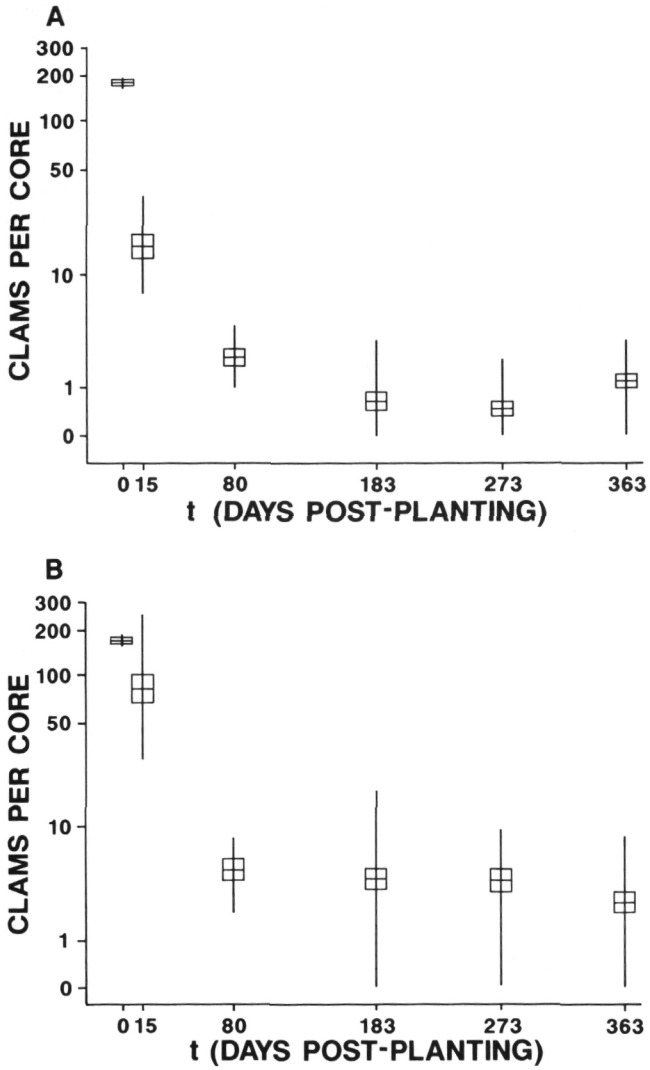

Figure 2. Changes in density (number per 0.032-m^2 core) over time of *M. mercenaria* transplanted to (A) uncaged and (B) caged experimental plots in Indian River shellfish-harvesting body B, 1989–1990. Symbols indicate range, mean, and ±1 standard error. Densities were significantly greater in the caged treatment on all dates ($p < 0.0001$).

shell height at t ($r^2 = 0.959$). The caged treatment shell growth was best expressed by a power curve where $SH_t = 0.002\ (t + 634.24)^{5.78}$ ($r^2 = 0.945$).

The substrate sediment profile was altered by the cage treatment. Large increases in both silt-clay (>222%) and organic fractions (>42%) and a slight (10.4%) reduction in the sand fraction were identified in the caged treatment, whereas silt-clay increased only slightly (28.8%) in the open treatment.

DISCUSSION

Clams transplanted into Shellfish Harvesting Area B grew at rates consistent with those estimated (from models generated by Arnold et al. 1991) for clams in other Indian River areas, rates that could be amenable to economical aquaculture. Differences in initial clam growth rates observed between caged and uncaged treatments were not detectable at the termination of the experiment. Caging artifacts can alter biologic processes, including growth (Virnstein 1977, Dayton and Oliver 1980, Riese 1985). Although we identified an altered sediment profile in the caged treatment, clam growth was ultimately not affected.

Mortality rates for unprotected clams were high and consistent with the 96–100% mortality over 3–12 mo reported for juvenile clams transplanted by other researchers (Menzel et al. 1976, Kraeuter and Castagna 1977b, Flagg and Malouf 1983, Kraeuter and Castagna 1985). The rapid decline in clam density followed by a slow but steady reduction in the open treatment is indicative of the density-dependent predation reported in other crab-clam assemblages (Mansour and Lipcius 1991, Boulding and Hay 1984). Despite the compromise created by a lack of replication, our data suggest that planting unprotected clams of less than 8 mm SH is neither an efficient stock-enhancement technique nor an economical method of aquaculture. In fact, mortality, although reduced in our caged treatment, was unacceptably high (as per Menzel et al. 1976) in either treatment for an aquaculture operation. Several

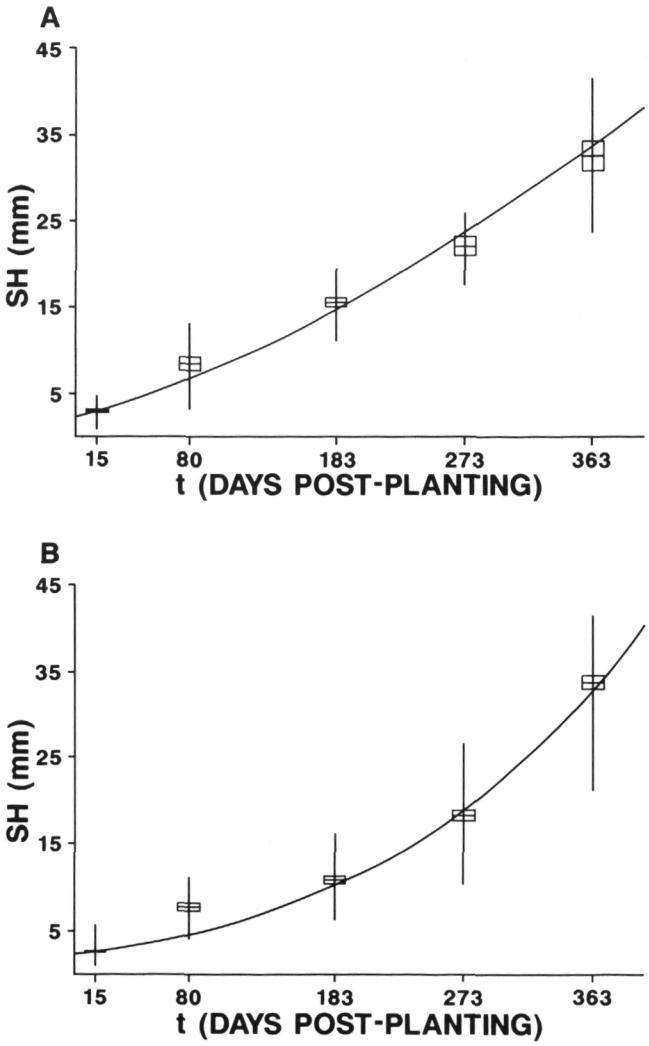

Figure 3. Size (SH) over time of *M. mercenaria* transplanted to (A) uncaged and (B) caged experimental plots in Indian River shellfish-harvesting body B, 1989–1990. Symbols indicate range, mean, and ±1 standard error. Curves represent best fit of models examined and are explained by the equations (a) $SH_t = 0.021\ (t + 78.99)^{1.603}$ and (b) $SH_t = 0.002\ (t + 634.24)^{5.78}$. Initial growth was higher in open plots ($p < 0.0001$), but SH did not vary by treatment at t = 363 days.

factors may have contributed to high mortality: initial clam sizes were much smaller than those of clams usually transplanted to Indian River field growout facilities (typically, 14–16 mm SL; Barry Moore pers. comm.), and mesh sizes used by aquaculturists in Indian River growout operations are much smaller (commonly 6.35-mm or 1/4″ mesh; Barry Moore pers. comm.) than the size we used. Although our cage was not specifically designed to exclude crabs tunneling into the treatment, no such behavior was apparent until the end of the experiment, when one stone crab (*Menippe mercenaria*) had taken up residence under the eastern edge of the mesh.

Increasing the initial size of the transplanted clams would reduce mortality. Caged clams experienced predation below the 10-mm mesh from infaunal or small epibenthic predators. Xanthid crabs are known to enter such cages and prey on juvenile *Mercenaria* (MacKenzie 1977, Eldridge et al. 1979, Walker 1984, Kraeuter and Castagna 1985, Bisker and Castagna 1989), as are juvenile blue crabs (*Callinectes sapidus*) (Walker 1984, Bisker and Castagna 1989). From an economic perspective, the smallest clams that can be protected and raised should be planted (Kraeuter and Castagna 1977a). Those authors insist that the greater losses of smaller clams can be offset by the lower cost of raising or purchasing smaller stock. Survival can be enhanced if protected clams are planted at larger sizes or planted in combination with predator-exclusion devices and/or predator-removal techniques (Eldridge et al. 1976, Menzel et al. 1976, Whetstone and Eversole 1977, Eldridge et al. 1979, Walker 1984, Kraeuter and Castagna 1985). Some of those authors also reported reductions in predation when clams achieved a SH of 15–20 mm (Menzel et al. 1976, Whetstone and Eversole 1977, Eldridge et al. 1979, Walker 1984). Our protected clams became effectively immune to predation at a SH of 8 mm (SL = 8.55 mm) under 10-mm mesh, although similarly sized clams in the open treatment were still vulnerable, suggesting a size refuge from predation by infaunal and small epibenthic predators at about 8 mm SH. Unprotected clams also achieved this refuge, but they continued to be exposed to larger epibenthic predators (brachyuran crabs, busyconid whelks, and fish).

Stock-enhancement or aquaculture operations for hard clams must mitigate predatory losses by protecting clams or planting at low densities (see Peterson et al. 1995). The growth and mortality rates we observed may not be directly applicable to clams in other areas, but they do suggest that clams can be economically cultured in Indian River Shellfish Harvesting Area B and, further, that protected clams can be successfully planted at a SH $\geq$8 mm (SL $\geq$8.55 mm).

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LITERATURE CITED

Allison, E. H. 1994. Seasonal growth models for great scallops (*Pecten maximus* (L.)) and queen scallops (*Aequipecten opercularis* (L.)). *J. Shellfish Res.* 13:555–564.

Arnold, W. S. 1984. The effects of prey size, predator size, and sediment composition on the rate of predation of the blue crab, *Callinectes sapidus* Rathbun, on the hard clam *Mercenaria mercenaria* (Linné). *J. Exp. Mar. Biol. Ecol.* 80:207–219.

Arnold, W. S., T. M. Bert, D. C. Marelli, H. Cruz-Lopez & P. A. Gill. 1996. Genotype-specific growth of hard clams (genus *Mercenaria*) in a hybrid zone: variation among habitats. *Mar. Biol.* 125:129–139.

Arnold, W. S., D. C. Marelli, T. M. Bert, D. S. Jones & I. R. Quitmyer. 1991. Habitat-specific growth of hard clams *Mercenaria mercenaria* (L.) from the Indian River, Florida. *J. Exp. Mar. Biol. Ecol.* 147:245–265.

Bertness, M. D. 1989. Intraspecific competition and facilitation in a northern acorn barnacle population. *Ecology* 70:257–268.

Bisker, R. & M. Castagna. 1989. Biological control of crab predation on hard clams *Mercenaria mercenaria* (Linnaeus, 1758) by the toadfish *Opsanus tau* (Linnaeus) in tray cultures. *J. Shellfish Res.* 8:33–36.

Boulding, E. G. & T. K. Hay. 1984. Crab response to prey density can result in density-dependent mortality of clams. *Can. J. Fish. Aquat. Sci.* 41:521–525.

Carriker, M. R. 1959. The role of physical and biological factors in the culture of *Crassostrea* and *Mercenaria* in a salt-water pond. *Ecol. Monogr.* 29:219–266.

Day, R. W. & G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. *Ecol. Monogr.* 59:433–463.

Dayton, P. K. & J. S. Oliver. 1980. An evaluation of experimental analyses of population and community patterns in benthic marine environments. pp. 93–120. *In*: K. R. Tenore and B. C. Coull. (eds.). Marine Benthic Dynamics. University of South Carolina Press, Columbia.

Eldridge, P. J., A. G. Eversole & J. M. Whetstone. 1979. Comparative survival and growth rates of hard clams *Mercenaria mercenaria*, planted in trays subtidally and intertidally at varying densities in a South Carolina estuary. *Proc. Natl. Shellfish Assoc.* 69:30–39.

Eldridge, P. J., W. Waltz, R. C. Gracy & H. H. Hunt. 1976. Growth and mortality rates of hatchery seed clams, *Mercenaria mercenaria*. *Proc. Natl. Shellfish Assoc.* 66:13–20.

Flagg, P. J. & R. E. Malouf. 1983. Experimental plantings of juveniles of the hard clam *Mercenaria mercenaria*. *J. Shellfish Res.* 3:19–27.

Folk, R. L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing, Austin, TX. 184 pp.

Gainey, L. F., Jr. & M. J. Greenberg. 1977. Physiological basis of the species abundance-salinity relationship in molluscs: a speculation. *Mar. Biol.* 40:41–49.

Hochberg, Y. 1974. Some conservative generalizations of the T-method in simultaneous inference. *J. Multivar. Anal.* 4:224–234.

Jones, D. S., I. R. Quitmyer, W. S. Arnold & D. C. Marelli. 1990. Annual shell banding, age, and growth rate of hard clams (*Mercenaria* spp.) from Florida. *J. Shellfish Res.* 9:215–225.

Kaufmann, K. W. 1981. Fitting and using growth curves. *Oecologia* 49: 293–299.

Kennish, M. J. & R. E. Loveland. 1980. Growth models of the northern quahog, *Mercenaria mercenaria* (Linné). *Proc. Natl. Shellfish Assoc.* 70:230–239.

Kraeuter, J. N. & M. Castagna. 1977a. An analysis of gravel, pens, crab traps and current baffles as protection for juvenile hard clams (*Mercenaria mercenaria*). Proceedings of the 8th Annual Meeting of the World Mariculture Society. Louisiana State University, Baton Rouge, LA. pp. 581–592.

Kraeuter, J. N. & M. Castagna. 1977b. *Mercenaria* culture using stone aggregate for predator protection. *Proc. Natl. Shellfish Assoc.* 67:1–6.

Kraeuter, J. N. & M. Castagna. 1980. Effects of large predators on the field culture of the hard clam, *Mercenaria mercenaria*. *Fish. Bull.* 78:538–541.

Kraeuter, J. N. & M. Castagna. 1985. The effects of seed size, shell bags,

crab traps, and netting on the survival of the northern hard clam *Mercenaria mercenaria* (Linne). *J. Shellfish Res.* 5:69–72.

Lefort, Y. 1994. Growth and mortality of the tropical scallops: *Annachlamys flabellata* (Bernardi), *Comptopallium radula* (Linne) and *Mimachlamys gloriosa* (Reeve) in Southwest Lagoon of New Caledonia. *J. Shellfish Res.* 13:539–546.

Linnaeus, C. 1758. Systema naturae per regna tria naturae. 10th rev. ed. vol. 1. Regnum animale. Stockholm, Sweden. 824 pp.

MacKenzie, C. L., Jr. 1977. Predation on hard clam (*Mercenaria mercenaria*) populations. *Trans. Am. Fish. Soc.* 106:530–537.

Mansour, R. A. & R. N. Lipcius. 1991. Density-dependent foraging and mutual interference in blue crabs preying upon infaunal clams. *Mar. Ecol. Prog. Ser.* 72:239–246.

Marelli, D. C. 1990. Recruitment of the estuarine soft-bottom bivalve *Polymesoda caroliniana* and its influence on the vertical distribution of adults. *Veliger* 33:222–229.

McCall, D., J. G. Cook, J. A. Lasater & T. A. Nevin. 1970. A survey of salinity levels in the Indian River-Banana River complex. *Bull. Environ. Contam. Toxicol.* 5:414–421.

Menge, B. A. 1978. Predation intensity in a rocky intertidal community: effect of an algal canopy, wave action and desiccation on predator feeding rates. *Oecologia* 34:17–35.

Menzel, R. W., E. W. Cake, M. L. Haines, R. E. Martin & L. A. Olsen. 1976. Clam mariculture in northwest Florida: field study on predation. *Proc. Natl. Shellfish Assoc.* 65:59–62.

Menzel, R. W. & H. W. Sims. 1962. Experimental farming of hard clams, *Mercenaria mercenaria*, in Florida. *Proc. Natl. Shellfish Assoc.* 53:103–109.

Muus, K. 1973. Settling, growth and mortality of young bivalves in the Øresund. *Ophelia* 12:79–116.

Peterson, C. H. 1982. Clam predation by whelks (*Busycon* spp.): experimental tests of the importance of prey size, prey density, and seagrass cover. *Mar. Biol.* 66:159–170.

Peterson, C. H., H. C. Summerson & J. Huber. 1995. Replenishment of hard clam stocks using hatchery seed: combined importance of bottom type, seed size, planting season, and density. *J. Shellfish Res.* 14:293–300.

Pohle, D. G., V. M. Bricelj & Z. Garcia-Esquivel. 1991. The eelgrass canopy: an above-bottom refuge from benthic predators for juvenile bay scallops, *Argopecten irradians*. *Mar. Ecol. Prog. Ser.* 74:47–59.

Riese, K. 1985. Predator control in marine tidal sediments. pp. 311–321. *In:* P. E. Gibbs (ed.). Proceedings of the 19th European Marine Biology Symposium, Plymouth, 1984. Cambridge University Press, Cambridge.

Summerson, H. C. & C. H. Peterson. 1984. Role of predation in organizing benthic communities of a temperate-zone seagrass bed. *Mar. Ecol. Prog. Ser.* 15:63–77.

Vaughan, D. E. 1989. Clam culture: state of the art in Florida. *J. Shellfish Res.* 7:546.

Virnstein, R. W. 1977. The importance of predation by crabs and fishes on benthic infauna in Chesapeake Bay. *Ecology* 58:1199–1217.

Walker, R. L. 1984. Effects of density and sampling time on the growth of the hard clam, *Mercenaria mercenaria,* planted in predator-free cages in coastal Georgia. *Nautilus* 98:114–119.

Walker, R. L. & C. M. Humphrey. 1984. Growth and survival of the northern hard clam *Mercenaria mercenaria* (Linné) from Georgia, Virginia, and Massachusetts in coastal waters of Georgia. *J. Shellfish Res.* 4:125–129.

Whetstone, J. M. & A. G. Eversole. 1977. Predation on hard clams, *Mercenaria mercenaria,* by mud crabs, *Panopeus herbstii*. *Proc. Natl. Shellfish Assoc.* 68:42–48.