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JUVENILE AND YEARLING GROWTH OF ATLANTIC SURFCLAMS *SPISULA SOLIDISSIMA* (DILLWYN, 1817) IN MAINE

CHRISTOPHER V. DAVIS,[1] KEVIN C. SCULLY,[2] AND SANDRA E. SHUMWAY[3]
[1]*Darling Marine Center*
University of Maine
Walpole, Maine 04573
[2]*Glidden Point Oyster Co., Inc.*
707 River Road
Edgecomb, Maine 04556
[3]*Natural Sciences Division*
Southampton College, Long Island University
Southampton, New York 11968

ABSTRACT With the recent emergence of a shellfish aquaculture industry in Maine, the development of alternative species would provide mariculturists some flexibility and stability by diversifying their product line and opening up coastal environments unsuitable to the oysters and mussels currently being cultivated. The Atlantic surfclam, *Spisula solidissima,* occurs naturally in Maine, and although it has not been commercially exploited, this mactrid clam may provide growers with a profitable new product line. What is not known is how well this species will grow in a culture setting throughout Maine's diverse marine environment. The goal of this study was to assess the growth and survival of two age/size classes of Atlantic surfclams under a variety of growing conditions. Juvenile (3-mm) and yearling (23-mm) surfclams were reared for one growing season in floating screened trays and intertidal sediments, respectively, at six study sites along the coast of Maine. After 4 mo of growth, mean size differences of juveniles among the six growing sites were significant. Juveniles reared at the upper Damariscotta River site grew the fastest (8.9 mm shell length [SL]) among the six sites. In comparison, those grown in Mud Hole Cove had the slowest growth (5.5 mm SL). Yearling surfclams at both planting densities grew the fastest in the Mud Hole Cove plot (40 mm SL) compared with the slowest growing sibling cohorts in the Deer Isle plot (27 mm SL). Similar trends among plots were observed with respect to both wet and dry weight gain. Surfclams reared in low-density treatments tended to grow faster than the high-density cohorts, although the means were not significantly different at any of the study plots. The optimal nursery sites for juvenile growth were different from the most productive areas for yearling growth, suggesting that growers may want to choose separate areas for different culture phases. This study is the first to document rates of growth and survival of Atlantic surfclams reared under varying growing conditions in northern New England waters.

KEY WORDS: Atlantic surfclam, growth, site selection, aquaculture

INTRODUCTION

The Atlantic surfclam (*Spisula solidissima*) is a subtidal mactrid species ranging in distribution along the eastern seaboard from Labrador, Canada, to South Carolina (Abbott 1974). Also referred to as the bar or hen clam, this species can grow to over 157 mm in shell length (SL) and typically inhabits sandy environments from just beyond the surf zone to deeper, offshore waters. A commercial fishery exists off the Middle-Atlantic Bight for 100–125 mm SL surfclams. Commercial landings of Atlantic surfclams in 1993 in the United States were 33,600 metric tons, valued at nearly $34 million (NOAA/NMFS 1994, Murawski et al. 1990). In recent years, interest has grown to evaluate the aquaculture potential of this species.

Goldberg and Walker (1990) assessed the growth and survival of cage-cultured yearling surfclams in the waters of Georgia to determine if this species would tolerate the southern waters beyond its natural southern range. They determined that growth rates of surfclams reared in coastal waters were greater than those grown in nearby intertidal rivers. Research by Walker and Heffernan (1990a, 1990b) assessed the effects of cage mesh size and planting height on growth and survival of surfclams in the coastal waters of Georgia. Mesh size had no effect on survival, and clams grew faster and had higher survival rates when planted lower in the intertidal zone.

Several studies have been undertaken to determine the mariculture potential of this species in New England waters. Goldberg (1980, 1989) assessed the potential of rearing surfclams in a raceway system in Milford, CT. In this study, juveniles grew from 18 to 55 mm in one growing season, suggesting that one could rear them to market size within 1 y, although growth in the natural environment could be considerably different. No studies to date have assessed the mariculture potential for this species in northern New England waters.

With the emergence of a shellfish aquaculture industry in Maine, the development of alternate species such as the Atlantic surfclam would provide mariculturists some flexibility and stability by diversifying their product line and possibly opening up new growing areas that are presently unsuitable for the species currently in culture. One Maine aquafarmer has been successfully rearing surfclams to 45 mm SL in 2 y. This size of product could compete with the cherrystone hard clam market.

The purpose of this study was to assess the growth of two age/size classes of Atlantic surfclams in various growing environments along the coast of Maine. Clams were reared for one growing season in floating screened trays (juveniles) or intertidally in sediment-filled containers (yearlings) at two planting densities at six study sites spanning the Maine coastline.

MATERIALS AND METHODS

Juvenile Growth Study

Juvenile surfclams measuring approximately 3 mm in SL were acquired from a commercial shellfish hatchery (Mook Sea Farm, Inc., Damariscotta, ME) in June 1992. The genetic heritage of the parental broodstock is unknown. Spawning, larval rearing, and early nursery growth occurred from April through June 1992. Juveniles were deployed in six intertidal plots along the coast of Maine (Fig. 1). They were initially reared in floating screened trays similar to those used by commercial growers. Tray assemblies consisted of 31 × 76 cm mesh envelopes supported by 36 × 81 cm rectangular frames made of 12.7-mm-diameter polyvinyl chloride pipe. Mesh envelopes were made of either fiberglass window screen (1-mm mesh size) or polyethylene netting (4.2-mm mesh size), depending on the size of the surfclams. The mesh envelope and frame assemblies were contained in 46 × 81 × 9 cm extruded polyethylene cages (ADPI OBC-3 cage with 12.7-mm mesh size). Each tray was fitted with foam flotation providing 3.6 kg of buoyancy. Trays were tied end-to-end and secured by a single-point mooring. Approximately 20 periwinkles (*Littorina littorae*) were stocked with the surfclams to help control biofouling. Trays were also scrubbed of fouling organisms as needed. Three replicate trays were placed at each study site, and surfclams were sampled monthly to estimate growth and mortality.

SL were initially measured by video image analysis. Subsequent monthly growth measurements used digital calipers (±0.1 mm) once the clams were large enough to be handled safely. Surfclams were deployed from June 12–22, 1992, at six intertidal sites from the Piscataqua River, York County, on the western Maine coast to Mud Hole Cove, Great Wass Island, Washington County, to the east (Fig. 1). Replicate trays were initially stocked with 430 individuals. Floating tray sites were located as close as possible to the intertidal bottom sites. Monthly sampling occurred from July to October 1992. Individuals were randomly sampled (without replacement) for subsequent measurement of shell length ($n = 24/\text{tray}^{-1}$).

Bottom Growout of Yearlings

The experimental design for the yearling surfclam growout study used 48 sediment-filled containers per study plot; one-half (24) were stocked with surfclams at a density of 12/unit (high density), and the remaining 24 were stocked at a density of 6/unit (low density). These high- and low-density treatments equate to 658 and 329/m^2, respectively. The design was replicated at each of the six study sites, yielding a total of 288 experimental units containing 2,592 surfclams. Fourteen-month-old surfclams were acquired from Mook Sea Farm, Damariscotta, ME. They had been reared in floating screened trays in the Damariscotta River the prior summer, were wet stored over the winter, and were then made available for this project. Before deployment, all clams were measured to determine initial SL (23 mm) and live weight (LW) (2.1 g). Surfclams were randomly allocated at the above-prescribed densities to each of 48 numbered experimental units for each of the six plots. Growing containers consisted of 15.2-cm-diameter by 15.2-cm-deep plastic flower pots filled to the brim with sediment from the mud flat adjacent to the experimental array within each study site. Although sediment type varied from site to site, it was homogeneous within the arrays at each site. Each pot was covered with polyethylene predator netting (4.2 mm mesh size), secured to the containers by heavy rubber bands. The containers were then buried in the mud flat with the tops flush with the surrounding sediment. Twenty-four low-density and 24 high-density treatments were randomly deployed in an 8 by 6 array adjacent to the water's edge at mean low water (MLW). Experimental arrays at each of the six study sites were thus submerged for an equivalent proportion of the tidal cycle. The location of each numbered container was noted for future retrieval. Monthly sampling from July through October 1992 consisted of randomly removing without replacement six experimental units from each of the two density treatments for subsequent measurement. Predator netting on the unsampled experimental units were checked for excessive fouling and cleaned as necessary. Mensuration entailed determination of shell height, LW, dry weight, and dry tissue weight. Counts of dead and/or missing individuals were noted. Dry tissue weights were determined by shucking the meats of each individual into a pretared weighing boat and drying to constant weight at 70°C.

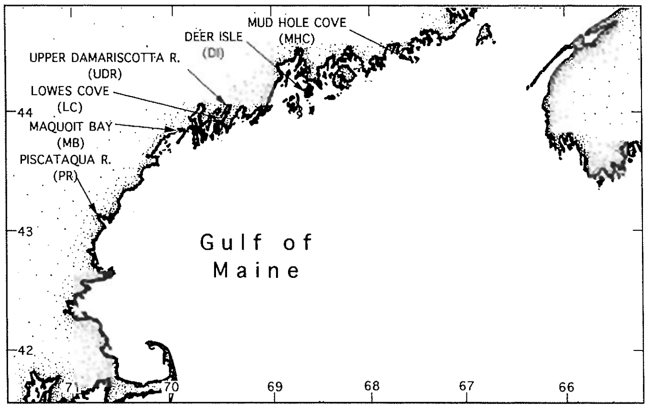

Figure 1. Location of the six study sites in the Gulf of Maine.

Statistical analysis was done with the SYSTAT statistical package (Wilkinson et al. 1992). Analysis of variance (ANOVA) was used to test for significant differences in SL, LW, dry weight, and dry tissue weight among cohorts or plots at each study site. The Tukey-Kramer HSD *post hoc* test for mean separation was used to further discriminate significant ($p < 0.05$) differences among cohort means between plots. The Student *t*-test was used to detect significant size differences due to density effects.

Descriptions of the Study Sites

Piscataqua River

This intertidal site is located on the northern shore of the Piscataqua River in the town of Eliot, York County (latitude, 43°05.7′N; longitude, 70°46.4′W) (Fig. 1). The study site is adjacent to the mouth of Spinney Creek, an artificially impounded bay that has historically been used for shellfish aquaculture. Current velocities in the Piscataqua River often exceed 180 cm/sec on the ebb tide. This portion of the river has a 2.6-m mean tidal range, and the steep gradient of the intertidal zone results in a narrow band of sediments varying from firm sand to course gravel. The experimental array was sited within the sandy portion of the beachfront.

Maquoit Bay

This site is located along the western shore of Maquoit Bay in the town of Brunswick, Sagadahoc County (latitude, 43°51.1′N; longitude, 70°01.8′W) (Fig. 1). Extensive mud flats at low water are covered by patches of eel grass (*Zostera marina*). The mean tidal range is 2.9 m. Intertidal sediments vary from soft mud to course sand proceeding up the intertidal zone. The experimental plot was located in soft mud. Maquoit Bay has historically supported large populations of soft-shell clams (*M. arenaria*), although a massive (30–40%) mortality of clams was observed in 1988 due to anoxic conditions after an unusually large dinoflagellate bloom (Heinig and Campbell, 1992).

Lowes Cove

Lowes Cove is located along the eastern shore of the Damariscotta River in the town of South Bristol, Lincoln County (latitude, 43°56.1′N; longitude, 69°34.6′W) (Fig. 1). The cove supports a soft-shell clam (*M. arenaria*) population in the very soft mud sediment found throughout the cove. The study site was located at the mouth of the cove and, because of the southwest exposure, was subject to considerable wave action from the prevailing summer southwesterly winds.

Upper Damariscotta River

This study site is located along the western shore of the Damariscotta River near the head of navigable waters in the town of Newcastle, Lincoln County (latitude, 44°01.8′N; longitude, 69°32.4′W) (Fig. 1). Extensive mud flats extend from the upper shore for several hundred meters. The upper portion of the Damariscotta River is highly regarded among aquaculturists because of its high productivity and warm waters during the summer months. A shellfish aquaculture nursery lease is located nearby. One nearby grower has been successfully rearing Atlantic surfclams in floating nursery trays and bottom cages for several years.

Deer Isle

Located at the southern entrance to Mud Cove on Stinson's Neck, Deer Isle, Hancock County (latitude, 44°12.6′N; longitude, 69°34.2′W), this site lies adjacent to a bottom culture mussel farm (Fig. 1). Sediments consist of a mixture of fine sand and soft mud interspersed with large boulders and outcrops of bedrock. The site has a mean tidal range of 3.3 m and has a southeasterly exposure.

Mud Hole Cove

This intertidal site is located in the upper reaches of Mud Hole Cove, Great Wass Island, Washington County (latitude, 44°27.5′N; longitude, 67°35.4′W) (Fig. 1). This long and narrow protected cove has intertidal sediments consisting of soft mud (mean tidal range of 3.5 m). Mud Hole Cove is also the nursery area for a nearby shellfish hatchery.

Environmental Monitoring

Monthly surface water temperature, salinity, and chlorophyll *a* measurements were taken at each of the study sites on the dates that the surfclams were sampled for growth and survival. Water samples were taken near the time of MLW. In addition, weekly chlorophyll *a* measurements were made at the two Damariscotta River sites at varying stages of the tidal cycle. Temperature (±0.5°C) was measured with a mercury thermometer. Either an optical refractometer or a hydrometer was used to determine the salinity (±0.5‰). Replicate water samples (n = 2) were gathered from 0.25 m below the surface. Levels of chlorophyll *a* were determined with a Turner Model 110 fluorometer, following the methods of Strickland and Parsons (1972).

RESULTS

Juvenile Growth

Juvenile growth in the floating screened trays varied considerably from site to site. Among the six sites, surfclams reared at the upper Damariscotta River site grew the largest by the end of the growing season in October (SL [±SD] of 8.94 [1.98] mm) (Fig. 2). In contrast, surfclams in Mud Hole Cove grew the slowest in the same time period (5.48 [1.17] mm SL). Surfclams at the remaining three areas grew to a mean size of 5.98 (0.13), 7.41 (0.32), and 6.64 (0.17) mm SL for the Piscataqua River, Maquoit Bay, and Lowes Cove sites, respectively. The experiment in Deer Isle was terminated when the three experimental trays were inadvertently lost from their mooring sometime between mid-July and mid-August.

ANOVA indicated highly significant ($p < 0.001$) differences in SL for clams in October. Tukey HSD multiple comparison tests showed that clams were significantly larger ($p < 0.05$) at the Upper Damariscotta River site than at all other sites. Clam size was not significantly different between Maquoit Bay and Lowes Cove or between the Piscataqua River and Mud Hole Cove sites (Fig. 2). Clam length was also not significantly different between the Lowes Cove and the Piscataqua River stations. Similar Tukey HSD multiple comparisons were made for the earlier sampling dates, and as would be expected, differences in size among sites became more pronounced as the growing season progressed.

Figure 3 illustrates the instantaneous growth rates for juvenile surfclams at five of the sites throughout the study period. Growth rates were greatest ($k > 1.25$) at all study sites during July and steadily declined as the summer progressed ($k < 0.5$). Mortality of juveniles was nil over the course of the study.

Yearling Growth

Considerable variation in mean growth rate of yearling surfclams was observed among plots. Growth occurred throughout the study period but was generally greater during July and August. The greatest growth in SL by October was observed at the Mud Hole Cove plot in both the high- and the low-density treatments. Mean sizes (±SD) for these groups were 40.2 (1.40) and 38.8 (3.49) mm, respectively. Surfclams reared at the Deer Isle plot had slowest

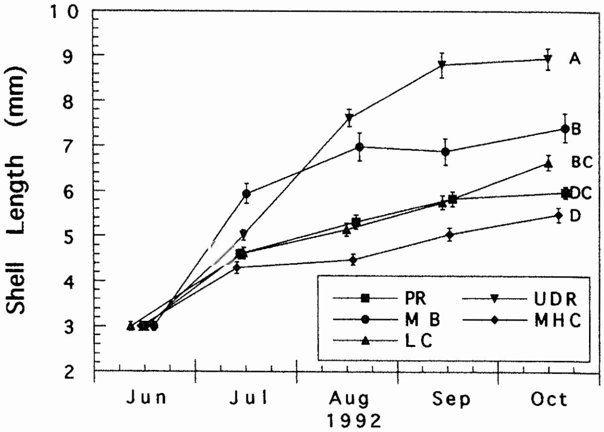

Figure 2. Changes in SL of juvenile surfclams at five study sites in Maine. Error bars indicate ±1 standard error. October means with differing letters are significantly different ($p < 0.05$) from one another. See Figure 1 for explanation of abbreviations.

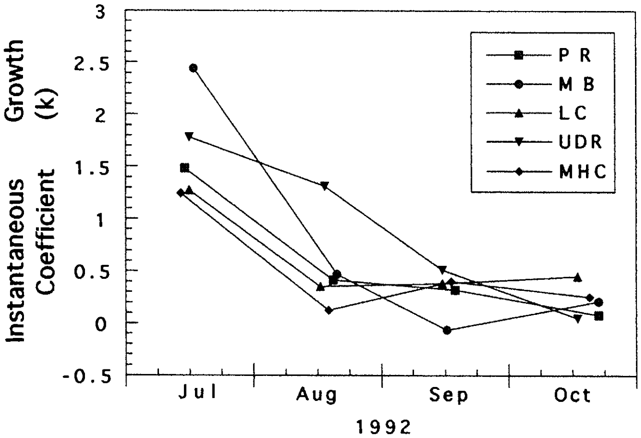

Figure 3. Plot of instantaneous growth rates for SL of juvenile surfclams reared at five study sites. Note that the plotted values are determined at the end of each sampling interval, but reflect the average growth rate for the preceding month.

growth among the six study plots in both the high- and the low-density treatments (27.1 [0.55] mm and 27.6 [1.34] mm SL, respectively). October mean sizes for the remaining high-density treatments were 39.4 (1.44), 37.3 (0.64), 33.7 (0.99), and 28.4 (1.39) mm SL at the Lowes Cove, Upper Damariscotta River, Maquoit Bay, and Piscataqua River plots, respectively. Corresponding low-density means were 37.5 (2.30), 38.6 (2.18), 32.8 (2.30), and 27.0 (2.16) mm SL, respectively. Changes in mean SL over the course of the experiment for the high- and low-density treatments for each of the plots are illustrated in Figure 4. ANOVA indicated that differences in mean SL among the six plots were highly significant ($p < 0.001$), although density and density × plot interactions were not ($p > 0.05$). Tukey HSD multiple comparison tests on size of surfclams cultured at both densities give similar results (Fig. 4). Mean clam sizes at the Upper Damariscotta River, Lowes Cove, and Mud Hole Cove plots were not significantly different from one another, but were significantly larger than clams from Maquoit Bay. Clams from Maquoit Bay were significantly larger than those from Deer Isle and Piscataqua River plots, which were not significantly different from each other (see Figure 4).

Similar comparisons were made for the LW data. By October, surfclams reared at high density at the Lowes Cove and Mud Hole Cove plots grew to 11.6 (1.29) and 11.5 (0.86) g mean LW, respectively. (The difference in weight between these two groups is not significant [$p > 0.05$].) The corresponding low-density treatments were 10.1 (1.39) and 11.1 (0.99) g LW. In comparison, surfclams from the Deer Isle plot only grew to 3.8 (1.24) and 4.0 (1.29) g LW for the high- and low-density treatments, respectively. October mean LW were 9.9 (0.49)/10.8 (1.98), 6.6 (0.56)/6.2 (1.17), and 4.1 (0.57)/3.7 (0.92) in the high-/low-density treatments for the Upper Damariscotta River, Maquoit Bay, and Piscataqua River plots, respectively. Figure 5 illustrates the changes in LW throughout the study period for the high- and low-density cohorts, respectively.

ANOVA indicated that differences in mean LW among the various plots were highly significant ($p < 0.001$). Similar results were observed for clams reared at high and low densities. Tukey HSD multiple comparison tests indicated that for October, there was no significant difference in the mean weight of surfclams between the Deer Isle and Piscataqua River plots or between clams from the Upper Damariscotta River, Lowes Cove, and Mud Hole Cove plots. The mean LW of clams from Maquoit Bay were statistically different ($p < 0.05$) from those of clams from all other plots (see Figure 5).

Mean dry animal and tissue (meat) weights were determined for cohorts for each plot (see Figure 6). ANOVA for each of these parameters were highly significant (both, $p < 0.001$) with respect to growing plot. Subsequent multiple comparisons based on mean dry tissue weight indicated that the Mud Hole Cove cohort was significantly greater ($p < 0.05$) than the other groups (0.640 [0.060] and 0.611 [0.079] g for high and low groups, respectively. The Maquoit Bay and Deer Isle groups had the lowest mean dry tissue weights (0.119 [0.017]/0.111 [0.041] and 0.126 [0.012]/0.133 [0.023] in the high/low treatments, respectively), but the means were indistinguishable from each other.

Combined cumulative mortality for all six plots by October was 0.81%. Cumulative mortality at individual study plots varied from 2.8% (Upper Damariscotta River) to <1.0% (Piscataqua River, Maquoit Bay, Lowes Cove, and Mud Hole Cove).

Environmental Data

Peak summer temperatures varied considerably from site to site. The Upper Damariscotta River site had the highest maximum surface water temperature (>20°C, June to August), whereas Mud

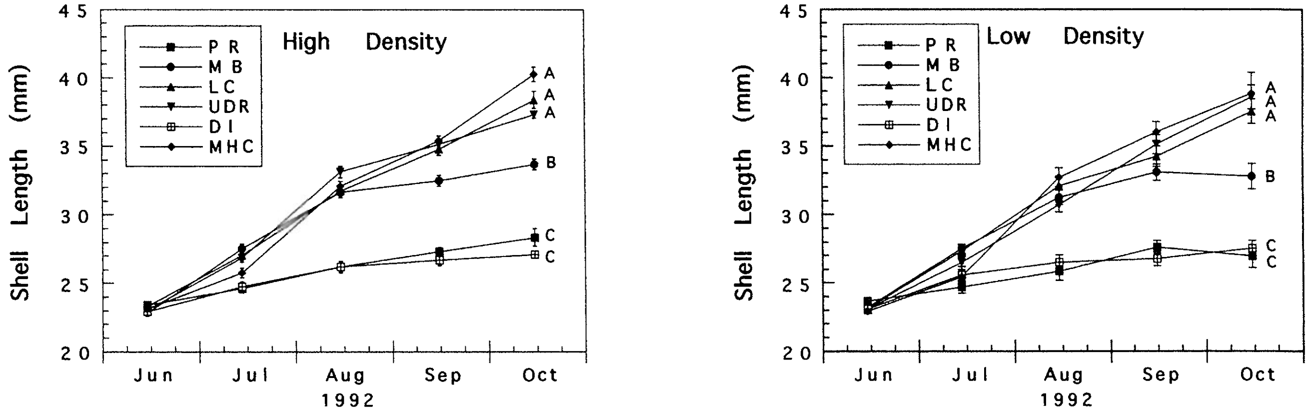

Figure 4. Changes in SL of yearling surfclams reared at high and low densities at six sites in Maine. Error bars indicate ±1 standard error. October means with differing letters are significantly different ($p < 0.05$) from one another.

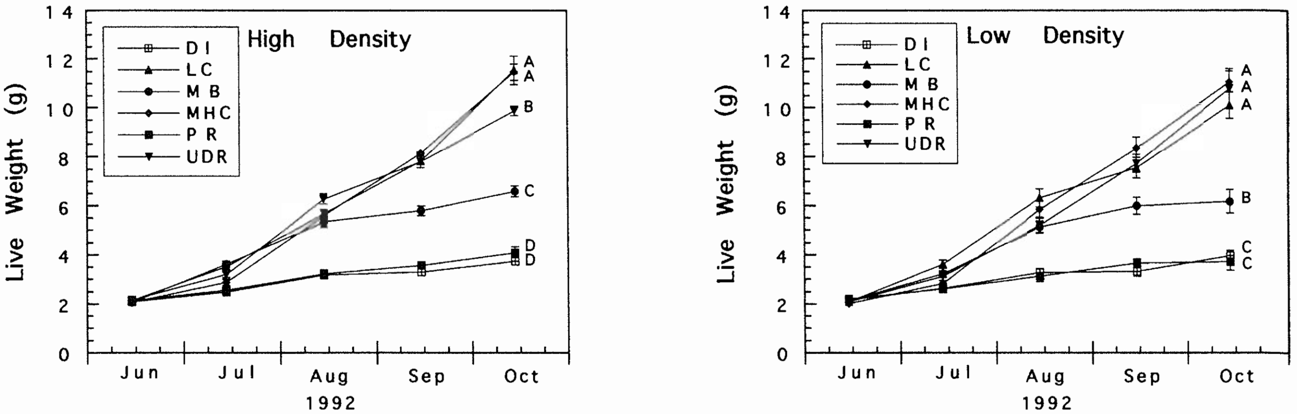

Figure 5. Changes in LW of yearling surfclams reared at high and low densities at six sites in Maine. Error bars indicate ±1 standard error. October means with differing letters are significantly different ($p < 0.05$) from one another.

Hole Cove had the lowest maximum temperature of 13°C in June and July (see Figure 7, dashed lines). Temperatures dropped precipitously at all sites after mid-September. Salinities from all of the study sites ranged from 30 to 34‰ (Fig. 7, solid lines) and never varied by more than 2‰ at any site. As would be expected, the two estuarine sites (Piscataqua and Upper Damariscotta Rivers) had slightly lower salinities than the more oceanic locations.

Concentrations of chlorophyll *a* may provide an approximation of the food available in the water column for shellfish consumption. The Upper Damariscotta River site had the highest chlorophyll *a* values (6.8 µg/L), whereas the Piscataqua River and Deer Isle sites had the lowest levels (Fig. 8). An early summer peak followed by an August crash was seen in the Upper Damariscotta River and is typical for that area (C.R. Newell, Pers. comm.). A similar profile was seen at the Deer Isle and Piscataqua River sites.

DISCUSSION

Significant variation in growth rates of Atlantic surfclams was observed among the six study plots. The relatively rapid growth of yearling cohorts from the Mud Hole Cove and Lowes Cove plots suggests that these areas may be superior locations for yearling growth of surfclams. Replication of the study plots within each site would be required to extrapolate these findings for the area in question. Interestingly, the least productive nursery site for juvenile growth (Mud Hole Cove) was one of the most productive sites for yearling growth, suggesting that growers may want to choose separate areas for different culture phases. The food quantity and quality, as well as temperature regimens of waters over the benthic intertidal zone, may vary considerably from subtidal surface waters several meters away.

Planting density had no significant effect on any of the growth parameters measured at any of the study plots. Apparently, within the 329–658 individuals/m^2 range, planting density has little effect on growth rate. In comparison, Goldberg (1989) did observe density-dependent effects for surfclams reared in bottom cages. Clams reared in Connecticut from June through November increased in mean size from 15.7 mm to 47.3, 40.8, and 32.0 mm in the 500, 1,000, and 2,000 clams/m^2 density treatments, respectively, thus suggesting that growth rate was inversely proportional to planting density under those growing conditions. It is possible that the lack of density-dependent effects in the Maine groups were due to the relatively low stocking densities compared with those in the Goldberg study. A comparison of the highest growth rates observed in the Goldberg (1989) low-density treatment (500 clams/m^2) to surfclam growth in this study indicates that the greatest yearling growth in the Mud Hole Cove plots (23 mm initial size to 40.2 mm by October at 658 individuals/m^2) were still less than those seen in the Connecticut study (15.7–47.3 mm).

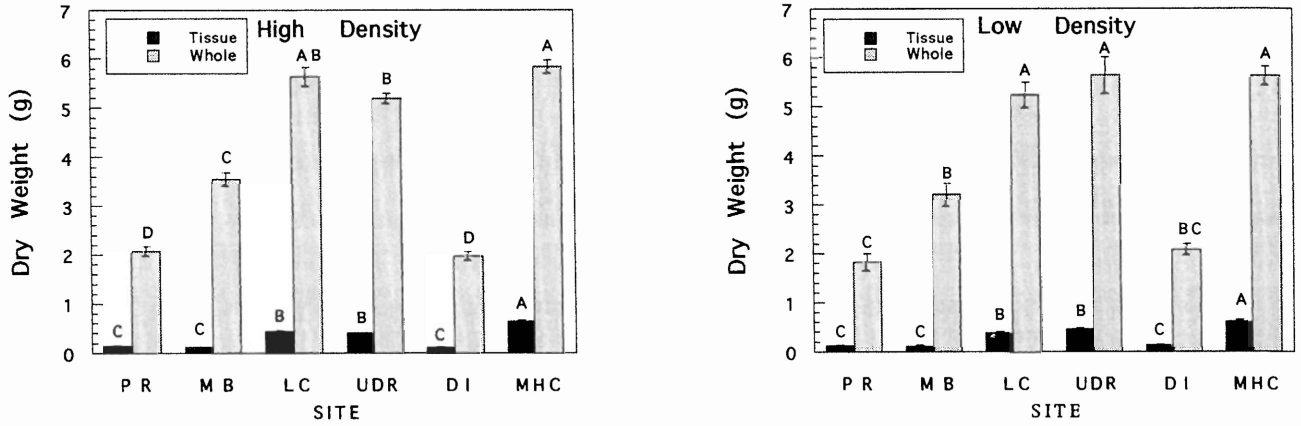

Figure 6. Dry whole-body and tissue weights for surfclams reared at high and low densities at six sites in Maine. Error bars indicate ±1 standard error. Means with differing letters are significantly different ($p < 0.05$) from one another.

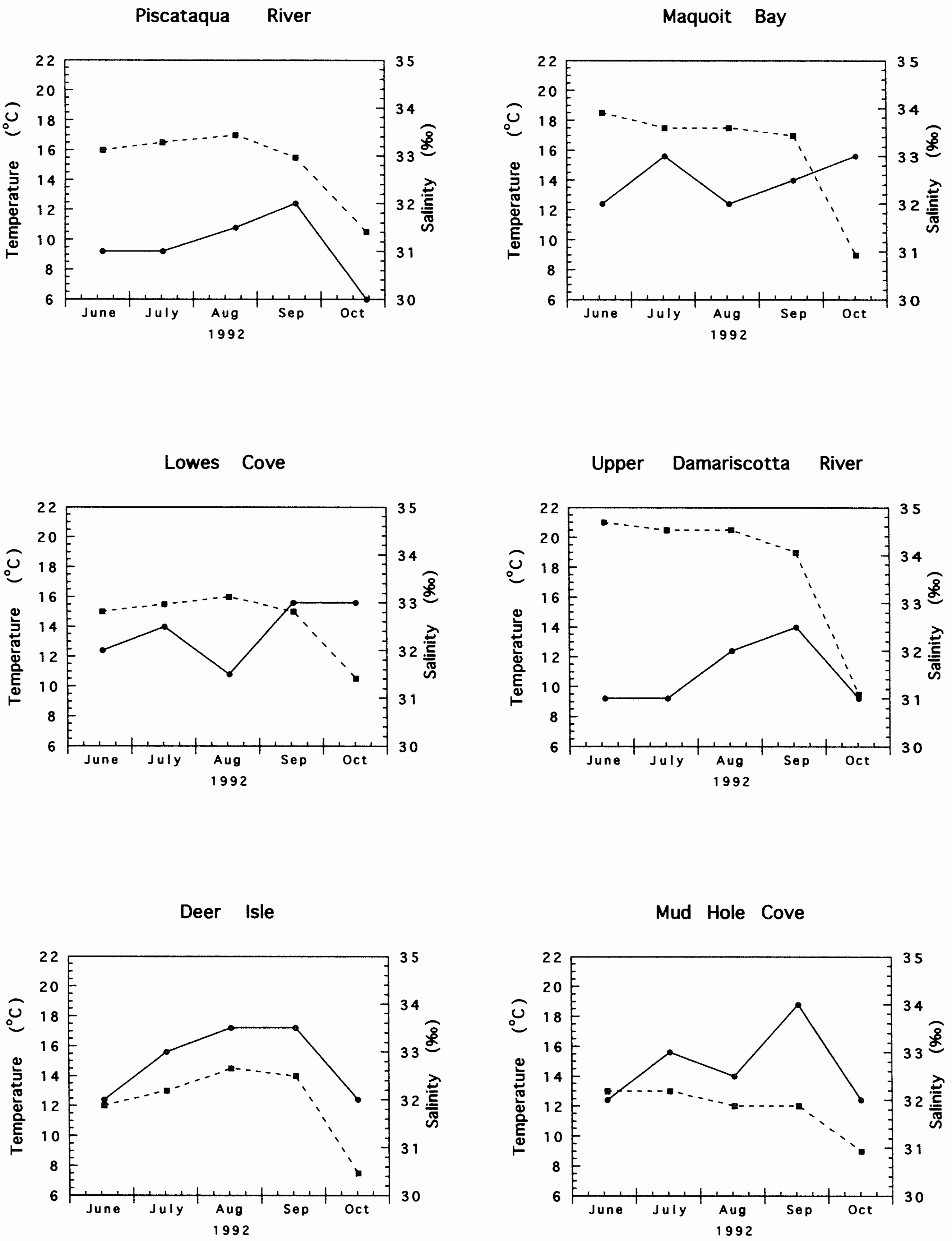

Figure 7. Temperature (°C) (dashed line) and salinity (‰) (solid line) profiles at the six field sites in Maine.

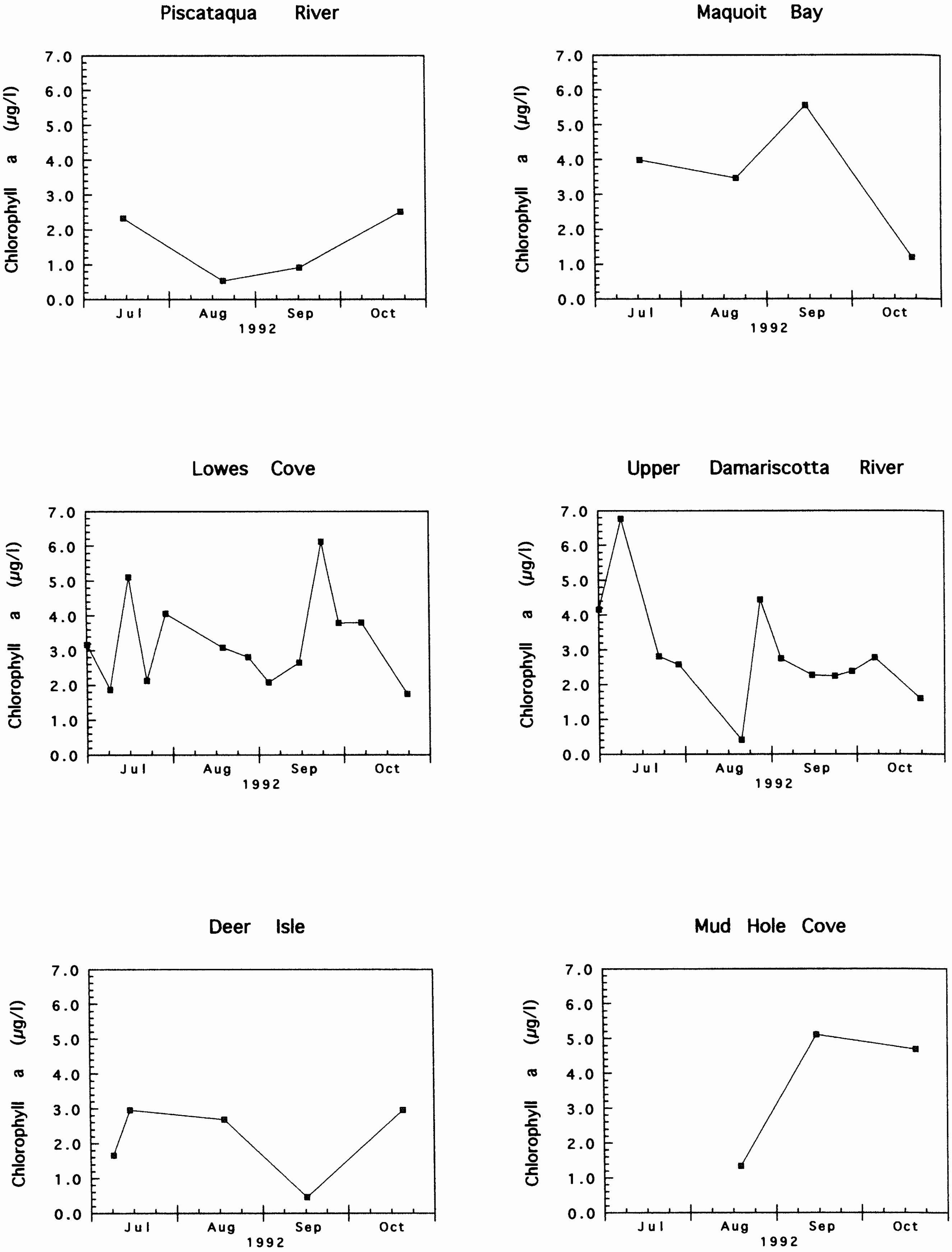

Figure 8. Chlorophyll *a* profiles at the six field sites in Maine.

Those sites with warmer water temperatures and higher levels of chlorophyll *a* tended to be associated with faster growing surfclams of both size/age classes (e.g., Upper Damariscotta River). In contrast, the poorer growth performance seen in the Piscataqua River and Deer Isle plots may reflect the lower chlorophyll *a* and water temperature profiles observed. All of the sites chosen for this study had stable and high summer salinities. The Atlantic surfclam is considered a stenohaline species and may not tolerate the lower springtime salinities of the riverine sites. Year-round environmental monitoring along with growth and survival trials for a proposed site is recommended.

The nature of the experimental containers (flower pots) for the yearling growth study clearly does not reflect the growout system that would be used in a production operation, but because of the intensive sampling nature of this project, the containers made the retrieval process a more manageable and less destructive exercise. Growth rates and survival could be very different if surfclams were to be directly seeded into a mud flat or reared in cages on the bottom. Furthermore, predator protection and harvesting ease must be considered when evaluating these methods. We only considered yearling growth in the low intertidal zone, but subtidal growout may be beneficial under conditions such as when there is interference with an existing intertidal shell fishery. Growth rates may also be enhanced in a subtidal culture setting, although predation problems may offset these gains. Goldberg (1989) showed that yearling surfclams grew faster at an 8-m depth versus shallower areas. This is an area needing further research.

Floating screened nursery trays are commonly used by shellfish mariculturists worldwide, but recent observations from experiments rearing another mactrid, Stimpson's surfclam (*Mactromeris polynyma*), in surface trays suggest that growth may be retarded compared with that of juveniles reared in sediment (C.V. Davis, unpubl. data). Surfclams spent considerable time (and presumably energy) foot probing the screen surface, presumably trying to burrow into the nonexistent sediment. Early planting of juvenile surfclams in sediment may be technically problematic, but on the basis of the *Mactromeris* data, growth rates may be enhanced.

This study underscores the importance of selecting an appropriate shellfish-rearing site, as indicated by the high variability of growth rates seen among the various growing areas. Undoubtedly, many variables beyond production-related ones will come into consideration when choosing a shellfish culture site. Factors such as access, protection, and compatibility with existing fisheries, etc., must be balanced with the need for a site with optimal growing and survivability conditions. The prudent mariculturist will evaluate several sites in a pilot study before beginning production.

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