Elevation and the Distribution of Salt-marsh Foraminifera, St. Catherines Island, Georgia: A Taphonomic Approach

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INTRODUCTION

The distributional patterns of selected salt-marsh foraminifera have been correlated to elevation within the marsh and used to identify marsh subdivisions that reflect elevation (Scott, 1976; Scott and Medioli, 1978, 1980a, 1986). Such studies provide the foundation for documenting Holocene sea-level fluctuations in coastal settings (Scott et al., 1981; Thomas and Varekamp, 1991; Gayes et al., 1995, 1996) and, to some extent, earthquake-induced subsidence (Guilbault et al., 1995, 1996). Most previous studies on North American salt-marsh foraminiferal distributions and their controlling factors have been conducted in regions other than the southeastern U.S. The pioneering studies, for example, were conducted primarily in Maritime Canada, New England, and California (Scott, 1978; Scott and Medioli, 1978, 1980a, 1986). Biogeographically, however, salt-marsh foraminifera of Georgia are comparable to those of the Gulf Coast and are more similar to those of the Gulf Coast than to those of other North American regions (Goldstein and Frey, 1986).

In addition, most previous work on salt-marsh foraminifera has relied on samples of only the top one cm of marsh sediments. Salt-marsh foraminifera, however, occupy not only epifaunal marsh habitats, but infaunal microhabitats as well (Akers, 1971; Matera and Lee, 1972; Steinbeck and Bergstein, 1979; Goldstein, 1988; Goldstein and Harben, 1993; Goldstein et al., 1995; Ozarko et al., 1997; Patterson et al., in press). Some salt-marsh foraminifera live as deep as 30 cm below the marsh surface and may have live, infaunal distributions that differ from those in surface sediments (Goldstein and Harben, 1993; Ozarko et al., 1997). This, in addition to the selective preservation of both calcareous and agglutinated tests in subsurface marsh sediments, may produce total assemblages (live + dead) in subsurface sediments that differ from those at the marsh surface (Goldstein and Harben, 1993; Goldstein et al., 1995).

The purpose of this study is first to determine the extent to which salt-marsh foraminifera of a Georgia barrier island reflect elevation within the marsh and to compare these distributional patterns with models developed elsewhere; and second, to evaluate the potential influence of both selective preservation and potential enrichment by infaunal dwelling taxa on these distributional patterns. St. Catherines Island, Georgia, served as an ideal location for this study. Salt marshes are very extensive on the island, and several USGS bench marks are present, thus facilitating the elevational study. In addition, the island has been maintained in pristine condition and protected from development.

PREVIOUS WORK

Previous work on the ecology of salt-marsh foraminifera is extensive (see reviews: Murray, 1971, 1991; Scott and Medioli, 1980a; Scott and Leckie, 1990). Early studies, many of which were descriptive, showed that salt-marsh microfaunas differed from those of other marine environments and that some species have fairly cosmopolitan distributions (Murray, 1971, 1991). In addition, salt-marsh foraminiferal assemblages vary with salinity (Parker and Atcham, 1959; Murray, 1971; Scott and Medioli, 1980a; De Rijk, 1995), pH (Pleger and Bradshaw, 1966; Scott and Medioli, 1980a), and geographic region (Pleger 1967; Scott and Medioli, 1980a). Foraminiferal associations were further shown to reflect salt-marsh habitat types, particularly the high- and low-marsh zones of Gulf Coast marshes (Pleger, 1965a, 1965b, 1970). Other investigations (many utilizing vital staining methods—Walton, 1952; Walker et al., 1974) addressed more specific distributional problems such as patchiness (Lutze, 1968; Schaefer, 1968; Boltovskoy and Lena, 1969; Buzas, 1970; Scott, 1976), seasonality (Buzas, 1965; Lutze, 1968; Boltovskoy...
and Lena, 1969), and the occurrence of epiphytic communities (Lee et al., 1969; Matera and Lee, 1972).

Building on pioneering studies (Phleger, 1965a,b, 1967) that documented a relationship between foraminiferal distributions and salt-marsh floral zones, Scott (1976) and Scott and Medioli (1978, 1980a, 1986) documented a correlation between certain species of foraminifera and elevation. They reported that, although the elevational distribution of halophytes may vary, elevational attributes of certain foraminifera remain fairly constant. A vertical zonation of foraminifera within salt-marsh environments has since been documented along the North Atlantic Seaboard (Scott and Leckie, 1990), the temperate Pacific Northwest (Jennings and Nelson, 1992), in a Pacific Northwest deltaic and marsh setting (Patterson, 1990), and the Texas Gulf Coast (Williams, 1994). In addition, Collins et al. (1995) reported foraminiferal distributions in relationship to elevation for a South Carolina marsh. De Rijk (1995) and De Rijk and Troelstra (1997), however, found a stronger correlation for salinity than elevation in explaining salt-marsh foraminiferal distributions in high marsh habitats of the Great Marshes of Massachusetts. They conclude that no single model on salt marsh foraminifera and elevation is applicable worldwide.

Many salt-marsh foraminifera may also have significant infaunal occurrences (Akers, 1971; Matera and Lee, 1972; Steineck and Bergstein, 1979; Goldstein, 1988; Goldstein and Harben, 1993; Goldstein et al., 1995; Ozarko et al., 1997; Patterson et al., in press). In addition, taphonomic processes may significantly impact the preservation of tests within at least the top 10 cm of marsh sediment (Patterson et al., in press; Goldstein and Watkins, in press). Although classical work on distributional patterns of salt-marsh foraminifera relied on sampling the top 1 cm of marsh sediment, assessment of the top 10 cm may provide a more accurate baseline for paleoenvironmental studies (Ozarko et al., 1997; Patterson et al., in press; Goldstein and Watkins, in press).

ST. CATHERINES ISLAND SALT MARSHES

St. Catherines Island, a Pleistocene barrier island on the Georgia coast, is located in Liberty County, and is separated from Ossabaw Island to the north and Sapelo Island to the south by large tidal channels (Fig. 1). St. Catherines is approximately 16.4 km long and ranges from 2 to 5 km wide. It is separated from the mainland by an expansive system of salt marshes that range from 6 to 10 km in width. The highest elevations on the island are approximately 6 m above mean sea level.

Barrier islands and salt marshes of the Georgia coast differ not only from those of the Gulf coast but also from those farther north along the Atlantic coast (Hayden and Dolan, 1979; Frey and Basan, 1985). Georgia islands consist mostly of short, curved, compound beach ridges separated by relatively stable tidal inlets. The barrier islands are complex, typically consisting of Pleistocene barrier remnants that have active Holocene beach ridges on the seaward side. Backbarrier environments include greater expanses of salt marsh and tidal channel networks than those anywhere else on the Atlantic seaboard (Howard and Frey, 1985). Unlike marshes of New England, peat deposits are extremely rare in southeastern marshes (Edwards and Frey, 1977). The entire coastal zone is part of a low- to moderate-energy, mesotidal system (Hubbard et al., 1979; Oertel, 1985).

Georgia salt marshes, which are well-vegetated tidal flats (Frey and Basan, 1985), consist of a broad, muddy, low marsh zone and a relatively narrow, sandy, high marsh zone (Edwards and Frey, 1977). A number of habitats and subenvironments have been recognized within each zone (Basan and Frey, 1977; Edwards and Frey, 1977; Basan, 1979; Letzsch and Frey, 1980; Table 1). Habitats within the high marsh are defined purely on botanical criteria and show little sedimentologic variation, and they generally form concentric bands about the highest reaches of the marsh. Habitats and subenvironments of the low marsh, however, are generally intergradational and defined primarily by geomorphic criteria, including relief of the marsh surface, that reflect their position relative to tidal channels that form a well-integrated dendritic drainage system (Edwards and Frey, 1977). The most extensive marsh habitat in Georgia marshes is the “meadow marsh” (Table 1), a broad low marsh zone with prominent stands of Spartina alterniflora. This differs from the high marsh “meadow” of New England marshes.

Marsh sites selected for this study are located at Persimmon Point, a backbarrier site on St. Catherines Island (Fig. 2; Table 2). This site borders the Intracoastal Waterway, but is otherwise separated from direct influence by the Atlantic. The low marsh zone is very extensive at this
TABLE 1—Classification of salt-marsh habitats and subenvironments summarized from Basan and Frey (1977), Edwards and Frey (1977), and Basan (1979).

<table>
<thead>
<tr>
<th>High Marsh Zone</th>
<th>Transitional Marsh Zone</th>
<th>Low Marsh Zone</th>
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<tbody>
<tr>
<td><em>Juncus</em> marsh barrens</td>
<td>Short-<em>Spartina</em> marsh</td>
<td>Streamside marsh</td>
</tr>
<tr>
<td><em>Distichlis</em> marsh</td>
<td></td>
<td>Levee marsh</td>
</tr>
<tr>
<td><em>Salicornia</em> marsh</td>
<td></td>
<td>Back-levee low marsh</td>
</tr>
<tr>
<td>Short-<em>Spartina</em> marsh meadow</td>
<td></td>
<td>meadow marsh</td>
</tr>
<tr>
<td>ponded water marsh barrens</td>
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site, as is typical of salt marshes on Georgia barrier islands. Low marsh habitats present at this site include streams, levee, meadow, and headwater marshes that form at the distal ends of small distributary channels. Transitional and high marsh zones, although present at Persimmon Point, are more restricted. A USGS benchmark is located at the juncture between the uppermost high marsh and the forest edge at Persimmon Point. The presence of the benchmark was instrumental in the selection of this site and was used for the measurements of elevation.

METHODS

Sampling stations representing a variety of marsh habitats were chosen to reflect the range of elevations found within the marsh at this site. Sites were selected within a mosaic rather than along a designated transect. This permitted replicate sampling of most habitats while collecting a manageable number of cores. Transect sampling would have given us a larger number of low marsh cores, but fewer cores from the transitional and high marsh zones. The elevation of each station was determined using a plane table and alidade and surveying from a 3-m benchmark. The 3-m datum is 3 m above mean low water (MLW); sea level is at approximately the half tide mark, or ~1.1 m on this scale. The elevation of representative low, transitional, and high marsh habitats and subenvironments was determined. A plane table and alidade were also used at a site on the southeastern end of the island to determine the relief within a comparable marsh at a second site; however, these measurements were not correlated to a bench mark.

Short cores were collected at sampling sites using an acrylic corer (4" diameter) with a bevelled edge. Cores were taken as close as possible to each of the measured sites while avoiding obvious burrows and exceptionally dense vegetation. To avoid excessive compaction, the edge of the corer was sharpened frequently and the corer rinsed with seawater before use. Cores with obvious compaction were discarded, and only cores with negligible or very minor compaction were included in the study. Cores were extruded and subsampled in the field at: 0–1, 1–3, 3–5, 9–11, 19–21, and 29–31 cm intervals. Previous studies indicated that significant changes in foraminiferal assemblages occurred within the top 10 cm of the marsh and that some species lived as deep as 30 cm below the marsh surface (Goldstein et al., 1989; Goldstein and Harben, 1993). Subsamples were placed in plastic sample bags and returned to facilities on the island.

Within 24 hrs (usually within 12) 30-cm³ subsamples of sediment were disaggregated by immersing in seawater and vigorously shaking in a Nalgene jar. Disaggregated samples were wet-sieved (using local seawater) over 0.85-mm and 0.074-mm sieves, the first eliminating the coarse organic particles and shells, and the second retaining foraminifera and associated meiofauna, plant detritus, and sediment. Material retained on the 0.074-mm sieve was fixed and stained in a 10% solution of buffered formalin (pH of 8 to 9, buffered with sodium carbonate) and 0.1% rose Bengal applied as a vital stain (after Walton, 1952). Although several previous studies have identified potential problems using rose Bengal, the method as outlined here provides reasonably reliable results for salt-marsh foraminifera (Goldstein et al., 1995). After fixation/staining for about one week, samples were washed with tap water to remove the fixative and excess stain and preserved in 30% ethanol [Note: 30% ETOH served as an adequate preservative for most samples, but not all. A few organic-rich samples degraded in spite of the presence of 30% ETOH. Increasing the concentration to 50% would reduce the likelihood of sample degradation while still avoiding excessive shrinkage of the preserved, rose-colored foraminiferal cytoplasm]. Samples were split where necessary, and...
foraminifera were picked wet (in tap water), identified, and tallied by species as stained or unstained. Although some samples were barren of foraminifera, or nearly so, enough splits were counted to include a minimum of 200 specimens per sample in most cases. For low marsh samples, the total number counted far exceeded this minimum; however, this minimum was not met for some high marsh samples. With the exception of a few nearly barren samples from fairly deep in the subsurface (29–31 cm) of the high marsh, these generally low abundances (~50–200 total individuals) are nonetheless adequate for the purposes of this study (see Patterson and Fishbein, 1989).

RESULTS

Elevation of St. Catherines Island Marshes

Marsh elevations measured at Persimmon Point range from ~1 to 1.8 m above MLW. The lowest elevations were measured in streamside marshes and are close to the lowest extent of *Spartina alterniflora* in the intertidal zone at this location. The highest elevation was measured within a patch of *Juncus* marsh, near the upper limit of the high marsh at this site. The uppermost extent of the high marsh was not measured, but is only slightly greater than 1.8 m above MLW. The total relief within the salt marshes at Persimmon Point, therefore, is slightly greater than 0.8 m.

The low marsh, as characterized previously (Basan and Frey, 1977; Edwards and Frey, 1977; Basan, 1979; Letzsch and Frey, 1980), includes an extensive meadow marsh, sparsely vegetated and non-vegetated ponds, natural levees, and the streamside marsh. The low marsh in general is dominated by *Spartina alterniflora*. The vegetated low marsh at Persimmon Point ranges in elevation from approximately 1 to 1.4 m above MLW. The transitional marsh, a zone characterized by stands of short *Spartina alterniflora* that separate the high and low marshes, ranges in elevation from approximately 1.4 to 1.7 m above MLW at Persimmon Point. The boundaries between the low, transitional, and high marsh zones are intergradational.

The high marsh consists of often discontinuous bands of *Salicornia, Distichlis, Juncus,* and high marsh barrens, although *Distichlis* is not common at Persimmon Point. The high marsh at this site begins at approximately 1.6 m and extends to at least 1.8 m above MLW.

Tidal datum levels were calculated from tide tables for the central Georgia coast (Table 3). These values are, however, in all likelihood not the absolute values that would be realized at Persimmon Point. The tidal range in marsh creeks is typically less than that measured in harbors or on open coasts because the elevation of the distributary channels lies above that of major channels or creeks. The elevation of both high and low water may also be increased in marshes for similar reasons (Redfield, 1972). The tidal datum levels of Table 2, therefore, provide only a general reference for the marsh.

The entire salt marsh at Persimmon Point begins at approximately the half-tide mark (approximately equal to sea level) and extends to approximately MHW or MHWN. This is similar to the tidal relationships found in other

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**TABLE 3**—Tidal datum levels (calculated from tide tables) and the elevation of marsh zones at Persimmon Point.

<table>
<thead>
<tr>
<th>Tidal datum levels in meters</th>
<th>Elevation of marsh zones at Persimmon Point</th>
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<tbody>
<tr>
<td>(Note: 0 m = MLW)</td>
<td></td>
</tr>
<tr>
<td>MHWS: 2.5</td>
<td>High Marsh: 1.6 – 2 + m</td>
</tr>
<tr>
<td>MHW: 2.2</td>
<td></td>
</tr>
<tr>
<td>MHWN: 2.1</td>
<td>Transitional Marsh: 1.4 – 1.7 m</td>
</tr>
<tr>
<td>Half Tide: 1.1</td>
<td>Low Marsh: –0.8 – 1.4 m</td>
</tr>
<tr>
<td>MLWN: 0.2</td>
<td></td>
</tr>
<tr>
<td>MLW: 0</td>
<td></td>
</tr>
<tr>
<td>MLWS: –0.2</td>
<td></td>
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</table>
marshes, although significant regional differences may exist (Reimold, 1977; Frey and Basan, 1985). Reimold (1977) reports that *S. alterniflora* typically occurs from approximately MSL to MHW. At Persimmon Point, *S. alterniflora* begins at about MSL, but has an upper extent approximately 0.5 m below MHW.

The total relief measured at a second marsh site on the southeastern end of St. Catherines is 1.3 m, which is somewhat greater than that measured at Persimmon Point. This probably reflects measurements taken at somewhat higher reaches of the high marsh as well as the occurrence of *Spartina alterniflora* at somewhat lower elevations in streamside marshes. Relief at this site, however, was not correlated to a benchmark.

Smith and Frey (1985) reported a similar range of relief (4 ft or ~1.2 m) for a backbarrier salt marsh on neighboring Sapelo Island. Relief was measured from a non-vegetated, ponded low marsh site to the uppermost extent of the high marsh. The low marsh occupies approximately 0.8 m of relief, whereas the ponded low marsh was ~0.6 m lower than the lowest *Spartina* in the streamside marsh. The lowest occurrence of *Spartina*, therefore, appears to vary and probably does not constitute a consistent datum. The relief of the transitional marsh was approximately 0.2 m, whereas the high marsh occupied approximately 0.3–0.5 m.

Foraminiferal Distributions and Their Relationship to Elevation

Twenty-four species belonging to sixteen genera were identified from salt-marsh environments at Persimmon Point. Agglutinated taxa were predominant, and taxa overall are characteristic of southeastern U.S. marshes (Goldstein and Frey, 1986). Based on a three-year seasonal examination of living (rose-Bengal stained) and total (live + dead) foraminiferal assemblages in surface sediments from Nova Scotia salt marshes, Scott and Medioli (1980b) reported that total assemblages more reliably reflect modern marsh environments than either living or dead assemblages alone. Consequently, most subsequent studies on salt-marsh foraminifera and elevation have utilized total assemblages (e.g., Scott and Leckie, 1990; Patterson, 1990; Williams, 1994; Gehrels, 1994; De Rijk, 1995; De Rijk and Troelstra, 1997; Ozarko et al., 1997). Distubutional patterns in this study, therefore, are based on “total” assemblages. The distribution of living populations was used to assess foraminiferal microhabitats (Goldstein et al., 1995) and their impact on distributional patterns in general.

The density of both living and total foraminifera varies with elevation within the marsh. In surface sediment (0–1 cm), density decreases with increasing elevation (i.e., from low marsh to high marsh), although this relationship becomes weaker in subsurface sediment due largely to selective preservation (Fig. 3). At the marsh surface, low marsh samples have considerably higher total densities than either the high or transitional marshes and contain an average of approximately 1700 tests per 10 cc of sediment; high and transitional marshes typically average around 500. Within the low marsh, meadow marsh habitats yield the highest densities with peaks averaging over 2000 foraminifera per 10 cc of sediment. The lowest density for any low marsh site was recorded at a streamside marsh site (677 tests per 10 cc sediment). Below the marsh surface, however, foraminiferal density is dramatically reduced and may be as much as an order of magnitude less in sediment 20–30 cm below the marsh surface. This reduction reflects the selective loss of most calcareous and many agglutinated tests (Goldstein and Watkins, in press).

The Shannon-Wiener Information Index was used to estimate diversity and to compare the habitats and core intervals sampled. The index is based on a proportional abundance of species (e.g., Magurran, 1988). Computed foraminiferal diversity is generally low in Persimmon Point marshes with the highest values found in the low marsh and the lowest diversities recorded in the transitional and high marsh zones (Table 4).

In general, diversity values were higher in subsurface sediment than at the marsh surface. In low marsh cores, the highest diversities were recorded in the intermediate and deep sampling intervals (from 9–31 cm). These core depths are positioned at the base of or below the taphonomically active zone or TAZ (sensu Davies et al., 1989), which generally comprises the 0–10-cm interval in these marshes (Goldstein and Watkins, in press; Walker and Goldstein, in press). The downcore increase in diversity probably reflects: (1) selective preservation diminishing the effects of the numerical dominance of some taxa (e.g., *Ammonia tepida, Miliammina fusca* in surface sediments, (2) the infaunal contribution of some taxa to total foraminiferal assemblages, and (3) potential time-averaging over seasonal or somewhat longer-scale perturbations.
Diversity values for the high and transitional marsh zones are quite low and more variable with the highest values recorded at somewhat shallower core depths (Table 4).

Most foraminifera that occur in salt marshes of the Georgia coast are epifaunal to shallow or intermediate infaunal dwellers (primarily 0–11 cm), and most have maximum living densities within the top 5 cm of marsh sediment (Goldstein et al., 1995). Only two species (Arenoparrella mexicana and Haplophragmoides wilberti) may have significant deep infaunal (29–31 cm) populations. The impact of taxa living infaunally and selective preservation was evaluated by comparing “surface distributions” of foraminifera (averaged over the 0–3 cm interval) with those in subsurface sediment (19–21 cm interval). The 0–1 cm and 1–3 cm intervals were considered collectively so as to include both the strictly epifaunal taxa as well as those with peak abundances in the 1–3 cm interval (see Goldstein et al., 1995).

Although about 30 species of foraminifera were found living in St. Catherines Island marshes (Goldstein et al., 1995), only 12 are locally common (Miliammina fusca, Ammonia tepida, Trochammina inflata, T. macrescens, Arenoparrella mexicana, Triloculina oblonga, Reophax nana, Textularia palustris, Siphotrochammina lobata, Ammotium salsum, Ammobaculites dilatatus, and Ammotium pseudocassis). The distribution of these taxa relative to elevation in both surface and subsurface sediment is summarized in Figures 4–9.

Within the 0–3-cm interval, Miliammina fusca is overwhelmingly the most abundant species, often accounting for more than half of any given assemblage (Fig. 5). Miliammina fusca occurred at every sampling station throughout the Persimmon Point marsh and, therefore, is not limited by elevation. Though less abundant, several other species also occur at all elevations: Trochammina inflata, T. macrescens, and Ammonia tepida (Figs. 5, 6). Ammotium pseudocassis (Figs. 4 and 7) also occurs throughout the marsh, although its abundances are low, and empty tests appear to degrade fairly readily; this species has only rare occurrences in subsurface sediment. Within surface sediment, Arenoparrella mexicana appears to have its greatest abundances in low marsh settings (Fig. 5). However, this species is often a deep infaunal dweller with significant infaunal populations in high marsh settings (Goldstein et al., 1995). Overall, A. mexicana is better represented in subsurface sediment, and it occurs at all elevations (Fig. 8) Ammotium salsum and Ammobaculites dilatatus also occur in low to high marsh settings (Figs. 6 and 9). However, these taxa are most abundant at ponded or particularly moist sites regardless of elevation.

No foraminifera were found to have distributions unique to the high marsh as has been reported for other regions (e.g., Scott and Medioli, 1986). However, several species are largely restricted to the low marsh, including Reophax nana, Textularia palustris, and Siphotrochammina lobata (Figs. 4 and 7). The miliolid Triloculina oblonga was also restricted to low marsh sites (Fig. 6), though its calcareous tests are generally not preserved in subsurface sediment (Fig. 9). Tests of these three agglutinated species are over 30 August 2019

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species were absent at all transitional and high marsh sites, with the exception of a single transitional marsh site where a few tests of both *R. nana* and *S. lobata* were found. In general, tests of these three taxa (*R. nana, T. palustris, S. lobata*) are restricted to elevations below approximately 1.4–1.5 m above MLW. At elevations in the marsh below 1.4–1.5 m, the tests of these three species are generally common in surface sediment, though not dominant. The relative abundance of each species ranges from ~3–15%, and density (of each species individually) ranges from ~20–300 tests per 10 cc of sediment.

For the elevational relationships observed in surface sediment to be applicable to studies on Holocene sea-level fluctuations, the elevational relationships of these several species should also be identifiable after assemblages have passed through taphonomic filters operating within the TAZ. Taphonomy affects agglutinated tests as well as calcareous ones and may alter the relative abundances (%) of species found in subsurface sediment (Goldstein and Harben, 1993). Taphonomic processes can remove up to ~90% of foraminiferal tests within the top 10 cm of southeastern U.S. salt marshes (Goldstein and Watkins, in press). Those agglutinated marsh species most susceptible to degradation in these settings include: *Pseudothurammina limnetis, Ammotium* spp., and *Miliammina fusca* Figs. (7–9). The three species that have distributions restricted largely to the low marsh (*Reophax nana, Textularia palustris, Siphotrochammina lobata*) are among those taxa...
most resistant to taphonomic degradation (Fig. 7). Other resistant agglutinated taxa include Arenoparrella mexicana, Haplophragmoides wilberti, and Trochammina spp. (Goldstein et al., 1995).

In subsurface marsh sediment, R. nana, T. palustris, and S. lobata all have distributional patterns comparable to those found in surface sediment. That is, at marsh elevations below 1.4 to 1.5 m, all three species have consistent occurrences in surface as well as subsurface sediment (Figs. 4 and 7). The occurrence of these three taxa, therefore, constitutes the best proxy for identifying Holocene low marsh environments in this region, specifically those portions of the marsh below 1.4–1.5 m above MLW.

The high and transitional marshes lack a distinctive or unique suite of foraminiferal species. Rather, such assemblages, in both surface and subsurface marsh sediment, are dominated by Arenoparrella mexicana, Trochammina inflata, and T. macrescens, taxa that occur throughout the high, transitional, and low marsh habitats, and are generally resistant to taphonomic degradation (Figs. 5 and 8). This high and transitional marsh assemblage is distinguished from that of the low marsh by the absence of R. nana, T. palustris, and S. lobata.

**DISCUSSION**

Salt marsh foraminifera of the barrier islands of the Georgia coast are more similar to comparable microfaunas of the Gulf Coast than to those of other regions of North America (Goldstein and Frey, 1986). It is interesting, therefore, to compare the elevational relationships of these southeastern U.S. assemblages to the models that have been developed elsewhere. Scott (1976) and Scott and Medioli (1978, 1980a) first documented a relationship between the distribution of salt marsh foraminifera and elevation, and demonstrated that these relationships had direct application in studies on the Holocene rise in sea level. A number of subsequent reports (Scott and others, 1981; Scott and Martini, 1982; Jones and Cameron, 1987; Scott and Leckie, 1990; Jennings and Nelson, 1992; Gehrels, 1994; Williams, 1994) have generally supported the Scott and Medioli model, though some of these identified slight variations (e.g., Jennings and Nelson, 1992; Patterson, 1990). More significant regional variations were identified in marshes of the Valdivia Estuary, south-central Chile, by Jennings et al. (1995). Significant variations were also documented by De Rijk (1995) and De Rijk and Troelstra (1997).

Scott and Medioli (1986, p. 441) summarized this model, which is based largely on foraminiferal distributions in Nova Scotia marshes, but supported by data from salt marshes of southern California (Scott, 1976). According to this model, Trochammina macrescens and Tiphrotrocha comprimata are restricted to and indicative of high marsh habitats. Trochammina inflata and Miliammina fusca characterize the “low marsh subzone A” (upper low marsh), whereas M. fusca, Ammotium salsum, and Elphidium spp. characterize the “low marsh subzone B” (lower low marsh). The elevational range for the Nova Scotia salt marsh examined is from –0.2 to 1.1 m above MSL for two of the study sites and greater at a third. That of the
southern California marsh is similar, ranging from −0.1 to 1.2 m.

The relationship of salt marsh foraminifera from St. Catherines Island, Georgia, to elevation differs from the Scott and Medioli model (Scott and Medioli, 1978, 1980a, 1986) in several regards:

1. Both of the high marsh indicators of the Scott and Medioli model, *Trochammina macrescens* and *Tiphotrocha comprimata*, occur throughout the high, transitional, and low marsh habitats of St. Catherines Island. This is true of both modern marshes and the Holocene relict marshes exposed on the shoreface of the island (Goldstein, 1988). *Trochammina macrescens* is moderately common in St. Catherines Island marshes, whereas *Tiphotrocha comprimata* is not.

2. *Trochammina inflata* and *M. fusca* characterize "low marsh subzone A" of the Scott and Medioli model, yet these two species likewise occur throughout high, transitional, and low marsh habitats of St. Catherines. In addition, tests of *M. fusca* are susceptible to post-mortem degradative processes in subsurface sediment (Fig. 8; Goldstein et al., 1995). Although this species is commonly the most abundant in surface and near-surface assemblages, it is much less common in assemblages recovered from deeper sediments.

3. *Ammotium salsum* characterizes the "low marsh subzone B" of Scott and Medioli (1986) along with *M. fusca* and *Elphidium* spp. In St. Catherines Island marshes, *A. salsum* also occurs in the lowest portions of the low marsh, but may occur within the high and transitional marsh zones in association with ponded settings. *Ammobaculites dilatatus* shares a similar distributional pattern in these southeastern U.S. marshes.

4. St. Catherines Island marshes lack a unique high marsh suite of foraminifera. Rather, the most reliable proxy for changes in elevation is an association of three low marsh species: *Reophax nana*, *Textularia palustris*, and *Siphotrochammina lobata*. These species occur in areas of the marsh below 1.4 to 1.5 m above MLW, an elevational range that extends within the transitional marsh. All three species have epifaunal to intermediate infaunal occurrences and tests that persist in subsurface marsh sediment (Fig. 7; Goldstein et al., 1995).

High marsh assemblages of St. Catherines Island are dominated by *Arenoparrella mexicana*, *Trochammina inflata*, and *T. macrescens*; in addition, *M. fusca* may occur in this association as well as several other taxa. However, these three dominant taxa occur at all elevations within the marsh, and their occurrence in any given assemblage will not necessarily indicate high marsh habitats. *Arenoparrella mexicana* is an epifaunal to deep infaunal species, whereas *T. inflata* and *T. macrescens* are epifaunal to intermediate infaunal dwellers. All three species have taphonomically resistant tests and persist in subsurface and Holocene relict marsh sediment (Goldstein, 1988; Goldstein et al., 1995). This "high marsh assemblage," therefore, is simply a taphonomically resistant assemblage that lacks the three low marsh indicators listed above.

Collins et al. (1995) included figures illustrating a vertical distribution of salt marsh foraminifera from Winyah Bay and North Inlet Estuaries, South Carolina, regionally the closest marsh sites to those examined for this study. Results of this study, although based only on surface sediment (0–1 cm) distributions, are broadly similar to the results of this study in that *M. fusca*, *T. macrescens*, and *T. inflata* appear to occur in all marsh zones. However, *S. lobata*, a low marsh indicator at Persimmon Point (this study), also appears to occur in all marsh zones in the South Carolina marshes. The highest elevation included in the study by Collins et al. (1995) is slightly above 1.5 m, which is below the high marsh elevations measured at Persimmon Point. *Reophax nana* and *T. palustris*, useful low marsh indicators at Persimmon Point, were not included in the report by Collins et al. (1995).

Differences between the Scott and Medioli model (Scott and Medioli, 1978, 1980a, 1986) and the elevational relationships of salt marsh foraminifera on St. Catherines Island, Georgia, may be explained by biogeographic differences and perhaps regional differences in the physiography of these salt marshes. Taxa such as *Arenoparrella mexicana*, *Textularia palustris*, *Reophax nana*, and *Siphotrochammina lobata*, common in Georgia marshes, are rare or absent in the regions where Scott and Medioli (1978, 1980a, 1986) did their pioneering studies. Salt marshes of St. Catherines Island occur at intertidal elevations similar to those marshes reported by Scott and Medioli (1978, 1980a, 1986), but differ physiographically. The "meadow marsh" on St. Catherines Island is an expansive low marsh environment dominated by the halophyte *Spartina alterniflora*, whereas in marshes of New England and Maritime Canada the "meadow marsh" is characterized by high marsh vegetation and the low marsh is more restricted.

The lack of a distinctive high marsh foraminiferal assemblage in the St. Catherines Island marshes examined for this report, in part, may reflect the areally limited nature of the high marsh. Alternatively, if salinity does indeed strongly control the composition of high marsh assemblages (De Rijk, 1995; De Rijk and Troelstra, 1997), then it may reflect the more limited freshwater runoff into the Persimmon Point marshes. Salt marshes of St. Catherines are situated several miles offshore and separated from the mainland by an expansive salt-marsh system. The Medway River and St. Catherines Sound, north of St. Catherines Island, and the South Newport and Sapelo Rivers and Sapelo Sound, south of St. Catherines, are both tidal estuarine systems with very limited freshwater runoff. Salinities measured in the St. Catherines Island marshes at the time of the study ranged from 28–30‰.

Whatever explanations might account for these differences, we fully concur with the recommendation by Scott and Medioli (1986) that the elevational relationships of salt marsh foraminifera be determined for each region before attempting to interpret sea level curves using the foraminiferal record. We further recommend, however, that taphonomy and the potential impact of infaunal microhabitats also be considered.

To summarize, significant differences distinguish the distributional patterns of salt-marsh foraminifera of coastal Georgia from those of other regions, particularly New England and Maritime Canada. As a result, the salt-
marsh foraminiferal elevation model of Scott and Mediodi (1986) is not directly applicable here for two primary reasons: (1) the high marsh species of this model (Tri
cammina macrescens, Tiphrotrocha comprimata) occur throughout high, transitional, and low marsh habitats of coastal Georgia, and (2) several regionally common species (Reophax nana, Tuxtularia palus
ris, Siphotrocha.

lobata) that are indicative of marsh habitats below 1.4–1.5 m above MLW in southeastern marshes are not included in the model.

Although distributional patterns differ regionally, salt marsh foraminifera of coastal Georgia are, nonetheless, applicable to sea level studies. Their distributional patterns reflect changing elevations within the marsh, and the tests of taxa that are important in this context are robust and preservable in subsurface marsh sediment.

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