# PROGRESS REPORT ON ANALYSIS OF ALABAMA BEACH SEDIMENT CHARACTERISTICS

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# INTRODUCTION

During Year 4 of the Sand Resources project, a quarterly sediment-sampling program was initiated on Morgan Peninsula (fig. 1). Sample sites are included as a layer ("Coastal Sediment Sampling Sites") in the ArcView project, and representative site photographs are included in this report as Appendix 2. Some site photographs are also hotlinked to the sample sites in the ArcView project. The purposes of this sampling program are to establish baseline data on beach sediment, to compare sediment on recently renourished beaches and other beaches on the peninsula, and to evaluate the effects of tropical cyclones (hurricanes and tropical storms) on beach-sediment characteristics. Particular goals of the sampling program include a comparison of the abundance and condition of shells on renourished and other beaches, and characterization of sand grain size characteristics. Both temporal and spatial trends in sediment characteristics are of concern in this study.

In this report we summarize results of work completed in the year ending September 30, 2002. Three quarterly monitoring trips and three storm monitoring trips were made this year. A total of 240 sand samples and 66 shell samples were collected at nine monitored sites. Two hundred fifty-five (255) field photographs were taken to document conditions at the monitored sites and elsewhere in Alabama's coastal region. Thirty-three (33) grain-size analyses were completed this year.

# METHODS AND ERROR ANALYSIS

Grain-size analysis followed standard methods used by previous researchers at the Geological Survey of Alabama (Survey) (Parker and others, 1997). Samples were collected from the beach surface and every attempt was made to sample as thin a layer as possible. Most samples represent the uppermost centimeter or less of sand. Sand samples were collected in pairs, indicated by the suffixes a and b. The "b" samples are alternates that are to be analyzed if the "a" samples are destroyed. In addition, some "b" samples were analyzed in order to determine the magnitude of grain-size variation over a shore-parallel distance of approximately 6 centimeters. The goal of these analyses was to evaluate the significance of differences between replicate analyses (multiple analyses performed on splits of single samples), performed as a part of error analysis. Samples ending with the numeric suffix 1 (followed by "a" or "b") were collected from the windrow where there were no beach cusps, and from the windrow at the apex of a ridge on cuspate beaches. Samples ending with the suffix 2 were collected from the windrow at a swale adjacent to the sampled ridge. Samples ending with the suffix 3 consist of shells and shell fragments, not sand. Samples ending with the suffix 4 were collected from the storm windrow. The nature of samples with suffixes higher than 4 is indicated in appendix 1. Samples collected in March and June of 2002 deviate slightly from this numbering system (appendix 1).

Samples were soaked in deionized water for a few hours and then dried at 150C. Samples were split twice to yield a sample between 30 and 55 grams for sieve analysis at quarter-phi intervals. The samples and fractions were weighed on a Sartorius electronic balance with a precision of 0.001 g. Repeated weighing of empty clean beakers indicated that the combination of balance accuracy and beaker cleaning techniques yielded measurements accurate to within 0.003 g. In addition, residue of fine dust retrieved from coarse sieves indicated that no more than 0.001 g of inappropriately fine material is dislodged from sieves by our methods.

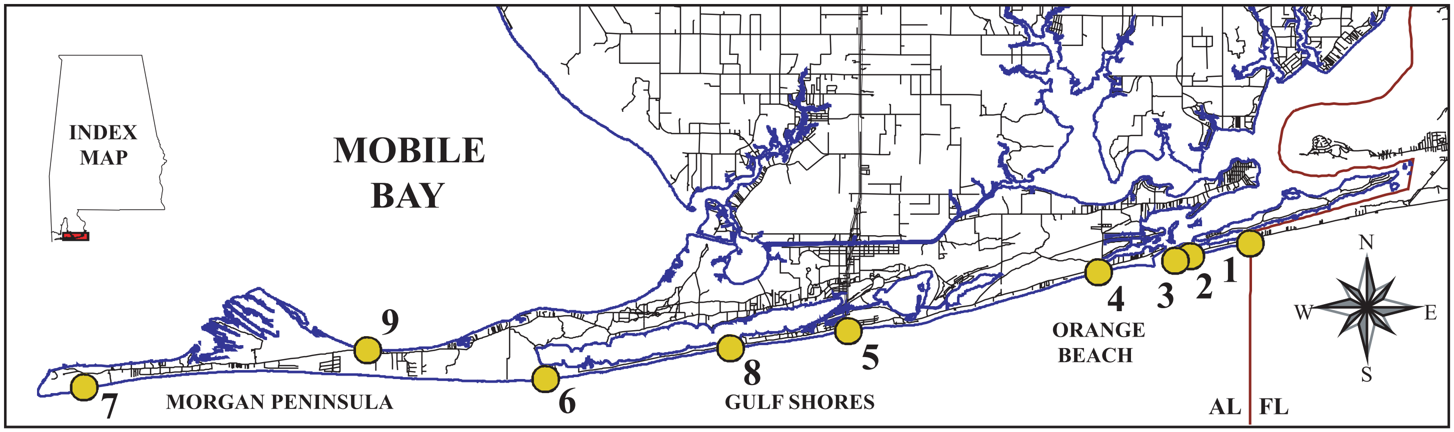


Figure 1. Map showing locations of coastal sediment monitoring sites.

The magnitude of analytical error was evaluated by measuring the grain-size characteristics of pairs of replicate analyses (fig. 2). Comparisons were made using the phi arithmetic mean (Folk, 1974, p. 50). In addition, pairs of adjacent samples (indicated by a and b suffixes) and pairs of neighboring ridge and swale samples (indicated by 1 and 2 suffixes) were analyzed to determine the magnitude of differences among distinct but similar samples. The results show that the analytical error measured by replicate analysis is less than the differences among adjacent samples (fig. 2).

Another measure of analytical error is the amount of sediment gained or lost during sieving. The average change in sample weight during sieving was 0.678 percent, which is well within the acceptable range. The maximum change was 2.189 percent.

Except at Gulf Shores Public Beach, shells were collected from the windrow as grab and pick samples. At Gulf Shores Public Beach, shells were sampled throughout the area of renourished beach. These samples yield species lists but do not provide quantitative data. In 2002-03 we propose to collect quantitative samples from beach sites and offshore (Federal waters) cores for a more rigorous analysis.

## GRAIN-SIZE ANALYSIS

### RESULTS

Two hundred forty (240) sand samples were collected as part of this project (table 1). Of these, 28 were sieved. In addition, 5 replicate samples were sieved as part of sensitivity analysis (see previous section). Results of sieve analyses conducted during year 4 of this project are too preliminary for interpretation at this time. Sieve data will be thoroughly interpreted when a sufficiency of samples has been analyzed.

Table 1. Summary of grain-size samples collected and analyzed during the project period

| Site number | Site description | Samples collected | Samples analyzed |
|---|---|---|---|
| 1 | Florida state line | 36 | 7 |
| 2 | Florida Point East | 26 | 8 |
| 3 | Florida Point West | 28 | 5 |
| 4 | Cotton Bayou | 30 | 3 |
| 5 | Gulf Shores | 31 | 2 |
| 6 | Pine Beach | 38 | 4 |
| 7 | Fort Morgan | 29 | 2 |
| 8 | Callaway Bridge | 21 | 2 |
| 9 | Pines boat ramp | 1 | 0 |
| TOTAL | | 240 | 33 |

During the first part of the 2002 hurricane season (through September 2002), three tropical storms affected the Alabama coast (table 2). The first two storms were relatively small and weak and provide important information about the effects of low-magnitude storm events on the beaches. Tropical Storm Isidore was (areally) a very large storm. Even though by the time it reached the coast its maximum sustained wind speeds were little higher than those of Tropical Storms Bertha and Hanna, Isidore’s effects on

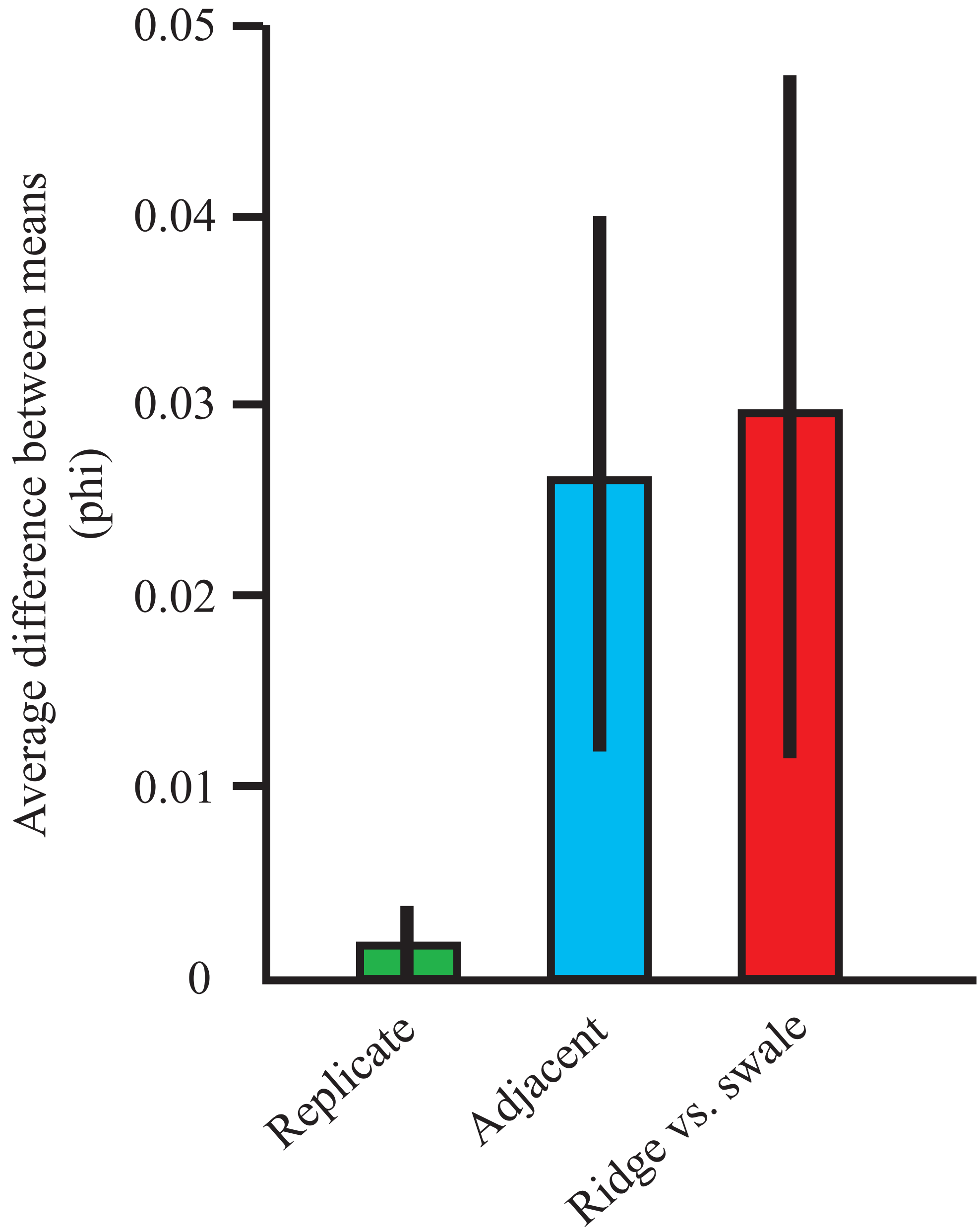


Figure 2. Average difference in phi arithmetic mean for all possible pairs of samples. Replicate analyses of single samples, adjacent ("a" and "b" samples), samples from neighboring ridges and swales collected on the same date. Error bars indicate +/- 1 standard deviation.

Alabama beaches were greater than those of the other two storms. Like its two predecessors, Tropical Storm Isidore caused little property destruction and no loss of life in Alabama.

Table 2. Tropical cyclones that affected the Alabama coast during the first part of the 2002 hurricane season

| **Name of Storm** | **Dates affecting Alabama coast** | **Maximum sustained wind speed of storm** |
|---|---|---|
| Tropical Storm Bertha | August 5, 2002 | 40 |
| Tropical Storm Hanna | September 14, 2002 | Not yet available |
| Tropical Storm Isidore | September 25-26, 2002 | Not yet available |

Qualitative and semi-quantitative field observations indicate that the first two, weak tropical storms had only transient effects on Alabama beaches (fig. 1). Storm windrows contained abundant *Sargassum* and locally contained shell fragments, plant debris, polychaete tubes, and trash. Both storms left two distinct storm windrows that recorded conditions at different times during the storms' transits of the beaches. Tropical Storm Bertha left a *Sargassum*-rich windrow high on the beach, evidently formed at the peak of storm surge (fig. 3). Locally, this windrow reached the first line of sand dunes, but caused little or no sediment redistribution in the dune area at monitored sites. This windrow resembled the typical fair-weather windrow found on these beaches. On the eastern beaches a windrow consisting almost exclusively of well-sorted *Sargassum* floats was located roughly half-way between the upper storm windrow and the post-storm fair-weather windrow (figs. 4, 5). This windrow was deposited when the influence of the storm on the beach was waning and was absent farther west (figs. 6, 7). At the Gulf Shores Public Beach, the fair-weather and storm windrows were separated by a wave-cut bench about 0.3 meters high (fig. 6) with no intermediate windrow. At Fort Morgan, storm waves reached almost to the base of the dunes (figs. 7, 8). In general, examination of the monitored sites (see figure 1) one to two days after the passage of Tropical Storm Bertha indicated that storm waves inundated most of the beach, but that the storm engendered little erosion or deposition on the beaches. Storm windrow samples are slightly coarser, on average, than fair-weather windrow samples collected at the same time. The difference in phi arithmetic mean grain size is 0.13 phi for those samples analyzed to date.

Tropical Storm Hanna caused noticeable erosion and deposition locally, especially in the western part of the study area. At Fort Morgan and at Pine Beach the storm windrow was actually in the dunes and included large pieces of wood (figs. 9E, 10B). Local erosion and deposition at this site considerably altered the shape of the sediment surface in and seaward of the dunes. Local erosion to a depth of greater than 0.3 meters occurred at Pine Beach and Florida Point West (fig. 11). In the eastern part of the

Figure 3. Two storm windrows left by Tropical Storm Bertha at Florida Point East, Site 2. The upper windrow consists chiefly of patches of *Sargassum,* whereas the lower windrow is dominated by well-sorted *Sargassum* floats.

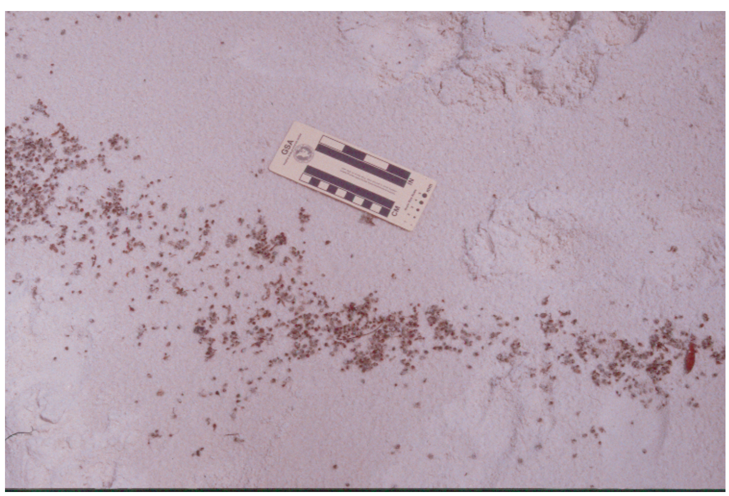

Figure 4. Close up view of lower storm windrow left by Tropical Storm Bertha at Florida Point East, Site 2. This windrow consists almost entirely of *Sargassum* pods. Scale in centimeters and inches.

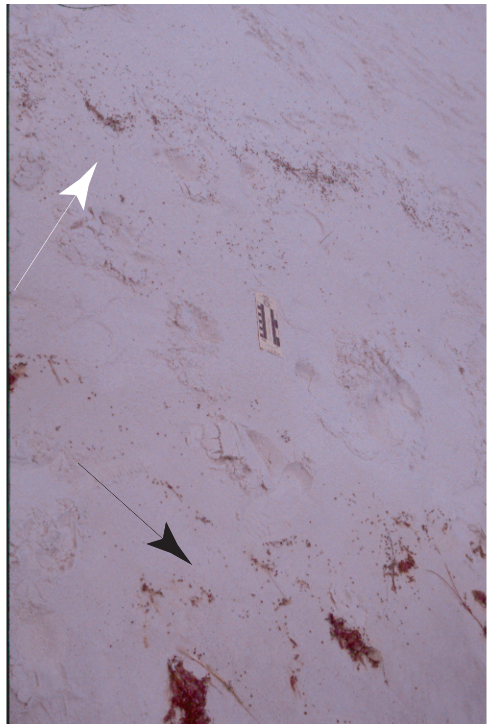

Figure 5. Fair-weather (black arrow) and lower storm (white arrow) windrows left by Tropical Storm Bertha, Cotton Bayou, Site 4.


Figure 6. Fair-weather (black arrow) and storm (white arrow) windrows left by Tropical Storm Bertha, Gulf Shores public beach, Site 5. Note erosional step separating the two windrows.

Figure 7. Fair-weather windrow (arrow) after Tropical Storm Bertha, Fort Morgan, Site 7. Fair-weather windrow here devoid of seaweed; marked by accumulation of small shell fragments. Note storm windrow near dunes.

Figure 8. Storm windrow (arrow) deposited by Tropical Storm Bertha, Fort Morgan, Site 7. Storm surge almost reached dune line.

A) Fort Morgan (Site 7), view westward, Sept. 3, 2002, fair-weather conditions.

B) Fort Morgan (Site 7), view westward, Sept. 16, 2002, after Tropical Storm Hanna.

C) Fort Morgan (Site 7), view landward, Sept. 3, 2002, fair-weather conditions.

D) Fort Morgan (Site 7), view landward, Sept. 16, 2002, after Tropical Storm Hanna. Lower storm windrow on beach; upper storm windrow in dunes.

E) Fort Morgan (Site 7), Sept. 16, 2002, after Tropical Storm Hanna. Upper storm windrow in dunes at end of access road.

Figure 9. Comparison of fair-weather and storm conditions at Fort Morgan, Site 7, 2002.

A) Pine Beach (Site 6), view landward, Sept. 4, 2002, fair-weather conditions.

B) Pine Beach (Site 6), view landward, Sept. 17, 2002, after Tropical Storm Hanna. Upper storm windrow in dunes. Scale on right end of log.

C) Pine Beach (Site 6), view westward, Sept. 4, 2002, fair-weather conditions.

D) Pine Beach (Site 6), view westward, Sept. 17, 2002, after Tropical Storm Hanna. Fair-weather and lower storm windrows.

E) Pine Beach (Site 6), view eastward, Sept. 17, 2002, after Tropical Storm Hanna. Lower storm windrow (black arrow) on beach flat; fair weather windrow (small black arrow) associated with shell lag (white arrow)

Figure 10. Comparison of fair-weather and storm conditions on Pine Beach (Site 6), 2002.

A

B

Figure 11. Erosion of beach at Florida Point West, Site 3, by Tropical Storm Hanna. A) Close up view of erosion near seaward end of boardwalk. B) Erosion at end of boardwalk (white arrow) associated with landward excursion of the storm windrow (black arrow).

study area, effects were minor (fig. 12). Tropical Storm Hanna left windrows higher on the beach than Tropical Storm Bertha and caused obvious sediment movement. Although the two storms were of similar intensity, the most intense part of Hanna made landfall on the coasts of Baldwin and Santa Rosa Counties. By contrast, Bertha came ashore in Louisiana, and only the outer portions of the cyclone affected Alabama’s coast. Both storms caused minor property damage (fig. 13). Based on observations made this year, it seems that small weak tropical storms have little effect on the characteristics of beach sand, but they can redistribute both shells and seaweed to temporarily change the appearance of the beach (e.g., figs. 4, 9, 10). This may have practical implications if the shells uncovered by storm waves are sharp.

Tropical Storm Isidore arrived at almost the very end of the project period. The eye of the storm made landfall near New Orleans, but the diameter of the storm was about 1,100 kilometers (National Weather Service National Hurricane Center Tropical Prediction Center [NHC] web site, http://www.nhc.noaa.gov). Consequently, coastal Alabama experienced storm surge up to nearly 2 meters in height, several days of long-period swells, and rainfall that locally exceeded 0.3 meters (NHC web site; D. W. Haywick, verbal commun., 2002).

Initial news broadcasts during the storm suggested that the renourished beach at Gulf Shores was “gone.” Reports of the beach’s demise were exaggerated. The Gulf Shores Public Beach (Site 5) experienced considerable sand deposition as a result of Tropical Storm Isidore. About 1 meter of sand partially buried the picnic tables on the seaward side of the Pink Pony Pub just east of the Gulf Shores Public Beach (Site 5), and wooden stairs giving beach access from the boardwalk were all but covered by newly deposited sand. The beach appeared to have narrowed and its landward side was elevated, resulting in substantial steepening. Beach steepening also was observed at the other seven monitored sites. For instance, the seaward line of dunes at Pine Beach (Site 6) was planed away, the sea oats were reduced to broken stubs, and the next row of dunes to landward experienced considerable sediment deposition. At Fort Morgan (Site 7) the seaward line of dunes was converted by massive deposition of sand into a smoothly rounded berm. On the berm crest, sea oats spikes were exposed, indicating deposition of up to about 2 meters of sand on the tops of the dunes. The seaward sides of many beachfront homes and other buildings were partially buried by sand that was transported inland by the storm. In gaps between buildings sand covered streets, highways, and parking lots. In addition, most beaches developed runnels; at Fort Morgan (Site 7), the runnel was especially deep: about 1.25 meters deep near the steep, eroded landward margin of the emergent bar that formed the runnel’s seaward boundary.

Beach biota appeared to have survived the storm in substantial numbers. The burrows of *Ocypode quadrata*, the ghost crab, were ubiquitous as usual, and five-lined skinks were common (in the dunes and at inland locations) at sites where they are found under fair-weather conditions. The Gulf Shores renourished public beach, characterized by a paucity of animal life on previous monitoring visits, bore only a few *O. quadrata* burrows and trails. Refugia may have been wanting on this flat, featureless beach that is backed by an urban area. The surf clam, *Donax* spp., was common to abundant at most monitored sites, but live specimens moved slowly to re-bury themselves. *Donax* were relatively uncommon at Pine Beach and Fort Morgan, where the runnels were deepest. A Great Blue Heron at the Lee Callaway Bridge (Site 8) behaved as if stunned, allowing

Cotton Bayou (Site 4), view landward, Sept. 3, 2002, fair weather conditions. Remnant of storm windrow from Tropical Storm Bertha visible.

Cotton Bayou (Site 4), view landward, Sept. 16, 2002, after Tropical Storm Hanna. Storm windrow visible.

Figure 12. Comparison of fair-weather and storm conditions at Cotton Bayou, Site 4, 2002.

A) Lee Callaway Bridge (Site 8), view westward, Sept. 3, 2002, fair weather conditions.

B) Lee Callaway Bridge (Site 8), view westward, Sept. 16, 2002, after Tropical Storm Hanna. Low mound of dredge spoil visible beyond wall of channel.

C) Lee Callaway Bridge (Site 8), view landward, Sept. 3, 2002, fair-weather conditions.

D) Lee Callaway Bridge (Site 8), view landward, Sept. 16, 2002, after Tropical Storm Hanna. Storm windrow within formerly fenced back yard.

Figure 13. Property damage at the Lee Callaway Bridge (Site 8) caused by Tropical Storm Hanna.

one of us to twice approach within about 1 meter of it. By contrast, five-lined skinks, abundant landward of Pine Beach, behaved normally.

The storm windrows contained larger numbers and diversity of shells than was observed after Tropical Storms Bertha and Hanna. Several taxa were collected for the first time, and fresh shells of nearshore marine species were particularly common. In addition, storm windrows were more numerous, the highest ones were higher on the beach, more trash was included, the total volume of material in windrows was greater, and more of the beach surface was covered with debris, by comparison with fair-weather conditions or with the effects of Tropical Storms Bertha and Hanna.

## DISCUSSION

During year 4 of the project, relatively few (33) grain-size analyses were completed. Consequently, it is only possible in this report to evaluate similarities and differences in grain-size characteristics of samples in a general way. However, the proposal for year 5 will include continuation of the beach monitoring program, analysis of all remaining "a" samples collected to date, and analysis of samples collected in the first three quarters of year 5. The proposed analytical program will be practical because sieve analysis procedures are now in place and operating efficiently, and because we will request the additional funds required to analyze the expected number of samples.

The proposal for year 5 will include a comprehensive study of the results of sieve analysis, with the goal of further identifying and interpreting temporal and spatial differences in grain-size characteristics on the beaches of Morgan Peninsula. In particular, longshore drift of sand as well as seasonal changes in beach sediment characteristics would be evaluated, as well as the effects of storms. We also propose that during year 5, the grain-size characteristics of beach sediment be compared to previously acquired data from cores collected in Federal waters off Morgan Peninsula of Alabama. This comparison would allow a better fit of potential sediment sources to beaches in need of replenishment.

# SHARP SHELLS

The sand used to renourish the Gulf Shores Public Beach contains an excessive amount of large, sharp shells, and visitors have complained. Although the amount of shells is not as great as that of some other natural beaches, visitors to the Alabama coast are not accustomed to stepping on sharp shells with their bare feet.

Shell fragments responsible for hurting feet were identified taxonomically so a better match of offshore sand to natural beach sand might be obtained in future renourishment projects. Shells from other beaches were identified for comparison, and also as a baseline, because few studies of Alabama seashells have been published (Chermock, 1974, p. 108-110; Parker and others, 1974).

## GULF SHORES PUBLIC BEACH

The shells responsible for hurting feet at Gulf Shores are mostly fragments of a few species of large bivalves and gastropods (table 3). The fragments are mostly subangular, that is, with the broken edges somewhat rounded. However, the corners are angular and very sharp. Strongly ribbed bivalves (*Dinocardium, Trachycardium, Argopecten*) tend to break along the ribs, so the fragments are squarish or rectangular. Relatively smooth but convex bivalves tend to break in a more irregular fashion (*Macrocallista, Mercenaria, Ostrea*), and the relatively flat and smooth *Dosinia* yields very sharp triangular pieces.

Most bivalve fragments have only slightly curved surfaces. In the short term, these are a problem because many of them are oriented within the sand with a sharp corner pointing upward. In the long term, the waves will rework these fragments until most lie flat, in which position they can be stepped on without hurting a bare foot. But the snails (*Oliva, Phalium, Polinices, Strombus*) are strongly curved and present a sharp surface upward when lying in a range of positions.

Most of the other common species in the renourished sand do not yield sharp edges and corners when they break; others are uncommon (table 4).

Many of the sharp shells at Gulf Shores Public Beach were buried or reworked during Tropical Storm Isidore on September 25-26,l 2002. Our observations confirm those of engineer Scott Douglass (McGaughey and Henderson, 2002). However, sharp shells remained common in windrows.

Table 3.—Species that yield the majority of sharp shell fragments in renourished sand at Gulf Shores Public Beach

| **Species** | **Common name** | **Relative abundance** |
|---|---|---|
| **Bivalves** | | |
| *Argopecten gibbus* | Calico Scallop | common |
| *Ostrea equestris* | Crested oyster | uncommon |
| *Trachycardium* sp. | Prickly *or* Yellow Cockle | uncommon |
| *Dinocardium robustum* | Giant Atlantic Cockle | common |
| *Macrocallista nimbosa* | Sunray Venus | common |
| *Mercenaria campechiensis* | Southern Quahog | common |
| *Dosinia discus* | Disk Dosinia | common |
| **Gastropods** | | |
| *Strombus alatus* | Florida Fighting Conch | uncommon |
| *Polinices duplicatus* | Shark Eye | common |
| *Oliva sayana* | Lettered Olive | common |
| *Phalium granulatum* | Scotch Bonnet | common |

Table 4.—Complete list of seashell species in renourished sand at Gulf Shores Public Beach, with generalized North American environmental data (Abbott, 1968, 1974). Species identified as problems at Gulf Shores Public Beach are **boldfaced**; most live in water less than 30 feet deep

| **Species** | **Common name** | Environmental data (water depth, substrate) |
|---|---|---|
| **Bivalves** | | |
| *Barbatia candida* | White Bearded Ark | shallow; rocks in sand |
| *Anadara ovalis* | Blood Ark | 6 to 100 ft |
| *Anadara* cf. *brasiliana* | Incongruous Ark | shallow sand |
| *Noetia ponderosa* | Ponderous Ark | shallow sand |
| ***Argopecten gibbus*** | **Calico Scallop** | **6 to 30 ft** |
| *Plicatula gibbosa* | Kitten's Paw | 0 to 200 ft, attached |
| *Anomia simplex* | Common Jingle Shell | 0 to 30 ft, attached |
| ***Ostrea equestris*** | **Crested Oyster** | **subtidal to 300 ft** |
| *Pseudomiltha floridana* | Florida Lucina | shallow to a few fathoms |
| *Divaricella quadrisulcata* | Dentate Lucina | 6 to 200 ft |
| *Carditamera floridana* | Broad-ribbed Cardita | shallow |
| ***Trachycardium* sp.** | **Prickly *or* Yellow Cockle** | **1 to 30 ft** |
| ***Dinocardium robustum*** | **Giant Atlantic Cockle** | 3 to 100 ft |
| *?Mactra fragilis* | Fragile Atlantic Mactra | shallow |
| *Spisula solidissima raveneli* | Southern Surf Clam | 0 to 100 ft |
| *Mulinia lateralis* | Dwarf Surf Clam | shallow sand |
| *Mercenaria* sp. | Southern Quahog | 3 to 50 ft |
| *Chione intapurpurea* | Lady-in-Waiting Venus | 12 to 60 ft |
| *?Pitar fulminatus* | Lightning Venus | 12 to 200 ft |
| *Macrocallista nimbosa* | Sunray Venus | 0 to 12 ft, sandy mud |
| ***Dosinia discus*** | **Disk Dosinia** | **6 to 40 ft** |
| **Gastropods** | | |
| *Cerithium atratum* | Florida Cerith | 0 to 20 ft |
| *Epitonium humphreysi* | Humphreys' Wentletrap | 0 to 306 ft |
| *Crepidula fornicata* | Common Atlantic Slipper-shell | 1 to 50 ft |
| *Crepidula plana* | Eastern White Slipper-shell | shallow |
| ***Strombus alatus*** | **Florida Fighting Conch** | **5 to 25 ft, sandy mud** |
| ***Polinices duplicatus*** | **Shark Eye** | **sand** |
| *Sinum perspectivum* | Common Baby's Ear | shallow sand |
| ***Phalium granulatum*** | **Scotch Bonnet** | **shallow sand** |
| ***Oliva sayana*** | **Lettered Olive** | **0 to 20 ft** |
| *Terebra dislocata* | Common American Auger | shallow |
| **Non-mollusks** | | |
| Colonial scleractinian coral | | |
| *Diopatra?* tubes | | |
| *Mellita quinquiesperforata* | | |
| Balanid barnacle | | |

## COMPARISON WITH SHELLS FROM NATURAL BEACHES

Species identified in samples from natural beaches in Baldwin County are listed in table 5. Most of these species are also represented in the renourished beach at Gulf Shores Public Beach. In natural beach samples, very few shells are excessively sharp, although a few recently broken shells can be found on searching almost anywhere. Fragments of the sharp-shelled species listed in table 3 also can be found on natural beaches, but the average shell size is much smaller and most of the fragments are more rounded than on the renourished beach.

Almost all the whole and fragmentary shells are of bivalves, accompanied by much smaller amounts of gastropod, sand dollar, colonial coral, and balanid barnacle shells and debris. Some shells are bored by clionid sponges, bryozoans, bivalves, or the spionid polychaete *Polydora*. Encrusting organisms with calcareous skeletons include serpulid polychaetes, bryozoans, balanid barnacles, and bivalves (especially oysters).

Only the bay-dwelling species, such as *Rangia cuneata* and *Crassostrea virginica,* show signs of extensive dissolution. Most of these have probably been eroded from old lagoon deposits that are now offshore.

## EFFECTS OF BEACH RENOURISHMENT ON LOCAL BIOTA

Effects of beach renourishment on local plants and animals are controversial and poorly understood, especially offshore (Canis and others, 1985; National Research Council Committee on Beach Nourishment and Protection, 1995). The bottom-dwelling fauna of the borrow pit is wiped out, and the resulting hole may become filled with anoxic mud. If bottom conditions are not altered too much and adjacent communities are left intact, then recovery may be expected to be rapid. If a site could be identified that has a naturally high flux of sand, or which is already often disturbed by human activity, this would minimize the disturbance caused by removal of sand.

Onshore beach communities are adapted to rapid change and are thought to recover quickly from burial under sand, although this inference is controversial. Again, where adjacent communities are left in a natural state, recovery is enhanced because animals can migrate from such refuge areas. The negative effects of burial can also be minimized by pumping sand chiefly on the upper part of the beach, which supports only a few species of animals. However, this has the unwanted effect of steepening the beach, setting the stage for higher waves reaching the shore and increasing the rate of erosion.

Table 5.—List of seashell species from natural beaches in Baldwin County, Alabama, with generalized North American environmental data (Abbott, 1968, 1974). Species also found at Gulf Shores Public Beach are **boldfaced**

| **Species** | **Common name** | Environmental data (water depth, substrate) |
|---|---|---|
| **Bivalves** | | |
| ***Barbatia candida*** | **White Bearded Ark** | **shallow; rocks in sand** |
| *Anadara transversa* | Transverse Ark | subtidal sandy mud |
| ***Anadara ovalis*** | **Blood Ark** | **6 to 100 ft** |
| ***Noetia ponderosa*** | **Ponderous Ark** | **shallow sand** |
| *?Atrina serrata* | Saw-Toothed Pen Shell | sandy mud, low tide to 20 ft |
| ***Argopecten gibbus*** | **Calico Scallop** | **6 to 30 ft** |
| ***Plicatula gibbosa*** | **Kitten's Paw** | **0 to 200 ft, attached** |
| ***Anomia simplex*** | **Common Jingle Shell** | **0 to 30 ft, attached** |
| ***Ostrea equestris*** | **Crested Oyster** | **subtidal to 300 ft** |
| *Crassostrea virginica* | Eastern Oyster | shallow, mainly brackish |
| ***Pseudomiltha floridana*** | **Florida Lucina** | **shallow to a few fm** |
| ***Divaricella quadrisulcata*** | **Dentate Lucina** | **6 to 200 ft** |
| ***Trachycardium* sp.** | **Prickly *or* Yellow Cockle** | **1 to 30 ft** |
| ***Dinocardium robustum*** | **Giant Atlantic Cockle** | **3 to 100 ft** |
| ***Spisula solidissima raveneli*** | **Southern Surf Clam** | **0 to 100 ft** |
| ***Mulinia lateralis*** | **Dwarf Surf Clam** | **shallow sand** |
| *Rangia cuneata* | Common Rangia | mainly brackish water |
| *Raeta plicatella* | Channeled Duck Clam | 6 to 40 ft |
| *Donax variabilis* | Coquina Shell | sandy beach |
| *Donax,* small sp. | | |
| ***Mercenaria campechiensis*** | **Southern Quahog** | **3 to 50 ft** |
| *Chione cancellata* | Cross-barred Venus | 3 to 60 ft |
| ***Chione intapurpurea*** | **Lady-in-Waiting Venus** | **12 to 60 ft** |
| *Chione grus* | Gray Pygmy Venus | shallow coarse gray sand |
| ***Macrocallista nimbosa*** | **Sunray Venus** | **0 to 12 ft, sandy mud** |
| ***Dosinia discus*** | **Disk Dosinia** | **6 to 40 ft** |
| *Gemma gemma* | Amethyst Gem Clam | shallow |
| *Cyrtopleura costata* | Angel Wing | soft sandy mud to clay |
| *Pholas campechiensis* | Campeche Angel Wing | offshore mud or wood |
| **Gastropods** | | |
| ***Polinices duplicatus*** | **Shark Eye** | **sand** |
| ***Phalium granulatum*** | **Scotch Bonnet** | **shallow sand** |
| *Busycon* sp. | Whelk | |
| **Non-mollusks** | | |
| ***Mellita quinquiesperforata*** | | **sand** |

# POSSIBLE SOLUTIONS

Several alternative approaches are available to deal with the problem of sharp shells.

The simplest approach is to make no special effort to mitigate the problem. In the natural course of events, sharp fragments tend to be abraded and rounded in the intertidal zone, and to be redeposited so as to lie flat. Also, people collect shells, removing some of them from the system. Tropical Storm Isidore buried many of the sharp shells at Gulf Shores Public Beach, though some remained on the surface. Eventually, the problem will disappear on its own. However, this will not be a satisfactory solution if the beach is to be renourished frequently, and it is unavoidable that occasionally a child will gash a tender foot.

A possible course of action would be to select sand for renourishment based on its grain size and color and to screen or sort out the shells during the pumping process. A screen having a mesh of about one-half inch should eliminate most of the sharp shells. Alternatively, the shells can be separated from the sand-water mix hydrodynamically, taking advantage of the fact that the shells are heavier than individual sand grains. The separated shells might be retained to be spread on the beachfront later, for the delight of children and collectors.

Incidentally, calcium carbonate shells and quartz sand are of about the same density. Calcite, which makes up oyster and scallop shells, has a specific gravity of 2.71, that is, 2.71 times an equivalent volume of pure water. Aragonite, which makes up most molluscan shells, has a specific gravity of 2.95, not accounting for organic matter or pore space, both of which tend to lower the number. Quartz has a specific gravity of 2.65, very close to that of oyster shell. Separating methods that rely on differences in density are not likely to work well.

A third approach is to go farther offshore for sand. Offshore sand can be evaluated by coring and analysis, but without guarantee of success. Still, most of the sharp-shelled species in the renourished sand are common in water less than about 30 feet deep (table 4). Of course, the farther one searches offshore, the more difficult it is to find a matching sand, because substrates farther offshore and deeper tend to be relatively muddy. One suspects that if the sand were suitable for the beach, it would also be suitable for the nearshore fauna anywhere on the continental shelf, regardless of water depth. But as to this, we are hampered by lack of data.

# FUTURE WORK

During year 4 of the project, relatively few (33) grain-size analyses were completed. The proposal for year 5 will include a continuation of the beach monitoring program, analysis of all remaining “a” samples collected to date, and analysis of all “a” samples collected in the first three quarters of year 5.

The proposal for year 5 includes a comprehensive analysis of sieved samples with the goal of further identifying and interpreting temporal and spatial differences in grain-size characteristics on the beaches of the Morgan Peninsula. In particular, longshore drift of sand, differences between fair-weather and storm-weather deposits, and seasonal changes in beach sediment characteristics would be evaluated. We also propose that during year 5, the grain-size and shell characteristics of beach sediment be compared to previously acquired data from cores collected in Federal waters off the Morgan Peninsula of Alabama. This comparison would allow a better fit of potential sediment sources to beaches in need of renourishment. A quantitative protocol for analyzing shell parameters, especially sharpness, will be developed and implemented in beach and core samples.

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Appendix 1. Sand Resources Beach Sample Collection Program

| | | | | | UTM location | | Decimal degree location | |
|---|---|---|---|---|---|---|---|---|
| Site | Site code | Description | zone | code | northing | easting | latitude | longitude |
| 1 | Florida | near FL state line | 16 | R | 450153 | 3349750 | 30.27978 | 87.51818 |
| 2 | FLPTE | Florida Point E | 16 | R | 447750 | 3349196 | 30.27503 | 87.54322 |
| 3 | FLPTW | Florida Point W | 16 | R | 447113 | 3349016 | 30.27326 | 87.54987 |
| 4 | Cotton | Cotton Bayou | 16 | R | 443994 | 3348596 | 30.26899 | 87.58215 |
| 5 | GulfSh | Gulf Shores | 16 | R | 433854 | 3346187 | 30.24684 | 87.68754 |
| 6 | PineB | Pine Beach | 16 | R | 421570 | 3344254 | 30.22865 | 87.81492 |
| 7 | FtMorgan | Fort Morgan | 16 | R | | | 30.22411 | 88.00942 |
| 8 | Callaway | Lee Callaway Bridge | 16 | R | | | 30.24034 | 87.73698 |
| 9 | PinesPBA | Pines public boat access | | | | | 30.23864 | 87.89011 |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | Spring '02 samplers | Spring '02 sand samples | Spring '02 shell samples | Spring '02 sample numbers | Spring '02 photos | Spring '02 date | Spring '02 time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | DCKM&AKR | 6 paired spls | | 020311-1-1a,b to 6a,b | 4 photos | 3/11/02 | 12:30 |
| 2 | FLPTE | Florida Point E | DCKM&AKR | 1 paired spl | | 020311-2-1a,b | 3 photos | 3/11/02 | 14:12 |
| 3 | FLPTW | Florida Point W | DCKM&AKR | 1 paired spl | | 020311-3-1a,b | 2 photos | 3/11/02 | 14:26 |
| 4 | Cotton | Cotton Bayou | DCKM&AKR | 4 paired spls | | 020311-4-1a,b to 4a,b | none | 3/11/02 | 15:22 |
| 5 | GulfSh | Gulf Shores | DCKM&AKR | 4 paired spls | 1 | 020311-5-1a,b to 4a,b | none | 3/11/02 | 16:22 |
| 6 | PineB | Pine Beach | DCKM&AKR | 5 paired spls | 1 | 020312-1-1a,b to 5a,b | 8 photos | 3/12/02 | 9:54 |
| 7 | FtMorgan | Fort Morgan | DCKM&AKR | 1 paired spl | 1 | 020312-2-1a,b | none | 3/12/02 | 12:18 |
| 8 | Callaway | Lee Callaway Bridge | | | | | | | |
| 9 | PinesPBA | Pines public boat access | | | | | | | |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | Summer '02 samplers | Summer '02 sand samples | Summer '02 shell samples | Summer '02 sample numbers | Summer '02 photos | Summer '02 date | Summer '02 time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | DCKM&AKR | 2 paired samples | 0 | 020606-1-1a,b to 2a,b | 3 | 6/6/02 | 14:30 |
| 2 | FLPTE | Florida Point E | DCKM&AKR | 2 paired samples | 1 | 020606-2-1a,b, 2a,b, 3 | 3 | 6/6/02 | 15:11 |
| 3 | FLPTW | Florida Point W | DCKM&AKR | 2 paired samples | 1 | 020606-3-1a,b, 2a,b, 3 | 4 | 6/6/02 | 15:40 |
| 4 | Cotton | Cotton Bayou | DCKM&AKR | 1 paired sample | 0 | 020606-4-1a,b | 6 | 6/6/02 | 16:39 |
| 5 | GulfSh | Gulf Shores | DCKM&AKR | 1 paired, 1 single | 2 | 020607-1-1a,b, 2a,b, 3 | 3 | 6/7/02 | 9:45 |
| 6 | PineB | Pine Beach | DCKM&AKR | 1 paired, 3 single | 1 | 020607-3-1a,b, 2a, 3, 4, 5 | 7 | 6/7/02 | 13:00 |
| 7 | FtMorgan | Fort Morgan | DCKM&AKR | 2 paired, 1 single | 1 | 020607-5-1a,b, 2a,b, 3, 4 | 3 | 6/7/02 | 14:55 |
| 8 | Callaway | Lee Callaway Bridge | DCKM&AKR | 2 paired, 1 single | 1 | 020607-2-1a,b, 2a,b, 3, 4 | 3 | 6/7/02 | 10:35 |
| 9 | PinesPBA | Pines public boat access | DCKM&AKR | 1 single | 0 | 020607-4-1 | 0 | 6/7/02 | 14:33 |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | T.S. Bertha samplers | T.S. Bertha sand samples | T.S. Bertha shell samples | T.S. Bertha sample numbers | T.S. Bertha photos | T.S. Bertha date | T.S. Bertha time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | DCKM&BG | 2 paired | 1 | 020806-1-1a,b, 2a,b, 3 | 3 | 8/6/02 | 11:06 |
| 2 | FLPTE | Florida Point E | DCKM&BG | 2 paired | 1 | 020806-2-1a,b, 2a,b, 3 | 8 | 8/6/02 | 11:30 |
| 3 | FLPTW | Florida Point W | DCKM&BG | 3 paired | 1 | 020806-3-1a,b, 2a,b, 3, 4a,b | 3 | 8/6/02 | 12:08 |
| 4 | Cotton | Cotton Bayou | DCKM&BG | 3 paired | 1 | 020806-4-1a,b, 2a,b, 3, 4a,b | 5 | 8/6/02 | 13:19 |
| 5 | GulfSh | Gulf Shores | DCKM&BG | 2 paired | 2 | 020806-5-1a,b, 3a,b, 4a,b | 5 | 8/6/02 | 13:54 |
| 6 | PineB | Pine Beach | DCKM&BG | 3 paired | 2 | 020807-6-1a,b to 4a,b | 11 | 8/7/02 | 11:22 |
| 7 | FtMorgan | Fort Morgan | DCKM&BG | 3 paired | 1 | 020807-7-1a,b, 2a,b, 3, 4a,b | 3 | 8/7/02 | 12:44 |
| 8 | Callaway | Lee Callaway Bridge | DCKM&BG | 2 paired | 1 | 020806-8-1a,b, 3, 4a,b | 2 | 8/6/02 | 14:28 |
| 9 | PinesPBA | Pines public boat access | | | | | | | |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | Fall '02 samplers | Fall '02 sand samples | Fall '02 shell samples | Fall '02 sample numbers | Fall '02 photos | Fall '02 date | Fall '02 time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | dckm | 2 paired | 1 | 020903_1_1a,b, 2a,b, 3 | 4 | 9/3/02 | 12:40 |
| 2 | FLPTE | Florida Point E | dckm | 2 paired | 1 | 020903_2_1a,b, 2a,b, 3 | 3 | 9/3/02 | 13:16 |
| 3 | FLPTW | Florida Point W | dckm | 2 paired | 1 | 020903_3_1a,b, 2a,b, 3 | 3 | 9/3/02 | 13:45 |
| 4 | Cotton | Cotton Bayou | dckm | 2 paired | 1 | 020903_4_1a,b, 2a,b, 3 | 5 | 9/3/02 | 14:32 |
| 5 | GulfSh | Gulf Shores | dckm | 2 paired | 1 | 020903_5_1a,b, 2a,b, 3 | 3 | 9/3/02 | 15:13 |
| 6 | PineB | Pine Beach | dckm | 2 paired | 1 | 020904_6_1a,b, 2a,b, 3 | 12 | 9/4/02 | 9:56 |
| 7 | FtMorgan | Fort Morgan | dckm | 1 paired | 1 | 020903_7_1a,b, 3 | 4 | 9/3/02 | 17:03 |
| 8 | Callaway | Lee Callaway Bridge | dckm | 1 paired | 3 | 020903_8_1a,b, 3, 4, 5 | 3 | 9/3/02 | 15:44 |
| 9 | PinesPBA | Pines public boat access | dckm | | | | | | |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | TS Hanna samplers | TS Hanna sand samples | TS Hanna shell samples | TS Hanna sample numbers | TS Hanna photos | TS Hanna date | TS Hanna time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | dckm | 3 paired | 1 | 020916_1_1a,b, 2a,b, 3, 4a,b | 3 | 9/16/02 | 13:13 |
| 2 | FLPTE | Florida Point E | dckm | 3 paired | 1 | 020916_2_1a,b, 2a,b, 3, 4a,b | 3 | 9/16/02 | 13:49 |
| 3 | FLPTW | Florida Point W | dckm | 3 paired | 1 | 020916_3_1a,b, 2a,b, 3, 4a,b | 9 | 9/16/02 | 14:19 |
| 4 | Cotton | Cotton Bayou | dckm | 2 paired | 1 | 020916_4_1a,b, 3, 4a,b | 5 | 9/16/02 | 15:10 |
| 5 | GulfSh | Gulf Shores | dckm | 3 paired | 1 | 020916_5_1a,b, 2a,b, 3, 4a,b | 4 | 9/16/02 | 15:43 |
| 6 | PineB | Pine Beach | dckm | 3 paired, 1 solo | 1 | 020917_6_1a,b, 2a,b, 3, 4a,b, 5 | 4 | 9/17/02 | 8:28 |
| 7 | FtMorgan | Fort Morgan | dckm | 3 paired | 2 | 020916_7_1a,b, 2a,b, 3, 4a,b, 5 | 8 | 9/16/02 | 17:42 |
| 8 | Callaway | Lee Callaway Bridge | dckm | 2 paired | 1 | 020916_8_1a,b, 3, 4a,b | 13 | 9/16/02 | 16:32 |
| 9 | PinesPBA | Pines public boat access | dckm | | | | | | |

Sand Resources Beach Sample Collection Program

| Site | Site code | Description | TS Isidore samplers | TS Isidore sand samples | TS Isidore shell samples | TS Isidore sample numbers | TS Isidore photos | TS Isidore date | TS Isidore time |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Florida | near FL state line | dckm &akr | 3 paired | 3 | 020929-1-1a,b, 2a,b, 3, 4a,b, 5, 6 | 10 | 9/29/02 | 13:08 |
| 2 | FLPTE | Florida Point E | dckm &akr | 3 paired | 4 | 020929-2-1a,b, 2a,b, 3, 4a,b, 5, 6, 7 | 7 | 9/29/02 | 14:04 |
| 3 | FLPTW | Florida Point W | dckm &akr | 3 paired | 2 | 020929-3-1a,b, 2a,b, 3, 4a,b, 5 | 8 | 9/29/02 | 14:58 |
| 4 | Cotton | Cotton Bayou | dckm &akr | 3 paired | 2 | 020929-4-1a,b, 2a,b, 3, 4a,b, 5 | 5 | 9/29/02 | 15:57 |
| 5 | GulfSh | Gulf Shores | dckm &akr | 3 paired | 5 | 020929-5-1a,b, 2a,b, 3, 4a,b, 5, 6, 7, 8 | 5 | 9/29/02 | 16:43 |
| 6 | PineB | Pine Beach | dckm &akr | 3 paired | 5 | 020930-6-1a,b, 2a,b, 3, 4a,b, 5, 6, 7, 8 | 17 | 9/30/02 | 12:10 |
| 7 | FtMorgan | Fort Morgan | dckm &akr | 4 paired | 2 | 020930-7-1a,b, 2a,b, 3, 4a,b, 5, 6a,b | 9 | 9/30/02 | 14:46 |
| 8 | Callaway | Lee Callaway Bridge | dckm &akr | 3 paired | 4 | 020930-8-1a,b, 2a,b, 3, 4a,b, 5, 6, 7 | 15 | 9/30/02 | 10:06 |
| 9 | PinesPBA | Pines public boat access | dckm &akr | | | | | | |

## Appendix 2. Field photographs of coastal sediment monitoring sites.

Representative photographs, taken under fair-weather conditions on September 3 and 4, 2002, show the salient features of the eight regular monitoring sites. These photographs were taken about a month after Tropical Storm Bertha made landfall, and the upper storm windrows deposited by Bertha are visible on the beach flat in some of the photographs. The photographs show views westward and landward from the fair-weather strandlines at each monitoring site.

## Appendix 2. Field photographs of coastal sediment monitoring sites.

| Views toward the west | Views toward the land |
|---|---|
|  |  |

Site 1. Florida state line

Site 2. Florida Point East

Site 3. Florida Point West

Site 4. Cotton Bayou

Appendix 2. Field photographs of coastal sediment monitoring sites.

Views toward the west | Views toward the land


Site 5. Gulf Shores


Site 6. Pine Beach


Site 7. Fort Morgan


Site 8. Lee Callaway Bridge

# Appendix 3. Technical summary of species.

## Bivalvia

*Barbatia* (*B.*) *candida* (Helbling, 1779) = White Bearded Ark
Abbott, 1974, no. 4965
Remarks: Ribs not as weak as shown by Abbott (1974).

*Anadara* (*Larkinia*) *baughmani* Hertlein, 1951 = Baughman's Ark
Abbott, 1974, no. 4976

*Anadara* (*Larkinia*) *transversa* (Say, 1822) = Transverse Ark
Abbott, 1974, no. 4977

*Anadara* (*Lunarca*) *ovalis* (Bruguière, 1789) = Blood Ark
Abbott, 1974, no. 4982

*Anadara* (*Cunearca*) *brasiliana* (Lamarck, 1819) = Incongruous Ark
Abbott, 1974, no. 4983

*Noetia* (*Eontia*) *ponderosa* (Say, 1822) = Ponderous Ark
Abbott, 1974, no. 4995

*?Atrina* (*Servatrina*) *serrata* (Sowerby, 1825) = Saw-Toothed Pen Shell
Abbott, 1974, no. 5115

*Argopecten gibbus* (Linné, 1758) = Calico Scallop
Abbott, 1974, no. 5198

*Plicatula gibbosa* Lamarck, 1801 = Kitten's Paw
Abbott, 1974, no. 5216

*Anomia* (*A.*) *simplex* Orbigny, 1842 = Common Jingle Shell
Abbott, 1974, no. 5232

*Ostrea equestris* Say, 1834 = Crested Oyster
Abbott, 1974, no. 5265

*Crassostrea virginica* (Gmelin, 1791) = Eastern Oyster
Abbott, 1974, no. 5274

*Pseudomiltha floridana* (Conrad, 1833) = Florida Lucina
Abbott, 1974, no. 5329

*Divaricella* (*Divalinga*) *quadrisulcata* (Orbigny, 1842) = Cross-hatched Lucina
Abbott, 1974, no. 5331

*Carditamera floridana* Conrad, 1838 = Broad-ribbed Cardita
Abbott, 1974, no. 5478

*Trachycardium egmontianum* (Shuttleworth, 1856)
Abbott, 1974, no. 5546

*Trachycardium muricatum* (Linné, 1758)

Abbott, 1974, no. 5549

*Dinocardium robustum* (Lightfoot, 1786) = Giant Atlantic Cockle
Abbott, 1974, no. 5580

*?Mactra fragilis* Gmelin, 1791 = Fragile Atlantic Mactra
Abbott, 1974, no. 5587

*Spisula* (*Hemimactra*) *similis* (Say, 1822) = Gulf Surf Clam
*Spisula* (*Hemimactra*) *solidissima similis,* Abbott, 1974, no. 5592

*Mulinia lateralis* (Say, 1822) = Dwarf Surf Clam
Abbott, 1974, no. 5602.

*Rangia* (*R*.) *cuneata* (Sowerby, 1831) = Common Rangia
Abbott, 1974, no. 5605

*Raeta plicatella* (Lamarck, 1818) = Channeled Duck Clam
Abbott, 1974, no. 5612

*Donax variabilis* Say, 1822 = Coquina Shell
Abbott, 1974, no. 5753

*Donax*, small species

*Mercenaria campechiensis* (Gmelin, 1791) = Southern Quahog
Abbott, 1974, no. 5864

*Chione* (*C*.) *cancellata* (Linné, 1767) = Cross-barred Venus
Abbott, 1974, no. 5865

*Chione* (*C*.) *intapurpurea* (Conrad, 1849) = Lady-in-Waiting Venus
Abbott, 1974, no. 5867

*Chione* (*Timoclea*) *grus* (Holmes, 1858) = Gray Pygmy Venus
Abbott, 1974, no. 5883

*?Pitar fulminatus* (Menke, 1828) = Lightning Venus
Abbott, 1974, no. 5930

*Macrocallista nimbosa* (Lightfoot, 1786) = Sunray Venus
Abbott, 1974, no. 5949

*Dosinia discus* (Reeves, 1850) = Disk Dosinia
Abbott, 1974, no. 5960

*Gemma gemma* (Totten, 1834) = Amethyst Gem Clam
Abbott, 1974, no. 5967

*Cyrtopleura* (*C*.) *costata* (Linné, 1758) = Angel Wing
Abbott, 1974, no. 6034
"Common in deep, soft, sandy mud in west Florida" (Abbott, 1974).

*Pholas* (*Thovana*) *campechiensis* Gmelin, 1791 = Campeche Angel Wing
Abbott, 1974, no. 6037
"Lives offshore in mud; rarely in wood" (Abbott, 1974).

## Gastropoda

*Cerithium atratum* (Born, 1778) = Florida Cerith
Abbott, 1974, no. 992

*Epitonium* (*E.*) *humphreysi* (Kiener, 1838) = Humphrey's Wentletrap
Abbott, 1974, no. 1229

*Crepidula* (*C.*) *fornicata* (Linné, 1758) = Common Atlantic Slipper-shell
Abbott, 1974, no. 1557

*Crepidula* (*Ianacus*) *plana* Say, 1822 = Eastern White Slipper-shell
Abbott, 1974, no. 1570

*Strombus* (*S.*) *alatus* Gmelin, 1791 = Florida Fighting Conch
Abbott, 1974, no. 1580

*Polinices* (*Neverita*) *duplicatus* (Say, 1822) = Shark Eye
Abbott, 1974, no. 1677

*Sinum perspectivum* (Say, 1831) = Common Baby's Ear
Abbott, 1974, no. 1705

*Phalium* (*Tylocassis*) *granulatum* (Born, 1778) = Scotch Bonnet
Abbott, 1974, no. 1737

*Busycon* sp.
Abbott, 1974, p. 222

*Oliva sayana* Ravenel, 1834 = Lettered Olive
Abbott, 1974, no. 2537

*Terebra* (*T.*) *dislocata* (Say, 1822) = Common American Auger
Abbott, 1974, no. 2836

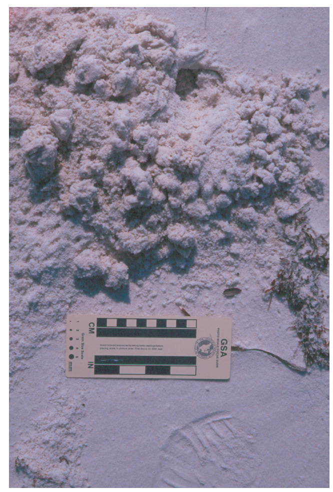
# Appendix 4. Photo essay on effects of Tropical Storm Isidore on Alabama beaches.

Storms commonly move sand offshore, creating bars that are separated from the beaches by runnels.

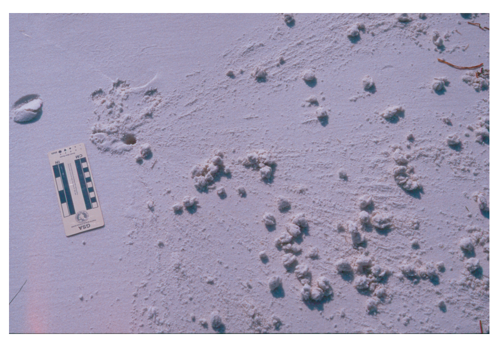
Ephemeral wetlands.

Beaches are littered with debris, including *Sargassum,* mollusk shells, woody debris, and trash.

Flood waters create ephemeral wetlands.



Beach biota, including the ghost crab, *Ocypode quadrata,* have to dig out from under thick layers of sand deposited by some storms.

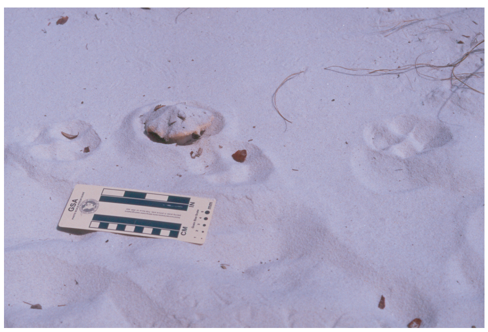


Ghost crabs expel sand balls when excavating.

# Appendix 4. Photo essay on effects of Tropical Storm Isidore on Alabama beaches.

Storms erode existing features, like this dune at Cotton Bayou.

T. S. Isidore eroded sand from the lower beach, depositing it on the upper beach, on dunes, and on anthropogenic features.



This mushroom took advantage of moisture brought by the storm.

More than one meter of sand was deposited on dunes at Fort Morgan.

Some members of the native fauna, like this Great Blue Heron, seemed disoriented and uncharacteristically approachable.

Bulldozers were used to push the sand back, likely with negative consequences for beach fauna.