CHAPTER 14
SEA TURTLE HABITAT DETERIORATION ON ST. CATHERINES ISLAND: DEFINING THE MODERN TRANSGRESSION

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Loggerhead sea turtles (*Caretta caretta* [Linnaeus, 1758]) nesting on Georgia's Golden Isles (Brannen and Bishop, 1993; this volume, fig. 1.1) have shown a significant, continuous decline since 1964 (Magnuson et al., 1990).[1] Although officially listed worldwide as "threatened," loggerhead sea turtles in the Carolinas and Georgia are a distinct subpopulation that is considered by the state of Georgia as endangered. The decline in loggerhead nesting in Georgia is exacerbated by continually rising sea level (Demarest and Kraft, 1987), entrapment of fluvial sediment in southeastern dams, and deepening of ship channels in southeastern ports leading to sediment deprivation of the southeastern coast. These conditions result in profound and rapid coastal erosion causing deterioration of backbeach nesting habitat used by sea turtles (Georgia Ports Authority/Department of the Army, Corps of Engineers, 1998). These deleterious habitat effects have been studied for 20 years on St. Catherines Island (Bishop et al., 2009), one of the most erosional of the Sea Islands (Griffin and Henry, 1984), and will act as a predictor of the fate awaiting the other southeastern barrier islands.

The target area for nesting loggerhead sea turtles (fig. 14.1) lies at the juncture of the beach and the backbeach area along and just above the spring high tide line (Bishop, 2003; Spotila, 2004; Gulko and Eckert, 2004; McCurdy, 2009). Some turtles will nest behind this line in the dunes or other backbeach area (Rodrigues and Shimizu, 1995). Because of the differing tidal height of neap and spring tides, some turtles that nest above high tide, responding to difference of temperature between cool tidal beach and solar heated backbeach (Stoneburner and Richardson, 1981), end up nesting below the higher level of the spring high tides, depositing "doomed" nests that are certain to be inundated and drowned on the next spring tide set (fig. 13.6C, this volume). Even those nests deposited at the highest spring high tide level are often inundated by storm tides or surges on nor'easters or associated with hurricanes and are considered "at risk" (see fig. 13.6A, B, this volume). All doomed or at-risk nests on St. Catherines are normally relocated into natural nesting habitat above the storm high tide line, nesting habitat used by naturally nesting loggerhead sea turtles. Conservation of in situ and relocated nests on St. Catherines protects them from abiotic destruction (inundation and washout) and biotic destruction (depredation), increasing their hatch success from an estimated 5% (if not conserved) to an actual success rate of ~72%–76% with conservation measures applied (Dodd and Mackinnon, 2006; Engeman et al., 2006; Hayes, Marsh, and Bishop, 1995). The unexpected emergence of sea turtles from 5–11 "wild nests" per year (i.e., nests that were missed during normal daily monitoring and successfully hatched on their own) indicates that there is some significant level of success for unprotected nests, but the very fact that these were missed by daily monitoring by humans probably also means that normal predators (raccoons, hogs, ghost crabs) (Anderson, 1981; Bishop, 2003) would have also missed them for the same reasons (storms, rain, exceptionally high tides with very short crawlways). The total number of unsuccessful wild nests remains unknown.

The nesting ethogram of loggerhead sea turtles (Hailman and Elowson, 1992) is a genetically controlled pattern of nine sequential behaviors that result in the production of a sea turtle nest, a suite of sedimentary structures that disrupts the normal sedimentary fabric of the beach. A typical loggerhead nest on the coast of Georgia consists of entrance and exit crawlways and a covering pit (Brannen and Bishop, 1993; Bishop and Brannen 1993; Bishop 2007); the covering pit hides underlying structures consisting of a body pit and egg chamber (fig. 14.2). Because of the fluctuating high tide line that varies with semidiurnal tides having a difference in tidal range of 2.0 m (6.5 ft) to 2.8 m (9.2 ft), nests deposited at the high tide line during neap tides will be "doomed" (see fig. 13.6C) and drowned by subsequent higher high tide levels on the spring tide sets. The Hailsman and Elowson (1992) ethogram has also been applied to the only known fossilized sea turtle nesting structures in the Cretaceous Fox Hills Sandstone of Colorado (Bishop, Marsh, and Pirkle, 2000; Bishop and Pirkle, 2008; Bishop et al., this volume, chap. 13).

Active processes shaping the Georgia beach include waves, tides, storms, longshore currents, and littoral drift of sediment (Clayton et al., 1992). The normal processes produce a winter beach that tends to be erosional and a summer beach that tends to be accretional. The dominant erosional agent of the Georgia beach is periodic northeasterly windstorms (nor'easters), which may have little or no impact on inland areas (and normally go unrecognized even in coastal weather forecasts except for "high surf advisories"). These storms frequently occur in the winter and move incredible amounts of sediment from the nearshore environment (Davis and Dolan, 1993), lowering the beach surface and eroding a backbeach scarp (fig. 14.3; see also fig. 13.6A). Hurricanes occur less frequently on the Georgia coast; however their erosional effects can be more profound, even with near misses. During the summer, the sand system of the Georgia coast usually moves sand back onto the beaches as a series of

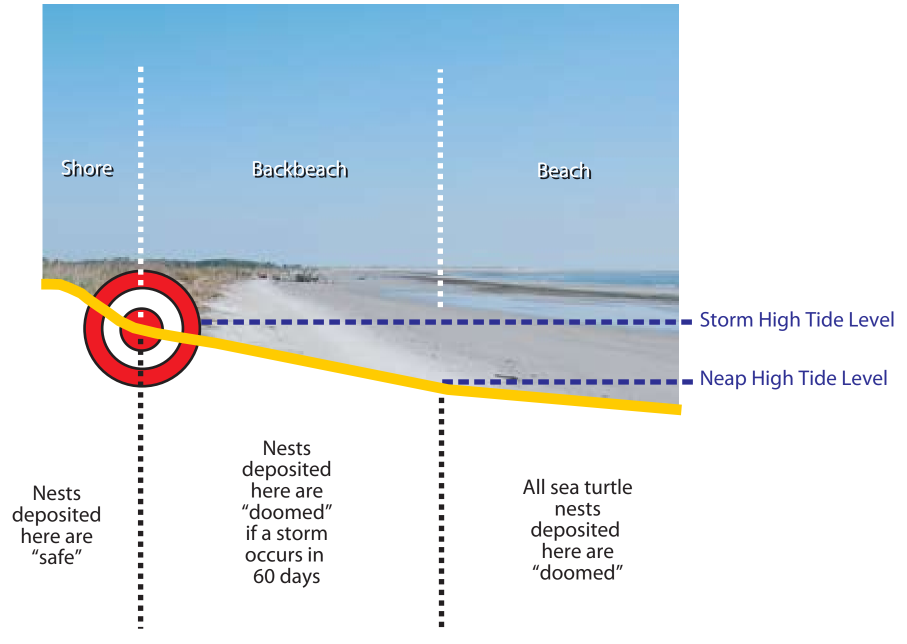

Fig. 14.1. Habitat nesting target of loggerhead sea turtles lies at the boundary between the shoreline and backbeach storm high tide line. Nests deposited between the storm high tide line and spring high tide line are susceptible to tidal inundation during storms, but will normally hatch, although with decreased success. Nests deposited below spring high tide line are inundated on spring high tide sets and storms, and are doomed to failure.

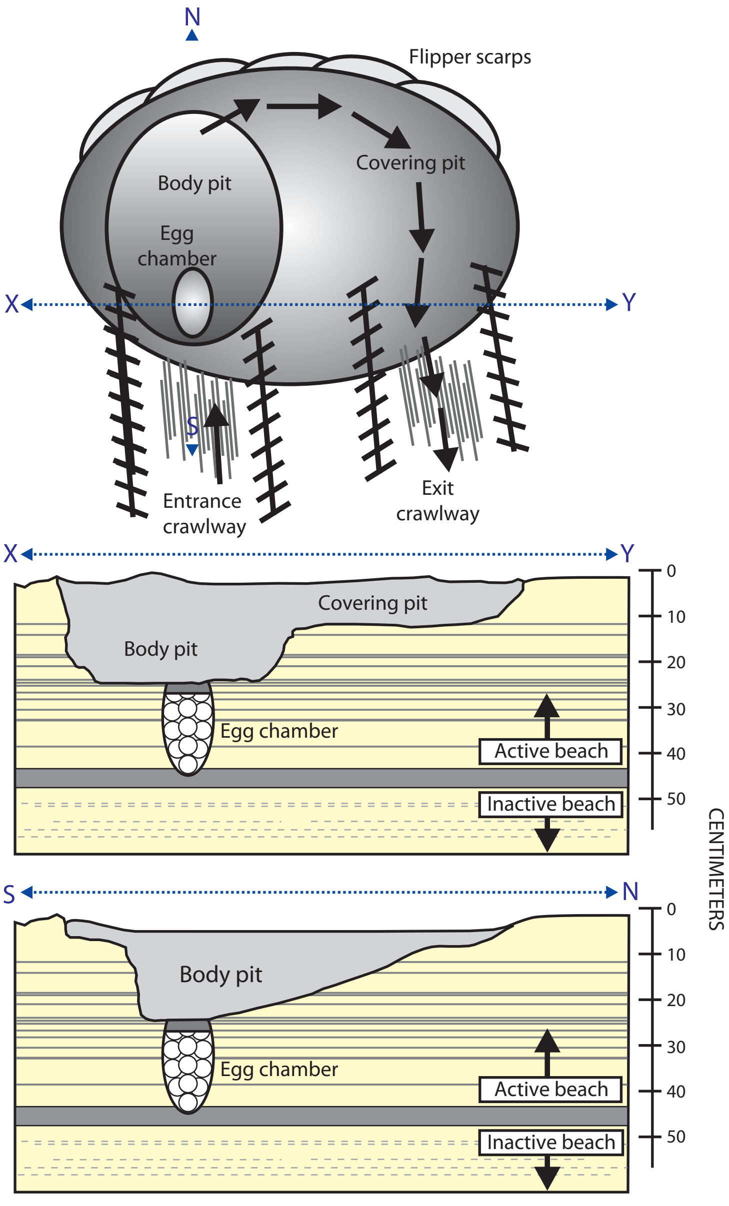

Fig. 14.2. Morphology of loggerhead sea turtle nests deposited on St. Catherines Island; with map view (top) and two cross sections running east-west (X-Y) and north-south (S-N) to show complete suite of sedimentary structures expected in sea turtle nesting. Note that the egg chamber and body pit are covered and obscured by the bioturbated sediment of the covering pit. The boundary between the horizontally laminated active beach is marked by a heavy mineral sand placer (black) and overlies the inactive beach characterized by diffused, ghostly horizontal laminations. Horizontal scale = 1.0 m.

ridge and runnel systems. This seasonal pattern of erosion and deposition is normal and often masks more profound changes, particularly for sporadic observations of occasional beach visitors (Henry, Farrell, Cofer-Shabica, 1993).

Erosional areas on the beach are often marked by a series of one or more features that indicate removal of beach sediment. These areas present themselves as a suite of geomorphic features that can be "read" in the field (Chamberlin, 1890; Bishop and Marsh, 1999b; Frodeman, 1995, 2003). Although the time frame of erosion (time of erosion and rate of erosion) usually cannot be determined with any degree of certainty without direct observation, the many clues that erosional conditions may be present in the environment can be read from even sporadic observational criteria. Short-term evidence of erosion (fig. 14.4) is indicated by lowering of the active beach (fig. 14.4B, C), backbeach scarping (fig. 14.4B), formation of washover fans (fig. 14.4D, E), and exposure of fresh roots in new scarps (fig. 14.4B). Long-term effects include evidence of beach retreat, exposure of relict marsh mud on the beach (fig. 14.4C), and formation of tree "boneyards" left behind as the shoreline migrates inland (fig. 14.4A).

Potter (personal commun.; see also chap. 7, this volume) discussed erosion of St. Catherines Island and surmised that:

> At Engineers Road on the north shore, a 0.8 m/yr southward migration of the beach into a forested Holocene dune field has left dead standing pines below the high tide mark. Growth of a large sand bar at the northeastern tip of the island has coincided with up to 20 m of lateral accretion below a 5 m-high Pleistocene bluff on the northern stretch of the east shore. In contrast, the southern 0.7 km-long stretch of this Pleistocene bluff has eroded at rates ranging from 1.3m/yr to 2.4 m/yr. South Beach extends 4.8 km southward from McQueen Inlet and has the highest rates of erosional retreat. Flag Pond was breached by 10.4 m of lateral erosion during a 1992 winter storm, and its freshwater flora and fauna has been replaced by saltwater species. Retreat of 2.1 m/yr at Beach Pond over the past six years has made the breach of this last fresh water pond along the eastern shore imminent. Washover of beach sand into marshes is common along much of South Beach, Middle Beach, and North Beach, resulting in exposure of marsh muds on the beach face as erosion progresses inland.

HABITAT DESCRIPTION

The sea turtle nesting habitat of St. Catherines Island is situated along the beachfront, sound margins, and small hooklike beaches lying behind the back shoulders of the island on the intracoastal waterway. This habitat consists of a mosaic of sediment packets that are largely erosional (figs. 14.4 and 14.5) with lesser units of neutral or accretional areas (fig. 14.5). This mosaic of habitats changes over time and continues to change dramatically from year to year (fig. 14.11). The shoreline of St. Catherines Island (bounded by St. Catherines Sound, Sapelo Sound, and the Atlantic Ocean) consists of approximately 21,141 m. Of this, 18,818 m (89%) are currently (1993–2006) undergoing erosion and 2323 m (11%) are currently (1993–2006) undergoing accretion. There are some extremely small transitional areas that seem to balance between erosion and accretion, but they are relatively insignificant.

Beaches of St. Catherines Island are predominantly composed of a firm, fine to very fine subangular quartz sand with interlaminated layers of heavy mineral sand, concentrated along the backshore (Bishop, 1990; Darrell, Brannen, and Bishop, 1993). The upper beach has a seaward dip of approximately 2° and the lower beach has a dip of approximately 1°. Interspersed along the beach are patches of relict marsh mud that may be covered by a thin veneer of sand or exposed (fig. 14.4C), depending upon the state or erosion of the beach. Small tidal flats are present at the northeast and southwest shoulders of the island, comprised of fluidized muddy sand. The St. Catherines Sound margin is currently highly erosional because the sound is apparently migrating southward, cutting into St. Catherines Island. Ebb deltas (fig. 14.5B) are present at St. Catherines Sound (where a large exposed bar is present along with ebb delta shoals), at the mouth of Seaside Inlet (Seaside Ebb Delta), at the mouth of McQueen Inlet, and at the mouth of Flag Inlet (as the very small Flag Ebb Delta). The north margin of Sapelo Sound has formed as a hook from St. Catherines beach, which swings westward to enclose a small lagoon (which we call south lagoon).

Erosional Habitats: When the removal of sediment exceeds its accumulation by deposition, an area will recede or erode (called transgression). On St. Catherines Island, erosional areas are usually marked (fig. 14.4) by bluffs, scarps, relict root zones, tree boneyards, relict marsh mud, and washover and washin fans.

Relict Muds: Barrier islands, being narrow accumulations of sand that fringe coastlines, are often associated with broad, protected marshes behind them and in Georgia often have seaside

Fig. 14.3. The erosional power of nor'easters is impressive when viewed up close during the storm event, with gale force (20–50 mph) winds, a moderate storm surge of 1 to 2 ft, and a 9 to 10 ft surf. **A,** Atlantic Ocean during nor'easter battering Yellow Banks Bluff, and washing over Seaside Spit forming washover fans. **B,** A nor'easter breached Flag Pond Isthmus forming a new lagoon (Flag Lagoon) and inlet (Flag Inlet) during the winter of 1992–1993.

Fig. 14.4. Erosional habitats usually offer clear evidence of the erosion. **A.** Yellow Banks Bluff not only exhibits a prominent erosional scarp, but also harbors an impressive "boneyard" of skeletal trees. **B.** As storms such as nor'easters impinge on the shore they excavate the beach, form pervasive scarps, and expose root balls and clean roots on coastal vegetation. **C.** When the beach is lowered by erosion, buried relict mud deposits are exposed, or lie just beneath a masking veneer of beach sand. **D.** In areas backed by low-lying maritime forests, sand may be washed over the backbeach area and into the forest, forming wash-in fans. **E.** In areas backed by low-lying marsh meadows, the sand washed over the backbeach forms washover fans.

Fig. 14.5. Neutral habitats, where erosion and deposition are in equilibrium, include ebb deltas and accretional terraces. **A.** Seaside Inlet seen at midebb tide—neutral habitat of this ebb delta is submerged (and would be deleterious to a sea turtle nest!). Note the washover fans on Middle Beach (left) and North Beach, and small dune trying to maintain itself on the north flank of Seaside Inlet. **B.** St. Catherines Sound seen from east at midebb tide—neutral habitats include St. Catherines Bar (ebb delta in foreground) and accretional terrace in front of and to right of small tidal pond on north end of North Beach (left background) (aerial photography by Artist in the Sky, April 24, 2008).

marshes on the oceanward side protected by spits (fig. 14.6A) or hooks. These marshes trap suspended mud and host a distinctive flora (e.g., *Spartina* grasses) and distinctive marsh fauna differing from those of the sandy coast or the terrestrial mainland. The sediment consists of variable mud textures with interspersed channel lag deposits of tidal streams and fringing bioherms built by lagoonal organisms (e.g., the oyster *Crassostrea virginica*) (Morris and Rollins, 1977). Root zones characteristic of marsh meadows and homogeneous muds often border tidal streams. As a coastline begins to retreat by erosion, the sands of the beaches are removed laterally or washed over the backbeach forming a bermlike wave of sand that progressively moves shoreward as washover or washin fans. If this erosion encounters marsh sediments, the sand will be dumped on top of the edge of the marsh and the marsh exposed as part of the "beach." These mud exposures (Morris and Rollins, 1977) are said to be relict marsh muds (fig. 14.4C) because they antedate the beach and are therefore older than the beach sediments with which they are associated. Relict marsh mud is exposed on the beach as patches of mud surrounded and veneered by beach sand. Marsh features clearly recognizable include *Spartina alterniflora* root peats, *Crassostrea virginica* oyster bioherms, in situ quahogs (*Mercenaria mercenaria*) and mussels (*Geukensia demissa*), and abundant burrows of fossorial shrimp (*Callichirus major)* and crabs.

Relict Root Zones: As the veneer of sand is rolled back over the front of an island in a series of washover fans or as a migrating berm, it buries the backbeach marsh beneath it, killing the marsh grasses (fig. 14.4E). As erosion continues, the buried soil zones reappear on the backbeach marked by zones of rooted stubble of grass and shrub stalks.

Tree "Boneyards": Hammocks or maritime forests inundated by the transgressing sea are first buried in the advancing sand wave if they are low-lying features or are undercut by wave notching and subsequently flounder by mass wasting onto the backbeach. The trees rapidly die and begin to decompose, losing bark and root ball soil, eventually forming skeletons of trees buried in the sand. These skeletal trees, called "boneyards," may topple or remain standing and can be moved about during high tides or storms (figs. 14.3A, B; 14.4A, B, D). They may accumulate along the shoreline scarp (fig. 14.4B) or bluff (fig. 14.4A) as an intertwined mass of wood or remain as discrete entities along the backbeach (fig. 14.4D) where they form armor on the beach and are slowly eroded by breakage and abrasion.

Scarps: Scarps are small-scale nearly vertical erosional drop-offs that often mark the boundary between the backbeach and island; they are formed by the erosion caused by the waves of the highest storm tides (fig. 14.4B). Scarps form by wave erosion and subsequent mass wasting. Newly formed scarps are characterized by "clean" exposed roots and nearly vertical facies, often showing sedimentary structures of the eroding backbeach facies. As scarps mature they become subdued; sedimentary structures become less obvious as the scarp is washed over by cascading sand carried in runoff or by sand-blasting by wind blown sand, often burying the toe of the scarp in a talus from above and from small secondary dunes deposited along the backbeach.

Bluffs: These are large-scale, nearly vertical drop-offs (fig. 14.4A) that mark the backbeach boundary in areas with considerable relief, or areas of high dunes or high land, as in the island core of St. Catherines Island (Bishop, 1990; Bishop et al., 2007; Linsley, Bishop, and Rollins, 2008; Reitz et al., 2008). The processes of formation are the same as for scarps, but erosional effects are magnified by their greater height so the slope angle of the bluff and the talus at its toe are more readily apparent.

Washover Fans: Washover fans form wherever the beach is backed by marsh meadows. Normal beach processes build a berm that often becomes vegetated, and subsequently the vegetation often catches sand in its wind shadow (the area baffled by grass decreasing the wind velocity, so suspended and saltating sediment drops out of suspension), causing small dunes or dune ridges to form. During exceptionally high water levels, spring tides, or storms, berms and dunes are overwashed by breaking waves and sediment is carried behind the beach as a series of tonguelike washover deposits (fig. 14.4E) up to ~20 cm thick. These washover deposits often form as a series of interbraided sand tongues thrown over the berm by subsequent high tides or coalesce into single, broad, ramplike landward-dipping washover fans (fig. 14.4E). Occasional reversal of density stratification has been observed with heavy minerals deposited on the washover surface over less dense quartz sand.

Washin Fans: On highly erosional islands, such as St. Catherines Island, washover fans develop along low backbeach margins bordered by maritime forest (fig. 14.4D). If the sand washes over the back of the beach and into the forest, it forms a type of washover fan that can be called a "washin fan."

Neutral Habitat

Neutral habitats occasionally occur that are neither erosional nor depositional. Among these are channels of tidal creeks or inlets emptying into the ocean as at Beach Creek at the southern tip of St. Catherines. Neutral habitats are (at least temporarily) in equilibrium with sediment movement along the coast (fig. 14.5). The ebb deltas of St. Catherines are treated herein as if they are sediment neutral, although they are one of the most dynamic of coastal environments, rapidly changing size and shape as tidal currents and storm currents move the sand in and out of the sounds and inlets as it is being transferred along the coast from north to south.

Ebb (and Flood) Deltas: Ebb deltas are formed from transported sand as strong tidal currents flow on the outgoing, or ebbing, tide (fig. 14.5). Normal ebb delta features include a bulge of sand built seaward from the inlet with bars, shoals, and distributary channels. At low tide, the ebb delta is almost fully exposed and wind, particularly nor'easters, blowing across the wide expanse of sand often will move great quantities as saltating grains into dune fields that build downwind of the deltas. As the tide changes and begins to flood, sand is carried by the rising tide back through the inlet and deposited as flood deltas (fig. 14.3B) within the tidal creeks.

Depositional Habitats

When the delivery of sediment exceeds its removal by erosion, an area will accrete, building forward into the adjacent ocean (called progradation or regression by geologists). On St. Catherines Island, accretional areas (fig. 14.6A) are usually marked by accretional terraces, progressively younger beach ridge systems, dune fields, and accretional terrains (fig. 14.6B).

Terraces: Terraces build as accretional waves of sand move onto the shore as a series of "ridge and runnel systems." Each progressive sand wave is moved onto the beach until it reaches equilibrium with the wave swash and is added to the backbeach as the beachfront builds seaward as an accretional area. This process often results in the establishment of a level backbeach area termed an "accretional terrace." Accretional terraces (fig. 14.5) build where the beachfront has prograded seaward, often at bends in the beach due to sounds, inlets, or offshore ebb-delta channels. These accretional areas are extremely vulnerable to rapid erosion during spring tide storms.

Beach Ridges: The wind can be seen moving sand grains across the low-tide beach on backbeaches with accretional terraces, dropping the sand building small dunes on wrack, clumps of vegetation, and flotsam. These small, ephemeral dunes are extremely dynamic, building rapidly and being just as rapidly destroyed by subsequent winds with different orientation. As the backbeach broadens, the dunes may coalesce into a low ridge of secondary dunes along the edge of the backbeach, which can rapidly build during wind storms as sand is blown off the exposed broad low-tide beach and moves as a sand "ground blizzard" along the flat beach surface and is lifted over the dune and rapidly falls into the wind shadow on the lee side of the accreting dune. In this way scattered backbeach dunes can evolve into a linear dune ridge along the edge of the backbeach (figs. 14.6, 14.9A).

Dune Fields: The wind blowing across the low-tide beach on wide backbeaches behind ebb deltas have a large source area in which to pick up drying sand on ebb tides. In these situations, particularly on nor'easters or southeasterly winds, great quantities of sand are moved inland and often form very dynamic sand dune fields, as at McQueen Dune Field (fig. 14.9B) behind the ebb deltas (Shadroui, 1990). This habitat is high and dry and makes excellent nesting habitat except for the dynamics of moving sand that can rapidly expose or bury sea turtle nests.

Accretional Terrains: As an island rapidly accretes seaward due to drop in sea level and/or increased sediment supply, it does so by "fits and spurts," rapidly accreting, then eroding back due to the effects of storms or changes in sediment supply. This gives rise to accretional wedges, called accretional terrains (Bishop, Vance, and Meyer, 2007), which are geomorphological units that have similar surface ridge patterns, similar parallel orientations, and similar internal structure (fig. 14.6). Accretional terrains are obvious on aerial photographs and orthophotomaps and can be sequenced by position on the island and crosscutting relationships

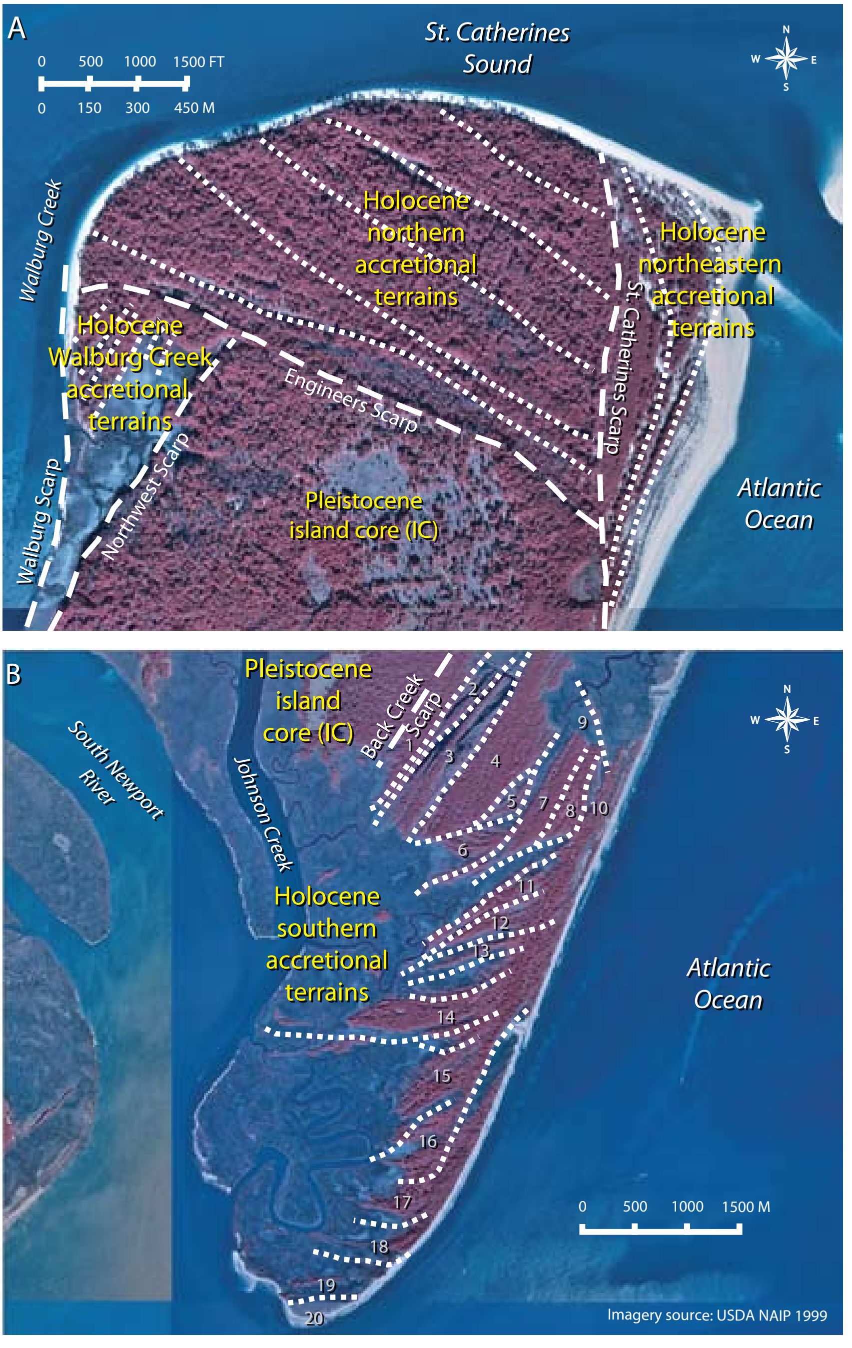

Fig. 14.6. Depositional habitats include accretional terraces, progressively younger beach ridge systems, modern dune fields, and accretional terrains: **A.** On the north end of St. Catherines Island showing the Pleistocene island core (IC), accretional ridge systems deposited by migration of Walburg Creek and St. Catherines Sound, and one of the only accretional areas on St. Catherines Island on northeast corner (compare this image taken on December 31, 1999 with fig. 14.6B, taken April 24, 2008). **B.** Holocene accretional terrains on the southeast part of St. Catherines numbered in sequential order, 1 is oldest and 20 youngest.

(fig. 14.6B). Absolute ages, often difficult to determine, can sometimes be established by radiometric dating of entrained shell, wood, or minerals within the depositional wedge as recovered by vibracoring (see chap. 10, this volume).

METHODOLOGY

In 1998 a qualitative assessment of the deteriorating sea turtle nesting habitat on St. Catherines Island was initiated. This documentation (Bishop and Marsh, 1995, 1998b) consists of a longitudinal survey of beach characteristics on a computer-generated longitudinal GPS grid (fig. 14.7) with a 0.001° point spacing overwritten with a sketch showing the nature of St. Catherines' beaches (fig. 14.7) (Leslie and Roth, 2003; Stanesco, 1991). At latitude of 30° north (or south), each degree subtends a distance of 68.881 mi of arc. Using arithmetic, the distance subtended by 0.001° of arc = 110.85 m per 0.001°.

The transitional methodology for habitat surveys developed in 1998 and modified in 1999 involved physically surveying the beach with a 100 m spacing with flagging and "permanently" marking points each 1 km. Beach benchmarks (beach entrances, channels, etc.) were subsequently located with GPS, and a longitudinal spreadsheet grid was constructed using a 0.001° spacing along the beach including the beach benchmarks. The spreadsheet, with each grid point printed as rows and beach criteria listed as columns, was printed (fig. 14.7) and carried in the field. A Rapid Habitat Assessment rubric was designed (table 14.1) to rapidly determine and quantify the nesting habitats presented along the beaches. This quantitative assessment has been done annually since 2000 on St. Catherines Island (Bishop, Vance, and Meyer, 2007).

The assessment technique involved a traverse of all beaches from one end of the island to the other, usually done within a few days time to avoid natural variation due to storms or seasonal changes. The surveys were done by driving an all-terrain vehicle from end to end, stopping every 0.001 degrees (~ 111 m), scoring beach condition against the rubric criteria (table 14.1), and recording the condition of the beach as sea turtle habitat on the spreadsheet pages in the notebook. The Rapid Habitat Assessments done in 1998 and 1999 were qualitative, done on a GPS grid, with a sketch map of the beaches actually drawn directly on the grid (fig. 14.7). In 1999 the Rapid Habitat Assessment tool was refined (Bishop and Marsh, 1999b) and a general set of erosional criteria was established with the scale expanded to 10 divisions (closely linked to "likely percentage of hatching success"). The annual habitat assessment (table 14.2) thus became thought of as a "chance of success" (or risk) assessment for a sea turtle nest deposited at the back of the beach at each GPS point. During most years, a sketch map was also constructed as scoring was noted, showing the presence of bluffs, scarps, ridges, maritime forest, washover and washin fans, terraces, relict marsh mud, ebb deltas, channels, and tree boneyards.

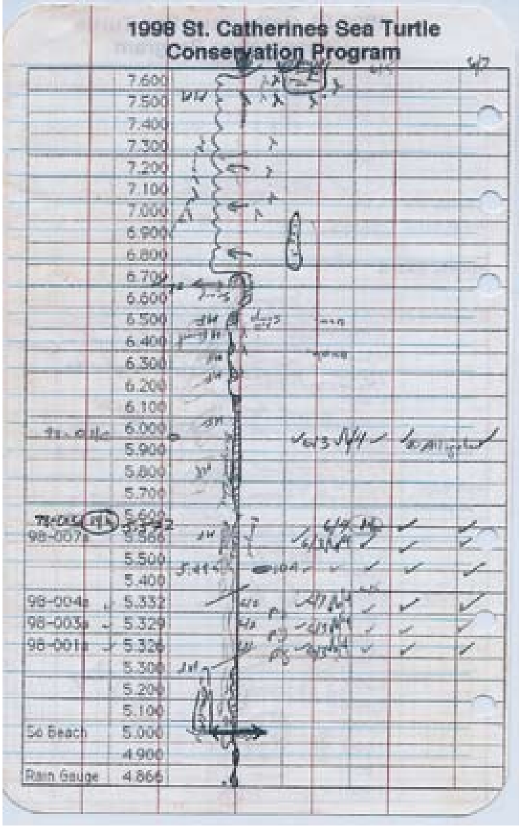

Fig. 14.7. Scanned image of 1998 sketch map depicting sea turtle habitat conditions that were documented as a qualitative sketch, oversketched onto the GPS monitoring grid to illustrate early attempts at characterizing deteriorating nesting habitat, with beach conditions drawn directly onto the grid.

TABLE 14.1
Rubric for Evaluation of St. Catherines Habitat Assessment

Geomorphic Feature	Normal Scoring Range	Assessment Factors
Channel	0	no hatch possible
Erosional Bluff	0-1-2	highly erosional, at risk
Erosional Scarp	0-1-2-3-4-5-6	erosional, at risk
Erosional Washover Fan	0-1-2	inundation, at risk
Erosional Relict Mud	0-1-2-3-4-5-6-7-8-9-10	depends on backbeach
Sub-surface Problem	0-1-2	define in untested areas?
Neutral Shoreface	3-4-5-6-7-8-9-10	adequate-abv avg-excellent
Accretional Terrace	3-4-5-6	adequate-abv avg-excellent
Accretional Ridges	3-4-5-6-7-8-9-10	adequate-abv avg-excellent
Dune Field	0-1-2-3-4-5-6-7-8-9-10	blowout possible, at risk

In order to better assess the deterioration of sea turtle nesting habitats on the beaches of St. Catherines Island, one of us (Meyer) constructed a shoreline map from historical documents, maps, and aerial photographs for the interval spanning 1859–2006. Data were captured electronically as digital imagery and superimposed over an aerial image of St. Catherines Island (from Google Earth™). The distance over which the shoreline has fluctuated was analyzed and compiled as a series of histograms along the beaches of St. Catherines Island to delineate the overall pattern of erosional and depositional (accretionary) conditions (fig. 14.11).

HABITAT ASSESSMENT RESULTS

Annual rapid sea turtle habitat assessments clearly document the decline in backbeach habitats along the entire length of the front of St. Catherines Island with less than 15% of beachfront considered to be adequate habitat for sea turtle nesting. Escalating erosion has been documented independently by physical measurement of shoreline retreat (see chap. 7, this volume) and indirectly by rapid habitat assessments of sea turtle habitat on St. Catherines beaches.

The quantification of habitat status remains somewhat subjective because the process is one of judgment by the habitat assessor. The quality of the process is dependent upon unbiased assessments (and thus would be difficult to substantiate). The data presented herein were taken annually and not assembled into a comparative format (table 14.2) until December 23, 2008, except for a prior comparison of cumulative beach index information for 2000 and 2001, leading us to believe that no prejudices are built into the technique.

The overall average of habitat quality on all of the beaches on St. Catherines Island has declined significantly over the last decade (fig. 14.8). It was 2.490 in 2000 and 2.516 in 2001 and declined rapidly to 1.994 in 2002 (notes are unavailable for 2003, so that value was computed as the average of values for 2002 and 2004), 1.942 in 2004, and continued to decline to 1.703 in 2005, 1.605 in 2006, and dramatically dropped to 1.207 in 2007, but rose to 1.543 in 2008 and 1.896 in 2009. This decline is largely attributed to an islandwide episode of erosion that has caused rapid retreat of the beaches (fig. 14.11; Potter, Padgett, and Trimble, 2007; Potter, this volume, chap. 7) along much of the front of St. Catherines

TABLE 14.2
Sea Turtle Habitat Scores by Year for St. Catherines Island's Beaches

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
En Rd West	31.698	—	—	—	—	—	—	—	—	—	—
En Rd East	81.143	—	0	—	0	—	1	0	0	—	—
SC Sound	81.142	—	0	0	0	—	0	0	0	0	0
SC Sound	81.141	—	0	0	0	—	0	0	0	0	0
SC Sound	81.140	—	0	0	0	—	0	0	0	0	0
SC Sound	81.139	—	0	0	0	—	0	0	0	0	0
SC Sound Margin	81.138	—	5	0	0	—	0	0	0	0	0
SC Sound Margin	81.137	—	5	4	0	—	0	0	0	0	0
SC Sound Margin	81.136	—	6	3	0	—	1	0	0	0	0
SC Sound Margin	81.135	—	6	4	0	—	1	1	0	0	2
SC Sound Margin	81.134	—	6	7	1	—	2	0	0	1	1
SC Sound Margin	81.133	—	7	4	1	—	1	2	2	3	1
SC Sound Margin	81.132	—	5	5	1	—	2	1	4	5	4
SC Sound Margin	81.131	—	5	6	5	—	2	6	—	4	4
NE Shoulder	81.131	—	—	—	—	—	—	—	—	—	—
NE Shoulder	31.696	—	2	7	—	—	—	—	—	—	—
Sand Pit Rd Rookery	31.695	—	1	6	5	—	3	3	3	8	5
Sand Pit Rd Rookery	31.694	—	5	5	1	—	2	5	2	3	0
Sand Pit Rd Rookery	31.693	—	5	4	3	—	2	6	0	1	0
Sand Pit Rd Rookery	31.692	—	5	3	3	—	2	0	0	0	0
Sand Pit Rd Rookery	31.691	—	7	5	3	—	1	1	4	0	6
Sand Pit Rd Rookery	31.690	—	8	8	7	—	4	7	5	3	4
Sand Pit Rd Rookery	31.689	—	9	9	7	—	4	3	7	8	5
Sand Pit Rd Rookery	31.688	—	8	9	7	—	7	5	5	7	7
Sand Pit Rd Rookery	31.687	—	9	7	8	—	6	7	7	8	6
Sd Pit Rd	31.687	—	—	7	—	—	—	—	—	—	—
Sand Pit Rd Rookery	31.686	—	7	5	9	—	5	10	6	7	4
Sand Pit Rd Rookery	31.685	—	5	6	8	—	5	6	3	5	5
Sand Pit Rd Rookery	31.684	—	4	5	8	—	1	2	3	3	3
Sand Pit Rd Rookery	31.683	—	3	4	5	—	2	1	1	3	2
T-Pipe	31.683	—	—	—	—	—	—	—	—	—	—
Yellow B Bluff	31.682	—	3	3	2	—	0	0	1	1	0
Yellow B Bluff	31.681	—	0	2	0	—	0	0	0	0	0
Yellow B Bluff	31.680	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.679	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.678	—	0	0	0	—	0	0	0	0	0

TABLE 14.2 — (*Continued*)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Yellow B Bluff	31.677	—	0	0	0	—	0	0	0	0	0
Yellow B Bluff	31.676	—	0	0	0	—	0	0	0	0	0
Seaside Ramp	31.676	—	—	—	—	—	—	—	—	—	—
Seaside Spit	31.675	—	0	0	0	—	0	0	0	0	0
Seaside Spit	31.674	—	0	1	0	—	0	0	0	0	0
Seaside Spit	31.673	—	0	1	0	—	0	0	1	0	0
Seaside Spit	31.672	—	1	1	0	—	1	0	2	0	1
Seaside Spit	31.671	—	1	1	0	—	0	0	0	0	0
Seaside Spit	31.670	—	0	1	0	—	0	0	0	0	0
Seaside Spit	31.669	—	0	0	0	—	0	0	0	0	0
Seaside Spit	31.668	—	0	0	0	—	0	0	0	1	0
Seaside Spit	31.667	—	0	0	0	—	1	0	0	0	0
Seaside Spit	31.666	—	0	0	0	—	1	0	1	0	0
Seaside Spit	31.665	—	0	0	0	—	0	0	0	1	0
Seaside Spit	31.664	—	0	0	0	—	1	0	0	0	0
Seaside Spit	31.663	—	0	0	0	—	0	1	0	0	0
Seaside Spit	31.662	—	0	0	0	—	0	1	0	0	2
Seaside Spit	31.661	—	0	2	0	—	1	2	2	0	1
SS Inlet	31.661	—	—	—	0	—	—	—	2	2	—
SS Inlet	31.658	—	—	—	—	—	—	—	—	—	—
Middle Beach	31.659	—	0	—	0	—	0	0	—	0	0
Middle Beach	31.658	—	0	0	0	—	1	2	0	0	0
Middle Beach	31.657	—	1	2	0	—	2	2	0	1	1
Middle Beach	31.656	—	1	0	2	—	4	5	2	2	1
Middle Beach	31.655	—	2	0	0	—	2	1	1	1	1
Middle Beach	31.654	—	0	1	0	—	1	2	1	2	2
Middle Beach	31.653	—	0	0	0	—	3	4	3	3	1
Middle Beach	31.652	—	0	1	0	—	0	0	2	2	2
Middle Beach	31.651	—	0	0	0	—	0	1	3	1	1
Middle Beach	31.650	—	0	0	0	—	0	0	0	0	0
Middle Beach	31.649	—	0	0	0	—	2	1	1	1	1
Middle Beach	31.648	—	0	1	1	—	3	1	3	0	0
Middle Beach	31.647	—	0	2	4	—	4	1	2	1	1
Middle Beach	31.646	—	1	2	3	—	2	2	1	0	0
Middle Beach Berm	31.645	—	2	3	5	—	5	6	4	0	0
Middle Beach Berm	31.644	—	3	3	5	—	6	4	5	1	1

TABLE 14.2 — (*Continued*)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Middle Beach Berm	31.643	—	3	4	7	—	6	1	3	0	0
Middle Beach Berm	31.642	—	1	4	8	—	5	3	0	0	0
Middle Beach Berm	31.641	—	2	1	1	—	1	5	1	0	0
Middle Beach Berm	31.640	—	3	6	5	—	1	3	5	0	0
Middle Beach Berm	31.639	—	4	5	6	—	5	2	1	1	1
Middle Beach Berm	31.638	—	4	5	6	—	4	2	0	3	1
Middle Beach Berm	81.137	—	2	—	6	—	2	2	0	1	0
Middle Beach Berm	81.138	—	—	—	5	—	8	1	0	3	0
Middle Beach	81.139	—	—	—	3	—	1	1	1	1	0
Middle Beach	81.140	—	—	—	0	—	—	—	1	1	0
McQueen Inlet	stump	—	—	—	—	—	—	—	0	—	1
McQueen Margin	—	—	—	—	—	—	—	—	—	—	1
McQueen Margin	—	—	—	—	—	—	—	—	—	1	3
McQueen Inlet	—	—	—	8	7	—	—	—	6	0	3
McQueen Rookery	31.633	—	3	8	8	—	2	1	9	5	4
McQueen Rookery	31.632	—	8	7	9	—	7	6	9	9	8
McQueen Rookery	31.631	—	9	7	9	—	8	8	5	8	8
McQueen Rookery	31.630	—	9	8	10	—	7	9	4	7	10
McQueen Rookery	31.629	—	9	10	10	—	10	9	6	0	10
McQueen Rookery	31.628	—	9	9	9	—	8	9	7	0	9
McQueen Rookery	31.627	—	10	10	9	—	9	9	7	2	10
McQueen Rookery	31.626	—	10	9	9	—	10	9	8	9	10
McQueen Rookery	31.625	—	8	3	5	—	5	10	9	9	10
McQueen Rookery	31.624	—	5	2	1	—	3	5	1	7	7
McQueen Rookery	31.623	—	8	5	7	—	6	8	8	4	5
Big Washover	31.622	—	5	3	3	—	2	3	3	1	2
Big Washover	31.621	—	0	0	0	—	0	0	0	0	0
Big Washover	31.620	—	0	1	1	—	1	0	1	2	2
Big Washover	31.619	—	0	3	5	—	0	3	5	1	3
Big Washover	31.618	—	0	1	0	—	2	0	0	0	0
Big Washover	31.617	—	0	2	1	—	2	2	5	1	1
Big Washover	31.616	—	0	0	0	—	0	0	1	2	3
Big Washover	31.615	—	0	1	0	—	4	2	4	1	2
Big Washover	31.614	—	1	2	0	—	3	1	3	2	1
Big Washover	31.613	—	0	0	0	—	1	0	3	2	3
Big Washover	31.612	—	0	1	0	—	0	0	4	3	1

TABLE 14.2 — (*Continued*)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Big Washover	31.611	—	1	2	0	—	0	0	0	0	1
—	31.610	—	1	2	1	—	0	0	0	2	1
—	31.609	—	2	2	1	—	1	0	0	0	0
—	31.608	—	1	2	2	—	0	0	0	0	0
—	31.607	—	2	2	1	—	1	0	1	1	1
—	31.606	—	1	1	3	—	1	0	3	1	—
—	31.605	—	3	1	3	—	2	1	0	0	0
Turtle Bowl Nurtury	31.604	—	7	7	2	—	1	0	0	0	2
Turtle Bowl Nurtury	31.603	—	6	4	2	—	1	1	0	0	1
Rattlesnake Rookery	31.602	—	7	6	5	—	2	0	0	0	0
Rattlesnake Rookery	31.601	—	7	4	4	—	6	5	5	1	1
Rattlesnake Rookery	31.600	—	7	4	0	—	3	0	0	0	0
Rattlesnake Rookery	31.599	—	9	8	0	—	3	0	0	0	0
Rattlesnake Rookery	31.598	—	6	7	0	—	3	3	0	0	0
Rattlesnake Rookery	31.597	—	5	7	0	—	0	3	0	0	0
So Beach Ent	31.596	—	—	—	—	—	—	—	—	—	—
South Beach Nurtury	31.596	—	8	8	1	—	1	2	3	0	1
Rain Gage Nurtury	31.595	—	7	6	2	—	6	4	0	0	0
Rain Gage Nurtury	31.594	—	6	2	1	—	1	0	1	0	0
—	31.593	—	4	1	1	—	6	1	0	0	0
High Dune Nurtury	31.592	—	5	1	1	—	2	2	0	0	0
—	31.591	—	4	1	2	—	2	3	0	0	0
—	31.590	—	4	1	1	—	2	4	0	0	0
—	31.589	—	3	0	1	—	3	2	0	0	0
—	31.588	—	2	3	2	—	5	2	3	0	0
—	31.587	—	1	1	3	—	3	0	1	0	0
—	31.586	—	0	0	1	—	1	0	0	0	0
—	31.585	—	1	1	0	—	1	0	0	0	0
—	31.584	—	0	0	0	—	0	0	0	0	1
Flag Inlet	31.583	—	—	—	0	—	—	0	—	1	—
—	31.583	—	0	0	0	—	0	0	0	0	0
—	31.582	—	0	0	0	—	1	0	1	0	0
—	31.581	—	1	2	1	—	0	0	1	1	0
—	31.580	—	1	1	1	—	0	0	0	1	0
—	31.579	—	1	1	2	—	0	0	0	0	0
—	31.578	—	0	0	2	—	0	0	0	0	0
—	31.577	—	0	1	2	—	1	1	0	0	0

TABLE 14.2 — (*Continued*)

Markers	Lat/Long	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
—	31.576	—	0	0	0	—	0	1	0	0	0
—	31.575	—	0	1	0	—	0	0	0	0	0
Jungle Road	31.575	—	—	—	—	—	—	—	—	—	—
—	31.574	—	0	0	0	—	0	0	0	0	0
—	31.573	—	0	1	1	—	0	1	0	0	0
—	31.572	—	1	0	1	—	1	0	0	0	0
—	31.571	—	2	1	0	—	1	1	0	0	0
—	31.570	—	0	0	0	—	0	0	1	0	0
—	31.569	—	0	0	0	—	1	0	0	1	0
—	31.568	—	0	0	0	—	0	0	0	0	0
—	31.567	—	0	0	0	—	0	0	0	0	0
—	31.566	—	0	0	0	—	1	1	0	0	0
—	31.565	—	1	1	0	—	1	0	2	0	1
—	31.564	—	1	2	2	—	1	2	2	3	1
South Ridge Nurtury	31.563	—	2	2	3	—	1	1	5	3	9
South Ridge Nurtury	31.562	—	2	0	0	—	4	0	0	0	3
South Ridge Nurtury	31.561	—	2	2	2	—	3	0	1	0	3
—	31.560	—	1	1	1	—	3	0	0	0	1
—	31.559	—	0	1	0	—	1	0	1	0	1
Beach Cr	31.559	—	0	—	0	—	—	—	—	0	—
Beach Cr	31.559	—	—	—	—	—	—	—	—	—	4
—	81.559	—	1	0	0	—	0	0	0	0	0
—	81.176	—	2	2	2	—	3	0	0	0	0
—	81.177	—	0	1	1	—	3	1	0	0	1
—	81.178	—	1	2	0	—	1	1	1	0	1
South Lagoon	81.179	—	2	5	6	—	2	4	3	3	4
South Lagoon	81.180	—	3	0	1	—	0	1	5	1	6
South Lagoon	81.181	—	1	0	3	—	0	—	3	0	4
—	81.182	—	—	2	0	—	0	—	—	4	2
—	81.182	—	—	4	0	—	—	—	—	0	0
—	81.183	—	—	3	0	—	—	—	—	0	0
—	81.183	—	—	0	—	—	—	—	—	0	0
—	81.183	—	—	—	—	—	—	—	—	0	0
—	81.184	—	—	—	—	—	—	—	—	0	—
Little Brunson Creek	—	—	—	—	—	—	—	—	—	—	—
—	—	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
—	average	—	2.490	2.516	1.994	1.753	1.942	1.703	1.605	1.207	1.497

Island (fig. 14.9). However, some areas of stability have remained as remarkably viable nesting habitat (fig. 14.9A, B), particularly the area north of Sand Pit Road entrance (Sand Pit Road rookery [fig. 14.9A]) and the dune field south of McQueen Inlet (McQueen rookery [fig. 14.9B]). Both these areas have undergone erosion and are retreating (Potter, this volume, chap. 7), but because of their former larger size and geomorphic configuration behind large ebb deltas, have provided a consistently high-quality habitat over the last decade and thus form the major sea turtle rookeries found on St. Catherines Island.

Deterioration of sea turtle nesting habitat on St. Catherines Island has been directly measured for over a decade (table 14.2) and could have been predicted by the erosion map presented by Griffin and Henry (1984). It is directly confirmed by the map and graph of the erosional history of St. Catherines Island 1859–2006 (fig. 14.11). This map and graph of erosion/accretion depicts the position of historical shorelines and quantifies the amount of erosion or accretion as a continuous histogram constructed along the beaches of St. Catherines Island, showing areas of accretion at the north end of North Beach and at the north end of South Beach at the previously mentioned dune field accretionary ridge systems lying behind the St. Catherines Ebb Delta bar and behind McQueen Ebb Delta. Except for these areas, the rest of the front of St. Catherines Island is erosional.

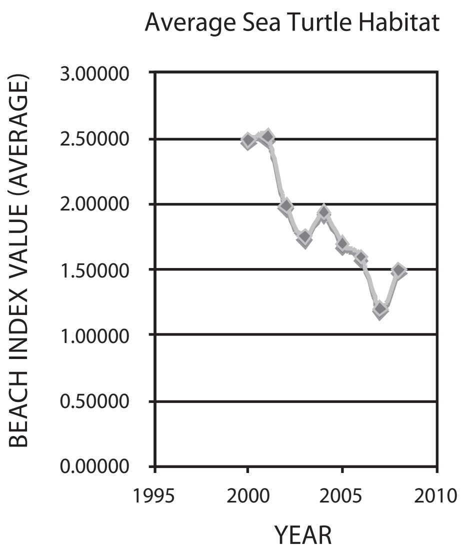

Fig. 14.8. Habitat quality of the beaches on St. Catherines Island has declined significantly over the last decade as indicated by average of all scored habitat values along the beaches from 1999–2008. Value for 2003 was calculated from average of 2002 and 2004 to smooth graph.

The shoreline dynamics of St. Catherines Island have been studied and evaluated by several researchers (Griffin and Henry, 1984; Potter, Padgett, and Trimble, 2007; Meyer et al., 2009) utilizing varying methods and chronological datasets. The research results have been consistent and successful in demonstrating both spatial and temporal variations during the recent history of the mean high-water shoreline. The recent history of the shoreline of St. Catherines Island is one that may be characterized by widespread retreat or erosion across the vast majority of the island with two small, isolated areas of accretion. These small accretional areas are located on the northeastern portion of the island and south of McQueen Inlet (fig. 14.10A, B). In the northern portion of the island, the rate of erosion on the St. Catherines Sound shoreline has been estimated to vary temporally from 0.8 m/yr to 1.4 m/yr during the time interval of 1859–2006. Erosion on North Beach immediately south of the aforementioned accretional area has caused a westward retreat of the shoreline at rates from 1 m/yr to over 3 m/yr, reaching a maximum of 3.3 m/yr along Seaside Spit and resulting in large washover fans being deposited over the marsh surface to the immediate west. The erosion on the eastern or seaside of the spit and deposition on the western or marsh side of the spit has caused the spit to migrate over 450 m to the west and exposed former marsh mud on the current beach surface and in the shallow subtidal area off North Beach. The Middle Beach portion of the island located between McQueen Inlet and Seaside Creek has shown consistent erosion rates of 2.2 m/yr to 3.1 m/yr for the years of 1859–2006. The most southern portion of the island has also experienced widespread and uninterrupted erosion. This area has undergone erosion rates ranging from 0.9 m/yr to 4.6 m/yr with the most severe rate of 9.2 m/yr at the southern terminus adjacent to Sapelo Sound. The retreat of the shoreline along South Beach has been responsible for inundation of Flag Pond, formerly

Fig. 14.9. Two extant sea turtle rookeries remained on St. Catherines Island in 2008: **A,** Sand Pit Road rookery on the north end of North Beach stretching from Yellow Banks Bluff northward for ~1.1 km to St. Catherines Sound (foreground). **B,** McQueen Dune Field rookery on the north end of South Beach stretching ~1.4 km from the big washover to McQueen Inlet (foreground) (aerial photography by Artist in the Sky, April 24, 2008).

Fig. 14.10. Small patches of beach habitat appear as erosion proceeds, exposing interdune swales and dune facies to access for nesting by sea turtles or for relocation of doomed or at-risk nests: **A,** small area, approximately 5.5 m wide, called "the Blowout," supported up to 11 relocated sea turtle nests on South Beach for several years until 2002; **B,** a second nearby area ~20 m long, called "the Turtle Bowl," supported up to 14 nests in 1998 and was still in use in 2009; **C,** South Ridge nurtury between 31.56378° N and 31.56260° N formed an area one dune wide near the south end of South Beach in 2008, but was barely in use by 2010. Scale: A, B, stakes are exposed ~1 m; aerial photography by Artist in the Sky, April 24, 2008.

a freshwater ecosystem, into Flag Lagoon (fig. 14.3B) that is currently a marine and saltwater marsh ecosystem. Accretion has occurred in two distinct and separate areas in the recent 150 years. The shoreline in the northeastern portion of the island has moved eastward over 550 m since 1859, resulting in accretion rates of 3.8 m/yr. The area immediately south of McQueen Inlet has prograded eastward or accreted to the east at a rate of 1.9 m/yr to 4.9 m/yr.

St. Catherines Sea Turtle Rookeries

The high-quality habitat of the Sand Pit Road dune ridges (table 14.1: Sand Pit Road rookery) consists of ~0.73–1.1 km (as measured on Google Earth™ and computed from table 14.2, respectively) of parallel dune ridges in this accretional terrain. Although the quality of this habitat is stable and consistently high, its utilization by sea turtles for nesting is also affected by the width of interswale terraces that form wide backbeaches as respective ridges are eroded in this fluctuating, accretional area. Because of its proximity to the ebb delta of St. Catherines Sound with its pervasive bars and shoals, the tidal currents, presence of St. Catherines bar, and offshore shoals often block access to this otherwise high-quality nesting beach (fig. 14.9A). South of Sand Pit Road entrance, subsurface conditions (a buried peat and marsh mud) dam island drainage into a high-standing water table capable of flooding interdune swales and flooding any nests deposited at or near sea level (see chap. 3, this volume). However, high dune ridges that occasionally grow across this terrain often provide an excellent habitat with sufficient elevation to consistently hatch clutches of eggs. The adequate to excellent habitat in this rookery has declined from 1443 m in 2001 to approximately 666 m (a devilish number!) in 2008.

The McQueen Dune Field (see fig. 14.9B; table 14.2, McQueen rookery) once consisted of an extensive area covered by multiple dunes and dune ridges (Shadroui, 1990) that was formed by northeasterly winds blowing across McQueen Ebb Delta and has since been dramatically eroded into a much smaller dune field, but has remained the best sea turtle nesting habitat available on St. Catherines Island for over two decades. The linear extent of this habitat measured parallel to the beach is ~1.07–1.44 km (as measured on Google Earth™ and computed from table 14.2, respectively), but its extent perpendicular to the beach has been reduced to a narrow strip one dune ridge wide at its south end to a maximum width of 85 m near its north end (in 2008). The adequate to excellent habitat in this rookery has declined from 1332 m in 2000 to 1110 m in 2008 (see this volume, chap. 8).

Two formerly stable rookery areas were present on St. Catherines until 2002. The south margin of St. Catherines Sound was bordered by good nesting habitat, the St. Catherines Sound margin rookery, which essentially disappeared in 2002 as St. Catherines Sound migrated southward, eroding that habitat away. A second stable rookery was located north and south of South Beach entrance on South Beach, which we called the rattlesnake dune rookery to the north, which at that time extended for approximately 1.44 km in 1998, but was nearly completely eroded away by 2002, except for sporadic pocket nurturies (two of which we informally called the Turtle Bowl and the Blowout [fig. 14.10A, B], the South Beach Dune, and the South Beach Rain Gage Nurturies are all gone, as of 2010). An ephemeral rookery with a total length of approximately 99 m appeared on Middle Beach in 2001 and reached its maximum length in 2002, but was gone by 2006.

Some areas of persistently poor habitat are also remarkably stable. These include Yellow Banks Bluff, Seaside Spit, and the washovers we call the Big Washover (table 14.2), and the south half of South Beach, from south of the beach entrance nearly to the south tip of the island.

St. Catherines Sea Turtle Nurturies

The beach to the south of McQueen Dune Field is occupied by a series of washovers (which we have called the Big Washover) that generally consists of poor-quality nesting habitat, except for ephemeral dunes that periodically build on this surface on annual cycles. Nests deposited in them are at risk because the prevalent landform remains a massive washover fan that is periodically reactivated during storm events.

South of the Big Washover is an area that previously formed an interval of good to excellent habitat developed on the edges of large dunes and dune ridges (informally called rattlesnake dunes) until about 2001 or 2002, when erosion became so pervasive that only small separated areas provided adequate nesting habitat. These patches provided small, but significant nurturies (fig. 14.10A, B) for several years (including small patch nurturies we called the blowout, turtle bowl, South Beach Entrance dune, high dune, and swale ridge) between the Big Washover and Flag Pond.

South Beach from the Big Washover to the south end of the island is now (2009) highly erosional and hosts only two small patches of adequate habitat (South Ridge nuturey [fig. 14.10C] and Lagoon Ridge on South West Beach). These small areas are very short, ~154 m and ~238 m, respectively, and each consists of a single dune ridge approximately 5–10 m wide that is extremely susceptible to erosion during storms, but each provides the little habitat left for hatching sea turtle clutches on the south end of South Beach.

Using the criteria established in 1998 and 1999 for rapid assessment of sea turtle habitat, the St. Catherines Island habitat has been measured annually with adoption of the standards set by the Coastal Resources Division of the Georgia Department of Natural Resources in 2001 (Dodd and McKinnon, 2006, personal commun.) In addition to habitat assessment in terms of estimated probability of hatching success, the data can be characterized as a beach index by computing total scored points for each year and normalizing to the number of stations measured (see table 14.2).

Conceptualization of St. Catherines Sea Turtle Nesting Habitats

Sea turtle nesting habitat seen on St. Catherines Island that remains unsuitable for hatching sea turtle clutches (~85% of the beaches in 2008) either lacks sufficient elevation to hatch clutches of sea turtle eggs or is so susceptible to erosion that it is unlikely to successfully hatch clutches of sea turtle eggs during any given season. These areas tend to be situated along low boundaries between the sea and the island: spits, channels, above buried mud layers that cause perched water table, or along obviously erosional areas marked by tree boneyards, bluffs, scarps, or washover or washin fans.

Sea turtle habitat seen on St. Catherines Island that is most suitable for hatching sea turtle nests (~15% of the beaches in 2008) usually possesses some elevation above the storm high tide line, is often marked by the presence of an indicator species, Sea Oats (*Uniola paniculata*), or lies on the face of the first sand dune or accretionary dune ridges backing the shoreline. Two types of adequate sea turtle nesting beaches comprise this 15° of beachfront: sea turtle rookeries that are persistent and stable dune or ridge fields that have been intact for nearly two decades (fig. 14.9A, B) and sea turtle pocket natural nesting sites, called nurturies, that represent small, ephemeral patches of habitat that are temporarily exposed as backbeach dunes or interdune swales or as narrow backbeach berms or ridges built by winds blowing across the beach (fig. 14.10) as the beaches continue to retreat due to erosion. These "pocket habitats" possess elevation sufficient to incubate clutches of sea turtle eggs, but are remarkably susceptible to erosion by storm surges during nor'easters or passing hurricanes (see Bishop et al., chap. 13; see also fig. 13.6A).

It should be emphasized that the successful hatching of clutches of sea turtle eggs is always stochastic. During mild (nonstormy) nesting seasons clutches deposited in low-success habitat may successfully hatch. During stormy seasons clutches deposited in high-quality habitat will be susceptible to being washed out or drowned. However, the overall chance of hatching success is always enhanced by relocation from low-quality to high-quality habitat. This is true as long as this relocation is done carefully and the relocations are placed back into natural habitats that are being used by sea turtles as natural nesting sites (hence the origin of the term *nurtury*, "to nurture," as in relocation to assure hatching of clutches of eggs).

The observations of 18 years of changes in sea turtle nesting habitat on St. Catherines Island have led to the conclusion that this very dynamic habitat can be remarkably stable for long intervals of time (months or even years) then suddenly change overnight due to nor'easters or passing hurricanes. These changes are dramatic and significant and can be characterized in the form of an erosion index. This said, it also must be emphasized that these pervasive changes that occur on the beach due to storm surges and wind may go completely unrecognized by observers immediately behind the beach (in the maritime forest) or on the mainland. In an attempt to emphasize this, we have constructed a coastal erosion index.

GEORGIA BARRIER ISLAND EROSION INDEX

Public concern for erosional conditions and dangerous rip tides on Georgia barrier islands has caused us to establish a qualitative and semiquantitative beach erosion index tool (table 14.3) to consistently characterize beach erosion from observational criteria and wind speed/direction data. Erosion is categorized as slight (2), moderate (4), strong (6), extreme (8), or catastrophic (10) based upon lowering of the beach to expose relict marsh mud and root zones, degree of scarping exposing new roots and/or causing the downing of trees and shrubs, activity of washover and washin fans, and effects on coastal structures and boats.

Since 2006, public awareness of beach ero-

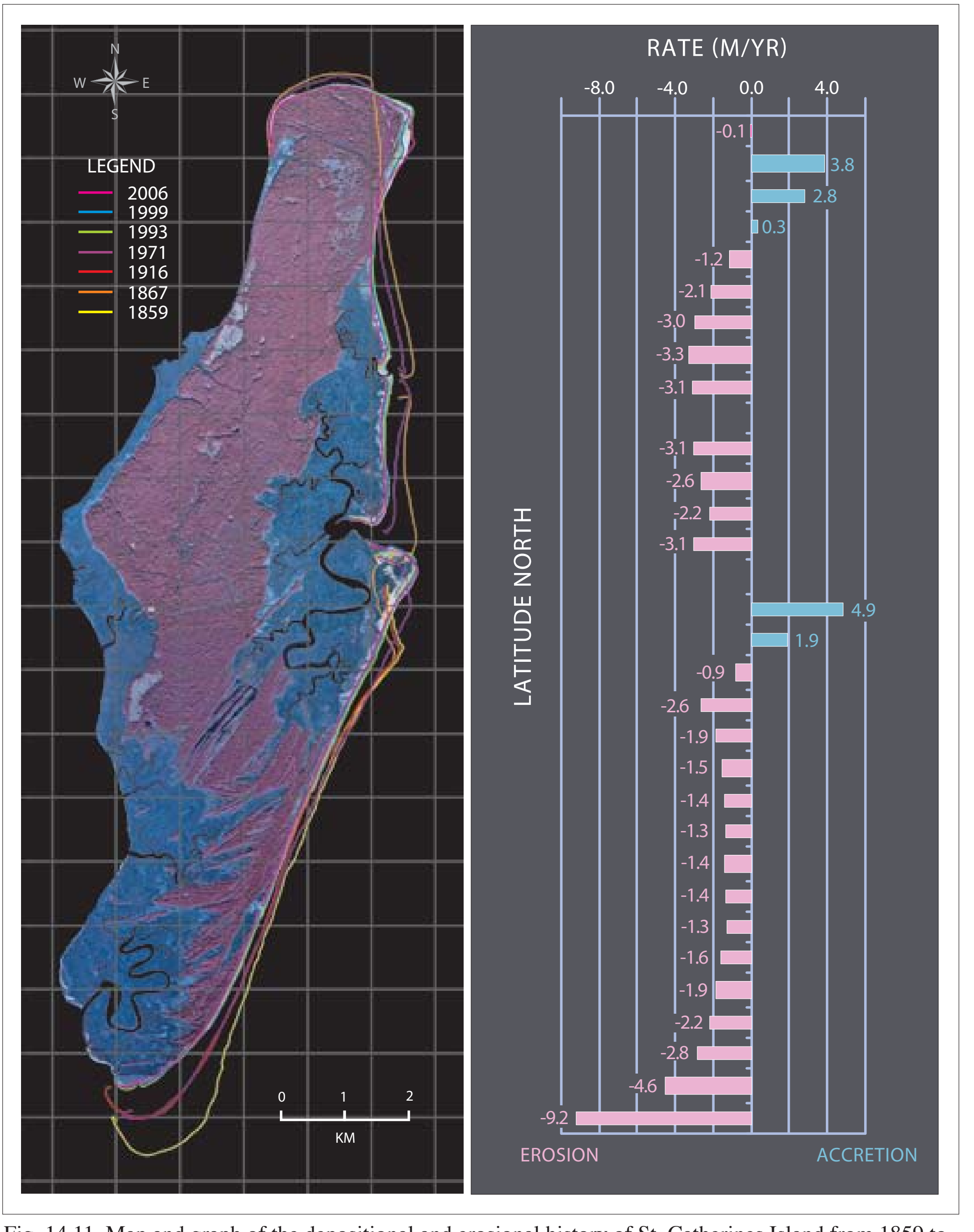

Fig. 14.11. Map and graph of the depositional and erosional history of St. Catherines Island from 1859 to 2006 showing limited accretional areas behind the ebb deltas at St. Catherines Sound and McQueen Inlet.

sion increased and NOAA Coastal Services Center contacted the St. Catherines Island scientific community to establish a formal reporting system for beach erosion and rip tides. In attempting to perform this function in 2007, it became apparent that criteria needed to be established to more precisely characterize habitat erosion on the beaches of Georgia in a consistent manner. The tentative beach erosion index is constructed based upon observational conditions previously documented in the annual Rapid Habitat Assessment and by direct observation on the beaches.

Using the Beaufort Observational Wind Scale as a model, a chart was constructed to characterize erosional effects on St. Catherines Island, linked to both observational criteria and to the Beaufort Observational Wind Velocity Scale. Erosion is characterized as slight, moderate, strong, extreme, or catastrophic based upon observable criteria listed in table 14.3.

CONCLUSIONS

The data presented indicate that the following conclusions can be supported:

(1) Deterioration of sea turtle habitat on St. Catherines Island indicates that the island is undergoing global inundation due to sea level rise against the island, a transgression.

(2) As the sea rises against the island, beaches are undergoing rapid erosion and the shoreline is retreating to the west.

TABLE 14.3
Observational Beach Erosion Chart for Georgia's Barrier Islands

Status	Observational Criteria	Wind Regime
No Erosion	High Tide below scarp or storm tide level; Sand waves arriving on beach forming Runnels; Backbeach sand is tracked by animals and burrowed by crabs.	0–12 knots
Slight Erosion	High Tide reaching base of storm scarp or storm tide line; Washovers and washins slightly over-topped; Beach lowered, some erosion at toes of scarps.	13–30 knots
Moderate Erosion	High Tide inundating scarps and impinging on storm tide line; Washovers and washins over washed; Beach lowered, often to inactive beach with roots and relict mud exposed; Active scarping on sand beaches, existing scarps exhibiting "clean" new roots; Trees and logs moving in surf.	Nor'easter 20–40 knots
Strong Erosion	High Tide over-topping scarps and storm tide line; Washovers and washins strongly overwashed; Beach lowered often showing inactive beach with roots and relict mud exposed; Active scarping exhibited by scarped sand and "clean" new roots on scarps; Trees downed; Trees and logs moved laterally in surf. Mud "rollers" form on beach behind relict mud.	Nor'easter 30–50 knots
Extreme Erosion	Tide overtopping scarps, and well above storm tide level; Washovers and washins very strongly overwashed; Beach lowered often showing inactive beach with roots and relict mud exposed for great distances; Active scarping and scarp migration exhibited by "clean" new roots on scarps; Live trees downed from scarps; Trees and logs moved along surf forming jumbles.	Nor'easter/Gales/ Hurricane CAT I–II
Catastrophic Erosion	Barrier Island overtopped by surge and/or surf; Saltwater inundates most freshwater habitats; Permanent structures inundated and/or destroyed; Boats grounded or sunk.	Hurricane CAT III–V

(3) Beach erosion is indicated by formation of scarps, the exposure of root zones, exposure of relict marsh mud, and development of tree boneyards in high areas and development of washover and washin fans in low areas.

(4) As erosion progresses the highly variable backshore presents a dynamic mosaic of nesting habitats that change on an annual, seasonal, monthly, and even daily schedule; a few of these present good to excellent, but very limited, sea turtle nesting habitats each year.

(5) Approximately 15% of St. Catherines beaches are classed as adequate to excellent sea turtle nesting habitat, areas largely confined to stable dune fields and dune ridges backing the shoreline at Sand Pit Road entrance on North Beach and McQueen dune field on the north end of South Beach.

(6) Loggerhead sea turtle nests deposited in erosional areas or below the spring high tide line are "doomed" or "at risk," and are relocated into the closest habitat (that is also still being used by nesting sea turtles) to increase their chance of hatching, i.e., into nurturies.

(7) As sea level continues to rise against the land in the Georgia Bight, more and more of Georgia's sea turtle habitat will deteriorate; what has happened to St. Catherines Island should migrate progressively up and down the coast of the eroding the Golden Isles.

(8) An index to erosion on Georgia barrier islands is developed and presented.

NOTES

1. Many organizations have supported the St. Catherines Island Sea Turtle Program over the last 19 years, including our major sponsors, the Georgia Higher Education Eisenhower/Improving Teacher Quality Program (~60% of funding) and the St. Catherines Island Foundation. Essential support of the teachers' programs has also been provided by Georgia Southern University, GeoTrec LLC of Fayette, Iowa, and the Georgia Department of Natural Resources (Non-Game Division). Occasional grants have been received from the Edward J. Noble Foundation (administered through the American Museum of Natural History), the St. Catherines Island Scientific Research Advisory Committee, the Turner Foundation, the JST Foundation, the M.K. Pentecost Ecology Fund, and the Partnership for Reform in Science and Mathematics (PRISM), an NSF-sponsored initiative designed to improve teachers' science and math content knowledge.

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