Living with the East Florida shore
1. Highway A1A—the road to riches

Highway A1A, the “boulevard” of Jimmy Buffett’s song, connects some of America’s most fabled real estate. From south to north the A1A traveler whizzes and bumps through the faded glory of Miami Beach, the fabulous wealth of Palm Beach, the youthful exuberance of Fort Lauderdale beaches, the engineering marvels of Cape Canaveral, the race-crazy community of Daytona Beach, and ancient, colorful St. Augustine, the oldest town in America. There are a lot of other things for the alert A1A driver to see: endless rows of condominiums hugging the beach, signs tacked to trees offering a few acres of land for millions of dollars, brand-new, sparkling white beaches pumped up from offshore at a cost of millions of dollars per mile, and, if the driver chooses to step out of the car and walk to the beach, seawall after seawall after seawall.

Florida’s shorelines, including the sections traversed by Highway A1A, are her greatest natural assets. What Florida tourism brochure has failed to feature a scene with some variation of the beautiful couple strolling down the sparkling white, palm tree-lined beach next to the beautiful blue sea? The advertisement is a reality. Florida does have a beautiful shoreline, and the shore is to a large degree responsible for much of the tourist trade and even for much of the state’s phenomenal growth of permanent residents (fig. 1.1). Thousands upon thousands of Americans from colder and harsher climes continue to pour south to the promised land of Florida. Thousands upon thousands also pour northward from the mercurial political regimes of the Caribbean. The common meeting ground is the infinite vista of the sea, the rumble of the surf, and the bracing smell of the shoreline.

If Floridians could be satisfied with just seeing, hearing, and smelling the sea, the problems and potential dangers of shoreline development could have been avoided. The beaches and islands could have been left as places to visit or stroll on, as places to swim, surf, or fish from, and simply as places to enjoy.

Because Floridians are subject to the laws of human nature, too, it has not worked out that way. Florida’s open ocean shoreline is the site of ever-larger, ever-closer-to-the-beach, and ever-more-exclusive development. The waterfront is so precious that hundreds of miles of canals have been dug on East Florida’s islands allowing more thousands of people to live right next to the water. The participants in this rush to the shore often hail from Indiana or Pennsylvania or someplace where one’s life experiences do not lead to an understanding of the forces of the sea. Some of those who rush to the Florida shore are simply taking advantage of tax benefits for those who buy vacation property. Orchestrating this rush are entrepreneurs, developers, and realtors who understandably intend to make a profit from the shore. In the normal scheme
of things in our democratic, free enterprise system, the views of those who come to make money should be balanced by the guardians of the quality of our life and environment, that is, the local governments. As in most rapidly developing parts of America, this balance in Florida has not worked very well; some are making money at the expense of undue destruction of the environment and the safety of people.

How else can the development on Florida’s coast be described other than unsafe? Consider the high density of development on hurricane-prone islands with only a drawbridge or two for escape routes; development that is increasingly in the form of high-rise buildings built very close to an eroding shoreline and protected by seawalls and other structures that in themselves increase the rate of erosion and beach degradation. Neil Frank, director of the National Hurricane Center, sometimes sounds like a broken record when he warns again and again that beachfront development in Florida is setting the stage for a great natural disaster. The unprecedented gap in big hurricanes since Hurricane Donna (1960) leveled the Keys has fostered a complacent attitude that is not justified by the facts.

Things are looking up, however. In the early 1980s a number of events came together that will have a positive impact on the future of Florida’s shore. In 1982 the federal government instituted barrier island legislation that effectively takes the federal government out of the development picture on heretofore undeveloped stretches of barrier islands. That is, the federal government will no longer help pay for bridges, roads, sewage and water facilities, and flood insurance for certain designated islands. Beginning in 1981 the Federal Emergency Management Agency (FEMA) began to raise the price of federal flood insurance to its real cost, so the taxpayer is not in the position of subsidizing unsafe development (figs. 1.2 and 1.3). Last, but not least, the state of Florida began to buy up undeveloped lands under the Save Our Coast (SOC) program.

But the news of the eighties is not all good. In 1983 the Environmental Protection Agency (EPA) dropped its “greenhouse effect”
bombshell with a report that warned of warming atmospheres, melting glaciers, and rising sea levels. The prestigious National Academy of Sciences said the same thing. What their warnings boil down to, as far as Florida's coastal areas are concerned, is continued and accelerated shoreline erosion. As discussed in chapter

3. a very small rise in sea level can cause a very large horizontal shoreline retreat.

Those who arrive on the east coast of Florida in coming years have an opportunity to benefit from the experience of the past and to build a better Florida. That is the purpose of this book: to let those who wish to know where the path of sound development lies, and to give those who wish to share in the Florida dream the wisdom to do so safely.
The stormy past

Juan Ponce de León, famous for his unsuccessful search for a fountain of youth, completed the first recorded cruise along Florida's east coast in the spring of 1513, a mere 21 years after the discovery of the New World. Some years later, in 1565, Pedro Mencadez de Aviles established a Spanish settlement at St. Augustine, and Florida's east coastal development began in earnest, albeit slowly. By 1599 the population of St. Augustine had survived Indians on the warpath and attacks by the British, plus a hurricane, and to those early residents Florida was not an impressively habitable place.

A shoreline milestone for East Florida was achieved with the completion of the St. Augustine seawalls, Florida's first, in 1690. By 1761 the English had pushed the Spanish out of Florida. During the next few years settlers dribbled in from several directions, but political instability continued as the British gave Florida back to Spain when they lost the American Revolution. Florida became U.S. territory in 1821 under the terms of the Adams-Onis Treaty. Shortly before the Revolutionary War, 100 plantations had been established along the east coast, but in the early 1800s development was hampered because the land was in the hands of people without much money; in addition, nobody wanted to buy land anyhow after the Seminoles went on the warpath in 1836.

Soon events along the east coast began to occur more rapidly. The site of Miami was picked in 1843. By 1854 Volusia County had a population (in the language of the day) of 300 plus 318 slaves. In 1865 the first land rush by northerners began. In 1868 Ormond (later called Ormond Beach) was founded, and in 1871 M. Day began to develop a tract of land that would someday be called Daytona. By 1875 Daytona's population had shot up to 70, but only 2 houses were on the adjacent island. In 1882 Henry M. Flagler, the first of a string of colorful Florida developers, appeared on the development scene with the purchase of a large portion of Miami Beach. In 1885 Flagler began buying marsh land near St. Augustine, which he filled in for development. He built the 450-room Ponce de Leon Hotel, among others, at a cost of $250,000. Flagler also was responsible for building the East Coast Railway to Miami, with the first train arriving in April 1896. In 1895 construction began on the Breakers Hotel in Palm Beach. It burned down in 1903 and was rebuilt in 1906 (fig. 1.4), burned down again in 1925 and was once more replaced—this time with the present-day structure.

In 1902 James Hathaway, trying out his Stanley Steamer on the beach, “discovered” the great Ormond-Daytona race course (fig. 1.5). In 1903 Ransom E. Olds and his “Pirate” hit speeds in excess of 57 mph on the beach, but beach racing received a black eye when F. Marriott totaled his car “Rocket” on an uneven stretch of sand. Car racing recommenced in 1927 at Ormond Beach; speeds now reached 200 mph. The big annual races continued until World War II. By 1913 Miami Beach was connected to the mainland by the Collins Bridge, and three developers (Messrs. Lummus,
**Fig. 1.4.** The 1917 version of the Breakers Hotel in Palm Beach. Note the wide beach where today no beach at all exists. Photo courtesy of the Palm Beach Historical Society.

**Fig. 1.5.** Horses, carriages, and beach strollers on the 1904 Daytona Beach. Library of Congress.
Fisher, and Collins) began to build what would soon be regarded as the world's most famous beach resort. By 1920 Miami Beach had a population of 644, and Miami contained more than 110,000 souls. A brand-new smuggling industry sprang up overnight with the onslaught of Prohibition, and Florida soon proved to be one of the "leakiest" states with regard to illicit booze.

The boom bubble burst for much of East Florida after the 1926 hurricane, to be followed shortly by the Depression. During the 1930s Floridians began to realize that they had to attract people 12 months a year, not just in winter, so at the end of World War II, with the advent of bulldozers and unprecedented individual wealth in America, the year-round boom was on. The results are there to see, for all who drive Highway A1A.

Throughout the history of Florida's east coast, hurricanes have played an important role in the success and failure of various development schemes. In fact, Florida and hurricanes became almost synonymous—a view that was helped along by Hollywood's penchant for emphasis of the violent and exciting. Who can forget the hurricane scenes in Key Largo, a Humphrey Bogart–Edward G. Robinson thriller still playing on late night TV screens?

One vivid memory of the senior author of this book was a visit to the Florida Keys a few days after Hurricane Donna struck in 1960. The sight of the destruction was awe-inspiring, but even more striking was the widespread pessimism of the survivors. Everyone seemed to feel that so many storms had hit the Keys in this century that Hurricane Donna had dealt a fatal blow to future development. However, the developers who came after Donna's

Fig. 1.6. The big hurricanes of the twentieth century: September 1926, September 1928, September 1947, October 1950 ("King"), September 1960 (Donna), August 1964 (Cleo), September 1964 (Dora), October 1964 (Isabella), August–September 1965 (Betsy), October 1969 (Gerda), August–September 1979 (David).
destruction ignored Mother Nature's danger signals. Now many thousands of new inhabitants live on sites cleared of debris from Hurricane Donna, and there is no way to evacuate the present population living on the Florida Keys in a hurricane emergency situation.

Figure 1.6 shows the paths of most East Coast hurricanes of this century and some of the big ones from times further past. Given Florida's past hurricane history, more lines will have to be drawn on this map in coming years.

Where would you want your parents to live?

During the final stages of writing this book, some of the authors (Pilkey, Jr., Neal, and Gruver) took a trip up Highway A1A, traveling the entire length of the east coast of Florida (fig. 1.7). It was a revealing experience and one that we would recommend to all potential beach-front homeowners before their purchase of property. The trip showed us far better than the reading of technical reports and the scanning of maps and aerial photographs what is happening to the Florida shoreline. The A1A traveler can see the wide variation in the quality of development practices along the shoreline. A surprising (to us) number of communities are doing the right thing by holding development back from the beach (for example, the beaches south of St. Augustine). But those communities are the exception rather than the rule. More often, newly developing areas are allowing buildings to crowd the shore (for example, the beaches south of Daytona Beach) where seawalls are often built simultaneously with high-rise construction.

As we drove along A1A, we decided the stiffest standard we could apply to judging the safety of a beach community was this one: would we recommend to our parents or our children that they live there? Recognizing fully that this is probably an unduly stringent standard by which to judge coastal development, we found few areas that would satisfy this criterion. Stepping back and looking at the big picture of all of Florida's shoreline, we have concluded (partly as a result of writing the West Florida companion volume to this book) that we would prefer that our parents live on the east coast of Florida rather than the west coast. This is because so many of West Florida's barrier islands are low in elevation and because in some areas (the Tampa-St. Petersburg coast) the evacuation problem borders on hopeless. Exceptions to these generalities may be found on the Panhandle coast.

Having settled on the east coast as the safest side of Florida for our parents, we found a number of communities here that we classified as low risk (see chapter 4 for our risk analysis). Even in some of the low-risk zones we would worry about the evacuation problem, especially for aging parents. Only two areas stand out as having few or minor evacuation problems, especially if one chooses a good site according to the criteria outlined in chapter 4. These are the Juno Beach area in Palm Beach County and Amelia Island in Nassau County next to the Georgia border.

The best way to satisfy your own instincts regarding the relative safety of your proposed living site is to make your own A1A odyssey. Take along this book and see for yourself.
Fig. 1.7. Index map of the east coast of Florida showing the main islands and communities.
2. How the shoreline works

Most of Florida's east coast consists of a chain of barrier islands. These barriers, including capes and peninsulas, are narrow strips of sand that in comparison with any other portion of the continents are extremely dynamic. These islands act as a buffer for storm waves—hence the term by which they are known. Barrier islands are found off every coastal plain coast in the world, and along U.S. shores the barrier chain extends from the south shore of Long Island to the Mexican border. The Florida Keys represent one of the few breaks in the chain. The Keys are a string of upraised coral reefs that flourished more than 100,000 years ago when the sea level was higher. They are hard, immobile rock, not unconsolidated, movable sand like barrier islands.

There is a considerable variation in the size and shape of barrier islands. For example, Fernandina Island near the Georgia border is 3 miles wide compared to Hutchinson Island, a mere 200 yards in width in places. This difference in shape and size is due to many factors, but the most important is the volume of sand that comes ashore from the beach. The difference between East and West Florida's barrier islands can be explained by sand supply. West Florida's islands are almost all narrow and much lower in elevation than East Florida's. Less sand has been blown ashore on the west side to form the all-important sand dunes, and as a consequence West Florida islands are generally less safe for development.

In this chapter we will discuss how the East Florida shoreline works. Ironically, considering how important it is to Floridians, the chain of Florida islands making up the east coast are the least studied of any such islands along the Atlantic coast. In contrast, the islands of North Carolina, South Carolina, Delaware, and Texas have been drilled, trenching, mapped, and photographed by a whole generation of coastal geologists. Nonetheless, the basic principles of island and beach evolution are well established, and we can apply them with confidence to East Florida.

If you plan to live in an East Florida beach community, you must understand the natural processes at work there. Your safety and well-being depend on it. The safety and well-being of your community depend on it. A good place to start in your understanding of the shore is with the origin of barrier islands.

Barrier islands: where they come from

Florida has barrier islands because of the interaction of a rising sea level with a coastal plain indented by river valleys (fig. 2.1). Approximately 15,000 years ago, when sea level was as much as 300 feet lower than today, the Florida shoreline was many miles offshore, on what is now the continental shelf. Vast glaciers covered the high latitudes of the world, tying up a great volume of water.

But then the ice started melting and the sea began to rise. The rising water flooded the valleys, forming bodies of water called
Stage 1: Flooding of river valleys

Stage 2: Formation of spits along headlands

Stage 3: Separation of barrier from mainland

Fig. 2.1. The origin of barrier islands in a rising sea level.
estuaries. If you look at a map of today's continental shoreline, you can see many such inundated valleys, especially along the Atlantic coast of the United States. Chesapeake Bay and Delaware Bay are two prominent examples. Along Florida's east coast the best examples of estuaries are the St. Johns and St. Marys rivers to the north.

If this were all that occurred, the shoreline today would be jagged. Nature, however, tends to straighten jagged shorelines. Wave action cut back the headlands—the areas of land that extended seaward between flooded valleys—and built spits extending from the headlands across the bay mouths. As sea level continued to rise, the low-lying land behind such spits, plus the sand dunes of the old headland shorelines, then became flooded. The flooding behind the old dune beach complexes resulted in their becoming detached from the mainland, and the barrier islands were born.

This concept of barrier island origin and growth was developed by a number of geologists, including the late John Hoyt of the University of Georgia and Donald Swift who is now with Arco Oil and Gas Company.

The operation of barrier islands

Islands on the move

You might ask why, if sea level continued to rise, the newly formed islands were not themselves covered by the sea. The answer, which only recently has been agreed upon by geologists, is that islands do not simply stay in one place when the sea level threatens to rise over them. The islands move or migrate toward the mainland. The more rapid the sea-level rise, the more rapid the island migration.

Needless to say, for the islands to have remained islands, the mainland shore must have moved, too. This is indeed what happened: the shoreline on the mainland retreated as the island advanced. Otherwise the islands would have run aground. Miami Beach probably migrated 5 or 10 miles to its present position. Fernandina Beach probably formed 50 miles or so offshore. Some barrier islands along the Texas and Mississippi Gulf coasts may have migrated more than 100 miles.

The sea-level rise was quite rapid until about 5,000 years ago, at which time it slowed down considerably (fig. 2.2). Hence, up until 5,000 years ago Florida's barrier islands were moving landward at an impressive clip. The most rapidly moving islands tend to be low, very narrow strips of sand. Cape Island, South Carolina, and Sand Key in Florida Bay (fig. 2.3) are small-scale examples of this kind of island. Fernandina Beach is an example of a wide, very slow-moving island.

When the slowdown in sea-level rise came, many islands stopped migrating altogether. And because they then remained in one position long enough for sand from various sources to accumulate, they also began to widen. This relative stability, however, has recently come to an end (fig. 2.4).

The accelerating rise in sea level

Recent studies suggest that in the 1930s the rise in sea level suddenly accelerated. Sea level is now rising at a rate of perhaps
slightly more than 1 foot per century. Keep in mind that this refers to a vertical rise. The horizontal change—the distance islands migrate as a consequence—is much greater (fig. 2.5) than the vertical rise. In theory, a 1-foot rise in sea level should produce a horizontal shoreline retreat of more than 1,000 feet. How much a specific island moves depends on the slope of its migration surface: the gentler the slope, the more the island will migrate.

The safest assumption you can make about the future of sea-level rise is that it will continue and accelerate. The National Academy of Sciences has warned that all evidence points to a warming of the earth's climate. The burning of fossil fuels has resulted in excessive production of carbon dioxide, which causes...
the atmosphere to retain heat. This warming is expected to increase the melting of the polar ice caps, which, in turn, will raise sea level.

The Environmental Protection Agency, in a report released during October 1983, suggests that sea level should rise between 2 feet and 10 feet by the year 2100. Four feet is the most plausible figure, but there is a lot of educated guesswork in these numbers. In any event, almost certainly the sea-level rise will accelerate and shoreline erosion will increase accordingly.

**Barrier Island migration**

Do you want to prove to yourself that barrier islands migrate? If you are standing on one now, walk to the oceanside beach and look at the seashells. Chances are that on most natural Florida beaches you will find the shells of oysters, clams, or snails that once lived in the lagoon or river on the back side of the barrier island between the island and the mainland. How did shells from the back side get to the front side? The answer is that the island migrated over the lagoon, and waves attacking and breaking up the old lagoon sands and muds threw the shells up onto the present-day beach. (This assumes you are looking at a natural beach where sand has not been pumped in from behind the island or from the shelf in front of the island; see chapter 3.) It follows that if some of the shells on Florida’s beaches are from preexisting environments, the average age of the shell material must be quite old. In fact, many of the shells one picks up on a Florida beach are several
Fig. 2.4. The sea-level rise illustrated by the level of barnacles on Miami Beach Pier. Photo by Harold R. Wanless.
thousand years old and are actually fossils. The U.S. Army Corps of Engineers, a few years back, obtained some radiocarbon dates of the shell material on three South Florida beaches. The samples dated contained a number of shells, and all 3 revealed ages of around 13,000 years. In addition, salt-marsh peats that formed in back of the islands at some earlier time are exposed occasionally on oceanside beaches after storms. On Whale Beach, New Jersey, a patch of mud that appeared on the beach after a storm contained (much to the surprise of some beach strollers) cow hooves and fragments of colonial pottery. The mud was formerly salt marsh on the back side of the island where a colonist had dumped a wagonload of garbage. Since colonial times this particular section of the island had migrated its entire width! On some Florida islands, evidence of beach erosion (or of the front side of the island moving back) can be seen by stumps on the beach. For example, stumps protrude from the beach at the north end of Jupiter Island and on portions of Hutchinson Island (fig. 2.6).

For an island to migrate (fig. 2.7), the side on the ocean (the front side) must move landward by erosion, and the side toward the mainland (the back side) must do likewise by growth. Also, as it moves, the island must somehow maintain its elevation and bulk. If you have not guessed already, island migration is the term that geologists use for what beach cottage or condo owners call beach erosion (fig. 2.8).
Fig. 2.7. A diagram showing how a barrier island similar to Anastasia Island might behave during the next 100 years. The island should be expected to initially thin by erosion on both the back and front sides, following which migration will begin in earnest (assuming an accelerating rise in sea level).
Front side moves back by erosion

The beach on the front side moves back because the sea level is rising. The rise in sea level is a major cause of beach erosion worldwide, although man can make erosion worse, sometimes much worse, by interfering with the sand supply. For example, the groins and seawalls on many of Florida's beaches have increased rates of erosion on nearby beaches. The seawall effect is amply illustrated by beachless Palm Beach. The impact of groins could once be seen during the sixties and seventies on beachless Miami Beach before the new beach was pumped up in 1981. Even greater erosion of beaches is usually caused by jetties and artificially cut inlets, examples of which abound on Florida's east coast. Jetties that have caused serious problems for nearby beaches include those for Miami Harbor, Lake Worth Inlet, and St. Lucie Inlet.

Back side moves back by growth

There are several ways for an island to widen. On the narrow, low Florida islands that are separated from the mainland by an open body of water (called a lagoon or a sound) rather than by a marsh, a common widening process is that of incorporation of old flood-tidal deltas from closed inlets.

An inlet is the channel of water between adjacent barrier islands. The inlet may be a permanent feature in front of the mouth of a river or stream, or it may be a short-lived feature that forms when water breaches the island during a hurricane. Eyewitness accounts and other evidence confirm that water sometimes breaks through

Fig. 2.8. A striking example of island migration. The jetties built at the south end of Ocean City, Maryland (top of photo), caused sand starvation of adjacent Assateague Island. In the early 1930s the 2 islands formed a more or less straight line.
the island from the sound side, or back side, as the storm subsides and high tides retreat. Over the years following the formation of an inlet, sand carried by incoming tides pours through the gap and into the sound. This mass of sand is called a flood-tidal delta (see fig. 2.3) and forms the shallows on which boats go aground and through which the Corps of Engineers must dredge to maintain channels. (There also is a delta, called an ebb-tidal delta, on the ocean side of an inlet. This is formed by currents flowing out of the sound during falling tide.)

After a few decades many inlets either close or they migrate away from the flood-tidal delta. Salt marsh establishes itself on the shallow delta, and then the salt marsh grasses trap sediment and cause the land to be built up almost to high-tide level. Thus, new land is added to the back of the island. The inlet’s former position is marked only by a marsh bulging into the lagoon.

When an inlet migrates laterally to a new position, the flood-tidal delta moves with it. In other words, as the inlet migrates, sand continues to pour into the lagoon, and a series of new flood-tidal deltas are formed along the entire area of inlet migration. In this way the island is widened over the full distance that the inlet shifts.

Another way that islands—especially narrow ones—can be widened is by direct frontal overwash of storm waves from the ocean side. All barrier islands receive overwash during storms. On large islands the overwash may barely penetrate the first line of dunes. On low, narrow islands overwash may be carried across the island to reach the lagoon. Overwash waves carry sand that is deposited in tongue-shaped or fan-shaped masses called overwash fans. When such fans reach into the lagoon, the island may be widened. If islands are backed by salt marshes or mangrove swamps, overwash sediment may bury them. Interestingly enough, the vegetation on many islands actually flourishes when buried by an overwash fan. In a few months some plants grow right up through the sand layer.

Overwash is the method of back-side growth used by islands in a hurry—that is, those that are migrating rapidly landward. Cape Island, South Carolina, and some of Louisiana’s islands are examples of islands migrating perhaps tens of feet per year. Between 15,000 and 5,000 years ago when the sea level was rising rapidly, most American barrier islands were probably of the overwash type. If the EPA is correct in its predictions concerning the upcoming accelerated rise in sea level, we can expect many of our islands to begin thinning down to use the overwash migration mechanism.

**The island maintains its elevation during migration**

The remaining problem of a migrating island is how to retain its bulk or elevation as it moves toward the mainland. This problem is solved by two processes: dune formation and overwash-fan deposits.

Dunes are formed by the wind, and if a sufficiently large supply of sand comes to the beach from the continental shelf via the waves, a high-elevation island can be formed. Winds blowing on shore across the beach carry sand that dune plants trap, causing the sand to accumulate and build up. The wider the beach the
more sand can be picked up by winds. Examples of well-developed ridges of dune sand on Florida's east coast include Daytona Beach, where several parallel ridges afford high elevation and a relatively safe location for construction. More commonly on East Florida's islands a single beach ridge or dune line is found next to the beach. Frequently Highway A1A, the coastal highway, occupies the top of this ridge. A particularly good example of a high dune ridge fronting a beach can be seen along the open ocean shore off Delray Beach and Boynton Beach. Such a ridge makes development safer, but not if condos and homes are built in front of the ridge, as often happens.

Sometimes the reason for the lack of dune formation on islands of low elevation (for example, many of Florida's west coast islands) is the lack of sand supply from the adjacent continental shelf. Sometimes dunes do not form on an island because the dominant winds do not blow across the beach and into the island. Finally, if the natural sand is too fine, it will not build up into dunes.

Size and shape of barrier islands

The most untrained eye can readily see that Florida's islands come in a wide variety of shapes and sizes. Ponte Vedra Beach and vicinity consists of a single ridge of sand a few yards wide, backed up by salt marsh. Fernandina Beach on Amelia Island occupies a wide, high island that is heavily forested. Amelia Island is actually the southernmost of the Sea Islands that make up the coast of Georgia. Miami Beach occupies a seemingly wide island with broad Biscayne Bay between it and the mainland. However, the natural island before clearing in 1882 was a fairly narrow strip of dune sand backed by a broad band of low-elevation mangrove swamps. At Fort Lauderdale the island is only an island because the intracoastal waterway separates a strip of land from the mainland. Before the development of Fort Lauderdale, a narrow mangrove swamp separated mainland and island, but all signs of this swamp have disappeared.

Cape Canaveral occupies a piece of land that geologists call a cuspate foreland. Cape San Blas on the other side of the Florida peninsula and Cape Hatteras, North Carolina, are similar features. There is no unanimity of opinion as to how such capes form, and their origin remains a major unresolved question for shoreline geologists. Offshore from each of the capes is a large bar of sand called a shoal that extends seaward and upon which many unwary mariners have come to grief.

The factors responsible for all of these differences in island shape are numerous. The most important of them is sand supply. If a lot of sand can come ashore from beaches either by wind or overwash, the island will be high and wide. Low sand supply produces narrow, low islands.

The dominant mineral in most of East Florida's beach sands is quartz, a very stable form of silicon dioxide. The nearest sources of quartz are the rivers of Georgia and South Carolina. The quartz sand has been slowly pushed south by the waves over a period of several millions of years, and some grains must have traveled as much as 400 miles. Looking at the sand supply problem from a
more immediate perspective in time, sand for a particular East Florida beach comes from two sources. It is pushed up from the shelf by waves, and it is pushed from north to south by longshore currents in the surf zone. (Longshore currents are further discussed in a later section of this chapter.) Some of the factors that affect sand supply and hence the shape of islands include island orientation, steepness of offshore slope, prevailing wind directions, prevailing wave and storm wave direction, and the tidal range. Fetch, or distance, over which wind-formed waves can travel is important, too. Miami Beach is protected from most large storm waves by the Bahama Banks. No such protection is available for most of Florida, however, and waves from storms hundreds of miles away may strike the shore.

One aspect of Florida’s barrier islands that is unusual along the east coast of the United States is the abundance of rock underlying them. Rock is particularly common on islands south of Cape Canaveral. Often the rock crops out on the beach and holds the island in place much like a massive seawall. The irregular shape of the front side of some of the islands is due to rock holding one part of the beach in place as other sections retreat landward. In times past some of the rocks were mined for building stone. Important examples of rocks outcropping on beaches include Seminole Shores and Blowing Rock in Martin County, and Singers Island, Ocean Ridge, and Boca Raton in Palm Beach County. An easily accessible 2-mile stretch of rocky beach is found just south of Marine-land in Flagler County.

**Barrier island environments**

Barrier islands consist of a number of distinct and recognizable environments (or ecosystems) including the beach, beach ridges, back-barrier flats, salt marshes, mangrove swamps, and maritime forests, to name a few (fig. 2.9). Beach ridges are lines of sand dunes parallel to the beach that often are the highest areas on an island. On most of Florida’s east coast islands the individual dune ridges are quite distinct. Many islands have only a single dune ridge—for example, Hutchinson Island and most of Flagler County. On the other hand, Daytona Beach sits astride several parallel ridges that can sometimes still be discerned in spite of heavy development. Back-barrier flats are, as the name clearly implies, flat portions of an island on the back or lagoon side. In southern Florida the fringes of the lagoon side of islands always are (or at least were before development) a strip of mangrove trees. North of Vero Beach salt marshes replace mangrove swamps as the dominant back-island fringe.

Each environment on a barrier island is part of an overall integrated system, and to some degree it depends on all the other environments. Perhaps the best example of one environment affecting others in the system is provided by the role of the oceanside beach. The beach is important because (1) it alters its shape during storms in such a way as to minimize fundamental damage to the island by waves, and (2) it is the major source of sand for the entire island. Examples of the ways in which man has interfered in the integrated system may best illustrate these functions.
Fig. 2.9. A generalized diagram showing the major environments of a barrier island. In South Florida the "low marsh" location on this diagram is occupied by mangroves, and the high marsh strip is often populated by Australian pines. Diagram by Paul Godfrey.
A particularly intriguing example of man's effect was discovered by Dr. Paul Godfrey of the University of Massachusetts. He observed that the long, continuous, artificial dune built on the open ocean side by the National Park Service on the Outer Banks of North Carolina near Cape Hatteras is causing erosion on the lagoon side of the island. The problem is that the artificial dune prevents overwash fans from crossing the island during storms. Before the dune was built, overwash frequently reached the back side of the island, and new salt marsh was formed on the edge of the new overwash fan. Newly formed *Spartina* marsh is an excellent erosion buffer against lagoon-side waves. By preventing overwash, the frontal dune on the ocean side of the island precludes new marsh growth. Old salt marsh (20 to 30 years old) is a poor erosion buffer, so the lagoon-side erosion rate increases.

If overwash on a low-elevation island (such as portions of Jupiter and Hutchinson islands) is not obstructed, the marsh in time (10 years or more) builds up its elevation and essentially chokes itself. The grass thins out and becomes shorter and less healthy. The most casual observers walking along the back side of any marsh-fringed island in its natural state note that they are walking through alternately tall and short grass. The tall grass is new or fresh grass on recent overwash; the short grass is old grass on an old overwash fan. Old marsh is a poor buffer against shoreline erosion and soon begins to give way.

The maritime forests found in Florida's larger islands also illustrate the integration of island environments. The large trees are salt-tolerant and form a canopy over the less tolerant undergrowth. The undergrowth, in turn, stabilizes the larger trees by holding down the soil. If trees are thinned or removed, salt spray can attack and eliminate the undergrowth. Loss of vegetation allows sediment to be eroded by wind or other processes, thereby destroying the larger trees.

Much has been said about the damage to islands by dune buggies and other off-road vehicles. This problem further attests to the integration of island environments. Dune buggies can prevent dunes from stabilizing (becoming stationary), and destabilization (moving sand) may result in destroyed dunes and vegetation, followed by sand dune migration into maritime forests or developments.

The most common cause of excessive sand movement on barrier islands is construction. The problem is particularly acute during the early stages of construction, and in many instances sand movement has halted a building project altogether. Also, a common mistake made on barrier islands is the type of road construction leading to developments. On many American barrier islands you can drive along roads that parallel the beach and observe that at the end of each feeder road there is a giant notch cut through the last row or two of dunes. Such notches are certain someday to provide a path for storm-wave overwash. Beach access roads should go over not through dunes, and they should be curved rather than straight.

**Beaches: the dynamic equilibrium**

The beach is one of the earth's most dynamic environments. The
beach—or zone of active sand movement—is always changing and always moving, and we now know that it does so in accordance with the earth's natural laws. The natural laws of the beach control a beautiful, logical environment that builds up when the weather is good, and strategically (but only temporarily) retreats when confronted by big storm waves. This system depends on four factors: waves, sea-level rise, beach sand, and shape of the beach (fig. 2.10). The relationship among these factors is a natural balance referred to as a dynamic equilibrium: when one factor changes, the others adjust accordingly to maintain a balance. When we enter the system incorrectly—as man often does—the dynamic equilibrium is destroyed.

**The beach quiz**

Answers to the following often-asked questions about beaches may clarify the nature of this dynamic equilibrium. It is important to keep in mind that the beach extends from the toe of the dune to a depth of 30 to 40 feet, which may be miles offshore. It is the zone of sand movement during storms. The part on which we walk or sunbathe is only the upper beach.

**How does the beach respond to a storm?**

Old-timers and storm survivors from barrier islands frequently have commented on how flat and broad the beach is after a storm. The flat beach can be explained in terms of the dynamic equilibrium. As wave height increases, the dunes at the back of the beach are eroded and sand is moved seaward across the beach, changing its shape. The reason for this storm response is quite logical. The beach flattens itself so that storm waves expend their energy over a broader, more nearly level surface. On a steeper surface—take a vertical seawall, for example—storm-wave energy would be expended on a smaller area, causing greater damage.

![Fig. 2.10. The dynamic equilibrium of the beach.](image)

**Fig. 2.10.** The dynamic equilibrium of the beach.
(Shaded area $A^1$ is approximately equal to shaded area $A$.)

Fig. 2.11. Storm response by the healthy natural beach.
dune and transport it to the lower beach. If a hot dog stand or beach cottage happens to be located on the first dune, it may disappear along with the dune sands. This also is the reason why condos must be built on deeply embedded stilts in case storm waves begin to eat away at the base of the building.

An island can lose a great deal of sand during a storm. Much of it will come back, however, gradually pushed shoreward by fair-weather waves. As the sand returns to the beach, the wind takes over and slowly rebuilds the dunes, storing sand to respond to nature's next storm call. In order for the sand to come back, of course, there should be no man-made obstructions—such as a seawall—between the first dune and the beach. Return of the beach may take months or even years.

Sometimes besides simply flattening, a storm beach also will develop one or more offshore bars. The bars serve the function of tripping the large waves long before they reach the beach. The sand bar produced by storms pulling sand offshore from the beach is easily visible during calm weather as a line of surf a few tens of yards off the beach. Geologists refer to the bar as a ridge and the intervening trough as a runnel.

**How does the beach widen or build seaward?**

Beaches grow seaward in several ways, principally by (1) bringing in new sand on the so-called longshore (surf-zone) currents, or (2) bringing in new sand from offshore by forming a ridge-and-runnel system. Actually, these two ways of beach widening are not mutually exclusive.

Longshore currents are familiar to anyone who has swum in the ocean; they are the reason you sometimes end up somewhere down the beach, away from your towel. Such currents result from waves approaching the shore at an angle; this causes a portion of the energy of the breaking wave to be directed along the beach. When combined with breaking waves, the weak current is capable of carrying large amounts of very coarse material for miles along the beach. The sand transported along the shore may be deposited at the end of the island, or it may cross to the next island.

In general, sand along the beaches of Florida travels from north to south. As mentioned earlier, over a period of many thousands of years the quartz sand that made up the old Miami Beach traveled from source rivers in faraway Georgia.

Ridges and runnels formed during small summer storms virtually march onto the shore and are welded to the beach. The next time you are at the beach, observe the offshore ridge for a period of a few days and verify this for yourself. You may find that each day you have to swim out a slightly shorter distance in order to stand on the sand bar.

At low tide during the summer, the beach frequently has a trough filled or partly filled with water. This trough is formed by the ridge that is in the final stages of welding onto the beach. Several ridges combine to make the berm, or beach terrace, on which sunbathers loll.

**Where does the beach sand come from?**

Along the east coast of Florida and along most of the Atlantic
portion of the American barrier coast—which runs approximately 10,000 miles from the south shore of Long Island down and around to where the Texas coast meets Mexico—the sand comes from the adjacent continental shelf. It is pushed up to the beach by fairweather waves. Additional sand, sometimes very large quantities of it, is carried laterally by longshore currents that move in the surf zone parallel to the beach. Rivers contribute sand directly to barrier beaches only along the Gulf coast, starting with Florida's Apalachicola River. Along the rest of America's barrier chain, sand carried by rivers does not make it to the coast. Rather it is deposited far inland at the heads of estuaries or behind man-made dams.

It is important for beach dwellers to know about or at least have some sense of the source of sand for their beach. If, for example, there is a lot of longshore sand transport in front of your favorite beach, the beach may well disappear if someone builds a groin or even a seawall upstream. Community actions taken on adjacent islands or inlets potentially could affect your beach, just as your actions may affect your coastal neighbors.

Where do seashells come from?

The main source of shells on a beach is from animal communities that line the nearshore zone adjacent to the beach. As we already have discussed, some of the shells on Florida's beaches were originally deposited behind the island and came to the beach after the island migrated right over them. If you use a shell book to identify all of the specimens from a beach, you will find a number of species that do not belong near an open ocean beach. Instead, they come from the lagoon or estuary.

Another source of shells on a number of beaches south of Cape Canaveral (for example, Boynton Beach, Vero Beach, and Jupiter Island) are outcropping rocks containing abundant fossil shells. As waves break the rock up, the fossil shells (which are often stained brown) become part of the beach sand and usually are transported south by longshore currents.

Why do beaches erode?

As we have already pointed out, beach erosion (figs. 2.12 and 2.13) is the cottage owner's term for the larger process called island or shoreline migration. Its principal cause is the sea-level rise—presently judged to average about 1 foot per century along American shores. We in Florida can be thankful that we do not have the more rapid 3-feet per century rise of portions of the New England coast. (The reason sea-level rise can be different in different coastal areas is that the land also may be sinking or rising slowly relative to sea level.)

On a year-to-year basis this sea-level rise is imperceptible. The actual erosion is still achieved by waves, so our short-term observation is to associate extensive erosion with a particularly intense storm. Our responses tend to be directed at such storm events when we design "protective" structures such as groins and revetments. The prime cause for erosion, however, is the sea-level rise. The impact of this rise is within one's lifetime and should not be regarded as such a long-term event as to be of no consequence.
Fig. 2.12. Beach erosion is about to catch up with this condo and has already caught up with the house down the beach. This is a low-tide scene from Vero Beach, looking north. Photo by Dinesh Sharma.

Increasingly, along the East Florida shore, man is becoming the major cause of shoreline erosion. Take jetties, for example. Almost every Florida inlet is jettied, and almost everywhere erosion is rampant south of the jetty. This is discussed in more detail in chapter 3.

Fig. 2.13. The roots on this palm tree on Key Biscayne are exposed due to beach lowering or loss of sand, that is, beach erosion. Photo by Bill Neal.
Are the shorelines on the back sides of our islands eroding?

The back side (lagoon side) of most American barrier islands is eroding just like the open ocean side. The reason for this, in large part, is the rise in sea level. However, most of Florida’s heavily developed islands now have seawalls on the back side that halt the erosion. Where development is less heavy, particularly north of Cape Canaveral, many examples of eroding marshes and beaches can be seen on the back sides of islands.

What can I do about my eroding beach?

This question has no simple answer, but it is briefly addressed in chapter 3. If you are talking about an open ocean shoreline, there is nothing you can do unless (1) you are wealthy or (2) the U.S. Army Corps of Engineers steps in. Your best response, especially from an environmental standpoint, is to move your threatened building back. The bottom line in trying to stop erosion of an open ocean shoreline is that the methods employed will ultimately increase the erosion rate. For example, the simple act of hiring a friendly bulldozer operator to push sand up from the lower beach will steepen its profile and cause the beach to erode more rapidly during the next storm. Pumping in new sand (replenishment) costs a great deal of money, and in most cases the artificial beach will disappear much more rapidly than its natural predecessor. For example, artificial beaches at Pompano Beach and Hobe Sound disappeared much faster than originally predicted.

There are many ways to stop erosion in the short run if lots of money is available. But, in the long run, erosion cannot be halted except at the cost of losing the natural beach.

If most ocean shorelines are eroding, what is the long-range future of beach development?

The long-range future of beach development will depend on how individual communities respond to their migrating shoreline. Those communities that choose to protect their front-side houses at all costs need only look to portions of the New Jersey shore to see the end result. The life span of houses can unquestionably be extended by stabilizing a beach (i.e., slowing the erosion). The ultimate cost of slowing erosion, however, is loss of the beach. The time required for destruction of a beach is highly variable and depends on the shoreline or island dynamics. Usually an extensive seawall on a barrier island will do the trick in 10 to 30 years. Often a single storm will permanently remove a beach in front of a seawall.

If, when the time comes, a community grits its teeth and moves the front row of buildings or lets it fall in, the beaches can be saved in the long run. Unfortunately, so far in America, the primary factor involved in shoreline decisions, which every beach community must sooner or later make, has been money. Poor communities (Folly Beach in South Carolina or Sargent Beach in Texas) let the island roll on. Rich ones try to stop it.

Therein lies a problem of high-density development right next to the surf zone. As the shoreline recedes naturally and predictably, it is one thing for a community to allow individual cottages to
fall in, but 20-story condominiums would be a “bit” more painful to allow to disappear.

The future of shoreline development in East Florida appears to be one of increasing expenditure of money leading to increasing loss of beach.

A word about storms and hurricanes

Sea-level rise may be the ultimate villain in the shoreline saga, but hurricanes are the most memorable actors. Coastal processes or wind, wave, storm surge (the increase in water level during a storm), and overwash are greatest during hurricanes, but the majority of today’s coastal residents and property owners have not experienced such storms. The relatively hurricane-free period from the 1960s to the present has contributed to an apathetic disregard of the hurricane menace and has increased development in high-hazard zones. Time is not on the side of such development.

Although hurricanes get the lion’s share of the publicity and public awareness campaigns, the shorelines of the east coast of Florida are probably more endangered by “common, old, everyday” winter storms, particularly northeasters. In the county-by-county descriptions of East Florida shoreline safety classifications (chapter 4) quite a bit is said about northeaster storms in recent years. Northeasters differ from hurricanes in that they hang around longer and pound the shoreline for days rather than hours. The two biggest storms in recent years were the Ash Wednesday storm of 1962 and the Lincoln’s Birthday storm of 1973. The 1962 storm was the biggest Atlantic storm of this century. It struck during the full moon, the time of spring tides, and it hovered offshore for 3 long days. A great deal of shoreline retreat and severe damage to buildings built too close to the shore were reported from South Florida to Massachusetts. The greatest damage was done along the New York–New Jersey shoreline. Flooding of low areas on barrier islands also can be severe during big northeasters. Floodwaters from the ocean are pushed up into lagoons and estuaries by these storms just as in the case of hurricanes. The wise Florida coastal dweller will watch out for northeasters as well as hurricanes!

Each year on June 1 the official hurricane season begins. For the next 6 to 7 months conditions are favorable for hurricane formation over the tropical to subtropical waters of the Western Hemisphere. Hurricanes that ultimately strike the eastern United States tend to originate in the Gulf of Mexico or Caribbean Sea early in the season, and later in the season (August, September, and October) in the eastern North Atlantic Ocean.

Although meteorologists are still seeking answers to the causes and mechanics of hurricanes, the basic model of what happens is known. During the summer the surface waters off West Africa heat up to at least 79°F. Evaporation produces a layer of warm, moist air over the ocean. This moist air is trapped by warm air coming off the African continent, but some is drawn upward. As the moist air rises, it cools and condenses, releasing heat, which in turn warms the surrounding air, causing it to rise. As a result of the increasing mass of rising air, a low-pressure area forms (tropical depression), and warm, easterly winds rush in to replace the
rising air. The effect of the earth's rotation deflects the air flow, and the counterclockwise-rotating air mass begins to take on the familiar shape of a hurricane. Air forced to the middle of the spiral can only move upward, producing a chimneylike column of rising air—the "eye" of the storm.

So a heat engine effect evolves, with rising, moist air cooling and condensing, releasing heat to cause more air to rise, allowing more air to rush in over the sea, an endless source of moisture. Heavy rainfall characterizes the edges of the cloud mass, and when sustained wind velocities reach 74 mph the storm is classed as a hurricane. The strongest winds of a hurricane may exceed 200 mph, and the maximum winds of the largest storms to hit coastal areas are generally unknown because the wind-measuring instruments are blown away!

Once formed, the hurricane mass begins to move and may continue to grow in size and strength. The velocity of this tracking movement can vary from nearly stationary to greater than 60 mph. If you consider that the diameter of a hurricane ranges from 60 to 1,000 miles, and that gale-force or higher winds may extend over most of this area, the total energy released over the thousands of square miles covered by the storm is almost beyond comprehension. No ship or seawall, cottage, condominium, or other static structure will be immune from the impact of such forces. For a hurricane making landfall on the east coast of Florida, these forces will be at their maximum in the area to the right (north or east) of the eye (fig. 2.14), but the entire landfall area will experience the severity of the storm. If the hurricane comes on a high tide, espe-
cially a spring tide during a full moon, the effects of storm-surge flooding, waves, and overwash will be magnified.

Today the hurricane watchers of the National Oceanic and Atmospheric Administration track hurricanes and provide advance warning for the evacuation of threatened coastal areas. Yet as little as 9 to 12 hours advance warning may be all that is possible, given the unpredictable turns a hurricane may take. That is not much lead time.

**Hurricane probability and rank**

In modern times, storms have been compared in terms of dollar loss, but this comparison reflects the nature of the development damaged rather than the strength of the hurricane. Likewise, smaller storms of less than a century ago were more deadly than the largest of today's storms. Today, advance warning, efficient evacuation, and safer construction should result in low casualty rates even in a major hurricane. But unsafe development, allowing population growth to exceed the capacity for safe evacuation, and complacency on the part of coastal residents could reverse this trend with shocking results.

Many of the areas of dense population on Florida's islands are virtually impossible to evacuate completely before the onslaught of a storm. In southern Florida care must be taken in choosing a place to evacuate because many inland areas also will be flooded by the same storm that will inundate the island. Juno Beach and environs is an example of a beach area where high elevations are available for evacuation immediately adjacent to the beach. But the Miami Beach-Fort Lauderdale shoreline stretch is backed by large areas of low-elevation mainland, and care must be taken to choose your storm haven.

The National Weather Service has adopted the Saffir-Simpson scale (Table 2.1) for communicating the strength of a hurricane to public safety officials of communities in the storm's potential path. The scale ranks a storm on three variables: wind velocity, storm surge, and barometric pressure. Although hurricane paths are still unpredictable, the scale communicates quickly the nature of the storm—what to expect in terms of wind, waves, and flooding.

Do not be misled by such scales, however. A hurricane is a hurricane. The scale simply defines how bad is bad. When the word comes to evacuate, do it. Wind velocity may change, or the configuration of the coast may amplify storm-surge level, so the category rank can change. Do not gamble with your life or the lives of others.

See appendix A for a checklist of things to do when a hurricane threatens.