Figure 2-1 is a 1998 aerial photograph of the Avon-Buxton segment of the Outer Banks showing the location of the Sea-View site. Figure 2-2A is a 1992 oblique aerial view and figure 2-2B is a 1999 aerial photograph of the Avon-Buxton site on Hatteras Island. These figures demonstrate how narrow the Avon-to-Buxton coastal segment is. It is a classic overwash barrier island that is basically sediment poor (relatively small quantity of available sand) and has the highest wave energy along the U.S. Atlantic coast. Consequently, the beach tends to be narrow and steep with coarse gravelly sand sediment (see table 2-1 in the lesson “Making a cross island topographic profile”).

In addition, the Avon-Buxton area has extremely high ocean shoreline erosion rates that regularly threaten N.C. Highway 12 and other ocean-front properties, including the Cape Hatteras Lighthouse. Beginning in the late 1930s, and particularly since the 1962 coastal storm, reconstruction and maintenance of ever higher and increasing numbers of temporary barrier-dune ridges have been built to protect N.C. Highway 12. This practice has significantly changed the physical processes and responses along this barrier island segment.

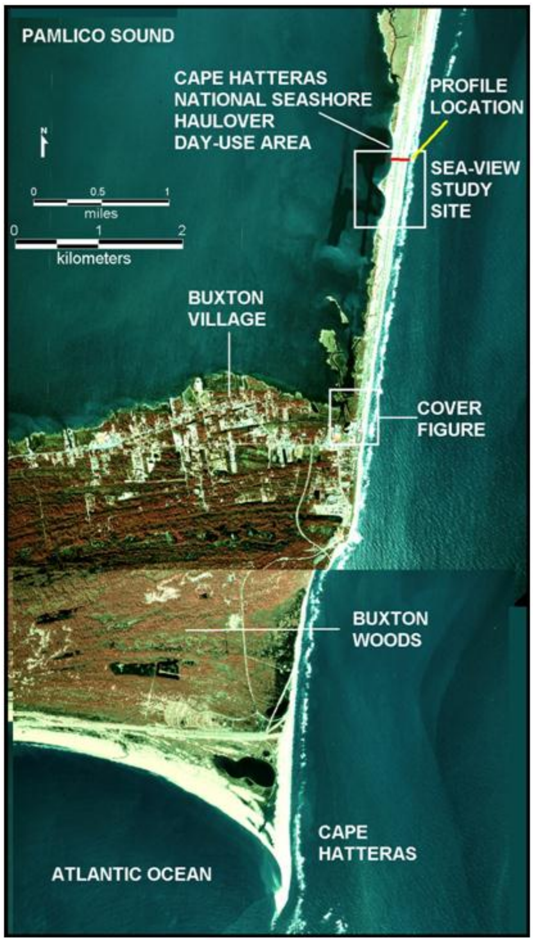



**Figure 2-1**. A 1998 aerial photograph shows the Avon-Buxton barrier island segment with Buxton Village and the extensive system of beach ridges that constitute Buxton Woods on the bottom of the photo. Figure is modified from Figure 8-2-6, p. 86 in Riggs and Ames (2003).

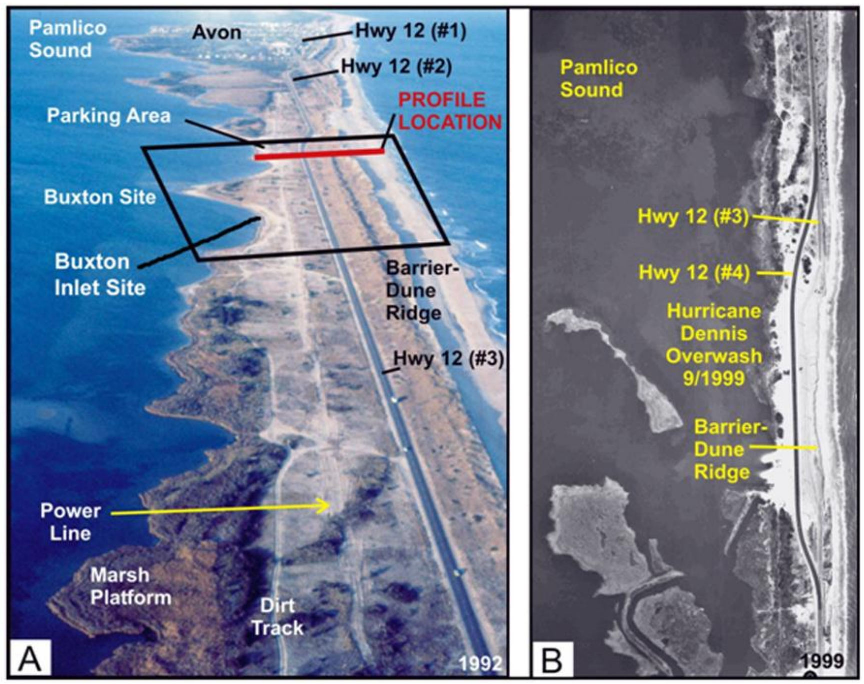
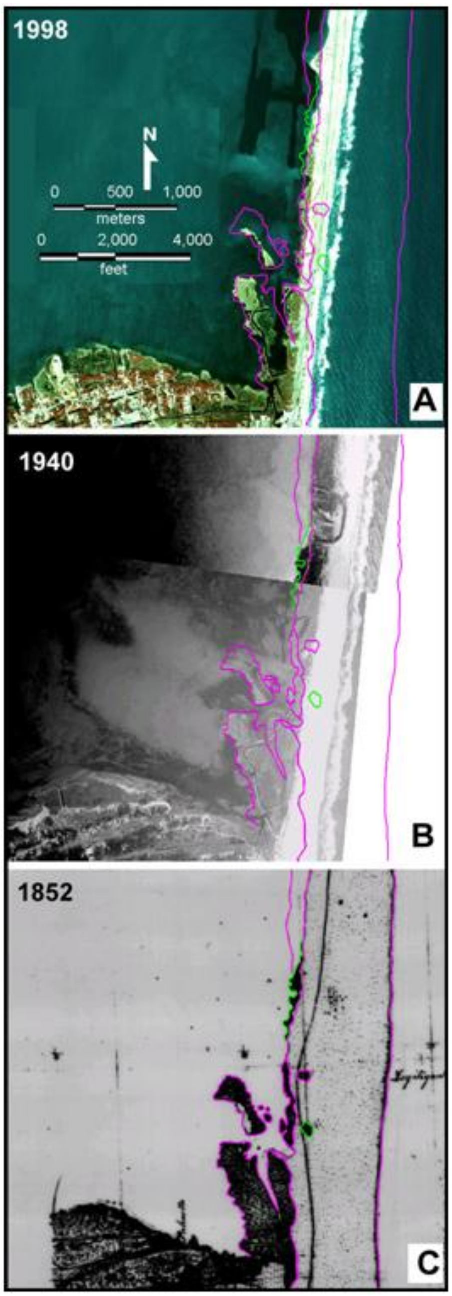



**Figure 2-2**. The Buxton Inlet site is one of the series of N.C. Hwy. 12 DOT “hot spots” where the coastal highway is in serious jeopardy. **Panel A**: A 1992 oblique aerial photograph shows the 1992 location, as well as two former locations of N.C. Hwy. 12 and the double barrier-dune ridges along the ocean beach built to protect the highway. The most seaward ridge has been severely eroded, and the small portion that remains is steeply scarped. The two former road locations were straight along the barrier island and were subsequently moved toward the estuary as shoreline erosion destroyed road segments through time. The red line across the island is the location of the topographic profile in table 2-1. **Panel B**: A 1999 aerial photograph shows a new fourth location of N.C. Hwy. 12 in response to a major overwash event associated with Hurricane Dennis in 1999. Figure 8-2-5, p. 85 in Riggs and Ames (2003).

Because the island is narrow and the ocean shoreline is severely receding, N.C. Highway 12 has been moved numerous times (figure 2-2A) in the last forty years, with the latest move in response to Hurricane Dennis in 1999 (figure 2-2B). N.C. Department of Transportation continuously rebuilds and maintains large barrier-dune ridges in an effort to protect N.C. Highway 12 and stop shoreline recession. This effort also eliminates the processes of barrier island overwash and inlet formation, essential for building island width and elevation. No matter how hard N.C. Department of Transportation tries, the barrier dune ridge is ultimately breached by a large storm or series of storms. If such a storm has opened an inlet, state workers rapidly fill the inlet and rebuild barrier-dune ridges. If the storms only produce major overwash fans across the island, the overwash sand is immediately pushed back onto the ocean side to rebuild the dune ridges. Thus, if the barrier dune ridge is in place, sand does not naturally move toward the sound side where it would build elevation and width to the island and produce sand shoal platforms for establishment of marsh grasses.

Figure 2-3 shows the change in ocean shoreline from the 1852 survey to the 1998 aerial photograph that has been georeferenced to the same scale as the 1852 survey. Notice that the N-S island segment is today only ~1/3 the width it was in 1852, and the island has moved generally westward through time. The N.C. Division of Coastal Management has measured the average erosion rates for a fifty-two year period from 1946 to 1998 of -8.8 feet per year with the central portion eroding at rates up to -10.5 feet per year. Based on studies by the authors, the estuarine shoreline has been receding for the period from 1962 to 1998 at an average rate of -2.6 feet per year with local areas receding at average rates up to -18.6 feet per year for brief time periods. Much of the latter erosion is probably in direct response to elimination of overwash and inlet processes to protect N.C. Highway 12 with construction of barrier-dune ridges.




**<u>Figure 2-3</u>**. A three-panel time series analysis of georeferenced aerial photographs shows the net change in both island location and width between 1852 and 1998 for the Buxton-Avon area. **Panel A**: This 1998 aerial photograph shows only a small portion of the original island (purple lines) remaining after 146 years of ocean shoreline erosion. **Panel B**: This 1940 photograph is the oldest known aerial for this area and shows major ocean shoreline recession since 1940. **Panel C**: This 1852 topographic survey shows an island that was about three times wider than in 1998 with the ocean shoreline significantly east of its present location.

On narrow sediment-poor barrier islands such as the Avon-Buxton segment, two basic processes are critical for both the short-term health and the long-term evolution of the barrier island: inlet formation and island overwash (figure 2-4). These processes are crucial for building island elevation and width in a rising sea level situation, as presently exists in the coastal region of northeastern North Carolina. As sea level rises, storms erode the ocean shoreline (figure 2-3). In order for a barrier island to survive in this situation, the back barrier must receive sand that increases both the width and elevation. The addition of back-barrier sand allows the island to move upward and landward in response to ongoing sea-level rise.


**Figure 2-4**. Inlets and overwash fans are critical barrier island building processes that are crucial for their short-term health and long-term evolution. **Panel A** is an oblique aerial photo of the active New Drum Inlet on Core Banks with a major flood-tide delta formed on the backside of the barrier. Photo is by D. Heron. **Panel B** is a 1992 oblique aerial photo of New Inlet on Pea Island that was closed naturally in 1945 and shows the extensive salt marsh that has grown on the shallow sand shoals of the flood-tide delta since the inlet closed. Photo is by S. Riggs. **Panels C and D** are 2003 ground photos of major overwash fans that took place during Hurricane Isabel. In Panel C, storm overwash carried sand over the island just south of the Sea-View site and deposited ~2 feet of sand across N.C. Hwy. 12 and into the adjacent shrub-scrub zone. In Panel D, storm overwash carried sand across the island and deposited up to three feet of sand in marsh. Because of the increased elevation in the marsh, the area will revegetate as shrub-scrub. Photos are by S. Riggs.

## Inlets

The formation of inlets along the Outer Banks is a natural process that has been occurring as long as the barrier islands have been in existence. Aerial photos and maps dating back to the late 16th century show a history of inlets that have formed as a result of storm activity; some still exist and others have closed as a result of natural processes or human intervention.

During the Ash Wednesday Nor'easter in 1962, Buxton Inlet opened in response to a combination of ocean shoreline recession and storm surge overtopping the island. Buxton Inlet (figure 2-5-1962) finally broke through the island in a particularly weak spot in the Avon-Buxton barrier segment that had been severely modified with a canal (figure 2-5-1940). Since the inlet did not close down during the post-storm period, a wooden bridge was constructed across the inlet for N.C. Highway 12 (figure 2-6A). However, the bridge was taken out by another nor'easter in early December 1962 (figure 2-6B). This prompted the N.C. Department of Transportation to initiate a dredging program to permanently close the inlet during the first two months of 1963 (figure 2-6C-D). However, during the ten months that Buxton Inlet was open, it was able to build a small flood-tide delta on the Pamlico Sound side of the barrier (figure 2-5-1963).

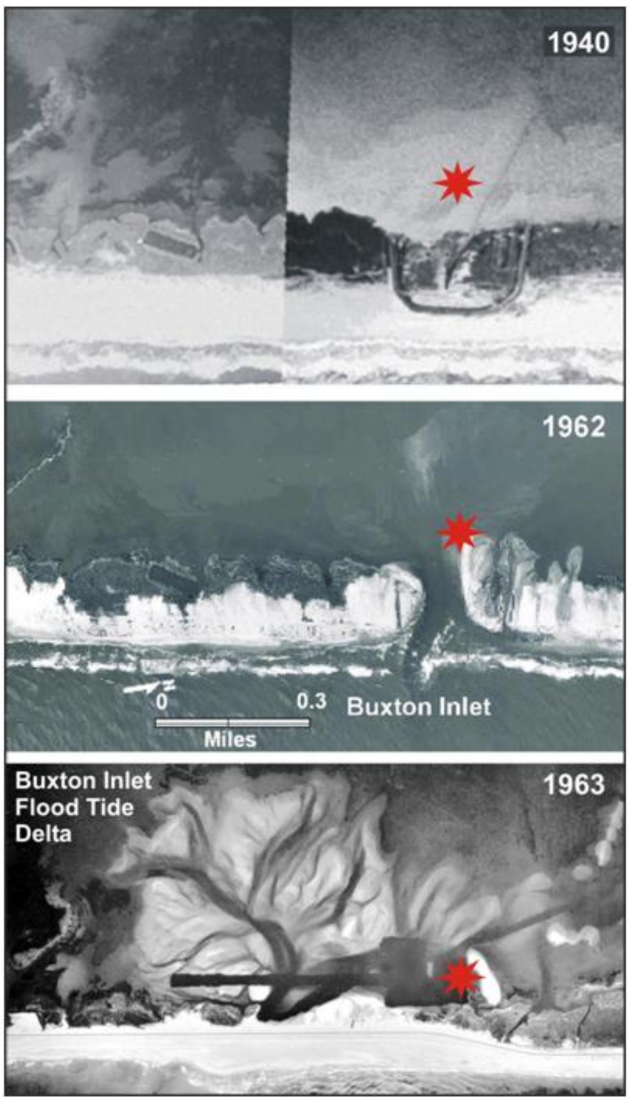



**Figure 2-5**. A georeferenced set of aerial photographs shows the location, development, and closure of Buxton Inlet.

**Panel-1940**: The photograph shows a U-shaped dug canal and dike around a dredged boat channel and harbor at the exact spot that Buxton Inlet will open in 1962 (red star).

**Panel-1962**: The photograph was taken in March 1962 after the Ash Wednesday Nor'easter opened Buxton Inlet and caused extensive overwash.

**Panel-1963**: The photograph was taken after Buxton Inlet was closed in February 1963 and shows the small flood-tide delta that had formed during the ten months the Inlet was open.

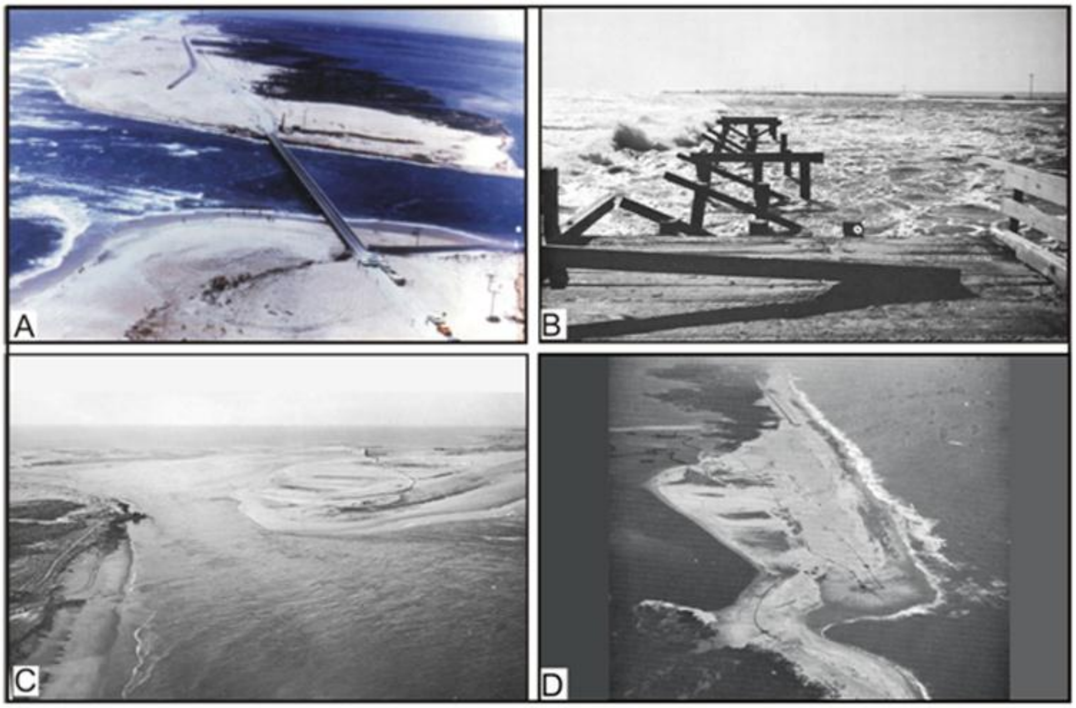


**Figure 2-6**. A four-part photo series shows the history of Buxton Inlet which opened in the Ash Wednesday Nor 'east storm in March 1962. **Panel A**: An oblique aerial photograph looking south shows the active inlet with a wooden N.C. Highway 12 bridge across it. Photograph is by Cape Hatteras National Seashore personnel. **Panel B**: A nor'east storm in early December 1962 took most of the bridge out. **Panel C**: An oblique aerial photo looking west was taken on January 29, 1963 and shows the dredge pumping sand from the sound side into the inlet. **Panel D**: An oblique aerial photo looking north was taken on February 21, 1963 when the inlet was finally closed. Photograph in Panels B, C, and D are from the U.S. Army Corps of Engineers (1963).

Isabel Inlet, like Buxton Inlet, opened in response to a major storm (Hurricane Isabel that came ashore on September 18, 2003). Conflicts between natural processes of storms and their effects on barrier islands on one hand and the needs of human inhabitants on the other hand occur with regularity on the barrier islands. After Buxton Inlet was closed in 1963, the management decision by different stakeholders was to secure the islands by constructing bigger and more extensive barrier-dune ridges. However, as fast as the barrier-dune ridges were rebuilt, the next series of storms would take them down. Buxton Inlet was not allowed to reopen, but at a great cost in a continuing effort to protect this road segment.

On September 18, 2003, Hurricane Isabel created a new Inlet on Hatteras Island between Frisco and Hatteras Village (figure 2-7). This new inlet cut highway access for residents to the southwest of the inlet. The location of Isabel Inlet was very similar to Buxton Inlet. They are both sediment-poor island segments that are severely eroding on both the ocean and estuarine shorelines, resulting in net island narrowing. Ultimately, both of these segments will narrow to the point where they collapse again with the formation of inlets. They desperately need inlets and the deposition of new back-barrier sand bodies to constructively increase island width and elevation. Because both inlets were closed almost immediately, these island segments did not benefit from the construction of back-barrier flood-tide deltas, which take a few years to develop. Thus, both areas are still in need of an inlet and are extremely vulnerable to future inlets.

In contrast to Buxton and Isabel Inlets, New Inlet on Pea Island has opened and closed periodically since the 1650s. It was last opened in the early 1930s and closed naturally in 1945. During the various times that New Inlet was open, a very extensive flood-tide delta was formed behind the Pea Island barrier. Since the last closure in 1945 the flood-tide delta sand shoals have evolved into a vast system of salt marshes (as indicated in figure 2-8). This island segment is extremely wide with a major sand base on which the barrier can migrate upward and landward through time in response to the ongoing rise in sea level.

Thus, the New Inlet segment of Pea Island is fairly healthy and only needs overwash now to give the island some more elevation. However, this is not presently in the management plans. With the paving of N.C. Highway 12 in the late 1950s and early 1960s, barrier-dune ridge construction became the dominant management priority to protect the highway from both overwash and the formation of another "New Inlet." The 1932 aerial photograph shows a small but active multi-channeled inlet with extensive back-barrier sand shoals that form the flood-tide delta and give the island tremendous width (figure 2-8B). The 1992 oblique aerial photo shows that the entire flood-tide delta system has evolved into a vast salt marsh system (figure 2-8C).

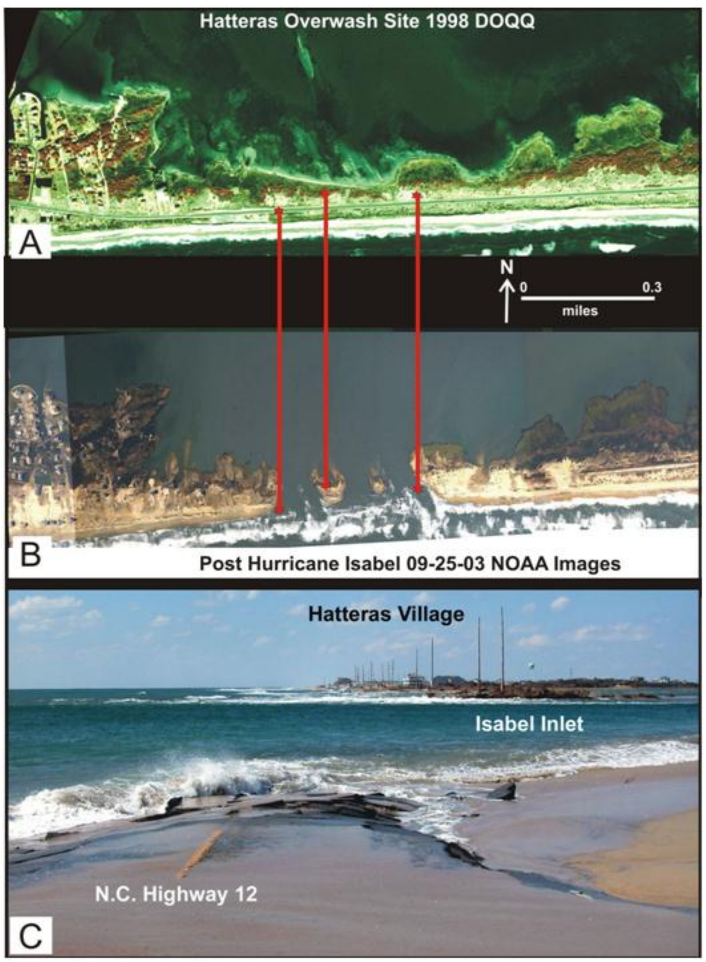



Figure 2-7. **Panel A:** A 1998 pre-Hurricane Isabel aerial photograph of a portion of Hatteras Island shows the future location of Isabel Inlet. **Panel B:** A 2003 post-Hurricane Isabel aerial photograph of the same portion of Hatteras Island shows the three channels of Isabel Inlet that opened on September 18, 2003. **Panel C:** A ground photograph looks SW across Isabel Inlet toward Hatteras Village. Notice the yellow center line of former N.C. Hwy 12 "going-to-sea." Photograph is by S. Riggs.

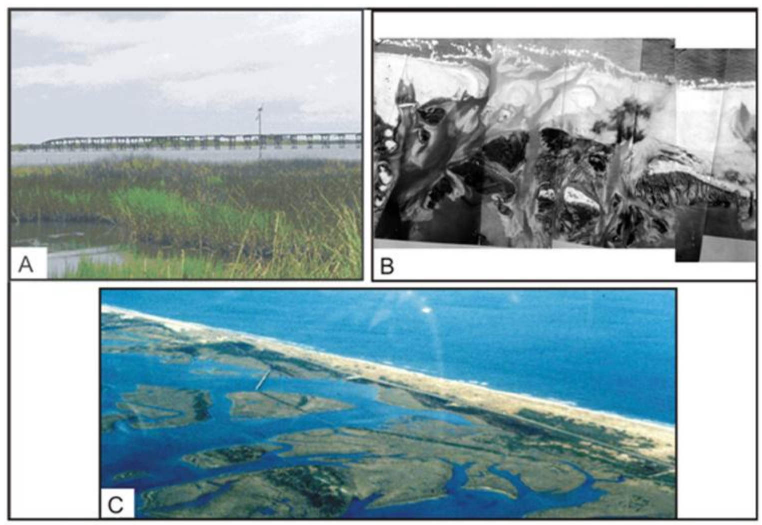



Figure 2-8. **Panel A:** A 2001 photograph of the New Inlet flood-tide delta sand shoals that have evolved into extensive salt marsh after the inlet closed naturally in 1945. Notice the remnants of a wood bridge built across New Inlet just before the inlet closed, when the bridge was abandoned. Photograph is by S. Riggs. **Panel B**: This 1932 aerial photograph shows a small but active multi-channeled New Inlet with a prominent flood-tide delta. Aerial photograph is from the U.S. Army Corps of Engineers, Field Research Facility. **Panel C**: this 1992 oblique aerial photo shows the New Inlet flood-tide delta sand shoals. The bridge remnant is visible in the photograph. Photograph is by S. Riggs.

## Overwash

Overwash processes take place during any storm when the storm surge is high enough that it can overtop the barrier island (figure 2-5-1962). As the storm tide rises above the beach berm, storm water begins to flow across the island carrying large quantities of beach sand that is deposited as large sediment fans in the scrub-shrub and platform marsh zones and sometimes as sand shoals into the back-barrier estuary (figure 2-9A). The volume of new sand depends on the size of the storm and resulting overwash event, but individual overwash fans commonly raise the island elevation by a meter or more and increase the width by hundreds of meters. These new sand bodies are quickly revegetated by the barrier island plans that are adapted to this process of frequent burial.

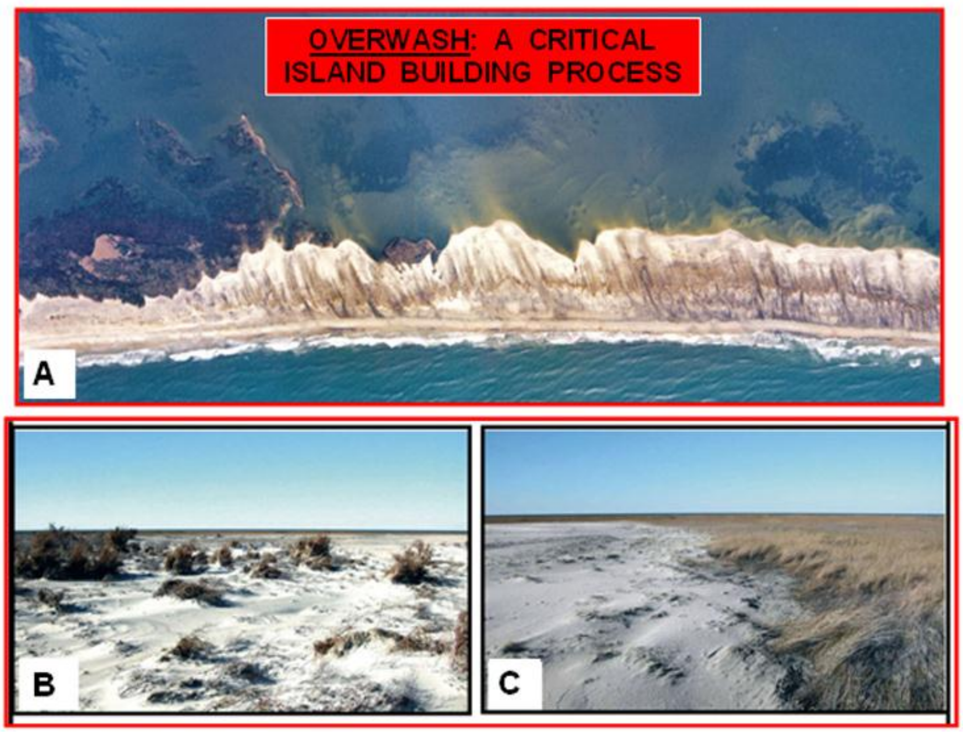



Figure 2-9. **Panel A**: Extensive overwash fans resulting from Hurricane Isabel (Sept. 18, 2003) buried much of the barrier island and deposited sand as sand shoals in the estuaries behind the barrier on North Core Banks with >1 meter of sand on this 2003 NOAA aerial photograph. **Panel B**: The two ground photographs show overwash burying the scrub-shrub zone and the back-barrier marsh platform (**Panel C**) with up to one meter of new sediment. Photograph is by S. Riggs.

## Humans and barrier-dune ridges

Starting in the late 1930s, North Carolina began a program of building barrier-dune ridges along the shoreline from the Virginia line south to Ocracoke Inlet (figure 2-10A-B). Barrier-dune ridge construction became the dominant policy for protecting N.C. Highway 12 after it was a paved road down the Outer Banks in the late 1950s and early 1960s. However, barrier-dune ridges, which act as a temporary fort wall to keep the ocean out, are totally out of equilibrium on the Outer Banks barrier islands and extremely vulnerable to ongoing coastal erosion (figure 2-10C-D). As soon as the dune ridges are constructed, they are attacked by ocean storm waves, become severely scarped, and are quickly breached (figure 2011). If the barrier-dune ridges that are protecting N.C. Highway 12 are breached, the overwash through the breach will either bury the highway with sand or take the highway out completely (figure 2-12).

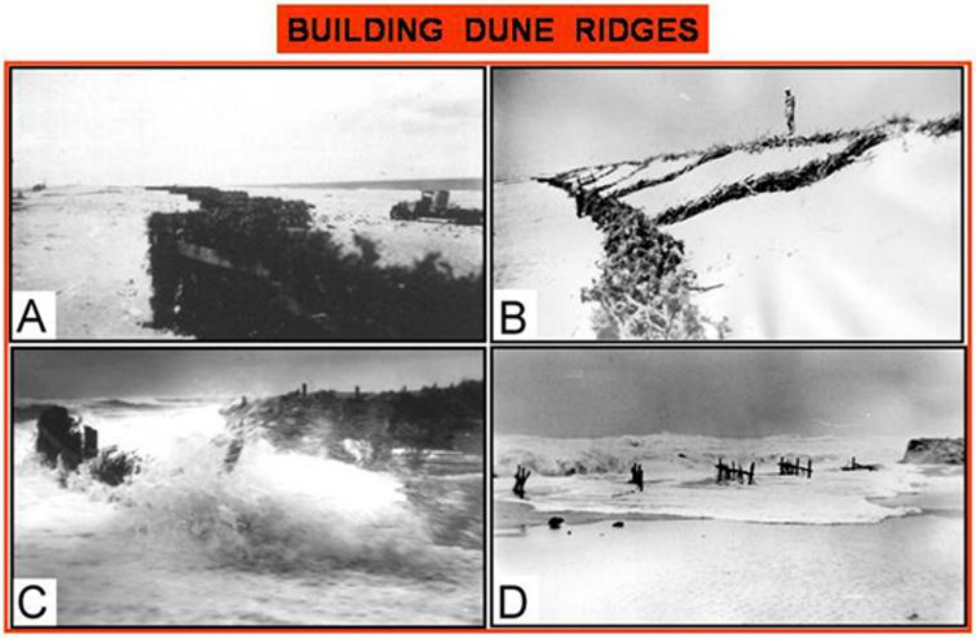



__Figure 2-10__. A series of historical photographs by Cape Hatteras National Seashore personnel show the various steps in construction of barrier-dune ridges that began in the late 1930s along the northern Outer Banks. **Panel A**: Shrub fencing was utilized to trap sand on the low overwash-dominated barrier beaches that were characterized by an equilibrium profile. **Panel B**: Additional shrub groins and revetments were utilized to stabilize the dune ridges once the shrub fencing had trapped a ridge of sand. **Panel C**: Because the barrier-dune ridges were not in equilibrium with the beach dynamics, the subsequent storms readily breached the ridges. **Panel D**: The storm eroded out much of the barrier-dune ridge and returned the beach back to its preferred profile of equilibrium. The dune ridge remnants that survived had been severely eroded and were left with vertically scarped front sides.

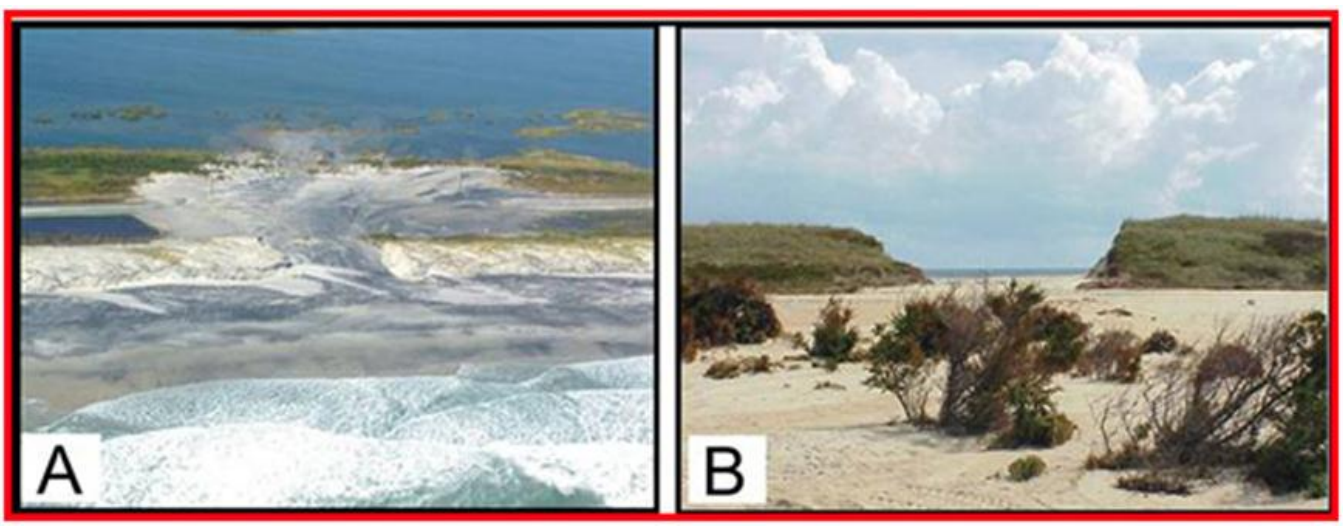



__Figure 2-11__. **Panel A**: An oblique photograph shows a scarped barrier-dune ridge that finally breached during Hurricane Isabel and deposited a small overwash fan across the back side of the barrier island. **Panel B**: A ground view of the same overwash breach shows the buried scrub-shrub zone buried beneath ~1/2 meter of overwash sand. Photographs are by Cape Hatteras National Seashore personnel.

After the storm takes out N.C. Highway 12, the process of rebuilding the barrier-dune ridges and the road starts all over again (figure 2-13), now with even higher dune ridges or, in some cases, even double dune ridges. But the barrier-dune ridge is still out of equilibrium with natural processes, and often before construction is completed, erosion has already steeply scarped the dune (figure 2-13C). If shoreline erosion has encroached too close to N.C. Highway 12 and there is enough room, the road will be moved back once again (figure 2-2). In many places, however, such as at the Sea-View site (figure 2-1), the island is already too narrow, and there is no longer upland space upon which to move the road.


**Figure 2-12**. N.C. Hwy. 12 "going-to-sea" as the storm tide washes over the road during a typical nor'easter. In some storms the highway is just buried in overwash sand that is cleared off the road and put back into a barrier-dune ridge. Other storms physically destroy the road as it finds itself in the surf zone. Photograph A is by O.H. Pilkey, Photograph B is by S. Riggs, and Photograph C is by Cape Hatteras National Seashore personnel.

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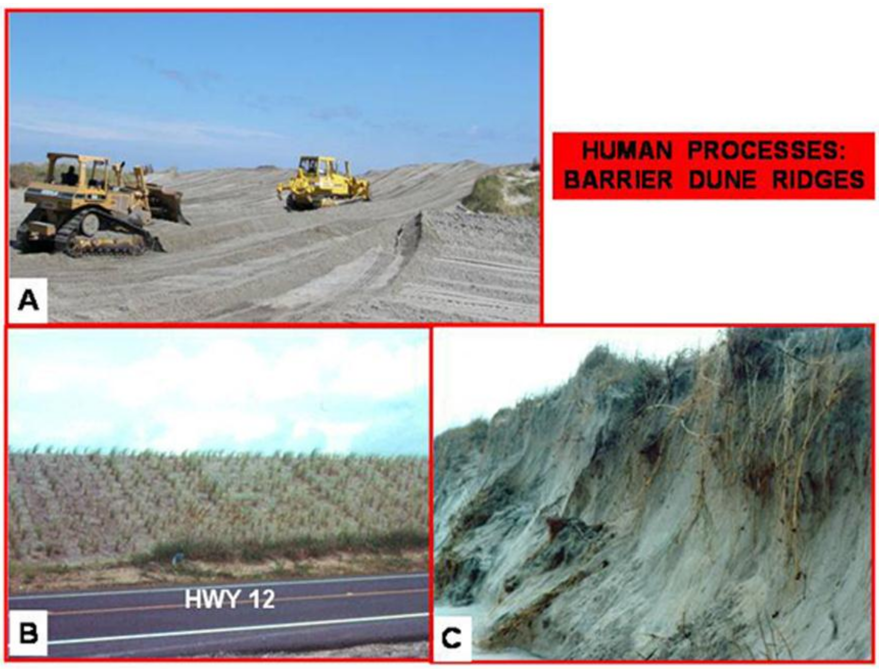


**Figure 2-13**. **Panel A**: Photo shows N.C. Department of Transportation bulldozers rebuilding a new barrier-dune ridge after Hurricane Isabel in 2003. **Panel B**: Looking east at the newly constructed and vegetated barrier-dune ridge built to protect the post-Hurricane Denis relocated N.C. Hwy. 12 (figure 2-2B). **Panel C**: Photograph of the ocean side of a recently constructed barrier-dune ridge that shows severe erosion and scarping of the barrier-dune ridge that is totally out of equilibrium with the ocean dynamics. Photographs are by S. Riggs.

The policy of building barrier-dune ridges down the Outer Banks since the late 1930s, and with particular regularity since the early 1960s in an effort to protect N.C. Highway 12, has had a significant long-term impact on the health of the overwash dominated barrier islands. The barrier-dune ridges have prevented natural island building by inhibiting the critical processes of overwash and inlet dynamics.

Three general consequences have occurred in direct response for maintaining this policy through time:

1. The ocean shoreline continues to erode.
2. The barrier-dune ridge is out of equilibrium with ocean dynamics and ultimately erodes, causing severe damage to N.C. Highway 12 and other ocean-front structures.
3. Little sand moves to the back-barrier habitats, and estuarine shoreline erosion increases – resulting in overall island narrowing.

Thus, human development practices (i.e., building barrier-dune ridges, roads, and extensive walls of ocean-front buildings) cause major changes in the natural processes associated with overwash and inlet dynamics. The inability of overwash or inlet sands to reach the back-barrier habitats and build both barrier island elevation and width results in increased erosion along the estuarine shoreline (Riggs and Ames, 2003). Pamlico Sound is a major inland sea with a significant fetch that can readily create storm surges up to five to ten feet above mean sea level. Such storms are highly erosive to the sound-side shorelines, particularly if these shorelines are not continuously maintained with new overwash sands and inlet flood-tide delta shoals.

The lack of cross-island sand delivery results in the back-barrier estuarine shoreline shifting from a shoreline dominated by constructive processes (i.e., marsh building) to one dominated by destructive processes as the marsh begins to recede around the edge through shoreline erosion, as seen in figure 2-14 (Riggs and Ames, 2003). Human intervention does not stop the ongoing recession of the ocean shoreline – as indicated by the four westward relocations of the highway (figure 2-2). Thus, the associated barrier-dune ridges have neither protected the highway nor allowed the natural processes of overwash to build and maintain the back barrier system, which is now in a destructive or erosional mode. The net result is an overall increase in island narrowing, rather than island building. Against the backdrop of barrier island evolution and rising sea level, this policy is like giving these weak barrier island segments a long-term death sentence. This is dramatically demonstrated by the ongoing collapse of many segments of N.C. Highway 12 and the prediction that large island segments will totally disappear within the next few decades (see chapter one, lesson eight).

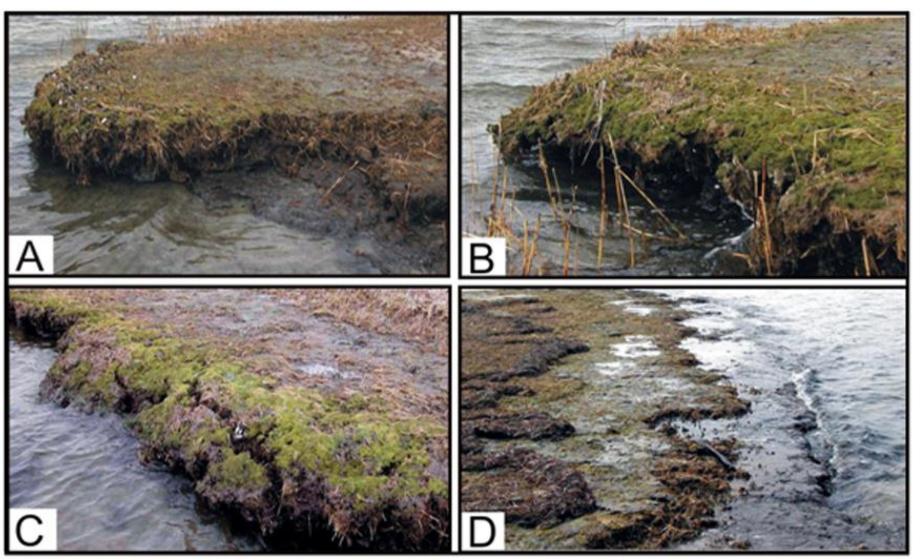


**Figure 2-14**. **Panel A**: Photograph of the outer marsh platform edge shows a vertically scarped peat shoreline that is eroding at an average annual rate of -2.6 feet per year with maximum rates locally up to -18.6 feet per year. Notice that wave energy has largely stripped off the marsh grass from the outer portion of the platform. **Panel B**: Photograph of the marsh platform shoreline shows the process of erosion by undercutting the upper root-bound zone causing the marsh edge to start sloping seaward. **Panel C**: The outer block of peat has recently cracked and will ultimately break off of the platform and slowly disintegrate in response to continued wave and biological activity. **Panel D**: If wave energy is high enough and the marsh peat consists of alternating layers of sand (stormy periods) and peat growth (non-stormy periods), the marsh can erode by stripping off successive peat layers from the upper surface, as show in in this photo. Photographs are by S. Riggs.

## Summary

The Avon-Buxton site provides an excellent example of coastal processes and conflicts that arise when those processes complicate the lives of humans. As this unit shows, understanding natural processes is important in making wise decision about use of this unique island environment. It is absolutely certain that we cannot control the work of wind and waves, but we can adjust our human activities to accommodate the inevitable changes that result.

Although the effects of storms and sea-level rise are particularly dramatic on the Outer Banks, natural processes produce changes in every environment. If you are knowledgeable about those processes in your own community, you are in a better position to make sound decisions that are in harmony with those conflicts rather than make decisions that are made in ignorance and that result in economic and human disaster.