Spatial and temporal variability in dune field: Pea Island, North Carolina

By

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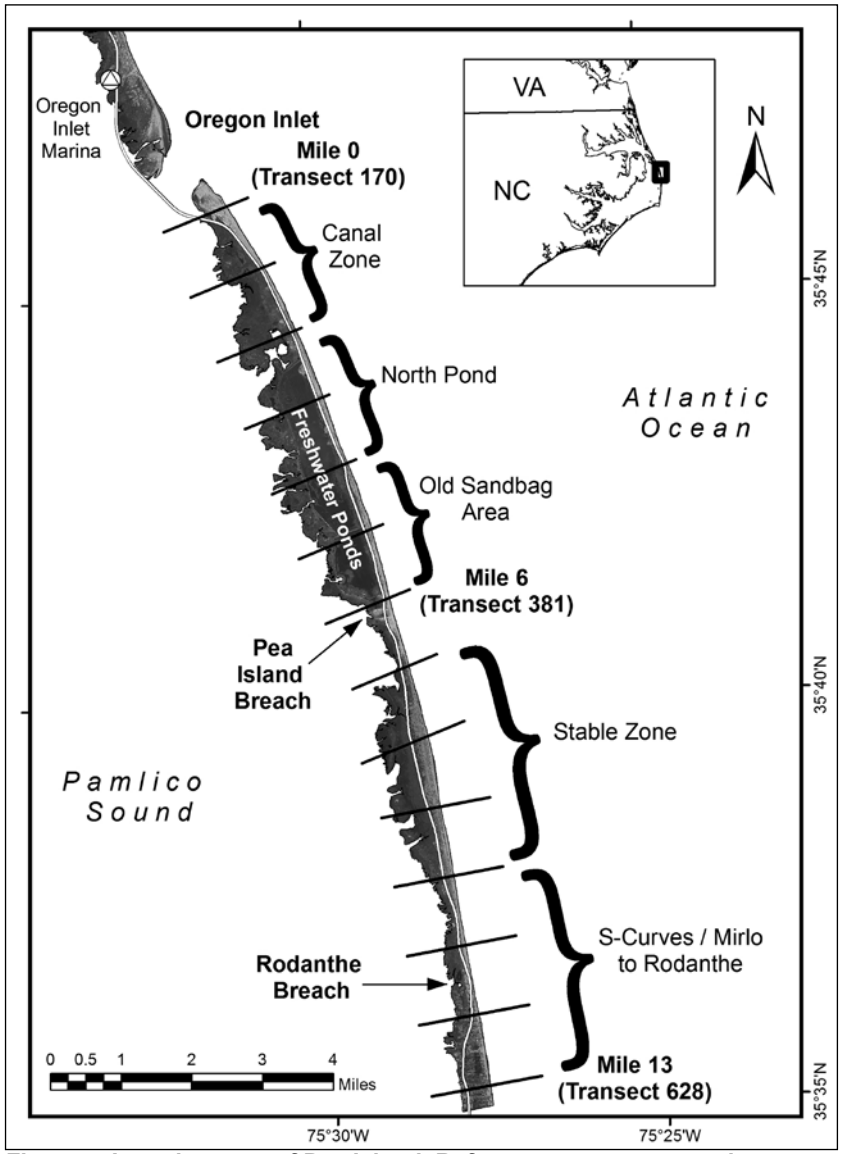


Figure 1. Location map of Pea Island. Reference transects are shown at 1-mile intervals along the coastal monitoring program study area. The location of the NOAA station ORIN7, Oregon Inlet Marina is shown for reference. The Oregon Inlet waverider buoy is located approximately 10 miles offshore east of Mile 1. The white line indicates the NC 12 highway location along Pea Island.

Pea Island is an approximately 13-mile stretch of primarily undeveloped barrier island along the North Carolina Outer Banks, extending from Oregon Inlet south to the town of Rodanthe (Figure 1). While named as an "island," this region now exists as the northern tip of Hatteras Island, with the shoreline adjacent to the inlet stabilized by a terminal groin built in 1989-1991. It is home to the Pea Island National Wildlife Refuge, established in 1938. The Cape Hatteras National Seashore, established in 1953, is co-located within the refuge boundaries on Pea Island and extends further north and south along the Outer Banks. There is limited infrastructure on Pea Island, consisting of a visitor's center and other facilities associated with the wildlife refuge, as well as the coastal highway NC 12.

NC 12 is the only north-south roadway connecting the Outer Banks with mainland North Carolina; it serves as the only terrestrial evacuation route for the 4,300 residents of Hatteras Island and all visitors to the Cape Hatteras National Seashore and local communities. According to the Outer Banks Visitors Bureau (2016), the Seashore had a total of 2,266,579 visitors during the year 2014.

As part of the long-range planning to maintain a transportation corridor connecting the northern Outer Banks (including Nags Head, Kitty Hawk, and Duck) with Hatteras Island (including the communities of Rodanthe, Buxton, and Hatteras Village), the North Carolina Department of Transportation (NCDOT) has been conducting a comprehensive monitoring study of Pea Island since 2011 (e.g. Overton 2015). This study is based on intensive data collection and analysis, with aerial photography taken six times a year, and digital photogrammetry processing to produce digital terrain models four times a year. These data are examined to assess the condition of

Figure 2. Construction of brush fencing., Photo courtesy National Park Service, Cape Hatteras National Seashore Collection (with permission).

the barrier island's dunes, back-barrier channels, shoreline position, and other morphologic factors affecting the vulnerability of the coastal highway.

This coastal observation was prepared using data from the NCDOT NC 12 Coastal Monitoring Program, and illustrates the spatial and temporal variability in the dune field along Pea Island over the 2014 study year.

HISTORICAL CONTEXT

Before the 1930s, Pea Island was a wide, flat beach regularly overwashed by waves, with inlets opening and closing with storms (Birkemeier *et al.* 1984). That changed during the early 1930s, when an extensive public works project was initiated in order to create a continuous line of vegetated, protective foredunes from the Virginia state line to Ocracoke Inlet as described in Weatherwax (1937), Dolan *et al.* (1972), Birkemeier *et al.* (1984), and others. This project was backed by the federal government through various agencies including the Works Progress Administration, and by 1937 was under charge of the National Park Service (Weatherwax 1937). The effort included construction of brush sand fencing and planting of vegetation (Figure 2). Multiple levels of sand fencing were often placed to increase the dune height. The constructed dune heights varied from 10 to 26 feet, and the dune base widths were approximately 80-330 feet (Birkemeier *et al.* 1984). Once the dunes were built to the desired height and width, the vegetation was planted, primarily beach grasses and shrubs (Weatherwax 1937).

The initial construction was fortified by the National Park Service along the Cape Hatteras National Seashore later in the 1950s using bulldozing, brush sand fencing, and plantings (Birkemeier *et al.* 1984; Dolan *et al.* 1973). Repair of barrier dunes by the National Park Service also occurred after the Ash Wednesday storm of 1962, at locations on Bodie, Pea, and Hatteras Islands (USACE 1965).

During the 1970s there was a shift in National Park Service policy, detailed in Behn and Clark (1976). This coincided with the publication of works by Dolan (1972) and Dolan *et al.* (1973) positing that the dunes created a barrier to sand transport and island migration and that the original state of the island did not support such features. Behn and Clark (1976) describe how, while the National Park Service did not make a public announcement that they were no longer maintaining the barrier dunes, this was in fact the official policy.

The coastal highway that is now NC 12 along Pea Island was first paved in the 1950s (FHWA, NCDOT 2010). Historically, as the NCDOT worked to maintain a transportation corridor along Pea Island, when erosion threatened the road, the preferred alternative was to relocate the road landward, away from the active shoreline. As a part of the cleanup of the prior location of the road and easement, dune restoration and planting of vegetation were often done to re-establish the beach-dune system. This strategy continued through the mid-1990s when road relocation projects allowed for restoration of dunes along the former highway easement.

However, in 1997 regulatory changes caused a shift in the management strategy for the coastal highway. The National Wildlife Refuge System (NWRS) was created in 1966 with passage of the National Wildlife Refuge System Administration Act. The NWRS includes the Pea Island National Wildlife Refuge. In 1997, the National Wildlife Refuge System Improvement Act was passed. This act amended the 1966 act to ensure that the NWRS is managed as a national system of related lands, waters, and interests for the protection and conservation of our nation's wildlife resources. The 1997 act established a formal process to determine "compatible use" of a wildlife refuge, and whether or not a proposed use would be allowed. Essentially a "wildlife first" policy is maintained with specified priority public uses for wildlife-dependent recreation (e.g. observation and photography, environmental education and interpretation, etc.; see the Comprehensive Conservation Plan for the Pea Island National Wildlife Refuge (U.S. Dept. of the Interior 2006)). Any proposed use or activity such as road relocation, beach nourishment, or dune construction must undergo an evaluation known as a Compatibility Determination, which also requires public notice and comment. Passage of this act required that any NCDOT activities outside of the existing NC 12 easement within the refuge would need to obtain a Compatibility Determination ensuring that those activities represented a compatible use of the wildlife refuge. Since passage of the act, all routine road maintenance, including minor road relocations, have occurred within the existing 100-ft easement. Major storm repairs have been allowed outside of the easement through Special Use Permits.

RECENT CONDITIONS (2011-2014)

In general, barrier dunes first constructed in the 1930s and sporadically maintained thereafter have been degraded over the intervening years by storms and long-term erosion. In late August 2011, the island was impacted by Hurricane Irene, and two breaches formed, one just south of Mile 6 and one in northern Rodanthe (approx. Mile 11.5), eliminating the dune field in those locations (Figure 1).

The breach near Mile 6 occurred where multiple historic inlets known as New Inlet have opened and closed (see Birkemeier *et al.* 1984; Clinch *et al.* 2012). This breach existed as a tidal inlet from 2011 until 2013 and was known as the Pea Island Breach (Velasquez-Montoya *et al.* 2015); the opening of this ephemeral inlet destroyed part of the NC 12 highway, which was closed for a month — requiring residents and visitors to access Hatteras Island via ferry — until

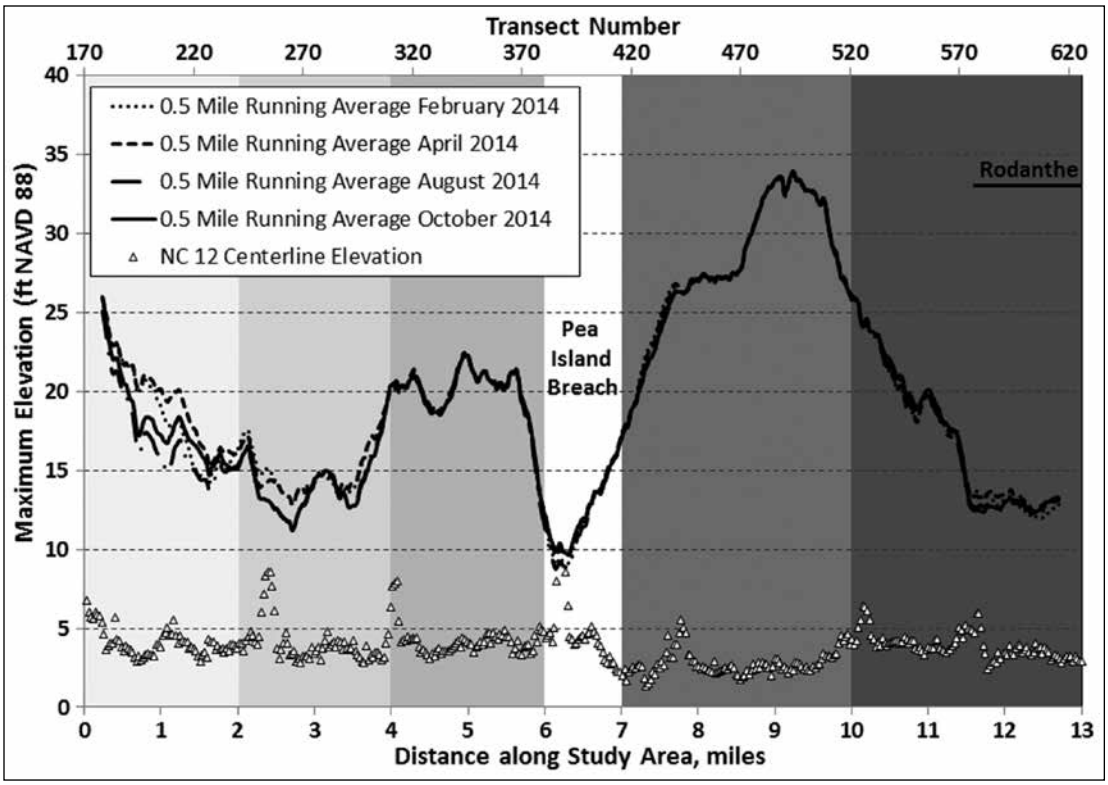


Figure 3. Lines show a 0.5-mile running average of maximum elevation at each transect displayed from north to south along the study area for each topographic data set. Elevations at the centerline of NC 12 are plotted in with hollow triangles for comparison. Background colors correspond to the locations described in Table 1. Modified from Overton (2015).

Table 1. Alongshore dune characteristics at Pea Island, North Carolina.

Location	Local name	Description	Average dune crest elevation in 2014 (ft NAVD88)	Average horizontal distance of dune crest from edge of pavement in 2014 (ft)
Miles 0-2	Canal Zone	NC 12 is immediately adjacent to dunes; dune sand is highly mobile via wind and water transport	20	194
Miles 2-4	Northernmost Freshwater Pond	NC 12 is immediately adjacent to dunes; overwash observed during Sandy; dunes have minimal vegetation.	14	90
Miles 4-6	Old Sandbag Area	NC 12 was relocated landward from original alignment in this area in 1996; some remnant dunes that were constructed at that time still exist.	20	236
Mile 6	Pea Island Breach	Temporary metal bridge in place at breach; dunes removed over most of this section, frequent overwash and flow through breach during storms.	12	322
Mile 7-10	Stable Zone	Wider island, NC 12 located at substantial distance from active beach; historical constructed dunes still in place over most of the area; dunes highly vegetated.	28	741
Miles 10-13	S-Curves/ Mirlo Beach to Rodanthe	NC 12 is immediately adjacent to dunes in portions of this section; beach is narrow; some remnant dunes exist but where highway is adjacent to beach, dunes have been reconstructed in easement.	18	163

a temporary metal bridge was constructed at that site. During storms or higher than usual tides, flow through the Pea Island Breach still occurs. The breach in Rodanthe was filled and repaired within the existing easement shortly after the storm as part of recovery efforts.

In October 2012, Hurricane Sandy caused elevated water levels and overwash along several stretches of the Pea Island dune field. Fall and winter nor'easters cause dune erosion each season. As a result of the cumulative impacts of these storms and long-term

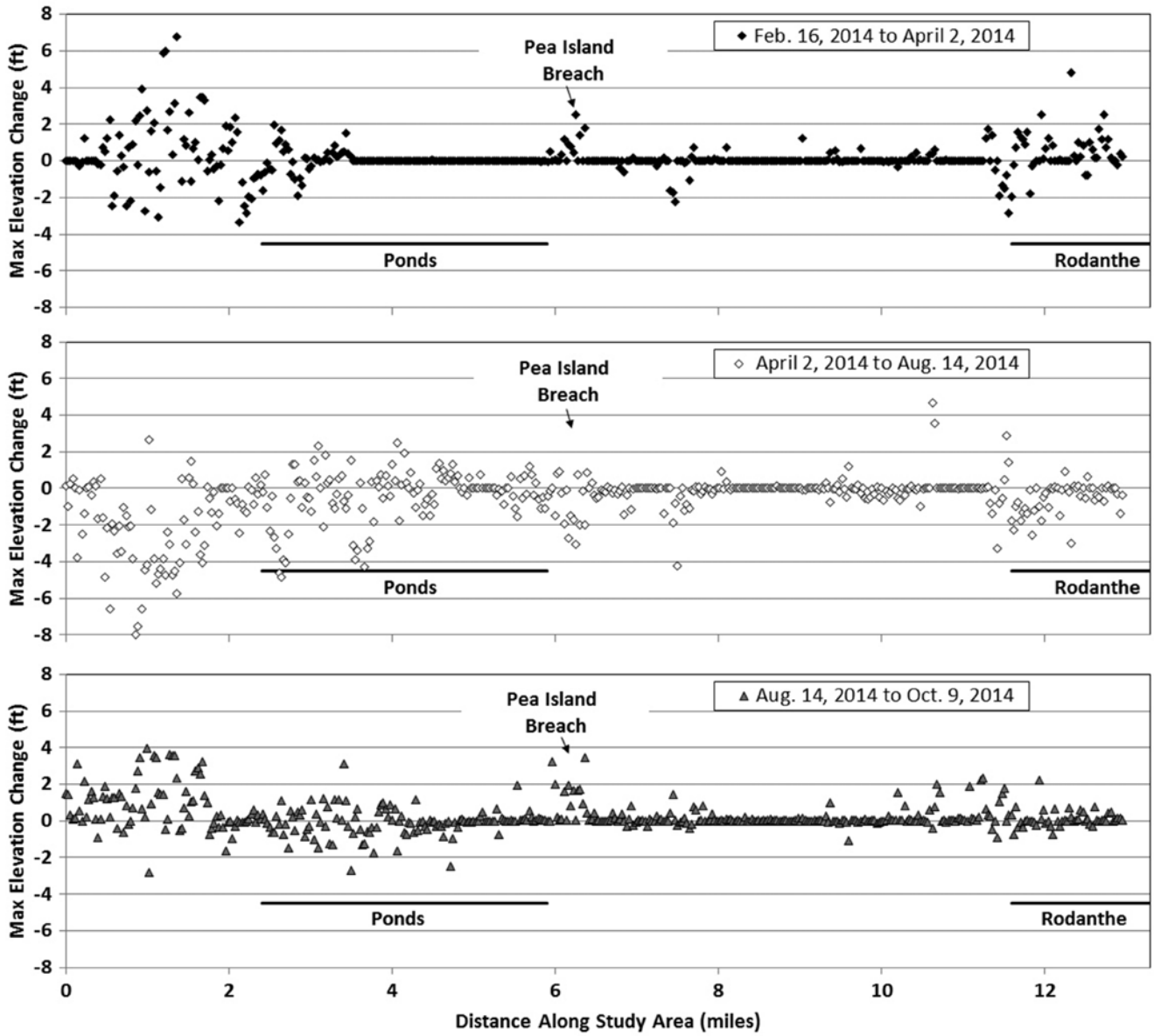


Figure 4. Change in maximum elevation between NC 12 and the shoreline from (A) 16 February 2014 to 2 April 2014, (B) 2 April 2014 to 14 August 2014, and (C) 14 August 2014 to 9 October 2014 at each transect along the study area from north to south. Modified from Overton (2015).

erosion, much of the dune field is now discontinuous and regularly impacted by high water levels and waves.

Since the 1997 act was enacted, NCDOT has not been able to relocate the road landward outside the existing easement, and any dune building activities have been generally restricted to within the easement. If activities are conducted outside of the easement, a permit must be obtained, and the extent in which work is allowed is restricted. Therefore, after storms or sustained periods of wind-blown sand accumulation, NCDOT conducts earth moving operations within the NC 12 easement to remove sand from the asphalt and push it up on the ocean side. This occurs so often that earth-moving equipment is staged permanently on Pea Island. It is noted that, based on feedback from the U.S. Fish and Wildlife Service, overwash fans west of the road are frequently left undisturbed.

After Hurricane Sandy in 2012, and continued impacts of nor'easter storms in early 2013, the governor of North Carolina declared a state of emergency, and a permit was requested for a beach nourishment project for temporary highway protection to be paid by Federal Highway Administration emergency response funding via the NCDOT. This project was designed by the U.S. Army Corps of Engineers and was conducted in late summer of 2014 over approximately 2 miles of the southern stretch of the Pea Island shoreline (approximately Miles 10-12 on Figure 1). This project included placement of approximately 1.5 M cy of sand, using material from an offshore borrow site. The northern portion of this project included a constructed dune with elevation +15 ft NAVD 88. It is noted that this project is on a far smaller scale than the original barrier foredune construction, and was designed to provide temporary protection while NCDOT developed alternatives for sustaining the transportation corridor along this highly vulnerable stretch of roadway.

ISLAND ELEVATION AND DUNE MORPHOLOGY

The data presented in this Coastal Observation were gathered as part of the

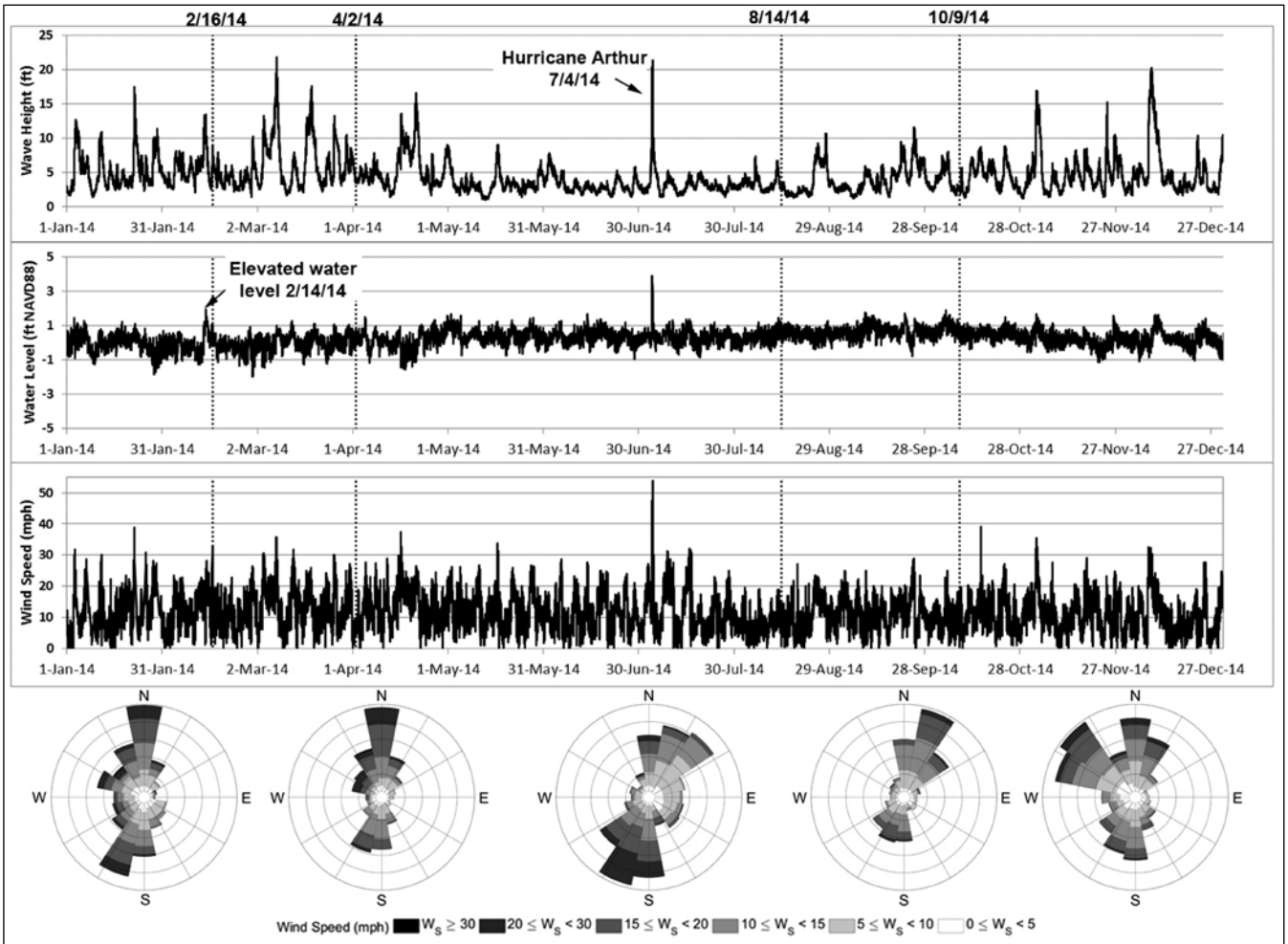


Figure 5. Significant wave height, water level, wind speed, and direction for 2014. Waves observed at the Oregon Inlet waverider buoy (USACE 2016), wind and water level data were observed at the Oregon Inlet Marina (Station ORIN7, NOAA 2016). Dotted lines indicate dates of photography; wind roses were developed for the time intervals between photo dates.

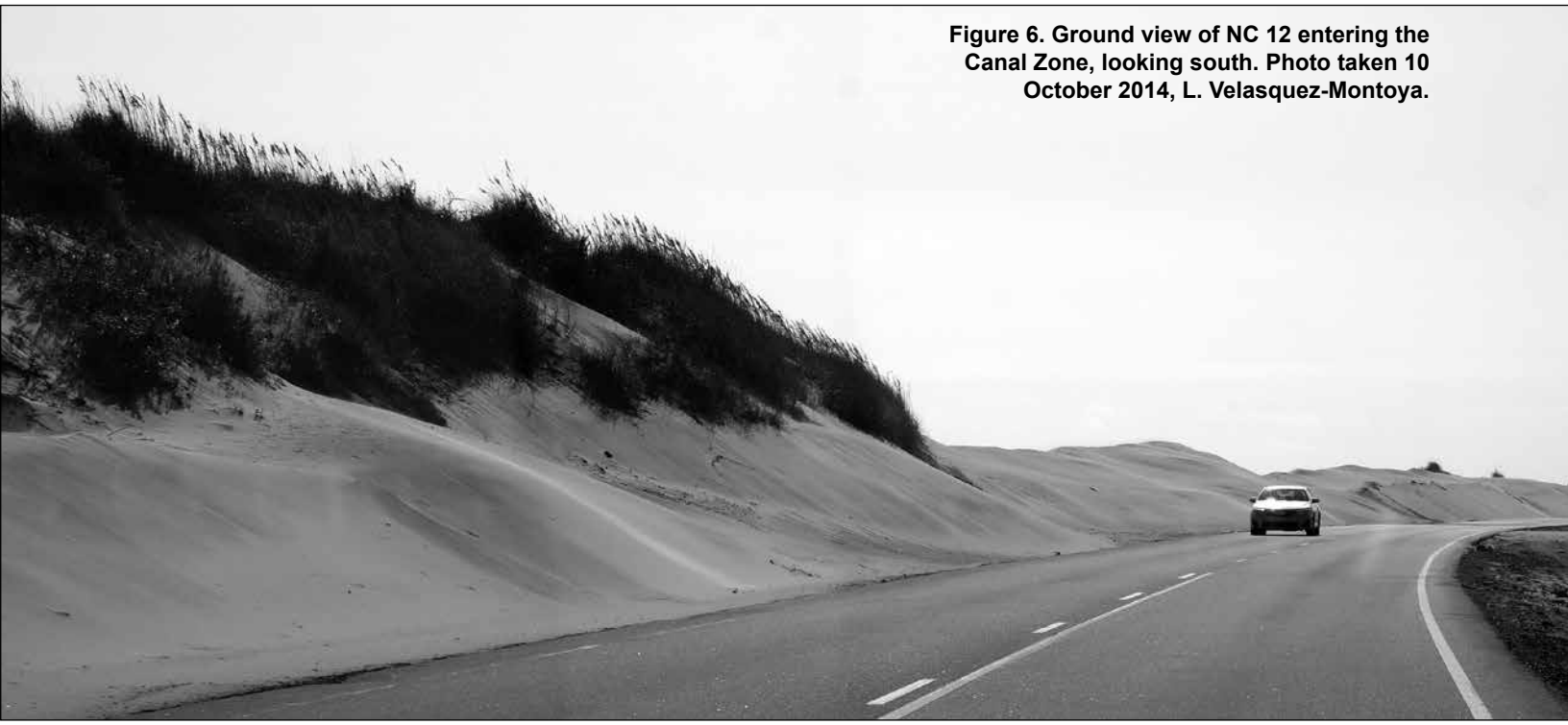


Figure 6. Ground view of NC 12 entering the Canal Zone, looking south. Photo taken 10 October 2014, L. Velasquez-Montoya.

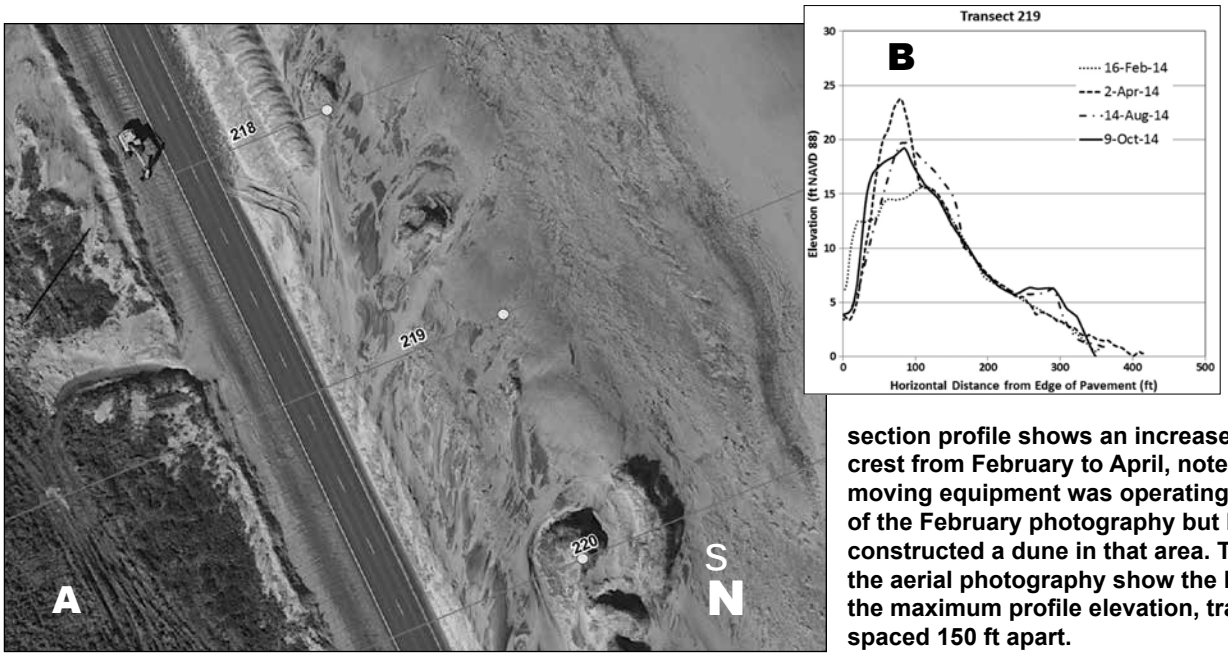


Figure 7. (A) Aerial photography dated 16 February 2014 and (B) example profile changes in the Canal Zone at Transect 219 (Mile 1.4). The cross-section profile shows an increase in dune crest from February to April, note that earth moving equipment was operating at the time of the February photography but had not yet constructed a dune in that area. The dots on the aerial photography show the location of the maximum profile elevation, transects are spaced 150 ft apart.

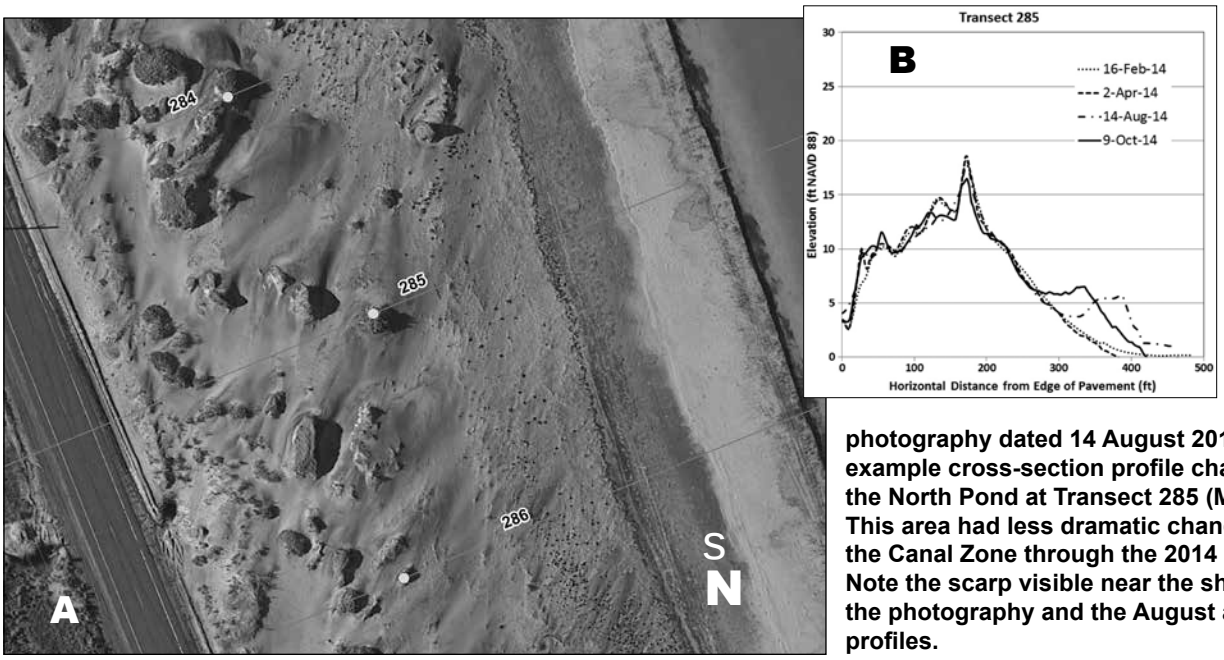


Figure 8. (A) Aerial photography dated 14 August 2014 and (B) example cross-section profile changes from the North Pond at Transect 285 (Mile 3.3). This area had less dramatic changes than the Canal Zone through the 2014 study year. Note the scarp visible near the shoreline on the photography and the August and October profiles.

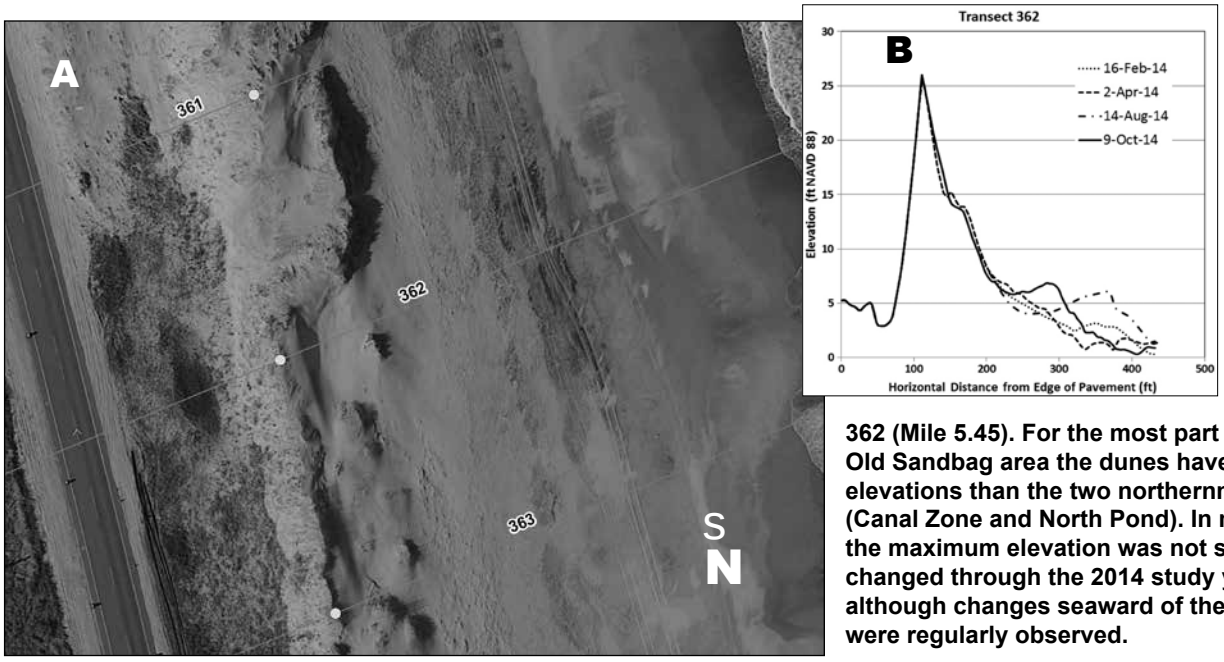


Figure 9. (A) Aerial photography dated 2 April 2014 and (B) example cross-section profile changes from the Old Sandbag area at Transect 362 (Mile 5.45). For the most part in the Old Sandbag area the dunes have higher elevations than the two northernmost regions (Canal Zone and North Pond). In many areas the maximum elevation was not significantly changed through the 2014 study year, although changes seaward of the dune peak were regularly observed.

NCDOT's comprehensive NC 12 Coastal Monitoring Program. The purpose of this program is to collect and analyze the data sets needed to develop strategies for maintaining a transportation corridor between Oregon Inlet and Rodanthe. These observations will inform NCDOT where and when the traditional asphalt, ground-based roadway in its existing location will no longer be feasible to maintain, so that alternatives can be developed. Bridges are already planned at two locations: an interim bridge to replace the temporary metal bridge at the location of the Pea Island Breach, and a permanent bridge from the southern end of the refuge to Rodanthe (approximately between Miles 11 and 13 and spanning the site of the breach caused by Hurricane Irene in Rodanthe).

The data show that the dunes along much of the Pea Island shoreline are highly variable, both spatially and temporally. In many places the variation is attributable to the impacts of storms and anthropogenic rebuilding of small dunes in the NC 12 easement. Remnants of the large dunes constructed in the 1930s-1950s exist along a portion of the shoreline but continue to degrade each year.

To capture the variability of the dunes, and relate the information to highway vulnerability, the maximum elevation between the coastal highway NC 12 and the ocean shoreline is determined at each of four yearly monitoring dates for which digital terrain models are available, and the subaerial beach profile between the road and the mean high water contour is evaluated. The following sections describe the variability in dune morphology along Pea Island observed over a one-year period (2014). The dune field is no longer a continuous barrier to storm impacts over much of the Pea Island shoreline, and this is reflected in the high levels of variability in maximum elevation and in the profile shape. Additionally, wind-blown sand transport contributes to the intra-annual variability, re-shaping the dunes on a near-daily basis.

SPATIAL VARIABILITY

The maximum elevation between the NC 12 edge of pavement and the ocean shoreline was determined at a series of transects with 150-ft spacing for each digital terrain model available in 2014 (16 February, 2 April, 14 August, and 9 October 2014) and used as a proxy for dune crest elevation. Along the approximately 13 mile study area, substantial spatial variability of the maximum elevation was observed. To visualize alongshore trends, a 0.5-mile running average of the maximum elevation was computed for each of the available dates. Results are shown in Figure 3.

Along the first four miles of the study area, the running average maximum elevations range from approximately 12-20 ft and are highly variable from date to date. From Miles 4 to 6, the maximum elevations are higher, at approximately 18-22 ft. Near Mile 6, at the site of the Pea Island Breach, dunes were completely removed and elevations are on the order of 10 ft. South of the breach the dune crest elevation increases, transitioning to a relatively stable section of Pea Island between Miles 7 and 10; within this stable area, remnants of the original constructed barrier dunes are still in place. From Miles 10 to 12, the road curves close to the active shoreline in several places, with dune crest elevations ranging from approximately 15-20 ft. South of Mile 12 at the town of Rodanthe, dunes are minimal, with maximum elevations on the order of approximately 12 ft. Table 1 summarizes the characteristics of the alongshore regions, which are also labeled in Figure 1.

TEMPORAL VARIABILITY

Changes in the maximum elevation in each alongshore region from date to date are shown in this section. Figure 4 shows the changes for all time intervals at each transect across the study area. Negative change means the elevation of the later date was lower than that of the earlier date (decrease in maximum elevation); positive change means that the maximum elevation increased between the two dates. As shown, changes on the order of +/-4 ft occurred frequently throughout the year, especially in the first four miles (Canal Zone and North Pond) and along the southern part of the refuge into Rodanthe (S-Curves/Mirlo Beach). If these changes are examined more closely it becomes clear that anthropogenic influences are responsible for most of the increases in maximum elevation, while decreases can be attributed to wind transport and/or high water levels.

For reference, significant wave heights observed at the 18-m-depth Oregon Inlet waverider buoy (USACE 2016), as well as water level, wind speed, and wind roses developed from data observed at the Oregon Inlet Marina (NOAA 2016) for the year 2014 are presented in Figure 5. A number of winter storms affected the area during 2014, including elevated water levels in February just before the coastal monitoring program photography was taken on 16 February. In addition, Hurricane Arthur impacted the area on 4 July 2014.

Canal Zone (Miles 0 to 2)

In the Canal Zone region, the dunes are immediately adjacent to the road as shown in Figure 6; sand frequently blows onto NC 12 and during high water levels, tides or surge may pass through breaks in the dunes or overwash low dunes, leading to water on the road. NCDOT regularly conducts earth moving operations along this section of NC 12. Aerial photography taken 16 February 2014 just after a nor'easter storm shows apparent areas of windblown sand and possibly high water being repaired along this region (Figure 7A). To illustrate the variability of the maximum elevations over the study year, the cross-section profile at Mile 1.4 (Transect 219) is shown in Figure 7B. This location showed an increase in maximum elevation from February to April, due to earth-moving operations, with subsequent profile data showing lowering of the crest and widening of the dune profile, likely due to wind-blown sand transport.

North Pond (Miles 2 to 4)

The dune line along the North Pond is discontinuous; some high dunes remain but breaks in the dune line are common along this stretch of the island. During past events, most recently Hurricane Sandy in 2012, overwash has pushed sand across the road into the pond in several places. The dunes are sparsely vegetated and relatively small changes in elevation (+/-2ft) occur regularly over the year due to wind-blown sand transport. Earth-moving operations are less common in this section of roadway than in the Canal Zone, although they may be required after storms.

Figure 8 shows an aerial photo of Transect 285 (Mile 3.3) as well as the cross-sectional profile changes over the 2014 study year. Changes at this profile were less dramatic than the changes shown in Figure 7; variability in the maximum elevation was on the order of 2 ft over the 2014 study year. The most significant changes along this transect oc-

Figure 10. Aerial photography showing the Pea Island Breach throughout the 2014 study year. Dots show the location of maximum profile elevation at individual transects.

Figure 11. Ground view of the temporary bridge over the Pea Island Breach from the south ocean side, looking north. Photo taken 10 October 2014, L. Velasquez-Montoya.

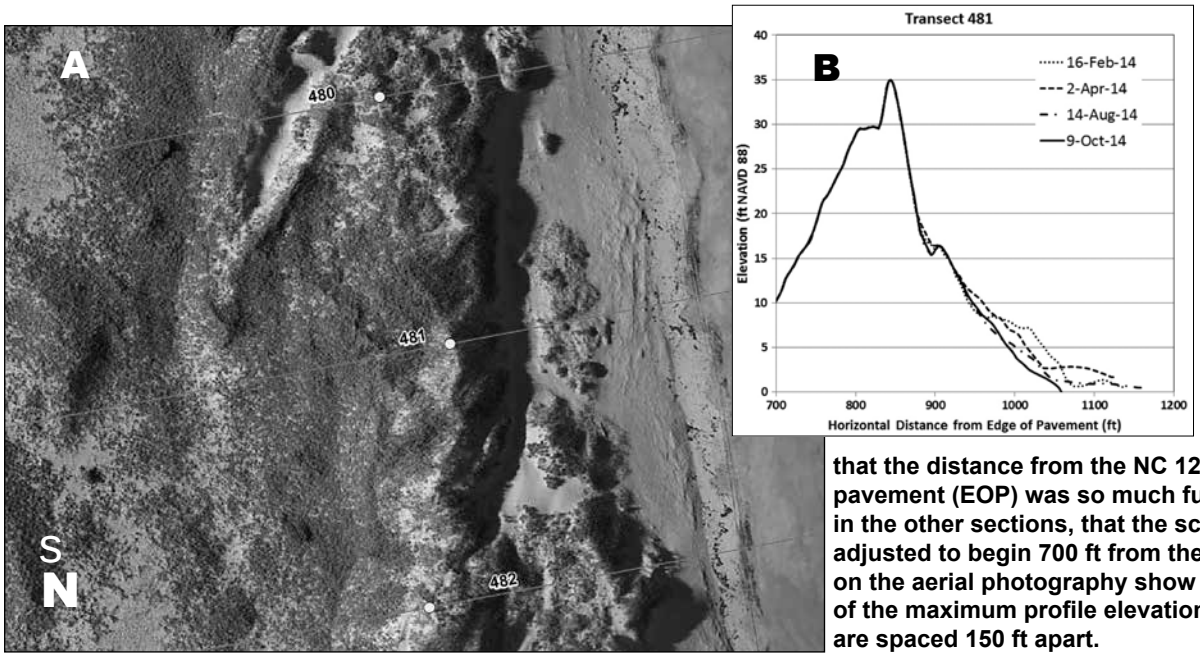


Figure 12. (A) Aerial photo dated 14 August 2014, showing the stable dune field near Transect 481 (Mile 8.8) The cross-section profile is shown in (B). Note that the distance from the NC 12 edge of pavement (EOP) was so much further than in the other sections, that the scale was adjusted to begin 700 ft from the EOP. Dots on the aerial photography show the location of the maximum profile elevation, transects are spaced 150 ft apart.

curred in the lower portion of the profile, where a landward-migrating berm scarp developed during the summer.

Old Sandbag Area (Miles 4 to 6)

NC 12 in the Old Sandbag Area was relocated landward in 1996, with dunes rebuilt and vegetation planted in the former location of the road. Because of that effort there is more distance from the edge of pavement to the shoreline and dunes with greater maximum elevation and more vegetation than those further north. In general these dunes are more stable, although there are discontinuities (breaks in the dune line) in a number of places. There were fewer changes in the maximum elevation along this section, than the two northernmost stretches. An example of a dune that did not have changes in the maximum elevation is presented in Figure 9 (Transect 362, Mile 5.45).

Pea Island Breach (Mile 6)

Figure 10 shows the evolution of the Pea Island Breach during the 2014 study year. The maximum elevations along the breach itself (where dunes were completely removed) were relatively low throughout the study year (on the order of 5 ft); adjacent areas where some type of dunes remained were on the order of 10-15 ft. In the February and April photographs, the breach was mostly dry with a relatively wide beach seaward of the temporary bridge. In the August and October photographs (after the passage of Hurricane Arthur in July 2014), water from the sound side is shown within the breach extending past the ocean side of the bridge. Figure 11 shows a ground view of the temporary bridge taken from the south ocean side of the bridge in October 2014. Standing water is visible in this photo as well.

During 2014, NCDOT was conducting preparatory work for installation of a permanent bridge over the breach (visible in Figure 10 in the April and August photographs). This work was halted as part of negotiations with environmental groups that had made legal challenges to the project to replace the Bonner Bridge over Oregon Inlet (NCDOT 2015).

Stable Zone (Miles 7-10)

About a mile south of the Pea Island Breach, a stable zone begins, extending approximately 3 miles, where NC 12 is positioned an average of 830 ft from the active beach (as determined by the location of the dune toe). Figure 12 shows an aerial photograph and the typical profile changes observed at the stable area between Miles 7 and 10. Transect 481 (located at approximately Mile 8.8) shows a highly vegetated dune with crest at approximately elevation 35 ft with smaller incipient dunes seaward; profile changes were limited to the beach face. Note that the distance of the dune from the edge of pavement of NC 12 is much greater than the examples shown in the previous sections, and the dune crest at elevation 35 ft is substantially higher than the dune crest in other areas.

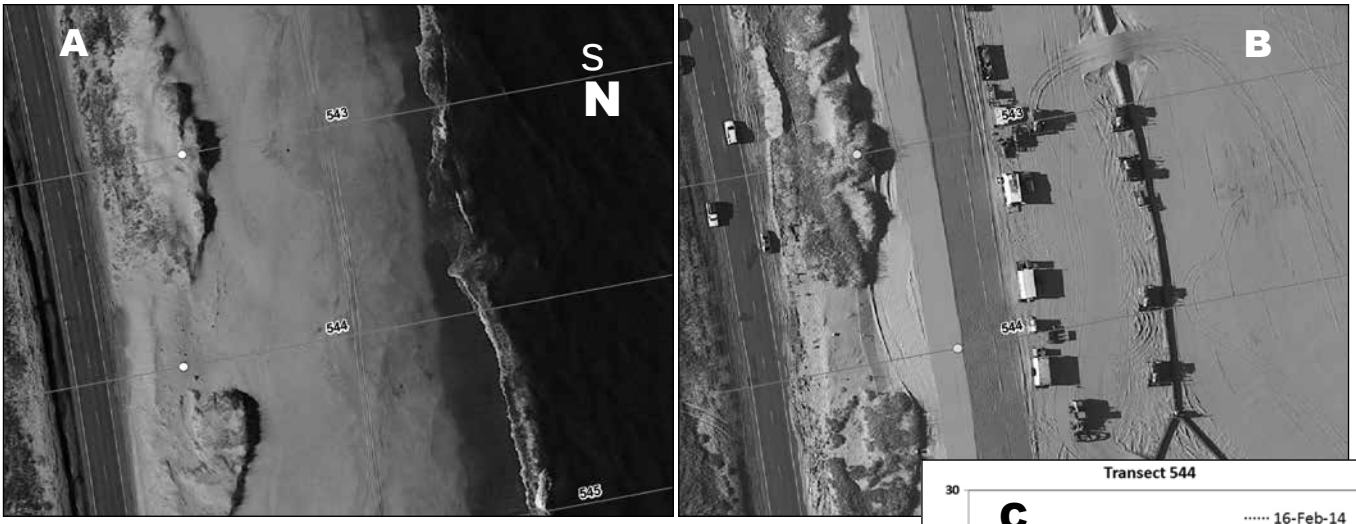
S-Curves/Mirlo Beach to Rodanthe (Miles 10-13)

The S-Curves/Mirlo Beach area requires frequent maintenance by NCDOT due to sand/water impacts from storms or especially high tides. In a number of places along this stretch of road, the dunes have been rebuilt repeatedly within the easement after the storms of recent years. Where NC 12 is very close to the active shoreline, some dunes have been reinforced with sandbags. As described previously, an emergency interim beach and dune nourishment project took place in this section August-September 2014, and a permanent bridge is planned for the area.

The largest increase in maximum elevation for the time period from April to August was attributable to the beach and dune construction efforts underway and occurred at Transect 544 near Mile 10.6 (see Figure 4). Figure 13 presents an aerial view of the beach nourishment project area before the project (2 April 2014), and when the project was in progress (14 August 2014), as well as a cross-sectional profile of Transect 544, which clearly shows the difference between the pre- (16 February, 2 April) and post- (14 August, 10 October) profiles. Note that Transect 543 just north of Transect 544 did not show a change in maximum elevation due to the project; this is because the existing dune field visible in Figure 13 had a maximum elevation greater than that of the constructed dune. Transect 544 was located in a break in that dune field and therefore clearly shows the increase in elevation.

DISCUSSION

This piece illustrates the high variability of the dunes along Pea Island,



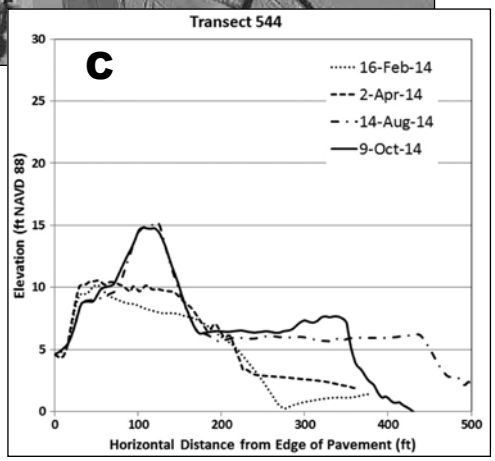


Figure 13. Aerial photos showing the location of the beach nourishment project (A) on 2 April 2014 (dune at Transect 544 (Mile 10.6) was minimal) and (B) on 14 August 2014 after the project was mostly in place, with a constructed dune (indicated by the arrow). The cross section at Transect 544 is shown in (C). Dots on the aerial photography show the location of the maximum profile elevation, transects are spaced 150 ft apart.

North Carolina, over the period of one year as a result of both natural and anthropogenic causes. While a continuous, well-vegetated, and stable dune line exists between Miles 7 and 10, most of the dune field has substantially degraded since the construction and maintenance of the dunes between the 1930s and the 1960s, which contributes to the variability observed over the one-year time frame.

The conditions as of 2014 indicate that well-established dunes are stable, but not increasing. Lower elevation, discontinuous dunes with sparse vegetation tend to degrade quickly under adverse weather conditions. The NCDOT has maintained dunes within the easement at a number of locations along NC 12 on Pea Island as a way to mitigate impacts of nor'easters and tropical storms, but Pea Island National Wildlife Refuge regulations and the size of the easement limits the size of the dunes that can be constructed therein.

Planned construction of two new bridges at the Pea Island Breach and S-Curves/Mirlo Beach sections will improve travel conditions and reduce the required earth moving operations in these areas. The establishment of a comprehensive monitoring program on Pea Island by NCDOT allows for periodic re-evaluation of conditions and activities relative to the objective of maintaining a transportation corridor and provides NCDOT essential data for determining management strategies.

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