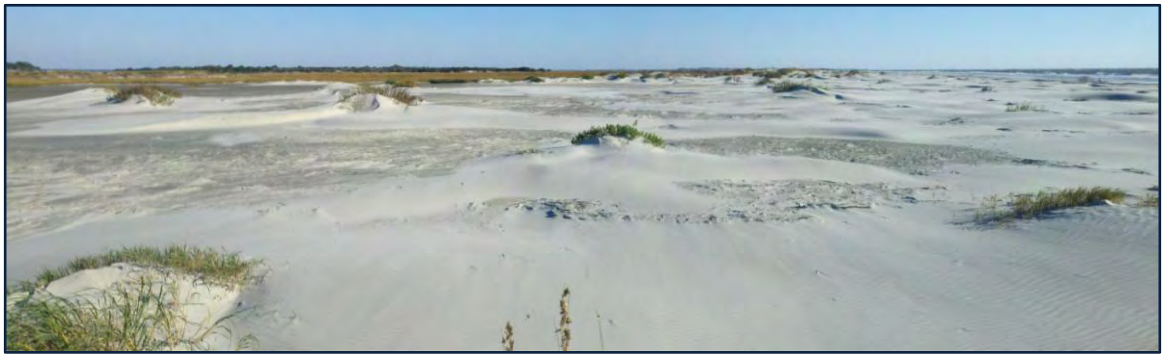
2006 EAST END BEACH RESTORATION PROJECT
KIAWAH ISLAND SOUTH CAROLINA

Survey Report No 5

May 2012



Prepared for:

Town of Kiawah Island

2006 EAST END BEACH RESTORATION PROJECT
Kiawah Island – South Carolina

SURVEY REPORT NO 5

Annual Beach and Inshore Surveys

Prepared for:

Town of Kiawah Island
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[CSE 2258YR5]
May 2012

COVER PHOTOS:

[UPPER] Ground photo from station 148+00 looking northeast in October 2011.

[LOWER] Aerial image of the eastern end and Ocean Course taken April 2011. [Photo by TW Kana]

SYNOPSIS

This report is the fifth in a series of annual monitoring reports following the 2006 east end beach restoration project. It presents results of detailed surveys encompassing the oceanfront of Kiawah Island with particular focus on the area around the Ocean Course and Stono Inlet.

CSE estimates that since the mid 1990s, Kiawah Island has gained nearly 6 million cubic yards of sand by natural accretion. Three major sand bars (offshore shoals) in Stono Inlet have been released from the delta and have been pushed onshore by waves. The first two bars added enough sand to build a new barrier beach 3 miles long which now wraps around the eastern end of the island and extends to the 16th fairway of the Ocean Course.

The new beach caused the shoreline to jump 1,000–1,500 feet seaward of the 1989 fore-dune, creating a tidal lagoon in between. The eastern half of the lagoon formed in the late 1990s and is now filled with mature salt-marsh vegetation. The western lagoon evolved over the past ten years and is likewise transforming rapidly from unvegetated sand flats to salt marsh.

The third sand bar emerged in 2007 off the prominent bulge (foreland) that marks the turn from the oceanfront to the Stono Inlet section of beach. That bar added another 765,000 cubic yards to Kiawah Island in the past five years.

To put these natural sand additions in context, they roughly equal the volume of sand pumped from offshore to North Myrtle Beach, Myrtle Beach, and Garden City (1996–1998, 26 miles) at a cost of (~)$54 million (SCDHEC–OCRM 2009). Kiawah gained a 3-mile-long barrier beach (which will serve to feed sand over the rest of the island over decades) and ~350 acres of lagoon habitat. The Grand Strand gained an average of ~75 feet of dry beach for its investment.

Natural accretion at Kiawah Island was so rapid between 1989 and 2006 that it created downcoast problems, particularly along the Ocean Course. As the new beach and lagoon formed, a flushing channel at the western end of the accreting bar encroached on the 18th fairway with as much as 700 feet of dune recession in one year. This led to the 2006 east end beach restoration project (permit #2005-1W-310).

The Town of Kiawah Island sponsored the east end project at a cost of $3,575,000 for purposes of mitigating encroachment on the Ocean Course and restoring the sand flow to downcoast beaches. The flushing channel was closed and a new channel was opened to the east. About 550,000 cubic yards of sand were scraped from the new outer beach and were placed along the Ocean Course. [LD Weaver Construction Company was the contractor, and all work was performed by land-based equipment between 8 June and 28 July 2006, a schedule based on recommendations by the US Fish & Wildlife Service.]

In addition to the goal of restoring the flow of sand to downcoast areas of Kiawah Island, the east end project was designed to prolong washover habitat. This was accomplished by removing excess sand in some areas (and transferring it downcoast) before a stable dune line could become established with vegetation.

The threatened species, *Charadrius melodus*—piping plover, prefers unvegetated washover habitat in close proximity to sheltered mud flats (source: USFWS) and abandons areas that become heavily vegetated. By reducing the volume of sand in portions of the new outer beach as it was forming, the east end project increased the chances of waves washing over the beach into the incipient lagoon. This "washover process" is the key to maintaining the type of critical habitat preferred by the piping plover. It was also a way for the new beach to equilibrate closer to the 1989 shoreline and reduce the prominence of the east end, a factor in the rate of sand flow to downcoast areas.

A measure of the success of the 2006 project can be seen in the habitat maps in this report (Figs 4.7–4.10) and in Figure A which is based on these maps. In 1999, the area analyzed consisted mostly of open-ocean waters. As Figure A shows, many acres of dunes, washover habitat, salt marsh, and sheltered lagoon environments have formed in barely one decade. Areas of salt marsh are expanding as sheltered intertidal flats become vegetated. The area of washover habitat has increased more than 50 percent since the 2006 project, while the area of protective dunes is also expanding. The report includes numerous details regarding these changes and also notes the generally healthy condition of downcoast areas to Kiawah spit.

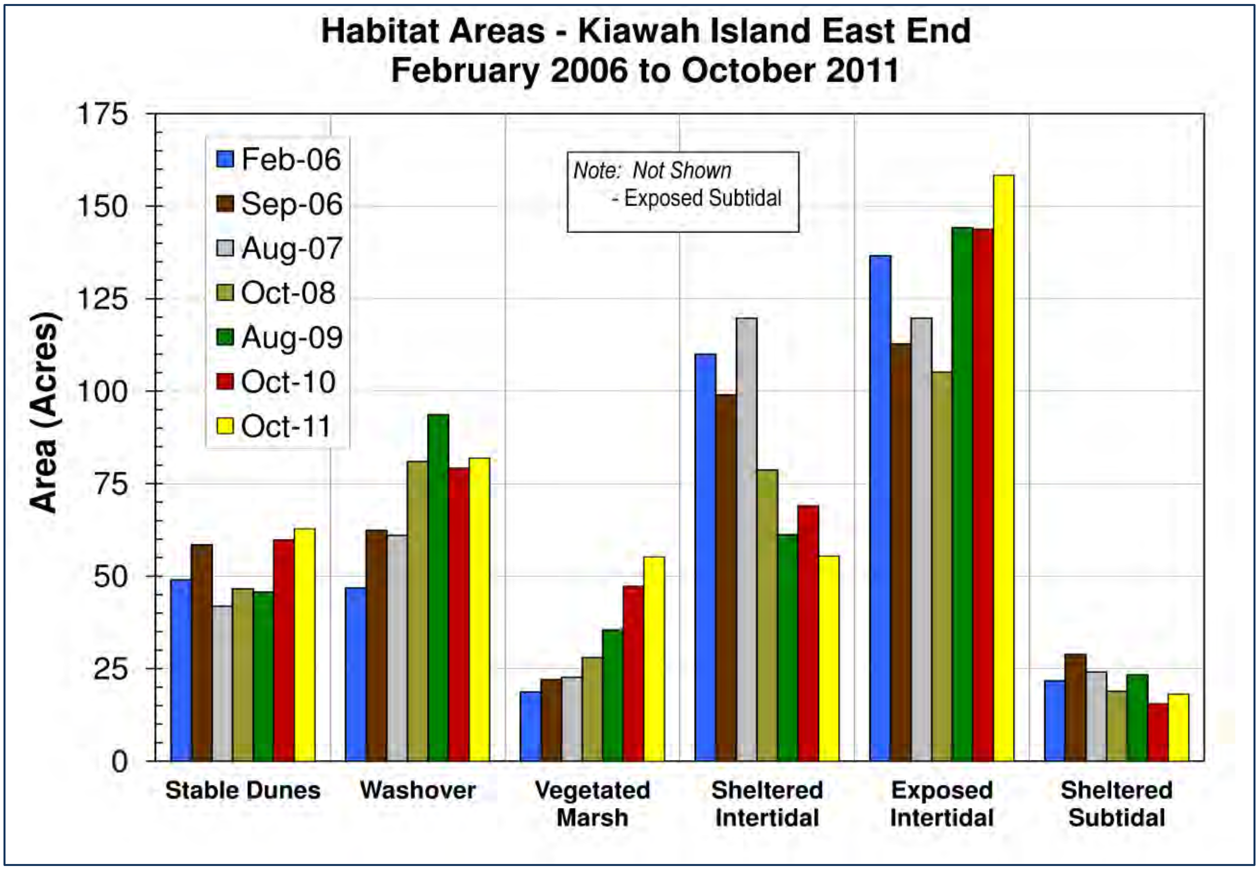

FIGURE A. Habitat area changes monitored by CSE since February 2006. [These data are produced from the maps of Figures 4.7 through 4.10 in this report.]

During the past monitoring year (September 2010 to September 2011), the island lost ~137,000 cubic yards (equivalent to an average beach recession of ~4 feet); 79 percent of the loss occurred at the east end. However, since August 2007, when the third bar attached at the eastern end, Kiawah Island has gained another 785,000 cubic yards. To put this amount in perspective, it nearly equals the volume pumped onto Isle of Palms from offshore in 2008 at a cost of (~)$8.4 million when the Links Course at Wild Dunes and numerous properties were dealing with the adverse consequences of a shoal-bypassing event.

Kiawah Island remains one of the healthiest beaches in the world. The results of shoreline monitoring and tracking the sand supply have provided new insight into the formation of barrier islands and rates of evolution of important habitats. Based on the results herein, the prognosis for the future is favorable for Kiawah's beach.

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1.0 INTRODUCTION

This report is prepared as part of a series of annual beach monitoring reports following the east end restoration project completed in July 2006 (CSE 2005, 2007). The Town of Kiawah Island (SC) is sponsoring annual surveys (as required under P/N 2005-1W-310P) and additional monitoring of the sandy shoreline for purposes of determining the rates of sand movement, accretion, and erosion adjacent to the project area. This is the fifth report of the series, and it follows a dozen shoreline erosion reports prepared by Research Planning Institute (RPI) and Coastal Science & Engineering (CSE) for Kiawah Island since the 1980s (eg – Kana et al 1983, CSE 1999). Annual post-project surveys were conducted in September 2006 (final project report), August 2007 (Year 1 monitoring report), October 2008 (Year 2 monitoring report), August 2009 (Year 3 monitoring report), October 2010 (Year 4 monitoring report), and October 2011 (present report).

The primary purpose of this report is to document the performance of the 2006 restoration project. The project was unique in that:

1) It was designed to stop erosion associated with a shoal-bypass event and restore the beach along the Ocean Course.
2) It involved manipulation of an incipient beach ridge such that washovers were maintained for the benefit of migratory birds.
3) It involved construction of a new channel and closure of an existing channel along with its associated impacts on an incipient lagoon.
4) It was a small project relative to the natural changes associated with the shoal-bypass event.

The goals of the project which are addressed in this report include:

- Reduction of the shoreline salient created by the attaching shoal of the shoal-bypass event.
- Safeguarding incipient washover habitat and lagoon habitat so that natural processes continue.
- Restoration of downcoast sand transport.

The secondary purpose of this report is to describe the current health of other sections of Kiawah Island as compared to past conditions. This involves documenting sand volume changes along the entire island (OCRM 2615 to CSE 252+00) to identify areas where the beach and dunes may be eroding or accreting. Annual monitoring provides a quantitative account of sand volume changes, which can then be used to infer sediment transport rates along the shoreline and predict future areas of concern before critical situations arise.

The scope of work for the annual monitoring efforts includes:

- Controlled aerial photography for habitat mapping.
- Ground surveys of the outer beach, lagoon, and inshore zone.
- Beach surveys downcoast of the project area.
- Sediment compaction monitoring along the nourished area (up to three years after nourishment).
- Delineation of principal habitats by a combination of topographic/bathymetric surveys and aerial photography analysis.

The next section presents a brief description of Kiawah Island and its historical shoreline changes. A summary of the methods used during surveying and data analyses follows in Section 3. Section 4 includes the results of the survey and habitat mapping. Section 5 presents a discussion of CSE's present findings and recommendations.

2.0 SETTING AND HISTORY

Kiawah Island continues to be one of the healthiest barrier islands in South Carolina. The addition of sand generated from Stono Inlet has led to stable dunes spanning the beachfront with only minor localized erosion in specific hot spots as sand migrates downcoast from Stono Inlet. The addition of sand through the process of inlet bypassing and the foresight of the island's developers to properly study the processes controlling the morphology of the island (Hayes et al 1975, Hayes 1977) make Kiawah Island an excellent example of beachfront development and a premier community along the South Carolina coast (Fig 2.1).

FIGURE 2.1. Kiawah Island's oceanfront at low tide on 15 April 2011. View is toward the west from Stono Inlet. [Photo by T Kana]

2.1 Geologic History of Kiawah Island

Kiawah Island has been studied in detail since 1974, when Professor Miles O. Hayes and colleagues at the University of South Carolina initiated field measurements and review of the geologic history of the island. Using Kiawah Island as a model, Hayes coined the term "drum-stick" barrier island, which today commonly describes barrier islands of the South Carolina coast and other "mixed-energy settings" (Fig 2.2) (Hayes 1977, 1994; Hayes & Michel 2008). The oldest part of the island, adjacent to the Kiawah River, was found to be about 4,000 years old. The island's eastern end has prograded several thousand feet seaward since the mid 1800s, leading to the creation of parallel dune ridges, each representing the shoreline at the time it was created.

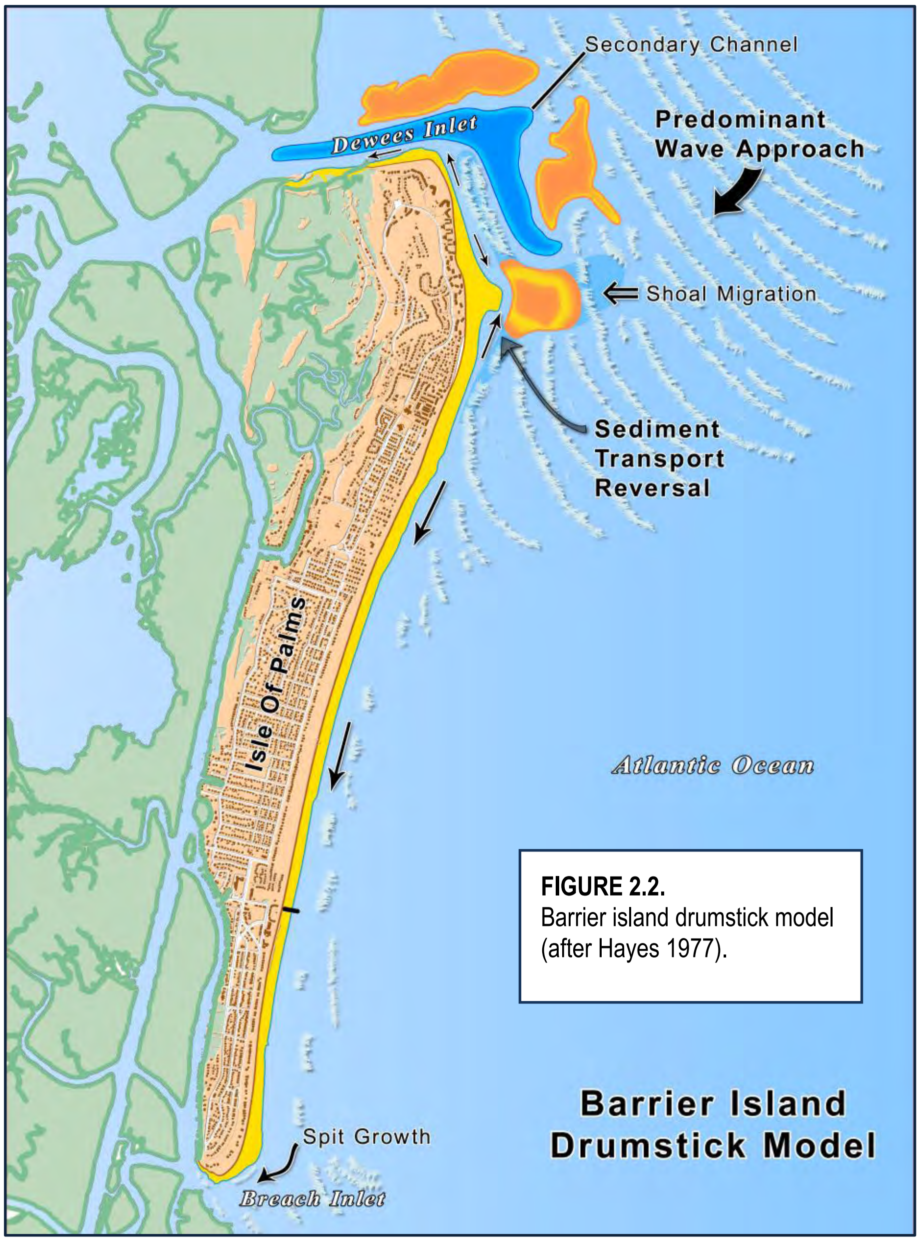


FIGURE 2.2.
Barrier island drumstick model (after Hayes 1977).

The island is roughly 10 miles long, bounded by Stono Inlet to the east and Captain Sams Inlet to the west (Fig 2.3). The eastern end episodically gains sand by way of shoal-bypassing events (Williams & Kana 1986, Gaudiano 1998), and the sand eventually spreads to downcoast parts of the island until reaching Captain Sams Inlet, where it accumulates and forms Kiawah spit. These shoal-bypassing cycles are responsible for the continued growth of Kiawah Island, but can also cause temporary erosion, which will be discussed later. The geologic history of Kiawah and the processes controlling sand movement along the island are discussed in more detail in CSE (1999).

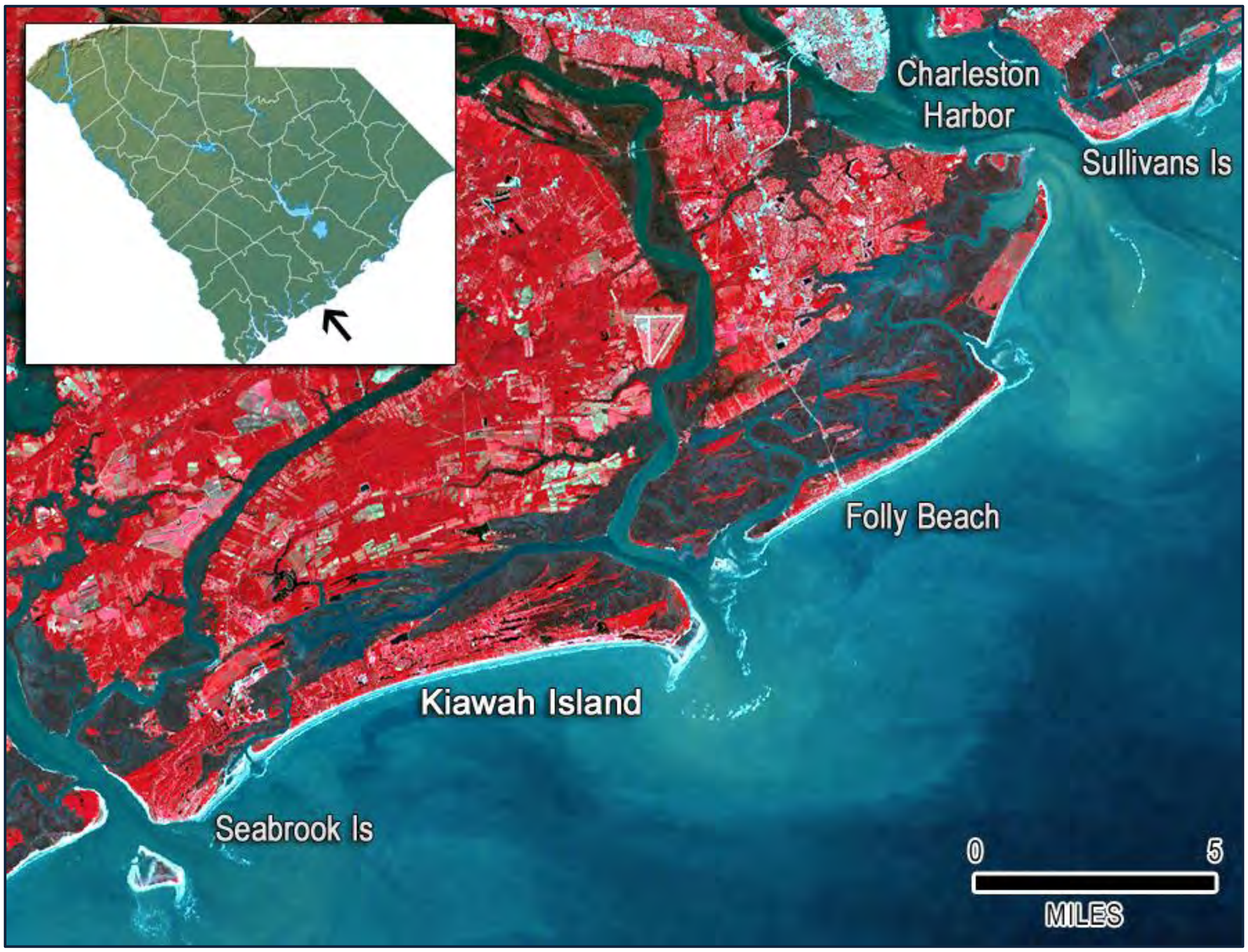


FIGURE 2.3. South Carolina coastline from Seabrook Island to Charleston Harbor. [Image courtesy Research Planning Inc and SCDNR]

2.2 Previous Shoreline Studies

The first shoreline assessment of Kiawah Island was performed by Hayes and his students in the early 1970s (Hayes et al 1975). Based on the geomorphology of the island, Hayes identified five zones along the beach and recommended two middle zones (West Beach and Turtle Point) as being suitable for development landward of the second dune ridge (Fig 2.4). The early development of the island was based on the findings of these studies, and it became one of the first localities in the State to implement rigorous setback lines.

From 1981 to 1987, regular monitoring efforts were conducted by Research Planning Institute Inc (RPI) and CSE (cf – Sexton et al 1981, Williams and Kana 1987). In July 1988, the Beach Management Act (BMA) of South Carolina was enacted, and by 1989, management of the State's beach monitoring programs was taken over by the State, ending CSE's involvement. In 1994, CSE was again contracted by the Town of Kiawah Island and conducted monitoring through 1999.

From 1981 through 1999, Kiawah Island either gained sand or remained stable. Specific areas showed sporadic erosion; however, the magnitude of sand loss was generally small. The West Beach area (encompassing Windswept Villas, Mariners Watch Villas, Eugenia Avenue, West Beach Village, and Kiawah Inn) remained stable, losing only 0.21 cubic yards per foot per year (cy/ft/yr) from 1983 until 1999 (with episodic accretion and erosion events). All other reaches showed gains in sand between 1983 and 1999. Details of volume changes from 1983 to 1999 are given in CSE (1999).

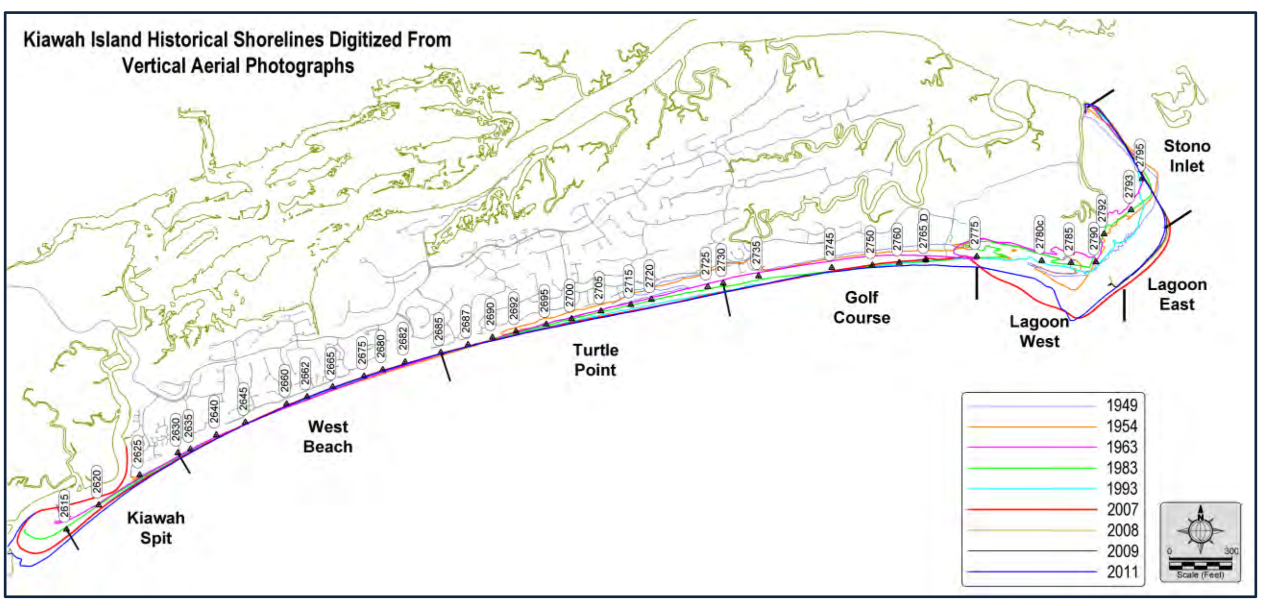


FIGURE 2.4. Historical shorelines (seaward vegetation lines). West Beach has been slightly erosional shoreline whereas all other reaches have been generally accretional since 1949. [Updated from CSE 1995]

2.2.1 Stono Inlet

Sand from Stono Inlet is the major littoral source for Kiawah Island (Kana et al 1981). Inlet ebb-tidal deltas often contain as much or more sand than the adjacent barrier islands along the southern two-thirds of the South Carolina coast (Sexton and Hayes 1996). In this mixed-energy environment (Hayes 1994), waves and tidal currents both have a significant impact on shaping the morphology of the inshore zone (Fig 2.5). Sand is moved seaward by strong ebb-tidal currents at the inlets. Waves then push deposited sand landward in the form of shoals. This produces characteristic features common to much of the central and southern South Carolina coast–such as lobate deltas extending miles offshore, marginal flood channels (small channels near the beach flanking the main channel and dominated by flood currents), and migrating shoals (cf – Figs 2.2 and 2.3).

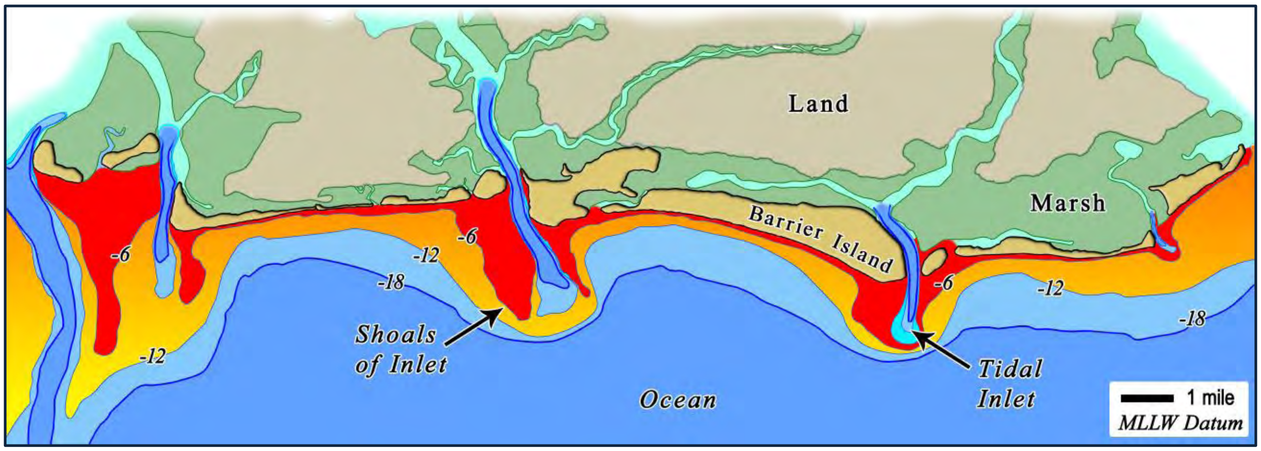


FIGURE 2.5. Nearshore bathymetry for a typical section of the central and southern South Carolina coast. Ebb-tidal deltas contain large amounts of sand, which alter the local bathymetry. This in turn directs wave energy and sediment transport patterns along the adjacent beaches.

Periodically, sand stored in the ebb-tidal delta of Stono Inlet is released when the inlet channel shifts position. Shoals on the downcoast (west) side of the channel are freed from the delta and pushed shoreward by wave action. During this process, the beach in the lee of the shoal builds because of decreased wave energy. Adjacent to the areas of accretion, erosional arcs are formed by changes in the wave patterns due to refraction around the offshore shoal. This process continues until waves have pushed the shoal to the point of attachment along the beach.

Once attached, the shoal is considered to be in Stage 3 of the shoal-bypass cycle (Kana et al 1985, Williams & Kana 1986). Waves continue to push the shoal landward and upward while spreading sand laterally along the beach. Shoal spreading (Stage 3) provides natural nourishment with sand moving downcoast via longshore currents. The time between release of the shoal by the inlet, and attachment and spreading depends on the size of the inlet and its ebb tidal delta. Large inlets, such as Stono Inlet, tend to initiate shoal-bypassing events every 7–8 years with individual shoal volumes often exceeding 0.5 million cubic yards (Gaudiano & Kana 2001).

Kiawah Island has recently experienced two impressively large shoal-bypassing events. The first formed offshore in 1994 and had completely attached to the eastern end of Kiawah by 1997. The second began attaching to Kiawah along its eastern flank in 1998. The western flank of the second shoal overlapped the eastern Kiawah shoreline as it built and migrated west and north between 1998 and 2004 (Fig 2.6). These two events were the largest ever documented on the South Carolina coast (CSE 2005). They contained such a large quantity of sand that wave action was not able to completely push the shoal against the original shoreline, and a new beach line and dune system were formed more than 2,000 feet (ft) seaward of the original shoreline. This created a lagoon between the new and old shorelines, along with a roughly 2-mile-long barrier beach (Fig 2.6). The recent shoal-bypass events showed how rapidly barrier islands can form, even in the presence of sea-level rise and other erosional forcing (Kana 2002).

By 2004, the shoals had completely attached at the eastern end but remained offshore at the western end as sand migrated westward, reaching near the (old) Ocean Course clubhouse (Fig 2.6). The shoals had not completely attached at the western end due to a natural channel maintained by tidal flushing of the lagoon. CSE (2005) estimated the two shoals added ~5 million cubic yards to Kiawah Island. Due to the overwhelming quantity of sand added at the eastern end, the shoreline near the Ocean Course jumped seaward and changed orientation. This protrusion altered the direction of approaching waves and caused focused erosion along the Ocean Course.

As longshore transport moved the shoal westward, the flushing channel migrated with the shoal, encroaching on the Ocean Course, specifically the 16th and 18th holes. The beach at the original Ocean Club clubhouse (near OCRM monument 2775) retreated over 500 ft between 2000 and 2005. The magnitude of the bypassing event was so great, it was apparent that severe erosion would continue for several years before the cycle would be complete (Gaudiano & Kana 2001). The Ocean Course remained vulnerable to erosion as the shoal and flushing channel migrated westward. This led to the plan for beach restoration by CSE (2005).

FIGURE 2.6. The eastern end of Kiawah Island in December 1998 (upper) and February 2005 (lower). Note the 1989 shoreline situated well inland from the outer beach. Shoals 1 and 2 added upward of 5 million cubic yards to Kiawah in the 1990s. As waves pushed the new sand shoreward, an incipient barrier island/lagoon/marsh formed. The new lagoon was flushed via a channel at the western end of the accreted beach. [From CSE 2007]

2.3 2006 East End Beach Restoration Project

In June and July of 2006, the east end beach restoration project (SCDHEC–OCRM permit No P/N 2005-1W-310-P, USACE permit No 2005-1W-310) was completed by L. Dean Weaver Company Inc. This project sought to artificially create Stage 3 of the shoal-bypassing cycle and avoid further erosion of the Ocean Course. The details of the project are given in the *2006 East End Erosion and Beach Restoration Project: Kiawah Island Final Report* (CSE 2007). The objectives of the project, which will be assessed in this report, were to:

- Accelerate the shoal-bypassing cycle so as to restore westerly sand transport along Kiawah Island.
- Eliminate rapid erosion along the Ocean Course, particularly around the 16th, 17th, and 18th fairways and the driving range.
- Maintain viable, piping plover beach habitat along the newly accreted barrier spit east of the Ocean Course, including areas of frequent washovers and the adjacent incipient dune habitat.
- Preserve the environmental, cultural, and aquatic resources of the Town.
- Provide protection to oceanfront recreational facilities and community infrastructure as a resource of tax revenue and income.
- Maintain the economic viability of tourism, the Town's largest industry.
- Make a new source of sand from the accreting shoal more readily available for natural nourishment along downcoast areas.

The project consisted of closure of the existing flushing channel, creation of a new channel to maintain the tidal environment of the lagoon, and excavation and transfer of nourishment sand from the new inlet and accreted shoal areas to eroded downcoast areas. These actions were designed to provide a smoother transition between Kiawah's main beach and the accreted shoal. The contracted volume for the project was 550,000 cubic yards (cy), the majority of which was placed between the new clubhouse and just west of the old flushing channel. The new flushing channel was positioned at the apex of the attached shoal in Reach "1" (Fig 2.7).

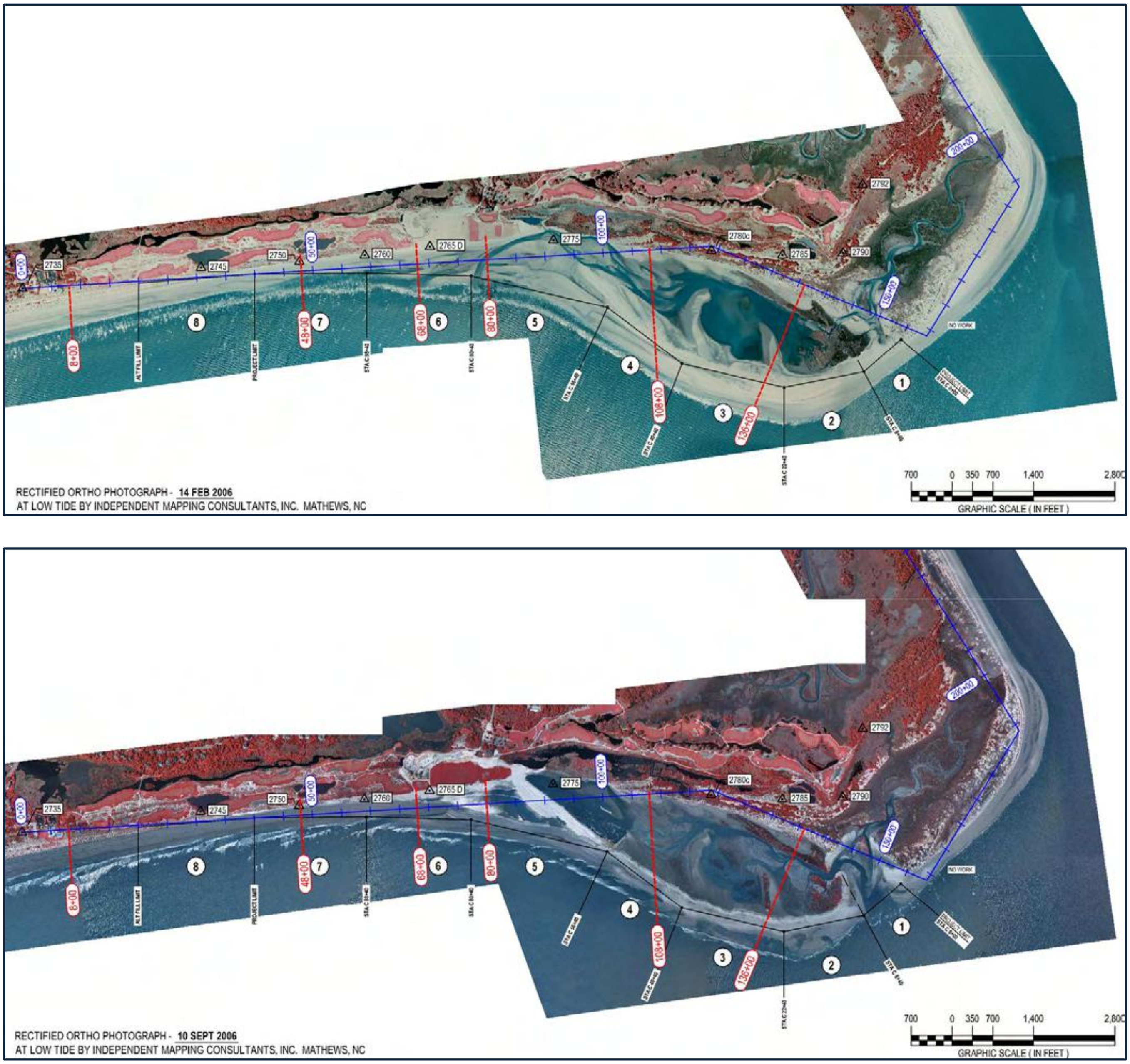


FIGURE 2.7. Rectified aerial photos of the project area showing pre-construction (February 2006, upper) and post-construction (September 2006, lower). The channel in Reach 5 was closed, and a new channel was constructed in Reach 1. Sand from Reach 1 to Reach 4 was excavated and transferred to Reaches 5–7.

A major goal of the project was to maintain habitat for piping plovers, which migrate to the area in early fall and utilize the area for foraging through the spring. Piping plovers make use of washover areas with little vegetation, particularly where the habitat is adjacent to sheltered tidal flats (M Bimbi, pers comm, April 2006). To maximize habitat, elevations along the new outer beach were maintained below +4.5 ft NAVD. This elevation allows frequent overtopping by waves during minor storm events. As recommended by the US Fish & Wildlife Service (USFWS), yearly monitoring of critical habitat for piping plovers was incorporated into the project and is being supervised by staff biologists for the Town of Kiawah Island.

In 2007, the constructed flushing channel naturally closed while a new flushing channel opened in Reach 4 (Fig 2.8). Several factors potentially led to the closure of the original flushing channel. The emergence of an offshore shoal to the west of the channel caused wave-focusing and significant erosion to the shoreline in the vicinity of the constructed channel. Sand lost from the dunes adjacent to the channel was deposited in and behind the channel. By September 2007, the constructed channel had completely infilled, and a new flushing channel had opened in Reach 4 (see Fig 2.7 for construction reach boundaries). The low elevations of the outer beach in Reaches 2–4 (intended to maintain washover habitat) left that reach susceptible to a breach. The new channel location provided a more efficient path for tidal flow. The emergent shoal off Reach 2 also increased the likelihood of a breach in Reach 4 because of wave-focusing around the sand bar.

The opening of the breach channel in Reach 4 was not surprising given that the goal of the project was to maintain washover habitat. By limiting the outer beach to a height less than storm tides and reducing the volume of sand in the profile so as to prolong the washover habitat, the project allowed the system to develop a channel in a more efficient location. The inlet of the new channel intersected monitoring station 104+00. It was ~75 ft wide at mean low water (MLW) at its narrowest point, and ~600 ft wide at mean higher high water (MHHW); however, at high tide, much of the area was subject to washover, and flow was not restricted through the inlet.

Between August 2009 and April 2010, the flushing channel had relocated ~2,500 ft to the east. This was facilitated by erosion of the outer barrier due to the most recent shoal-bypass event. This erosion left relatively little sand volume on the outer beach, making it susceptible to breaching. Southerly migration of the old channel was also inhibited by large sand volumes in the closure dike area. Section 4 contains details of the evolution of the lagoon along with pre-project and post-project changes in sand volumes and habitat areas.

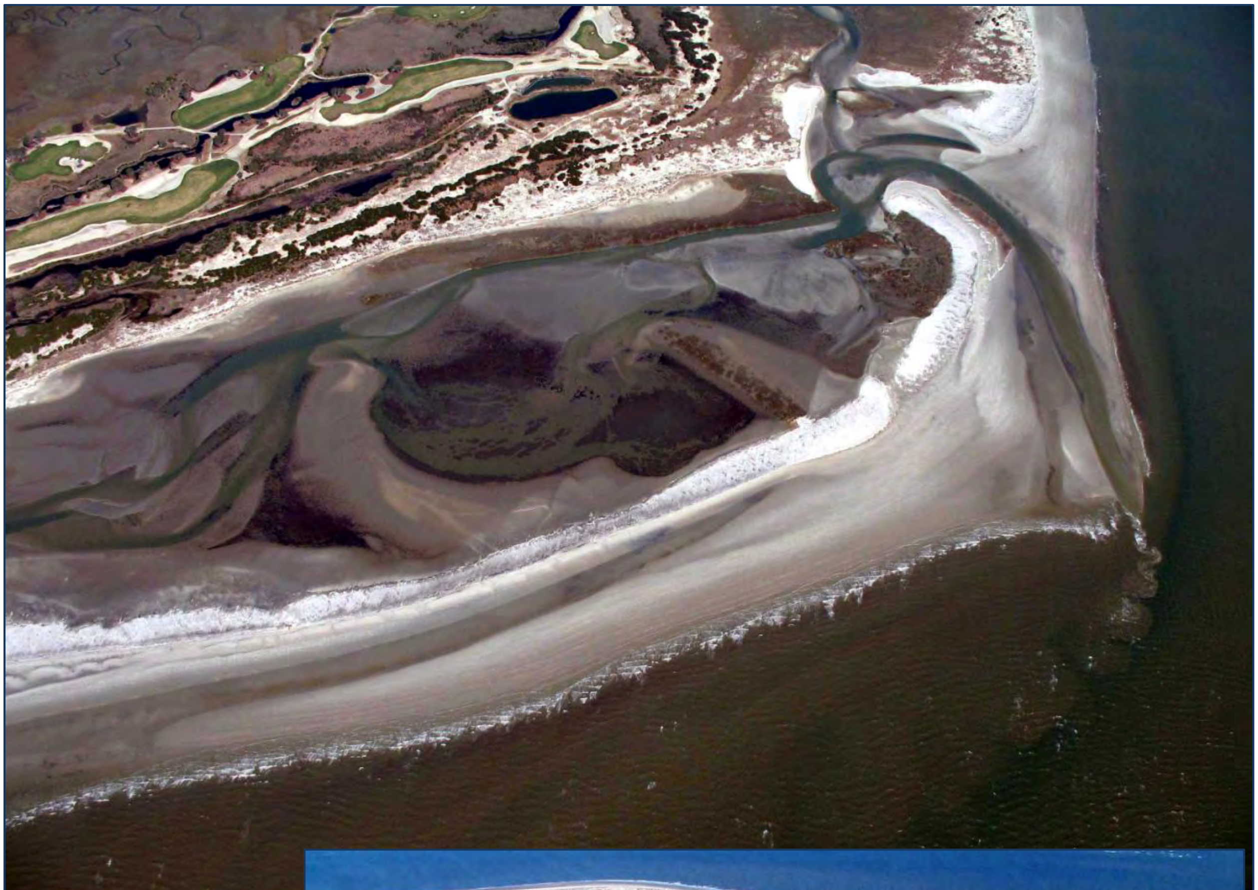


FIGURE 2.8.

[UPPER]
Aerial view of the outer beach in the project area between Reaches 1 and 4 on 17 February 2007. Note shoaled flushing channel at right side of image (Reach 1).

[LOWER]
The same area at low tide on 5 December 2007 after formation of a breach channel in Reach 4 and natural closure of the constructed channel.

3.0 METHODOLOGY

This section describes the methodologies of the topographic survey and habitat mapping used by CSE to monitor changes at Kiawah Island.

3.1 Survey

The present survey was conducted by RTK-GPS* (Trimble™ R8 GNSS system) in October 2011. Profiles along Kiawah Island were surveyed perpendicular to the local shoreline (CSE baseline) azimuth from the control points to a minimum of −12 ft NAVD (the depth equal to the normal limit of sand movement in this setting) or at least 3,000 ft from the dune. Surveys were conducted by combining a land-based survey and a bathymetric survey (Fig 3.1). Land surveys were accomplished using an RTK-GPS between the foredune and low-tide wading depth [(~)−6 ft NAVD], whereas overwater work was accomplished via RTK-GPS combined with a precision echo-sounder mounted on CSE's shallow-draft boat, the *RV Congaree River*.

*[*Real-time kinematic global positioning system]*

Working around the tidal cycle, data collected on land were extended into shallow depths in the surf zone at low tide. Then data were collected from the boat at high tide such that overlap of the two surveys occurred close to shore (Fig 3.2). Appendix A includes profiles for the most recent survey compared to earlier surveys.

For the present survey, CSE reoccupied 87 stations along the length of Kiawah Island (Fig 3.3). Twenty-three of these stations (OCRM 2615–2730) encompass the beach downcoast of the 2006 project area. These stations represent most of the developed (residential) shoreline of Kiawah Island and use OCRM monuments as survey controls. The remaining stations follow the 2006 project baseline and encompass the Ocean Course, incipient lagoon, and Stono Inlet shorelines. For this area, CSE reoccupied 64 stations at 400-ft spacing.

The locations of stations along with offset and cutoff distances are given in Table 3.1. Station numbers increase from west to east with the area downcoast of the project site based on the OCRM monument number (2615–2730). The project area and Stono Inlet shoreline are based on CSE stationing (0+00 through 252+00). CSE's stationing is in engineering format in that it marks the distance along the baseline (distance along the beach) from a starting point—that is, station 4+00 is 400 ft from station 0+00, while station 12+00 is 1,200 ft upcoast of station 0+00.

FIGURE 3.1.

CSE's survey methods involve land based data collection via RTK-GPS (upper Left) and hydrographic data collection via RTK-GPS linked to a precision echo-sounder. CSE's shallow-draft vessel the *R/V Congaree River* is shown in the lower image.

FIGURE 3.2.

CSE combines land-based and hydrographic data collection to produce continuous profiles of the beach. Land-based work is accomplished at low tide, while hydrographic work is performed at high tide. This allows for overlap of the two data collection methods and ensures quality data and a complete profile.

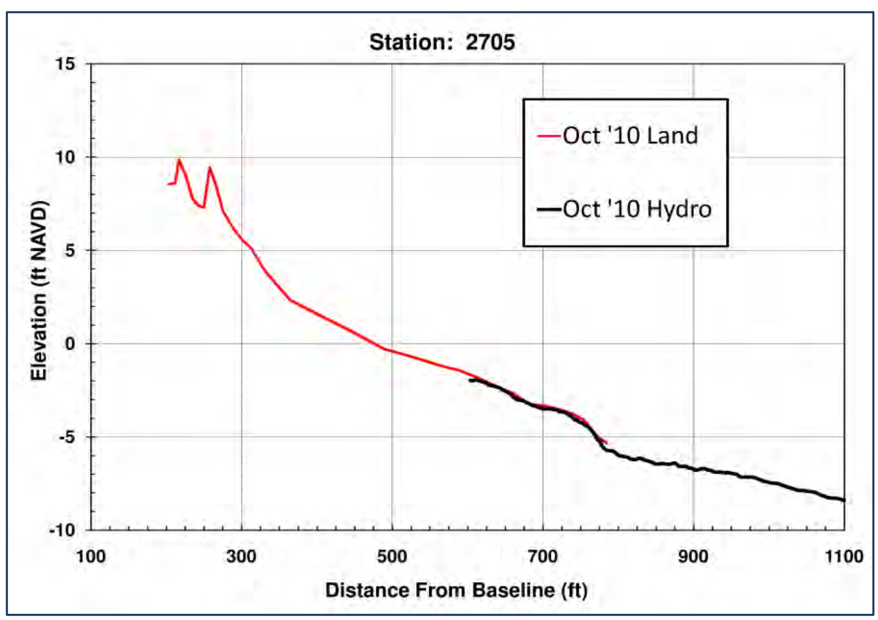


FIGURE 3.3. General location of beach stations and reaches monitored for the present report. The construction baseline is illustrated by a thin dashed line. The monitoring baseline is illustrated by a thick solid line.

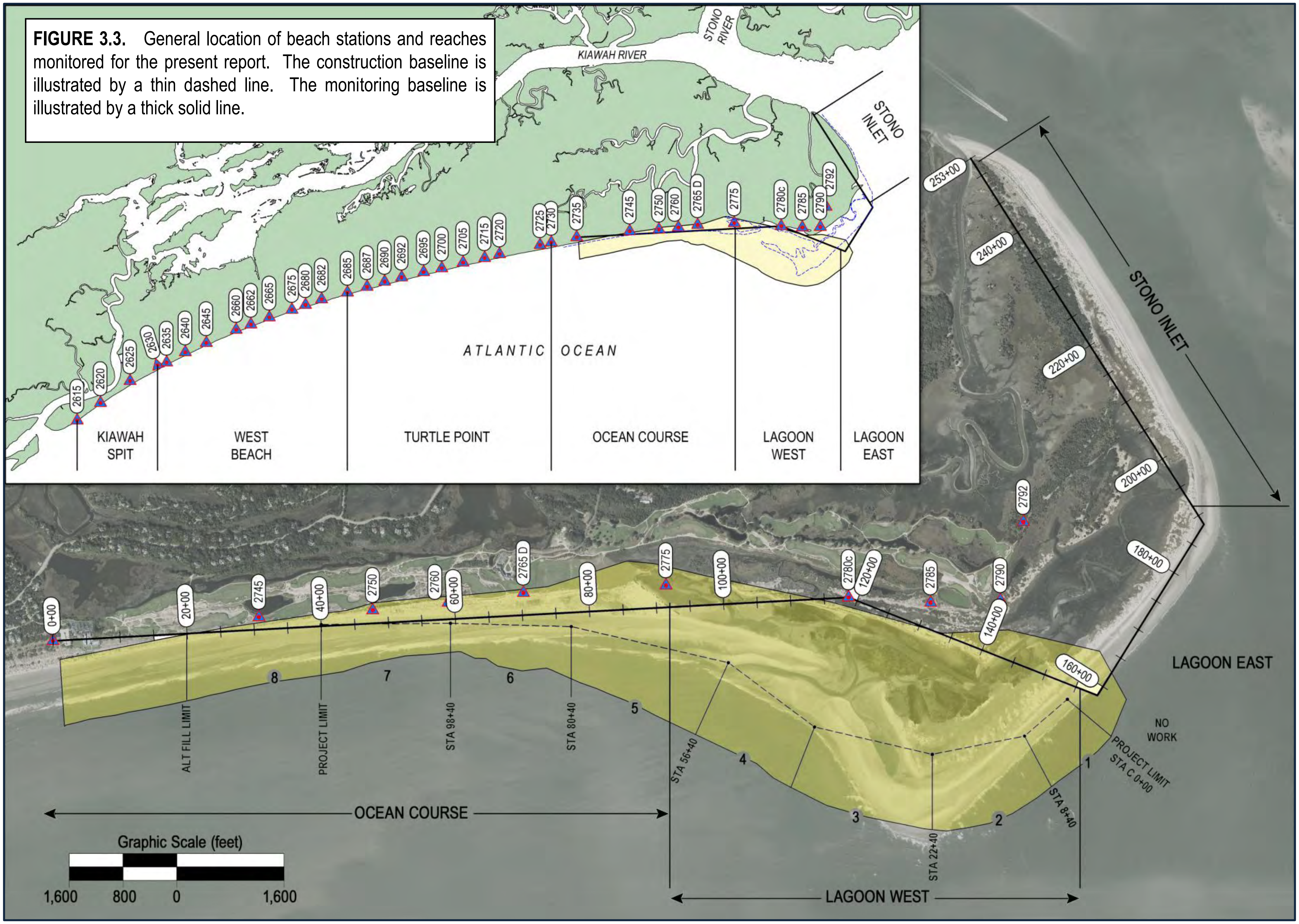


TABLE 3.1. Kiawah Island beach monitoring stations referenced in the present report. Order is generally west to east. Offset and cutoff refer to distances from the benchmark/baseline for the start and end of beach volume calculations.

CSE Baseline Station	Northing (ft)	Easting (ft)	Offset (ft)	Cutoff (ft)	Distance to next (ft)
OCRM 2615	273138	2265063	140	1500	1689
OCRM 2620	274152	2266415	86	1300	2127
OCRM 2625	275417	2268125	189	1500	1842
OCRM 2630	276333	2269724	152	1500	547
OCRM 2635	276491	2270247	41	1500	1231
OCRM 2640	277083	2271327	94	1500	1357
OCRM 2645	277620	2272544	47	1200	1891
OCRM 2660	278383	2274274	28	1100	2051
OCRM 2665	279099	2276196	22	1000	1383
OCRM 2675	279542	2277506	0	1100	831
OCRM 2680	279822	2278288	46	1300	2531
OCRM 2685	280538	2280718	10	1200	1033
OCRM 2687	280861	2281852	40	1500	1214
OCRM 2690	281167	2282876	93	1300	1145
OCRM 2692	281415	2283856	279	1500	1201
OCRM 2695	281719	2285131	119	1400	1080
OCRM 2700	281944	2286188	100	1400	1268
OCRM 2705	282269	2287414	130	1500	1278
OCRM 2715	282536	2288663	145	1500	889
OCRM 2720	282753	2289526	208	1500	1291
OCRM 2722	282849	2289925	436	1600	1125
OCRM 2725	283289	2291876	322	1600	666
OCRM 2730	283431	2292527	316	1600	1504
0+00 (OCRM 2735)	283729	2294001	355	1500	400
4+00	283754	2294400	279	1500	400
8+00	283778	2294800	222	1500	400
12+00	283802	2295199	189	1500	400
16+00	283827	2295598	115	1500	400
20+00	283851	2295997	88	1500	400
24+00	283875	2296397	25	1500	400
28+00	283899	2296796	-25	1500	400
32+00	283924	2297195	-71	1500	400
36+00	283948	2297594	-95	1500	400
40+00	283972	2297994	-140	1500	400
44+00	283997	2298393	-159	1500	400
48+00	284021	2298792	-185	1500	400
52+00	284045	2299192	-227	1500	400
56+00	284069	2299591	-290	1500	400
60+00	284094	2299990	-297	1500	400
64+00	284118	2300389	-238	1500	400
68+00	284142	2300789	-298	1500	400
72+00	284167	2301188	-286	1500	400
76+00	284191	2301587	-294	1500	400
80+00	284215	2301986	-314	1500	400

CSE Baseline Station	Northing (ft)	Easting (ft)	Offset (ft)	Cutoff (ft)	Distance to next (ft)
84+00	284239	2302386	-440	1500	400
88+00	284264	2302785	-300	1700	400
92+00	284288	2303184	35	2000	400
96+00	284312	2303583	-362	2000	400
100+00	284337	2303983	-287	2000	400
104+00	284361	2304382	-90	2400	400
108+00	284385	2304781	0	2500	400
112+00	284409	2305180	106	1550	400
116+00	284434	2305580	224	775	400
120+00	284404	2305970	222	2100	400
124+00	284250	2306339	184	2000	400
128+00	284097	2306709	176	2325	400
132+00	283943	2307078	1375	3020	400
136+00	283790	2307447	1266	3500	400
140+00	283636	2307817	1130	3800	400
144+00	283483	2308186	471	3300	400
148+00	283329	2308556	140	3300	400
152+00	283176	2308925	-100	2500	400
156+00	283022	2309294	-151	1000	0
160+00	283019	2309616	-666	1000	400
164+00	283359	2309827	-500	500	400
168+00	283698	2310039	-411	500	400
172+00	284037	2310251	-363	1000	400
176+00	284377	2310463	-250	600	400
180+00	284716	2310675	-185	700	400
184+00	285055	2310886	-178	800	400
188+00	285394	2311098	-212	800	0
192+00	285732	2310966	22	800	400
196+00	286069	2310751	233	900	400
200+00	286406	2310536	250	900	400
204+00	286744	2310320	285	900	400
208+00	287081	2310105	352	900	400
212+00	287418	2309890	404	900	400
216+00	287755	2309675	400	900	400
220+00	288092	2309460	409	900	400
224+00	288429	2309244	364	900	400
228+00	288767	2309029	400	900	400
232+00	289104	2308814	409	900	400
236+00	289441	2308599	407	1100	400
240+00	289778	2308383	392	1200	400
244+00	290115	2308168	348	1200	400
248+00	290452	2307953	327	1000	400
252+00	290789	2307738	120	1000	0

The construction baseline and reaches used in the 2006 project are shown in Figure 3.3. This construction baseline follows the orientation of the project area and is referenced in this report to identify general locations (construction reaches) along the outer beach in the project area. As the area continues to evolve, the construction baseline will no longer be applicable as the shape of the coastline is expected to more closely match the monitoring baseline.

The present report presents volume changes for seven reaches along Kiawah Island (Fig 3.3; reports prior to 2008 defined five reaches). The use of reaches allows regional trends to be determined, and reduces local variability often observed in individual profiles. CSE modified the upcoast reach (Stono Inlet) used in pre-2008 reports to include three separate reaches: (1) Lagoon West encompassing the western lagoon (project area), (2) Lagoon East encompassing the eastern lagoon, and (3) Stono Inlet spanning the more stable Stono Inlet shoreline. The boundary between the Turtle Point reach and the Ocean Course reach was also moved to OCRM 2730 (CSE 0+00). The reaches are defined in Table 3.2 and are illustrated in Figure 3.3.

TABLE 3.2. Kiawah Island reaches referenced in the present report. See Figure 2.4 and Figure 3.3 for maps showing reach boundaries.

Reach	Approximate Geographic Boundaries	Stations
Kiawah Spit	West end of Kiawah Island to Beachwalker Park	2615 - 2630
West Beach	Beachwalker Park to Turtle Point	2630 - 2685
Turtle Point	Turtle Point Area	2685 -000+00
Ocean Course	Ocean Course Area	000+00 - 92+00
Lagoon West	Western Lagoon	92+00 - 156+00
Lagoon East	Eastern Lagoon	156+00 - 192+00
Stono Inlet	Stono Inlet Reach	192+00 - 252+00

3.2 Volume Calculations

To estimate changes in the sand volume along Kiawah Island, survey data were entered into CSE's in-house custom software, Beach Profile Analysis System (BPAS), which calculates volumes based on 2-D profile data (in X–Y) and distances between subsequent lines. The resulting volumes provide a more quantitative and objective way of determining ideal minimum beach profiles and how changes in sand quantities (volume per unit length of shoreline) compare with the desired condition (Kana 1993). Volume results calculated via this method provide a more accurate means of comparing historical profiles, as the volume method produces a measurement of sand volumes in the active beach zone rather than an extrapolated result based on simulated models or single-contour shoreline position.

Unit-volume calculations allow for distinguishing the quantity of sediment in the dunes, on the dry beach, in the intertidal zone to wading depth, and in the remaining area offshore to the approximate limit of profile change. Figure 3.4 depicts the profile volume concept. The reference boundaries are site–specific but ideally encompass the entire zone over which sand moves each year.

For the present survey (2011), sand volume was calculated between the primary dune and −10 ft NAVD. The −6 ft NAVD contour has been used in past reports for consistency with earlier studies and limitations of pre-2007 data. While most sand movement occurs above −6 ft NAVD, some profile changes do occur between −6 ft and −10 ft NAVD. Significant changes can occur within this lens when underwater bars form or change and as shoals move onshore and alter morphology. Especially at the northeastern end, volume calculations were cut off at a set distance (profile specific) due to data coverage or morphological considerations (ie – the profile flattens over the ebb-tidal delta before reaching −10 ft NAVD). Profiles and calculation limits are shown in Appendix A.

> *NOTE: Prior reports calculated profile volumes to −5 ft NGVD, which is approximately equal to −6 ft NAVD. NAVD'88 is now the industry standard datum for vertical reference. CSE has converted prior Kiawah data to NAVD for direct comparison. CSE updated the calculation limit for the present report to −10 ft NAVD, which better encompasses total volume change. Volumes for all profiles and dates were recomputed using the lower calculation limit, therefore, volumes in the present report will differ from previous reports, which used the shallower limit.*

Figure 3.5 shows representative profiles from two reaches. The lower portion of each graph tracks the standard deviation in elevation based on the mean profile elevation of the set of profiles at a station. A standard deviation of <0.25 ft over several hundred feet at the outer end of a profile is evidence of little change in bottom elevation over the period encompassed by the data. This analysis confirms that nearly all measurable volume change along Kiawah's beach occurs above −10 ft NAVD and that the "depth of closure" (DOC*) at decadal scales is <10 ft. [**DOC is the depth beyond which there is negligible change in bottom elevation.*]

Comparative volumes and volume changes were computed using standard procedures. [CSE incorporates the average-end-area method in which the average of the area under the profiles computed at the ends of each cell is multiplied by the length of the cell to determine the cell's sand volume.] Volume results at each profile line were extrapolated to the next line. Net volumes were calculated for each profile as well as for project reaches (see Tables 3.1 and 3.2).

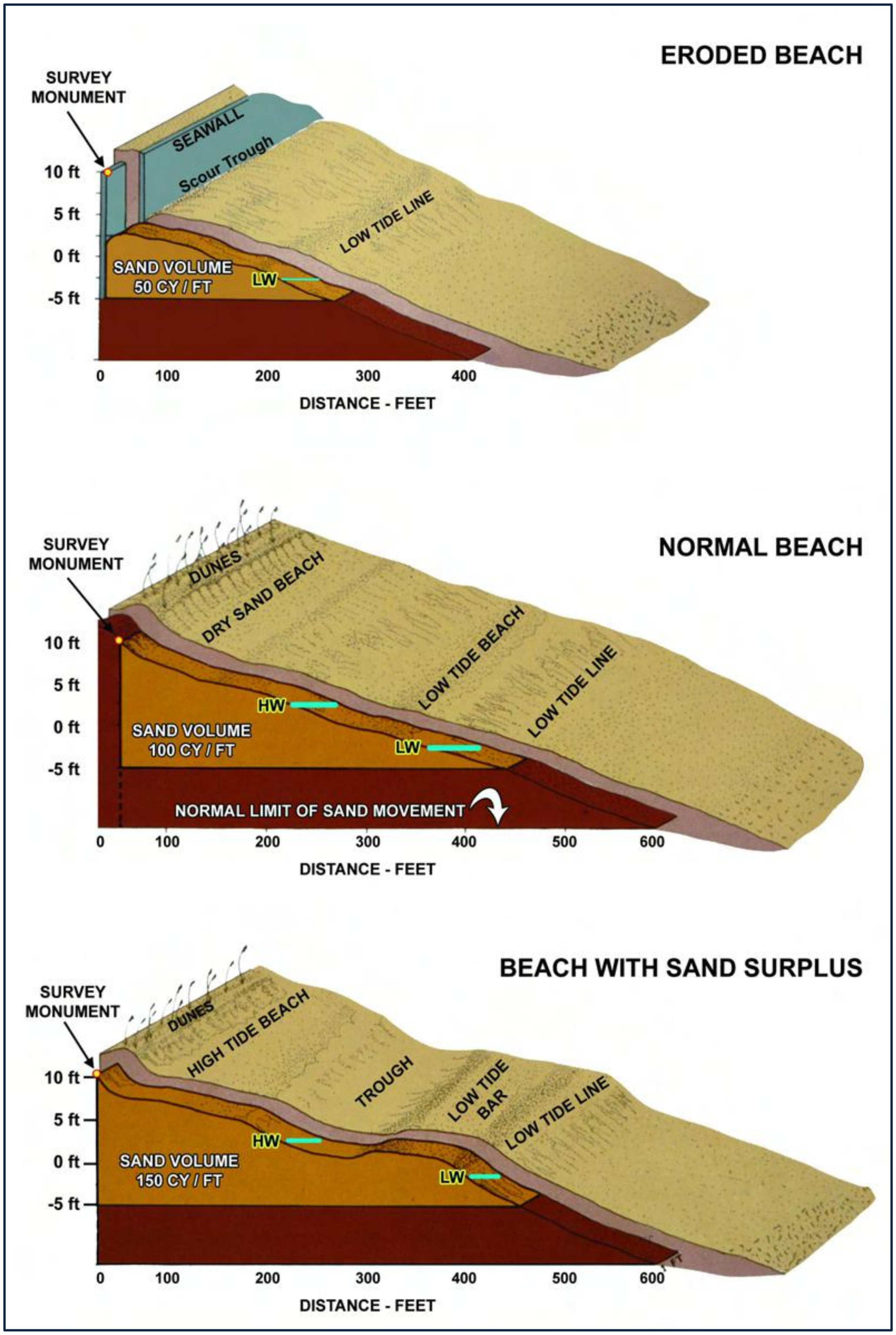
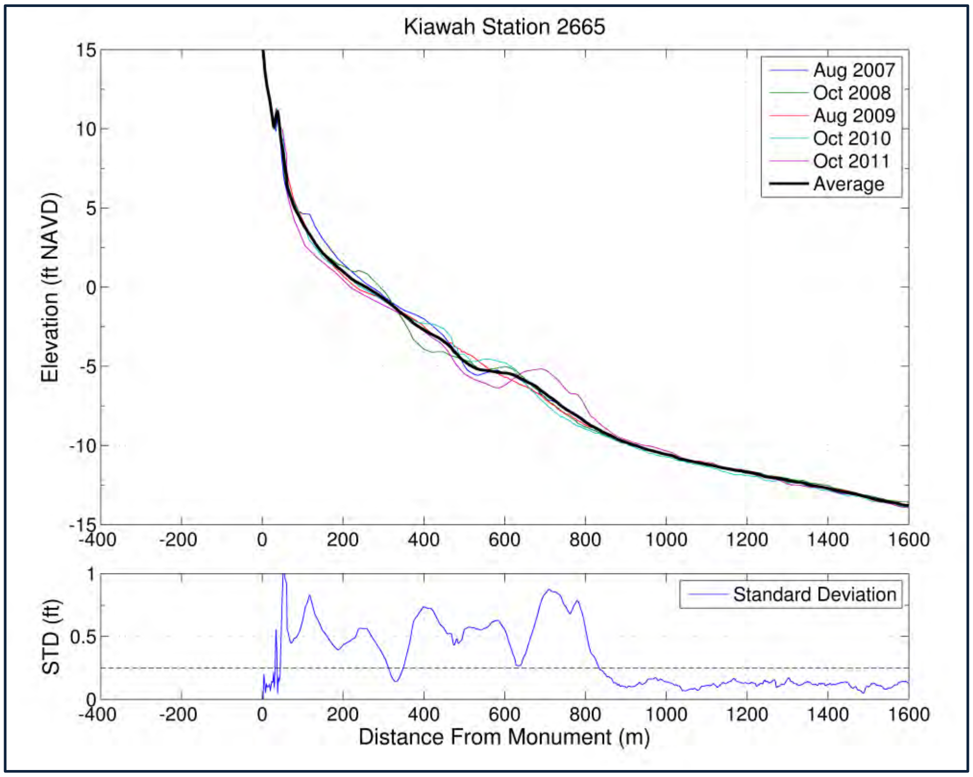


FIGURE 3.4. The concept of profile volumes – the volume of sand between defined contours over a 1-ft (unit) length of beach. [After Kana 1990]



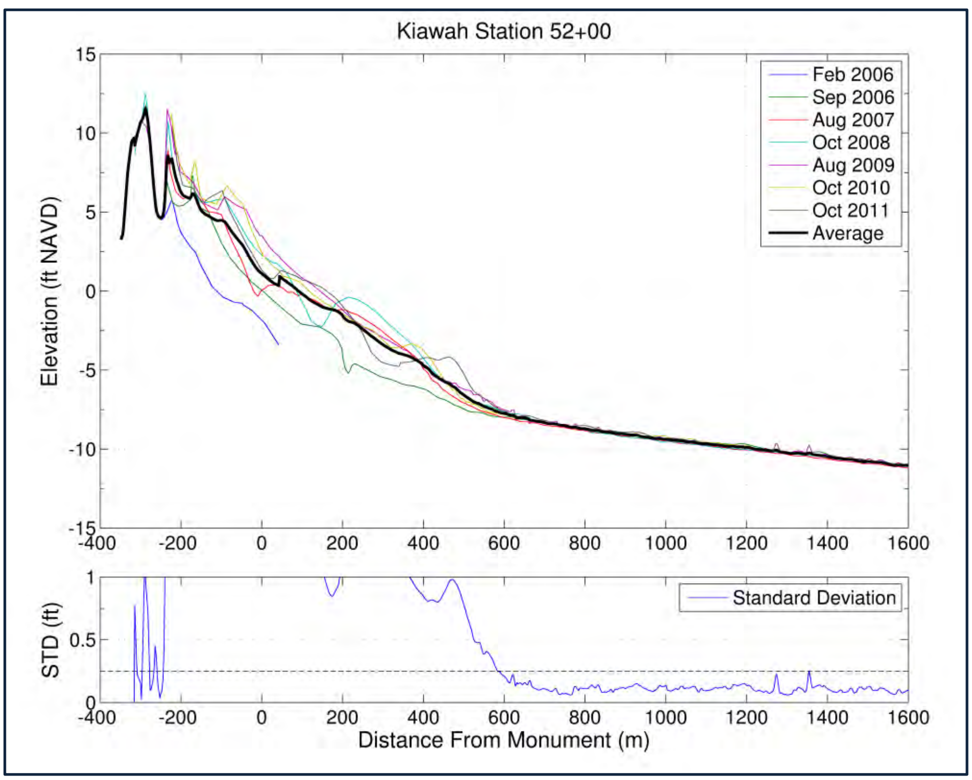


FIGURE 3.5. The lower portion of each graph tracks the standard deviation (variation from the average elevation) at any given point along a set of profiles. A standard deviation of <0.25 ft over several hundred feet is evidence of little change (ie – approximate DOC).

3.3 Sediment Compaction

As required by the permit (P/N 2005-1W-310P), sediment compaction tests were made prior to turtle-nesting season (May–October) in 2007, 2008, and 2009. No further testing was required by project permits.

3.4 Habitat Mapping

Shoal-bypassing events have the potential to rapidly create a variety of coastal habitats. However, due to the ever changing nature of these events, the habitats can be destroyed just as rapidly. One of the primary goals of the 2006 project was to prolong favored habitat for piping plovers. The project sought to maintain the integrity of the lagoon and specifically to maintain unvegetated washover habitat, which is commonly used by piping plover.

Efforts were made during construction to limit the natural buildup of the outer beach ridge, which is typical for shoal-bypassing events of this magnitude. This was accomplished by scraping sand off the outer beach in construction reaches 2–4 (see Fig 3.3). Washover habitat quickly evolves to higher vegetated dune habitat with an influx of new sand or is lost and converted to intertidal habitat if the sand supply is eliminated. Washovers are generally maintained if the elevations of the accreting barrier ridge remain below +6 ft NAVD. This allows periodic overtopping during high tides and minor storm waves which, in turn, moves sand across the washover into the lagoon and deters vegetation, keeping the area suitable for piping plovers.

To assess the performance of the project regarding this goal, habitat mapping using aerial photography and detailed topographic models were incorporated into the project. As per special conditions of the project permit, aerial photos were obtained during low tide on 26 October 2011. The controlled aerial photos were combined with CSE's beach/lagoon survey to allow delineation of habitat areas within fixed boundaries as outlined in the project final report (CSE 2007).

A digital terrain model (DTM) was prepared in a similar manner as the pre-project and post-project models given in the final report. Habitat areas were delineated based on ground-truth data and experience from similar settings. The elevation ranges for identified habitats (Fig 3.6) are the NAVD-datum equivalent of the NGVD ranges reported in CSE (2007), specifically:

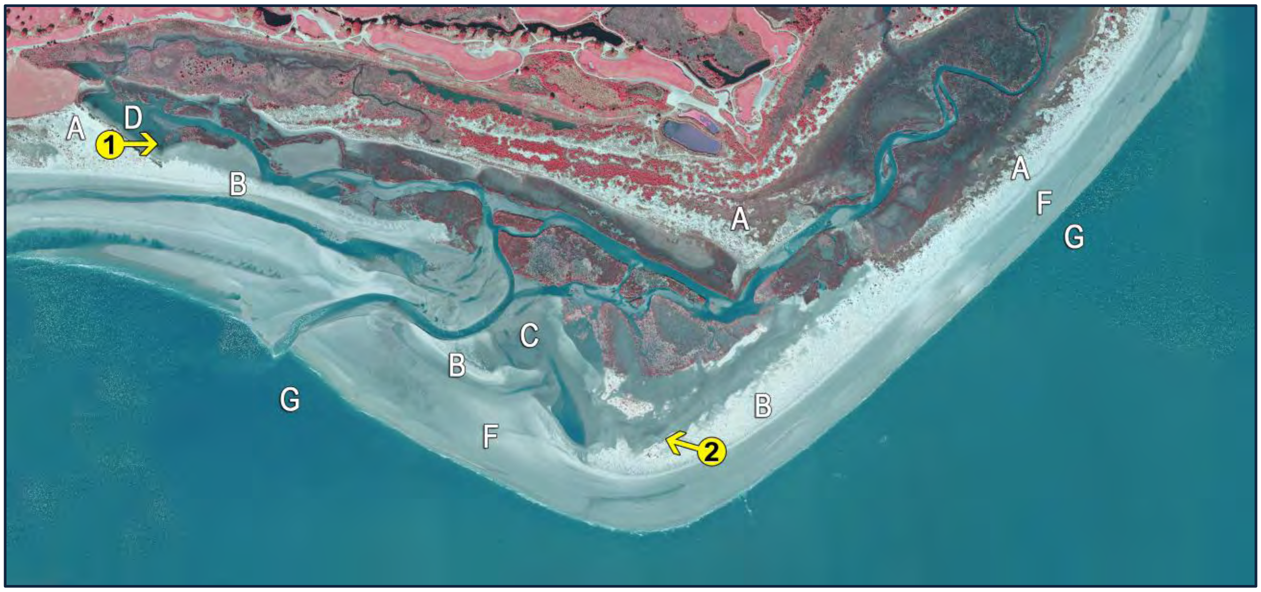
- Subtidal Habitat: −3.0 ft NAVD (~MLW) or deeper
  - Exposed – Areas seaward of the barrier beach
  - Sheltered – Areas landward of the barrier beach (ie – open-water lagoon)
- Intertidal Habitat: −3.0 ft to +2.5 ft NAVD (~MLW to MHW)
  - Exposed – Areas along the outer beach subject to ocean waves
  - Sheltered – Areas around the margin of the lagoon subject to estuarine waves and currents
- Washover Habitat: +2.5 ft to +6.0 ft NAVD
  - Areas subject to occasional flooding, wave runup and overtopping, generally devoid of vegetation or relief
  - Washover elevations span a wide elevation band and are directly related to local high-tide levels and wave heights with highest elevations corresponding to areas experiencing highest waves and runup
- Stable Dune Habitat: (>)+6.0 ft NAVD
  - Areas generally above the peak astronomic tide and normal wave runup – generally vegetated or likely to become vegetated in the next growing season – hummocky topography and distinctive ridges common
- Marsh Habitat: −1.0 ft to +1.0 ft NAVD
  - Sheltered intertidal habitat close to local mean high water containing stands of salt-marsh species – easily delineated using rectified aerial photography

CSE used the limits of survey data to define a 636-acre (ie — ~1 square mile) polygon encompassing the project area. The above-listed elevation bands were then applied within the polygon to delineate corresponding areas in those ranges. The resulting subdivisions were color-coded and super-imposed on the October 2011 digital orthophotograph. Areas of marsh habitat were digitized using the aerial photography and removed from the remaining (intertidal) areas. Subjectivity was required when determining whether to select certain areas containing new marsh vegetation. Certain areas showed substantial new growth but lacked sufficient density or maturity to include in the present areas. As previously reported, these incipient marsh areas are expected to grow and mature rapidly over the next several years. Sheltered habitats were distinguished from exposed habitats by establishing logical sub-boundaries along the outer beach alignment. Intertidal areas seaward of the outer beach are considered exposed, while areas on the landward side are considered sheltered.

Barrier island–inlet lagoon systems have site-specific tide ranges related to the efficiency of tidal exchange through inlets. In the present case, the tide range in the lagoon will depend on the particular configuration, location, and scale of the inlet.

FIGURE 3.6. [following page] Habitat areas were delineated based on elevation and vegetation cover. The 2011 aerial image (upper) shows the distribution of habitats. The ground photos show typical habitats from the denoted areas in the upper photo (yellow labels): Location 1 (middle) and Location 2 (lower). Habitat areas are defined as follows:

(A) Stable dune	(B) Washover	(C) Sheltered intertidal	(D) Sheltered subtidal
(E) Vegetated marsh	(F) Exposed intertidal	(G) Exposed subtidal	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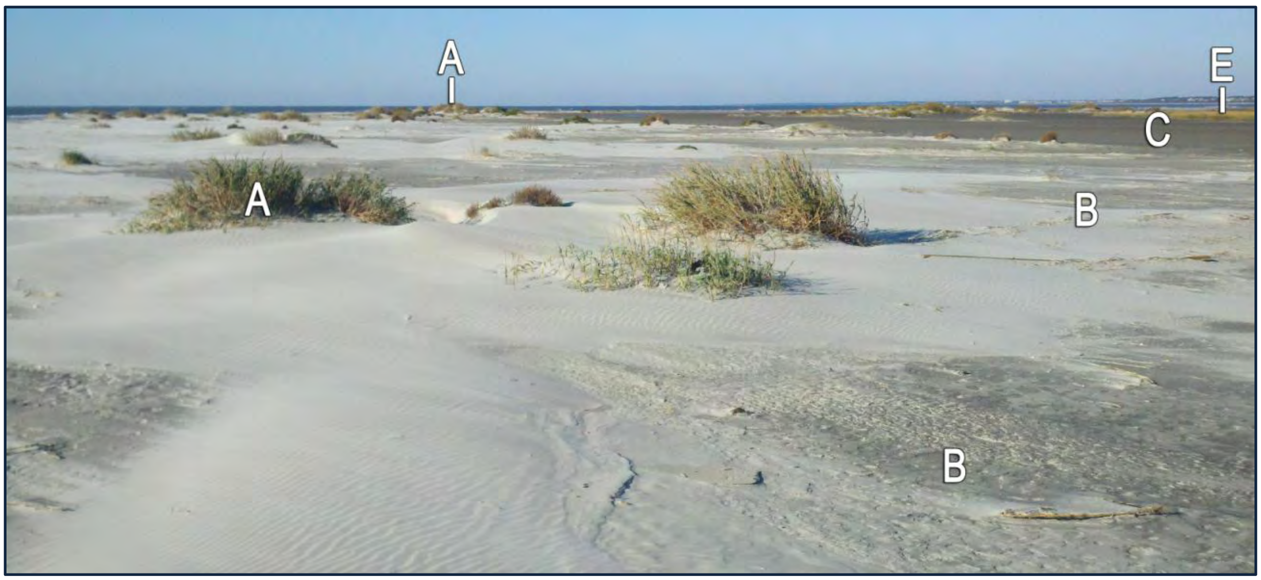
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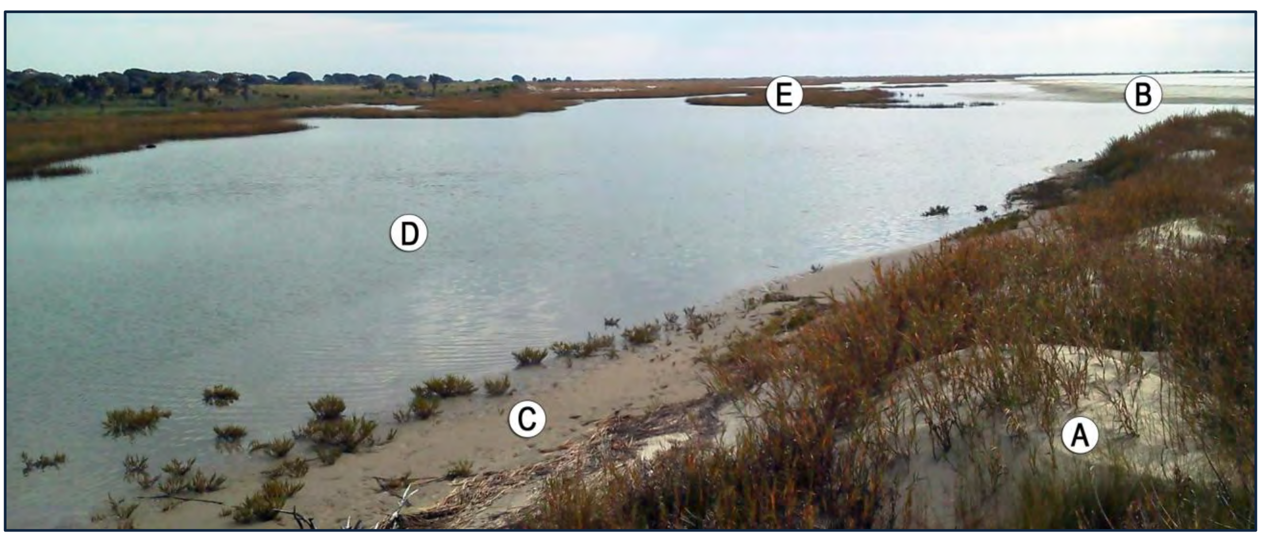
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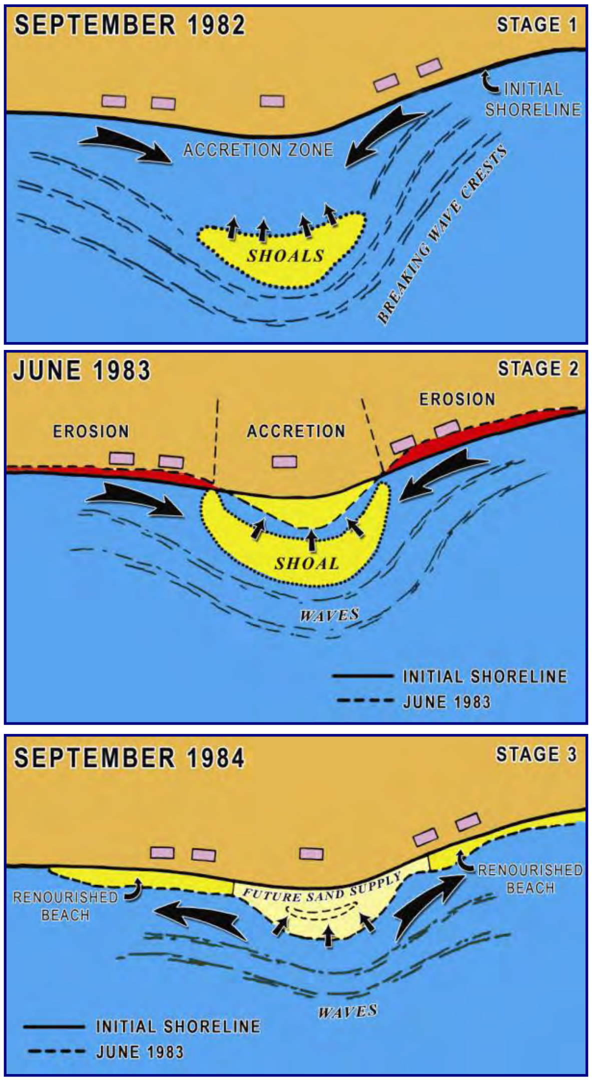
THE THREE STAGES OF SHOAL BYPASSING



[LEFT]
Schematic of the shoal-bypass cycle originally modeled from a bypass event at Isle of Palms (SC). During Stages 1 and 2 of the cycle, accretion in the lee of the shoal is accompanied by erosion on either side of the attachment site. (After Kana et al 1985)

[RIGHT]
Aerial views of shoal-bypass events at the northeastern end of Isle of Palms (SC). The upper photo shows a shoal in Stage 1 of the bypass cycle in March 1996. The middle image, taken in 1997, shows that the shoal is beginning to attach to the beach and is in Stage 2 of the bypass cycle. The lower image (from December 1998) shows the shoal completely attached (Stage 3), and sand has spread to previously eroded areas.

4.0 RESULTS

Results from the 2011 monitoring survey are given in the following sections. The first section describes observed changes in the project area. Section 4.2 presents an updated evolution of habitat change in the project area. Section 4.3 summarizes the volume changes within the project area. Section 4.4 describes sand volumes for the length of Kiawah west of the 2006 project site. The 2011 data are compared with 1999 volumes to quantify changes over the last twelve years.

4.1 Project Area Observations

CSE has monitored the 2006 project yearly for the Town of Kiawah Island. CSE expected the project area (west lagoon) to evolve into a similar system as the eastern lagoon, with dense marsh and incised tidal channels. This process is facilitated by sand overtopping the outer berm during high tides and storm events. The outer berm migrates landward and the lagoon infills, creating suitable elevations for marsh propagation.

Two significant, but related, events have occurred in the project area since construction. The first was formation and emergence of an incipient shoal near the southern apex of the bulge created by the previous events (Fig 4.1). This shoal followed the typical shoal-bypass progression (graphics on facing page), reaching Stage 3 in 2010. While in Stage 2, the breakwater effect of the shoal contributed to severe erosion of portions of the outer barrier adjacent to the shoal, and accretion in its lee. The attachment site has eroded over the past year, contributing to gains in adjacent areas (Fig 4.2).

Rapid and large-scale volume changes led to closure of the original (constructed) flushing channel and opening of a new channel in the summer of 2007 (cf Fig 2.6). The new flushing channel was located near the center of the west lagoon, and migrated west between 2007 and 2009. It began to encroach on the constructed dike as it continued to migrate west. During this time (2007 to 2009), the outer barrier eroded via overtopping and sand spreading to the lee of the shoal, leaving it low, narrow, and susceptible to another breach. A new breach occurred between August 2009 and April 2010, and the old channel closed naturally. The new inlet was again located near the central portion of the west lagoon, near the attachment site of the western edge of the incipient shoal. The seaward end of the channel has meandered between 2010 and 2011; however, the channel throat has remained in the same general location (Fig 4.1).

FIGURE 4.1. Oblique aerial photos of the west lagoon at the northeastern end of Kiawah Island. In December 2006 (upper left), an incipient shoal was present offshore of the eastern end of the lagoon. By May 2008 (upper right), the shoal was nearing attachment. A shoreline salient had formed on the outer barrier, as sand eroded from adjacent areas was deposited behind the shoal. The flushing channel had also relocated to the west and migrated westerly into the closure dike. The shoal had attached by April 2010 (middle), creating a small lagoon (black arrow) seaward of the original outer barrier. The flushing channel again relocated from the closure dike area (red arrow) to the central portion of the lagoon. Erosion of the shoal attachment site and downcoast spreading of sand rounded off the point of land from 2010 to April 2011 (bottom).

The significant changes between 2010 and 2011 included:

- Erosion of the "2007" shoal attachment site allowing shoal sand to spread to downcoast areas.

- Seaward growth of the beach west of the lagoon flushing channel.

- Continued infilling and marsh propagation in the western lagoon (discussed in detail in later sections).

- Growth of washover/dune area along the southeast facing shoreline east of the shoal attachment site.

- Continued vertical growth and vegetation of dry beach areas west of the dike (in front of the Ocean Course clubhouse).

Figures 4.3–4.6 present low-tide vertical aerial images of the eastern end of the project area from February 2006 to October 2011. Observations previously mentioned are visible in the photos—especially note attachment of the incipient shoal from 2007 to 2010, landward migration of the outer barrier beach of the western lagoon, and three relocations of the flushing channel in:

- 2006 (via construction),
- 2007 (as the constructed channel infilled and a more efficient channel formed off the center of the western lagoon), **and**
- 2010 (in connection with the 2007 shoal attachment and associated erosion).

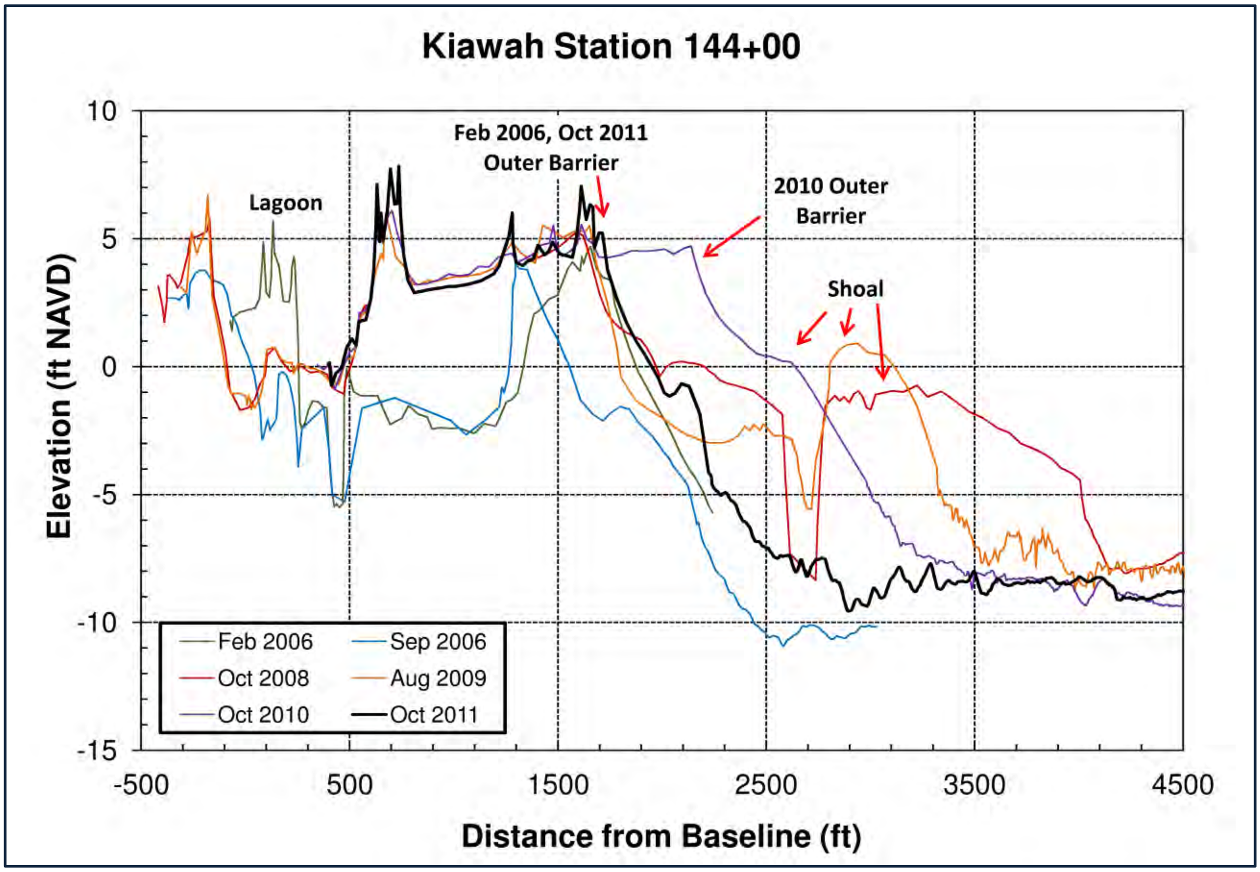
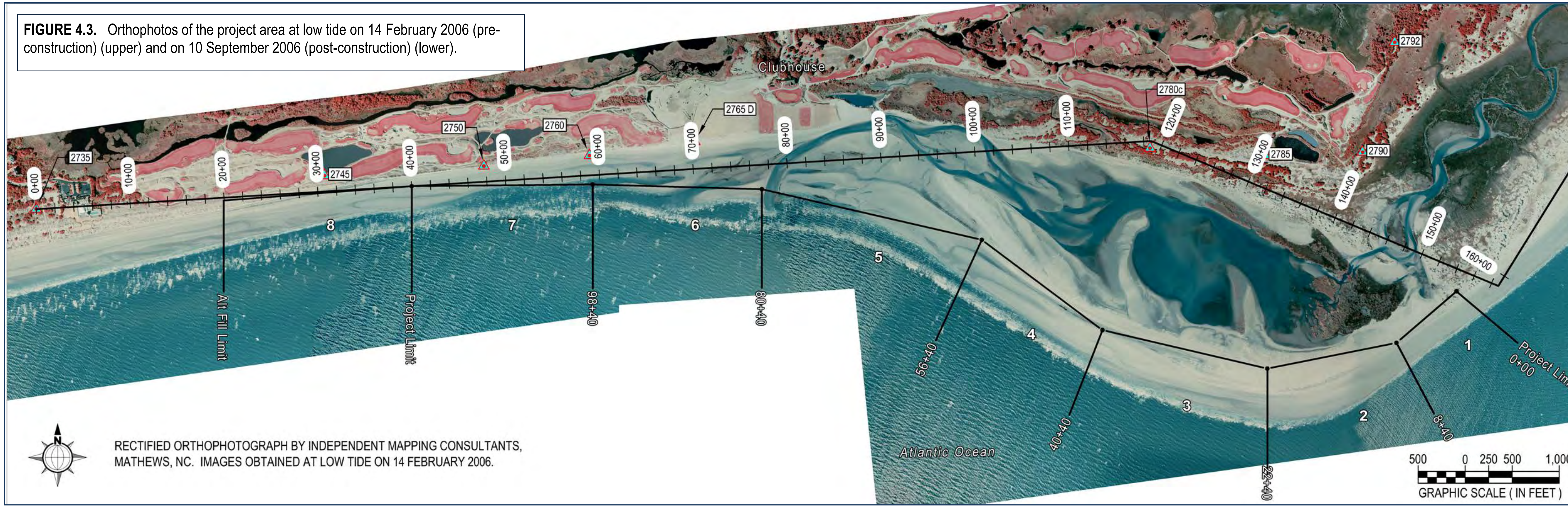
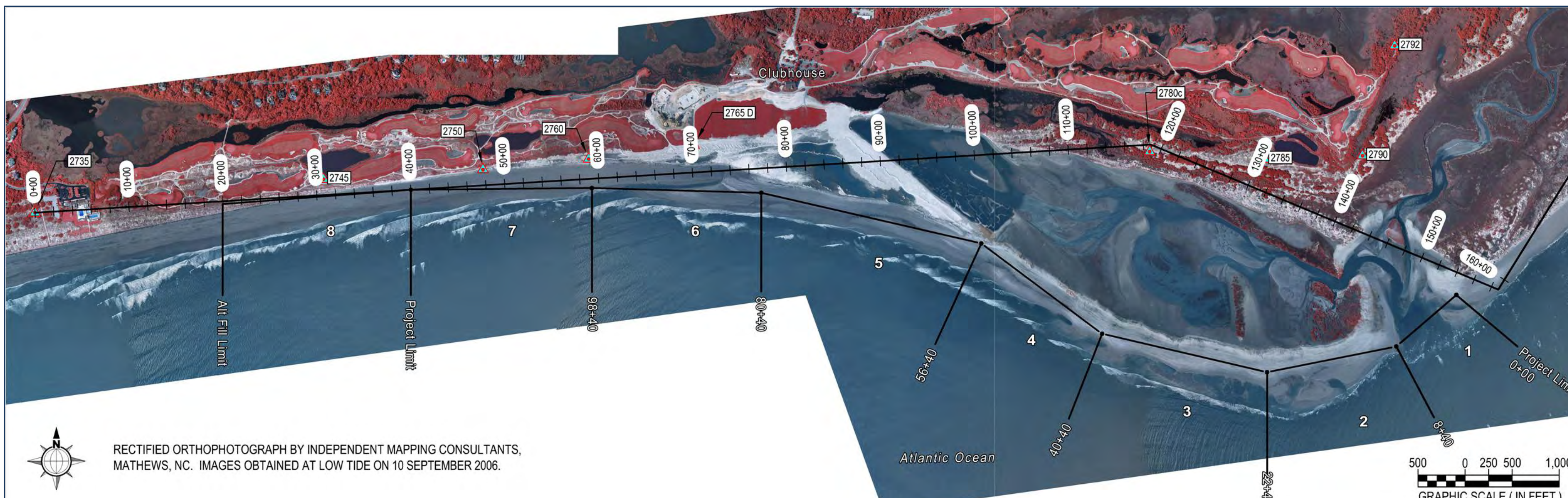


FIGURE 4.2. **[UPPER]** Profiles from station 144+00 showing attachment of a shoal between 2007 and 2010 and spreading (erosion) in 2011. The profile of the outer berm (dry beach) built seaward as the shoal approached, then the upper profile accreted as the shoal sand merged with the berm from 2009 to 2010. The profile eroded over 500 ft from 2010 to 2011 as shoal sand spread to adjacent areas **[LOWER]** The aerial photo from April 2011 shows the location of the profile. A small lagoon (**A**) which was formed during the latest shoal attachment remains as of April 2011.

FIGURE 4.3. Orthophotos of the project area at low tide on 14 February 2006 (pre-construction) (upper) and on 10 September 2006 (post-construction) (lower).

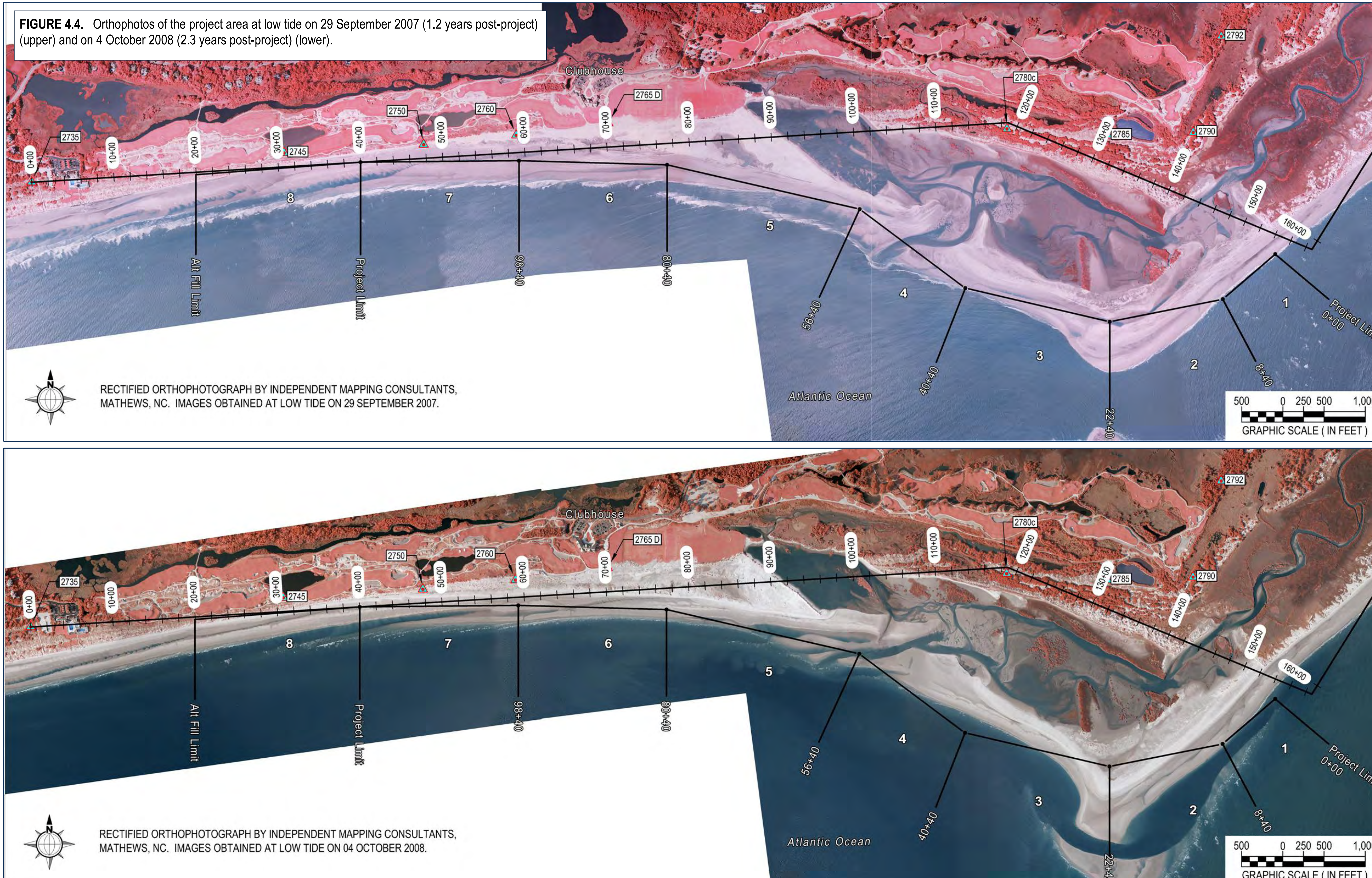


RECTIFIED ORTHOPHOTOGRAPH BY INDEPENDENT MAPPING CONSULTANTS, MATHEWS, NC. IMAGES OBTAINED AT LOW TIDE ON 14 FEBRUARY 2006.



RECTIFIED ORTHOPHOTOGRAPH BY INDEPENDENT MAPPING CONSULTANTS, MATHEWS, NC. IMAGES OBTAINED AT LOW TIDE ON 10 SEPTEMBER 2006.

FIGURE 4.4. Orthophotos of the project area at low tide on 29 September 2007 (1.2 years post-project) (upper) and on 4 October 2008 (2.3 years post-project) (lower).



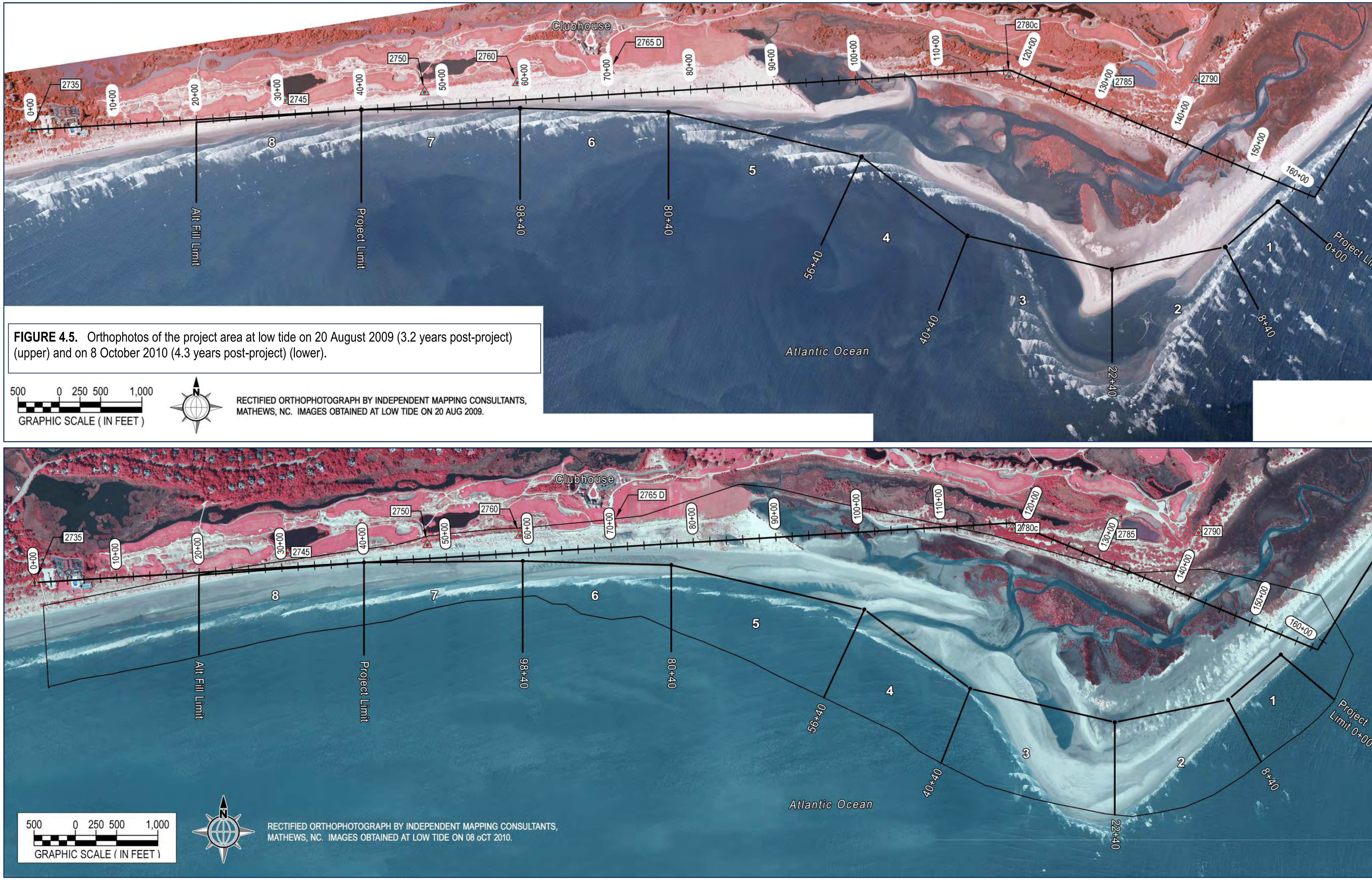


FIGURE 4.5. Orthophotos of the project area at low tide on 20 August 2009 (3.2 years post-project) (upper) and on 8 October 2010 (4.3 years post-project) (lower).

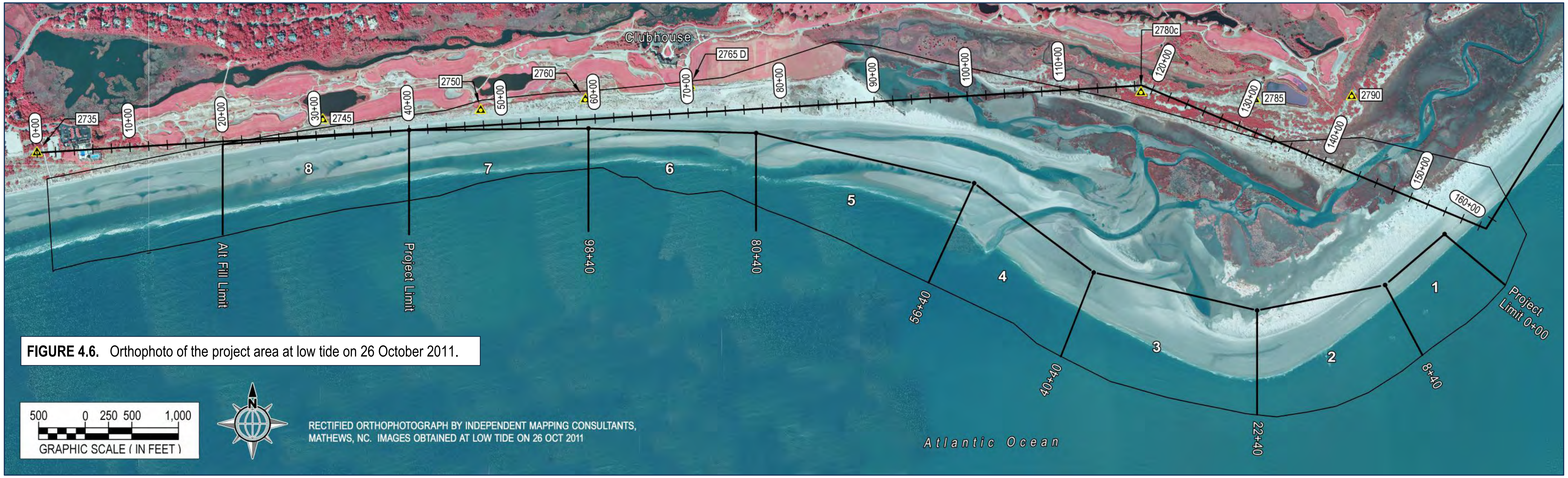


FIGURE 4.6. Orthophoto of the project area at low tide on 26 October 2011.

4.2 Habitat Area Changes

CSE used the common reference area of 636 acres encompassing the 2006 east end beach restoration project to define habitat areas within these boundaries. Figures 4.7–4.10 (fold-outs) provide the delineation of habitats for six available dates (February 2006, September 2006, September 2007, October 2008, August 2009, October 2010, and October 2011). The habitat areas have been color-coded and superimposed on the orthophotographs with the aid of a digital terrain model (DTM). Table 4.1 summarizes the habitat area changes for the six available dates.

TABLE 4.1. Habitat areas along the eastern end of Kiawah Island. Habitats have been monitored since February 2006, prior to the east end restoration project.

Habitat Areas along east end of Kiawah Island - changes through 2011.

Habitat	Elevation	Feb-06	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Change - Pre-Post project
Type	Range (ft-NAVD)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	(Acres)
Stable Dunes	>+6.0 ft	49.0	58.5	41.9	46.6	45.7	59.8	62.8	10.8
Washover	+2.5 to 6.0 ft	46.8	62.4	61.0	81.0	93.6	79.2	81.9	32.4
Vegetated Marsh	~-1.0 to 1.0 ft	18.7	22.0	22.7	28.0	35.4	47.3	55.2	28.6
Sheltered Intertidal	-3.0 to +2.5 ft	110.0	99.0	119.7	78.7	61.2	69.1	55.4	-40.9
Exposed Intertidal	-3.0 to +2.5 ft	136.6	112.8	119.7	105.1	144.2	143.8	158.4	7.2
Sheltered Subtidal	-3.0 ft or deeper	21.7	28.8	24.0	18.9	23.3	15.6	18.1	-6.1
Exposed Subtidal	-3.0 ft or deeper	253.2	252.5	247.0	277.8	232.6	221.2	204.2	-32.0
Totals		636.0	636.0	636.0	636.0	636.0	636.0	636.0	0.0

Habitat Areas along east end of Kiawah Island - changes since previous survey.

Habitat	Elevation	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11
Type	Range (ft-NAVD)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Stable Dunes	>+6.0 ft	9.5	-16.6	4.7	-0.8	14.1	3.0
Washover	+2.5 to 6.0 ft	15.6	-1.4	20.0	12.6	-14.4	2.7
Vegetated Marsh	~-1.0 to 1.0 ft	3.3	0.7	5.3	7.5	11.9	7.9
Sheltered Intertidal	-3.0 to +2.5 ft	-11.0	20.7	-41.0	-17.5	7.9	-13.7
Exposed Intertidal	-3.0 to +2.5 ft	-23.8	6.9	-14.6	39.0	-0.4	14.6
Sheltered Subtidal	-3.0 ft or deeper	7.1	-4.8	-5.2	4.5	-7.7	2.5
Exposed Subtidal	-3.0 ft or deeper	-0.7	-5.5	30.8	-45.2	-11.4	-17.0

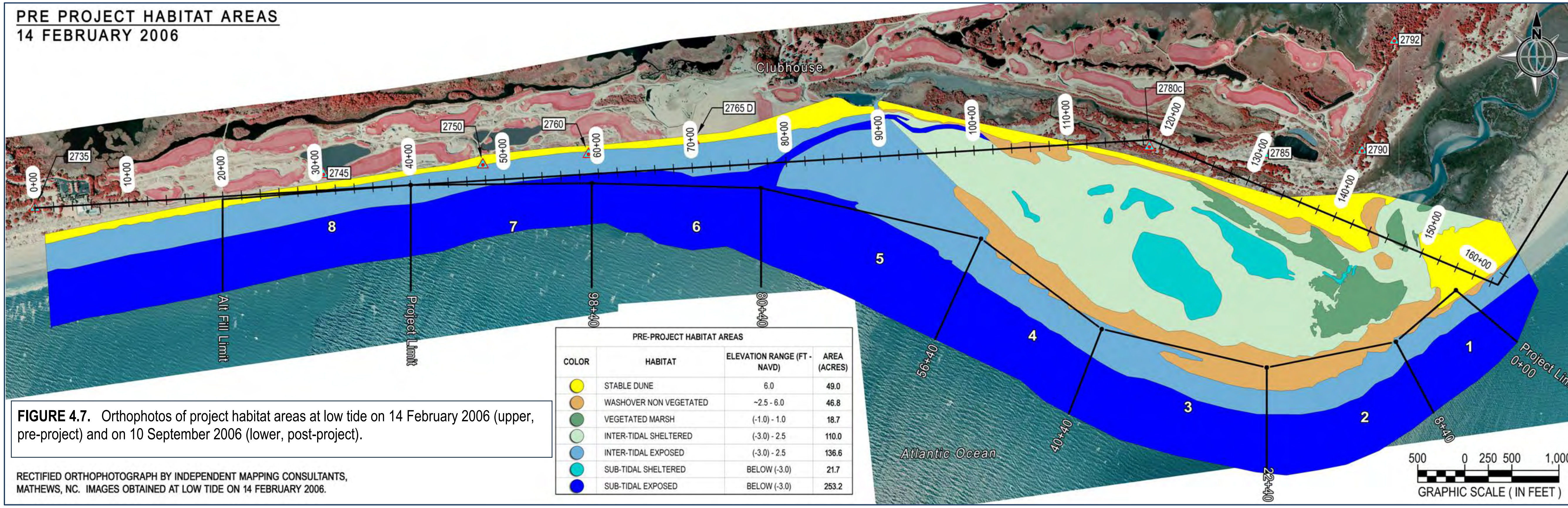
Habitat Areas along east end of Kiawah Island - changes since Feb 2006.

Habitat	Elevation	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11
Type	Range (ft-NAVD)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)	Area (Acres)
Stable Dunes	>+6.0 ft	9.5	-7.1	-2.5	-3.3	10.8	13.8
Washover	+2.5 to 6.0 ft	15.6	14.2	34.2	46.8	32.4	35.1
Vegetated Marsh	~-1.0 to 1.0 ft	3.3	4.0	9.3	16.7	28.6	36.5
Sheltered Intertidal	-3.0 to +2.5 ft	-11.0	9.7	-31.3	-48.8	-40.9	-54.6
Exposed Intertidal	-3.0 to +2.5 ft	-23.8	-16.9	-31.5	7.6	7.2	21.8
Sheltered Subtidal	-3.0 ft or deeper	7.1	2.3	-2.8	1.6	-6.1	-3.6
Exposed Subtidal	-3.0 ft or deeper	-0.7	-6.2	24.6	-20.6	-32.0	-49.0

The most significant change in habitat area was loss of exposed subtidal area (−17.0 acres) and gain of exposed intertidal area (+14.6 acres). This was the result of sand spreading to the west from the recent shoal attachment site. Westward-moving sand was impacted by the meandering flushing channel, resulting in a wide intertidal beach and seaward displacement of the low-tide line compared to the 2010 condition.

The nourished area of the beach along the Ocean Course (between stations 40+00 and 90+00) has continued to increase in elevation and develop into a mature beach and dune system, contributing to gains in stable dune area and loss of washover area in this region. Stable dunes are also expanding in the recent shoal attachment area (eg — station 144+00, see Fig 4.2), as washover area is vegetating and building in height (Fig 4.11). Sheltered intertidal area decreased by 13.7 acres, over half of which can be attributed to vegetated marsh increasing by 7.9 acres. Additional losses of sheltered intertidal area resulted from transition to washover between stations 140+00 and 156+00. Sheltered subtidal area has continued to decrease as deeper areas infill with sand and mud. Channelization within the lagoon has remained fairly consistent, which is a sign that the lagoon is becoming more mature with incised drainage channels.

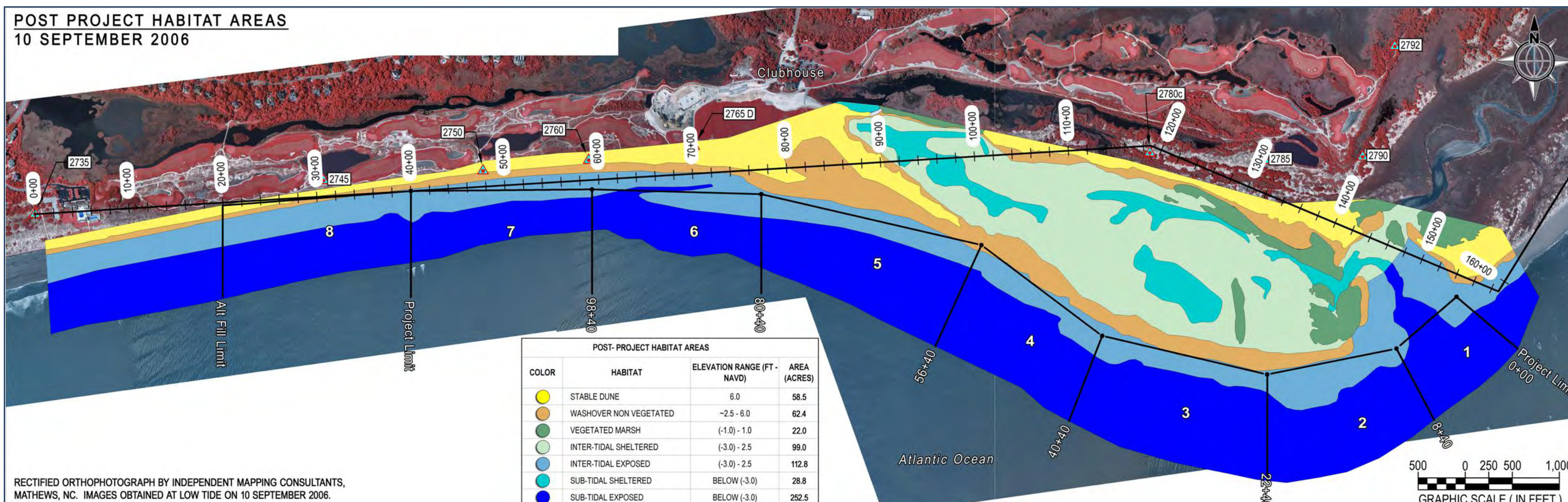
Habitat areas are shown in Figure 4.12. Table 4.1 gives the changes between consecutive surveys and since February 2006. Washover areas and vegetated marsh have both shown large increases in area since February 2006 (pre-construction). Marsh is expected to continue to expand, although as the lagoon matures, less sheltered intertidal area is available to transition to marsh. Washover habitat will evolve dependent on sediment inputs from attaching shoals. Dune area is expected to expand moderately as some washover habitat increases in elevation; however, washover habitat may decline elsewhere as the outer barrier beach migrates landward and erosion continues in the shoal attachment area. The speed at which the new shoal migrates toward the beach will play a major role in habitat evolution over the next few years. This will be especially apparent in the area in the lee of the attaching shoal.



PRE-PROJECT HABITAT AREAS

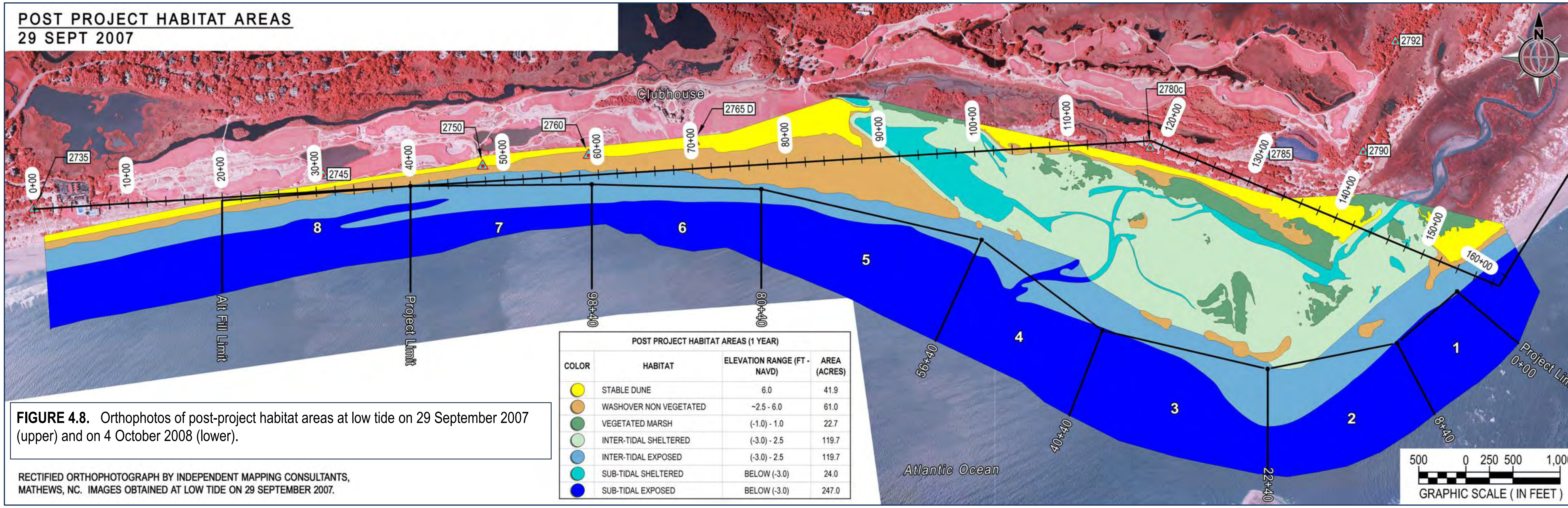
COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	49.0
	WASHOVER NON VEGETATED	~2.5 - 6.0	46.8
	VEGETATED MARSH	(-1.0) - 1.0	18.7
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	110.0
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	136.6
	SUB-TIDAL SHELTERED	BELOW (-3.0)	21.7
	SUB-TIDAL EXPOSED	BELOW (-3.0)	253.2

FIGURE 4.7. Orthophotos of project habitat areas at low tide on 14 February 2006 (upper, pre-project) and on 10 September 2006 (lower, post-project).



POST- PROJECT HABITAT AREAS

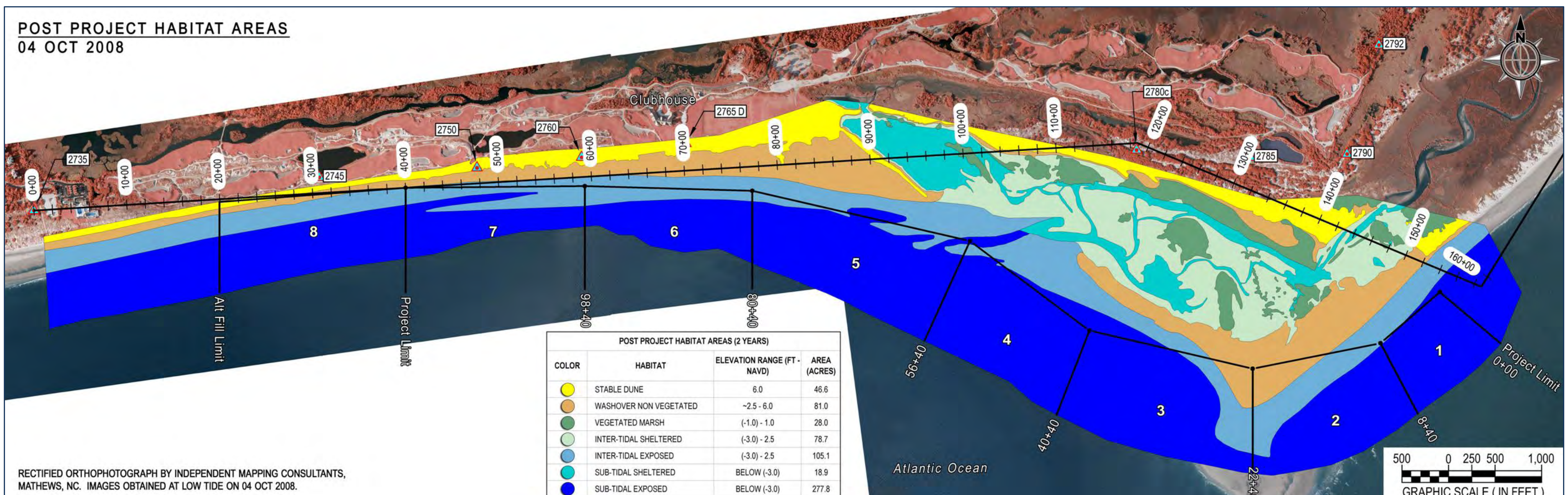
COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	58.5
	WASHOVER NON VEGETATED	~2.5 - 6.0	62.4
	VEGETATED MARSH	(-1.0) - 1.0	22.0
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	99.0
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	112.8
	SUB-TIDAL SHELTERED	BELOW (-3.0)	28.8
	SUB-TIDAL EXPOSED	BELOW (-3.0)	252.5



POST PROJECT HABITAT AREAS (1 YEAR)

COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	41.9
	WASHOVER NON VEGETATED	~2.5 - 6.0	61.0
	VEGETATED MARSH	(-1.0) - 1.0	22.7
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	119.7
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	119.7
	SUB-TIDAL SHELTERED	BELOW (-3.0)	24.0
	SUB-TIDAL EXPOSED	BELOW (-3.0)	247.0

FIGURE 4.8. Orthophotos of post-project habitat areas at low tide on 29 September 2007 (upper) and on 4 October 2008 (lower).



POST PROJECT HABITAT AREAS (2 YEARS)

COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	46.6
	WASHOVER NON VEGETATED	~2.5 - 6.0	81.0
	VEGETATED MARSH	(-1.0) - 1.0	28.0
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	78.7
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	105.1
	SUB-TIDAL SHELTERED	BELOW (-3.0)	18.9
	SUB-TIDAL EXPOSED	BELOW (-3.0)	277.8

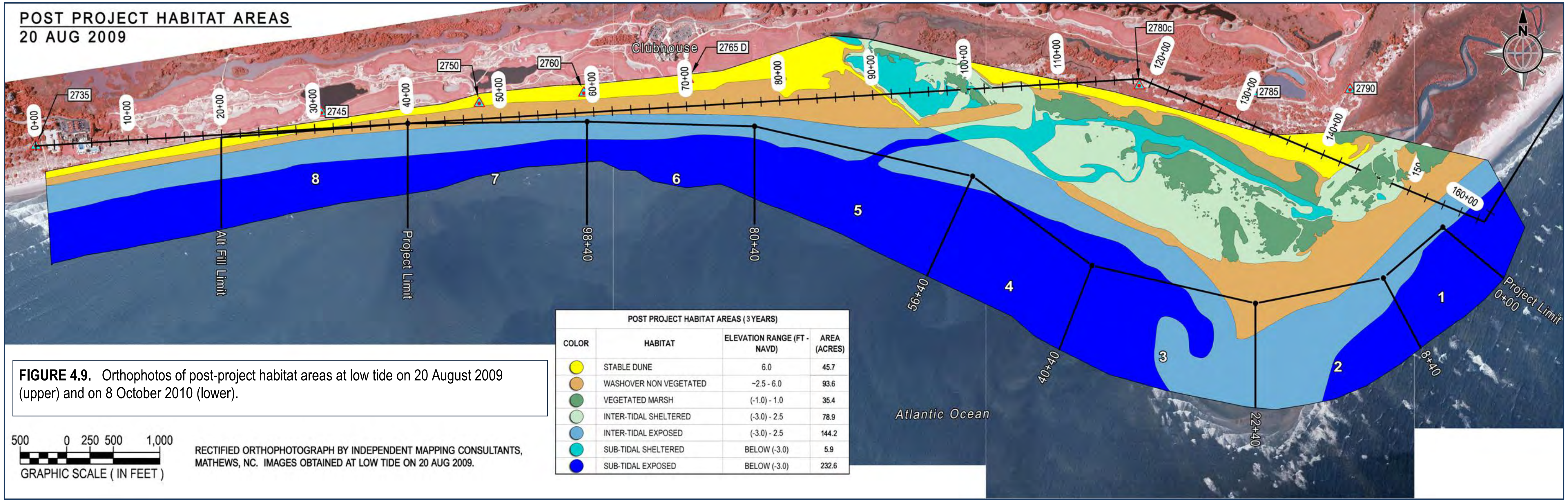
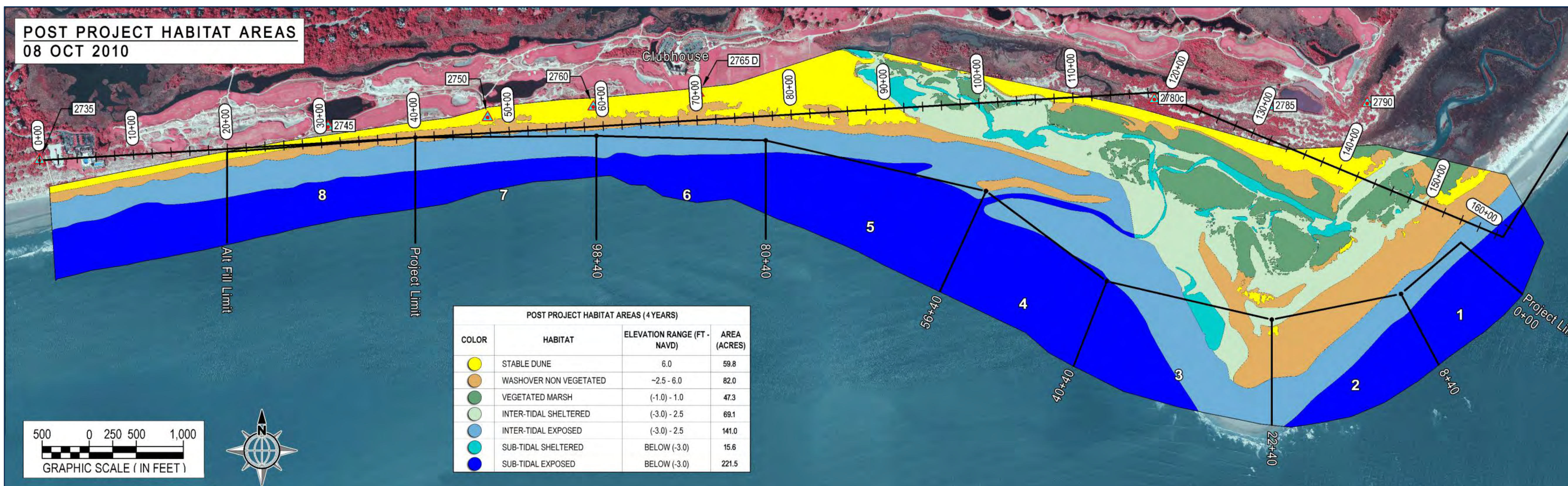


FIGURE 4.9. Orthophotos of post-project habitat areas at low tide on 20 August 2009 (upper) and on 8 October 2010 (lower).

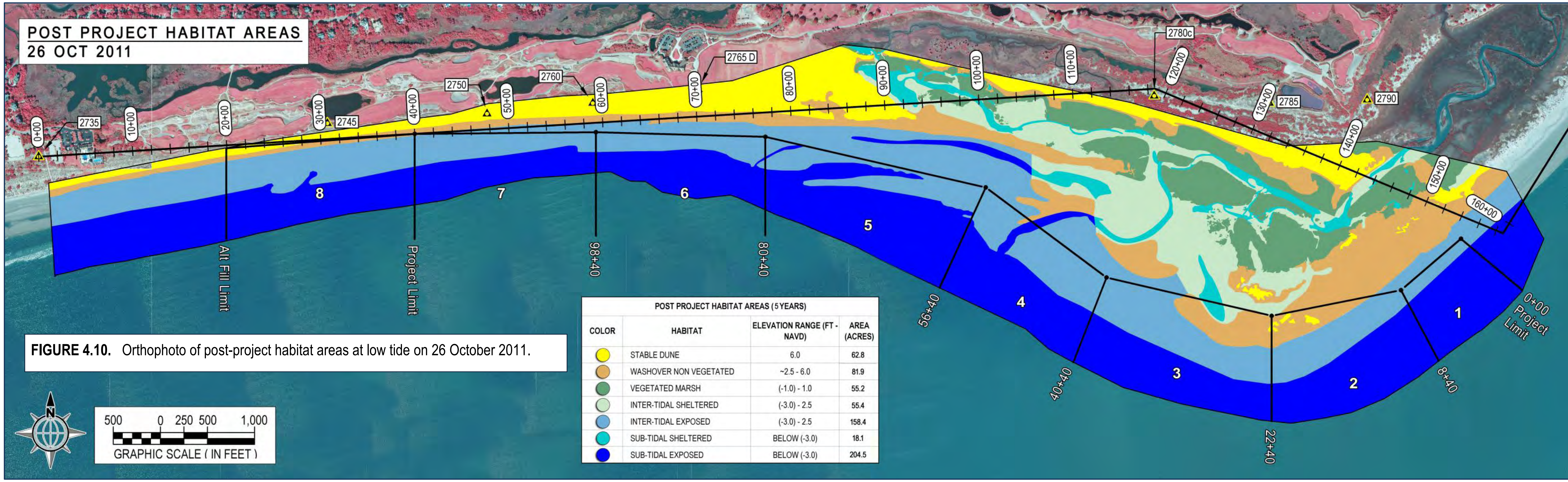
POST PROJECT HABITAT AREAS (3 YEARS)

COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	45.7
	WASHOVER NON VEGETATED	~2.5 - 6.0	93.6
	VEGETATED MARSH	(-1.0) - 1.0	35.4
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	78.9
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	144.2
	SUB-TIDAL SHELTERED	BELOW (-3.0)	5.9
	SUB-TIDAL EXPOSED	BELOW (-3.0)	232.6



POST PROJECT HABITAT AREAS (4 YEARS)

COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	59.8
	WASHOVER NON VEGETATED	~2.5 - 6.0	82.0
	VEGETATED MARSH	(-1.0) - 1.0	47.3
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	69.1
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	141.0
	SUB-TIDAL SHELTERED	BELOW (-3.0)	15.6
	SUB-TIDAL EXPOSED	BELOW (-3.0)	221.5



POST PROJECT HABITAT AREAS (5 YEARS)

COLOR	HABITAT	ELEVATION RANGE (FT - NAVD)	AREA (ACRES)
	STABLE DUNE	6.0	62.8
	WASHOVER NON VEGETATED	~2.5 - 6.0	81.9
	VEGETATED MARSH	(-1.0) - 1.0	55.2
	INTER-TIDAL SHELTERED	(-3.0) - 2.5	55.4
	INTER-TIDAL EXPOSED	(-3.0) - 2.5	158.4
	SUB-TIDAL SHELTERED	BELOW (-3.0)	18.1
	SUB-TIDAL EXPOSED	BELOW (-3.0)	204.5

FIGURE 4.10. Orthophoto of post-project habitat areas at low tide on 26 October 2011.

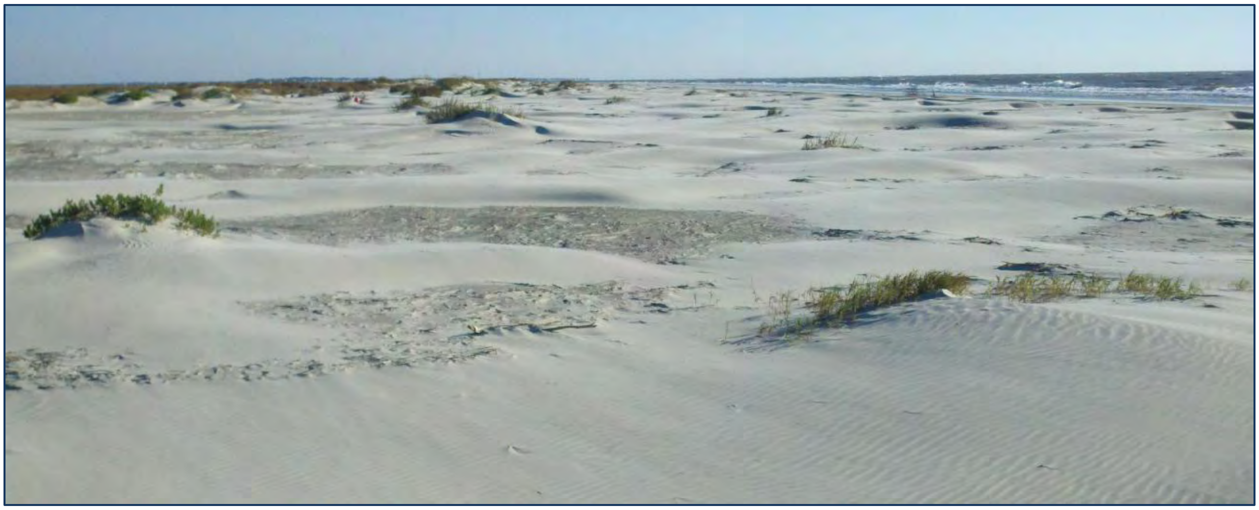


FIGURE 4.11. October 2011 ground photo looking northeast from station 148+00. Here washover habitat is transitioning into stable dune habitat. If the area continues to accrete, dune formation and expansion of vegetation should continue. If erosion occurs, this area will revert to washover habitat. Over the next few years, sand volume change will be impacted by the oncoming shoal bypass event.

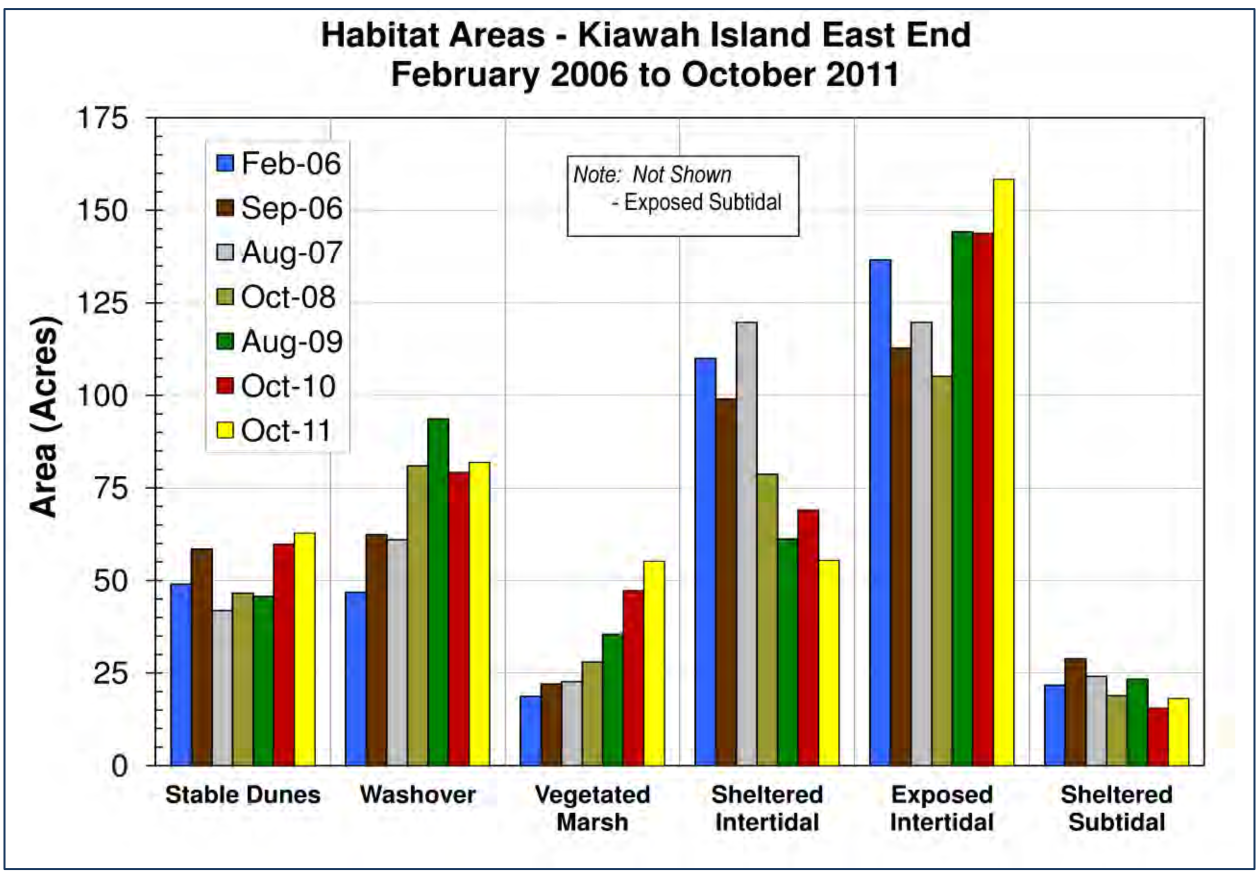


FIGURE 4.12. Habitat area changes monitored by CSE since February 2006. These data are produced from the maps of Figures 4.7 through 4.10.

4.3 Project Area Sand Volumes

Shoal-bypassing events are dynamic; therefore, typical volume analysis in the vicinity of by-passing events can often be misleading. Large volumes of sand can move quickly from one location to another in both the exposed and sheltered areas of the attachment site. Comparing sand volumes for individual profile lines from one year to the next may not fully represent the processes controlling morphologic change in the system.

For this report, volume changes are reported for all profiles surveyed in the project area as well as for the entire beach to Kiawah spit. [The reaches used in this report are illustrated in Figure 3.3.] In the project area, reach-wide volume changes yield a better representation of actual changes in the system. In most cases, local changes observed in individual profiles are due to evolution of the lagoon and the 2007 shoal-bypass event, and general trends are not easily interpreted. Volume changes are reported in Table 4.2, beginning from the upcoast reaches and moving downcoast (ie — east to west). Figure 4.13 shows station unit volumes in the project area since 2006. Profiles are given in Appendix A.

Volumes for the present report were calculated to −10 ft NAVD'88. Cross-shore calculation limits (offset and cutoff distances) were also adjusted as necessary to match available data. Total and unit volumes were recalculated using these new limits for all available surveys (see Table 3.1 for station-by-station limits). CSE computed volumes for the West Lagoon Reach via Digital Elevation Models (DEMs). This was necessary due to the large fluctuations of the shoreline in response to the 2007 shoal-bypass event and data availability. It is becoming difficult to conduct land-based surveys through the expanding marsh in the west lagoon. Elevation models were produced for all surveys since September 2006. An area encompassing the outer beach ridge (berm) and subtidal zone was selected to compute volumes to −10 ft NAVD for each survey date (Fig 4.14). This allows for a simple and consistent approach to measuring beach volume. The remaining reaches were characterized by more typical shoreline changes, and volumes were computed via traditional average-end-area methods.

TABLE 4.2. Unit volumes and unit volume changes (cy/ft) for Kiawah Island monitoring stations from February 2006 to October 2011.

Station	Reach	Offset	Cutoff	Dist to Next (ft)	Unit Volume (cy/ft) to -10 ft NAVD						Unit Volume Change Since Previous (cy/ft)				
					Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Sep '06 to Aug '07	Aug '07 to Oct '08	Oct '08 to Aug '09	Aug '09 to Oct '10	Oct '10 to Oct '11
2615	Kiawah Spit	140	1500	1689		392.4	392.1	391.9	406.7	392.1		-0.2	-0.2	14.8	-14.6
2620		86	1300	2127		361.9	361.1	375.2	384.1	380.9		-0.8	14.2	8.9	-3.2
2625		189	1500	1842		309.0	309.9	321.6	334.7	331.0		0.9	11.7	13.1	-3.7
2630	West Beach	152	1500	547		300.9	299.1	303.6	318.5	317.1		-1.7	4.5	14.9	-1.3
2635		41	1500	1231		289.3	290.4	300.2	307.1	312.3		1.0	9.9	6.9	5.1
2640		94	1500	1357		261.1	257.9	273.1	273.1	275.4		-3.2	15.1	0.1	2.2
2645		47	1200	1891		252.3	248.5	257.7	258.2	259.3		-3.8	9.2	0.5	1.1
2660		28	1100	2051		254.5	252.8	258.3	260.3	253.0		-1.8	5.5	2.0	-7.3
2665		22	1000	1383		236.9	229.7	231.1	232.6	229.9		-7.3	1.5	1.5	-2.6
2675		0	1100	831		243.8	239.0	239.3	237.4	239.2		-4.8	0.3	-1.9	1.8
2680		46	1300	2531				222.0	220.0	226.8				-2.0	6.9
2685	Turtle Point	10	1200	1033		253.9	249.0	252.2	253.0	257.3		-4.8	3.2	0.7	4.4
2687		40	1500	1214				257.1	255.3	259.0				-1.8	3.7
2690		93	1300	1145		250.7	244.3	248.7	245.3	248.4		-6.4	4.4	-3.4	3.1
2692		279	1500	1201				259.9	251.7	258.3				-8.2	6.6
2695		119	1400	1080		262.7	274.3	279.7	270.2	277.2		11.6	5.4	-9.5	7.0
2700		100	1400	1268		278.2	291.8	295.2	292.3	300.8		13.6	3.4	-3.0	8.5
2705		130	1500	1278		321.9	313.4	325.8	323.1	322.1		-8.5	12.3	-2.7	-1.0
2715		145	1500	889		322.6	325.1	326.4	331.6	326.8		2.5	1.3	5.2	-4.8
2720		208	1500	1291		306.2	302.0	306.9	309.3	305.3		-4.1	4.9	2.3	-4.0
2722		436	1600	1125				224.2	229.8	225.6				5.6	-4.1
2725		322	1600	666		252.1	250.3	253.3	254.5	245.4		-1.8	3.0	1.2	-9.0
2730		316	1600	1504		257.4	258.4	259.9	263.7	257.8		1.0	1.5	3.7	-5.8
000+00	Ocean Course	355	1500	400	216.4	222.9	223.2	226.0	231.6	225.4	6.6	0.2	2.9	5.6	-6.2
004+00		279	1500	400	232.4	236.2	238.2	240.7	249.8	235.3	3.8	2.0	2.4	9.1	-14.4
008+00		222	1500	400	232.5	241.9	238.1	244.8	248.8	240.3	9.3	-3.7	6.7	4.0	-8.5
012+00		189	1500	400	221.1	221.2	214.8	229.3	232.6	229.5	0.1	-6.4	14.5	3.3	-3.1
016+00		115	1500	400	231.2	229.0	225.4	244.5	251.3	250.1	-2.2	-3.6	19.1	6.8	-1.3
020+00		88	1500	400	214.4	212.5	217.1	236.2	238.3	235.7	-1.9	4.7	19.1	2.1	-2.6
024+00		25	1500	400	219.2	235.6	238.2	251.9	250.1	248.7	16.4	2.6	13.7	-1.8	-1.3
028+00		-25	1500	400	220.9	233.2	246.8	253.9	258.8	262.0	12.3	13.6	7.2	4.8	3.3
032+00		-71	1500	400	221.7	246.9	256.9	265.2	269.5	266.8	25.2	10.1	8.3	4.2	-2.7
036+00		-95	1500	400	219.7	242.7	250.3	265.3	272.0	272.1	23.0	7.6	15.0	6.7	0.1
040+00		-140	1500	400	231.3	247.4	262.8	273.8	287.0	288.0	16.2	15.3	11.1	13.1	1.0
044+00		-159	1500	400	234.4	235.3	266.0	283.7	286.2	280.5	0.9	30.7	17.7	2.5	-5.6
048+00		-185	1500	400	231.4	245.7	277.7	291.2	289.9	286.5	14.3	32.0	13.5	-1.3	-3.4
052+00		-227	1500	400	251.0	286.0	308.6	319.0	315.5	311.7	35.0	22.6	10.4	-3.5	-3.8
056+00		-290	1500	400	291.7	338.4	361.0	347.7	356.2	352.1	46.7	22.6	-13.4	8.5	-4.1
060+00		-297	1500	400	296.2	356.5	348.3	352.8	364.2	357.6	60.3	-8.2	4.5	11.4	-6.6
064+00		-238	1500	400	268.9	338.1	317.9	334.9	338.1	340.9	69.1	-20.2	17.0	3.2	2.8
068+00		-298	1500	400	349.3	396.8	360.3	388.2	379.5	384.7	47.5	-36.5	27.9	-8.7	5.2
072+00		-286	1500	400	376.1	418.9	371.1	384.6	387.7	391.9	42.8	-47.8	13.6	3.1	4.2
076+00		-294	1500	400	439.7	456.8	417.7	426.7	412.8	448.2	17.1	-39.1	9.0	-13.9	35.4
080+00		-314	1500	400	515.0	509.7	463.4	475.5	451.7	497.8	-5.3	-46.3	12.0	-23.8	46.1
084+00		-440	1500	400	611.7	618.6	564.5	581.9	543.0	568.9	6.9	-54.1	17.4	-38.9	25.9
088+00		-300	1700	400	605.3	615.4	551.3	587.1	524.4	533.1	10.0	-64.0	35.8	-62.7	8.7

TABLE 4.2 (cont). Unit volumes and unit volume changes (cy/ft) for Kiawah Island monitoring stations from February 2006 to October 2011.

Station	Reach	Offset	Cutoff	Dist to Next (ft)	Unit Volume (cy/ft) to -10 ft NAVD						Unit Volume Change Since Previous (cy/ft)				
					Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	Sep '06 to Aug '07	Aug '07 to Oct '08	Oct '08 to Aug '09	Aug '09 to Oct '10	Oct '10 to Oct '11
092+00	Lagoon West	35	2000	400	487.1	462.8	418.7	411.7	361.1	401.8	-24.3	-44.1	-7.1	-50.6	40.7
096+00		-362	2000	400	627.5	578.8	532.2	526.6	538.9	614.6	-48.7	-46.6	-5.6	12.2	75.8
100+00		-287	2000	400	631.9	593.4	557.1	576.8	577.8	704.7	-38.5	-36.3	19.7	1.0	126.9
104+00		-90	2400	400	746.4	701.7	556.3	562.0	615.5	730.8	-44.7	-145.4	5.7	53.4	115.4
108+00		0	2500	400	809.1	719.5	650.1	620.5	692.3	825.7	-89.6	-69.3	-29.7	71.9	133.4
112+00		106	1550	400	490.0	503.4	567.2	576.4	560.2	543.1	13.4	63.8	9.2	-16.3	-17.1
116+00		224	775	400	182.1	205.7	215.6	219.6	216.3	216.3	23.5	9.9	4.0	-3.3	0.0
120+00		222	2100	400	731.2	687.2	674.3	658.8	669.9	669.9	-44.0	-12.9	-15.5	11.1	0.0
124+00		184	2000	400	650.4	636.9	674.9	645.6	663.6	663.6	-13.5	37.9	-29.3	18.0	0.0
128+00		176	2325	400	721.4	727.4	681.7	733.8	818.9	837.7	6.1	-45.8	52.1	85.1	18.8
132+00		1375	3020	400	369.0	327.6	390.1	500.2	540.5	516.4	-41.3	62.5	110.1	40.3	-24.1
136+00		1266	3500	400	416.7	418.3	637.4	720.8	799.6	657.8	1.6	219.2	83.3	78.9	-141.8
140+00		1130	3800	400	395.5	490.2	938.2	962.6	958.0	726.3	94.8	448.0	24.4	-4.6	-231.7
144+00		471	3300	400	553.9	769.8	1132.3	1133.2	1221.5	932.5	215.8	362.5	0.9	88.3	-289.0
148+00		140	3300	400	580.7	700.1	962.4	1342.5	1100.6	928.6	119.4	262.2	380.1	-241.8	-172.1
152+00		-100	2500	400	453.3	523.0	751.1	795.8	805.2	697.4	69.6	228.2	44.7	9.4	-107.8
156+00		-151	1000	0	351.0	196.8	156.5	223.6	267.2	225.5	-154.2	-40.3	67.1	43.6	-41.6
160+00	Lagoon East	-666	1000	400	469.2	372.4	297.6	354.2	387.0	363.9	-96.8	-74.7	56.5	32.8	-23.1
164+00		-500	500	400	372.1	307.1	209.9	263.6	303.3	287.7	-65.0	-97.3	53.7	39.8	-15.7
168+00		-411	500	400	370.5	315.0	219.7	251.8	294.6	287.6	-55.5	-95.2	32.0	42.9	-7.1
172+00		-363	1000	400	459.8	401.9	303.1	325.6	359.1	352.1	-57.8	-98.8	22.5	33.4	-7.0
176+00		-250	600	400	372.0	333.7	244.1	246.9	268.1	275.0	-38.2	-89.6	2.9	21.2	6.9
180+00		-185	700	400	382.3	344.4	273.7	272.0	272.3	282.2	-37.9	-70.7	-1.8	0.4	9.9
184+00		-178	800	400	401.7	378.8	311.4	306.2	298.2	319.5	-22.9	-67.5	-5.2	-8.0	21.3
188+00		-212	800	0	370.0	335.9	293.3	313.3	278.4	288.2	-34.1	-42.6	20.0	-34.9	9.7
192+00	Stono Inlet	22	800	400	321.0	311.4	268.6	218.4	186.1	219.3	-9.6	-42.8	-50.2	-32.3	33.2
196+00		233	900	400	212.7	220.1	210.8	191.7	156.2	150.9	7.4	-9.3	-19.0	-35.6	-5.3
200+00		250	900	400	183.5	193.6	206.1	209.8	189.8	162.1	10.1	12.5	3.7	-20.0	-27.7
204+00		285	900	400	169.2	168.5	186.2	184.8	175.5	154.7	-0.8	17.7	-1.4	-9.3	-20.8
208+00		352	900	400	145.1	140.8	153.8	152.4	154.6	143.8	-4.3	13.0	-1.4	2.2	-10.8
212+00		404	900	400	129.5	123.2	128.1	123.6	136.2	131.9	-6.4	4.9	-4.4	12.6	-4.3
216+00		400	900	400	146.5	143.7	141.0	137.4	156.9	164.0	-2.8	-2.7	-3.5	19.5	7.1
220+00		409	900	400	154.8	152.9	147.3	148.5	165.7	179.1	-1.9	-5.6	1.3	17.2	13.4
224+00		364	900	400	184.4	187.5	184.8	183.5	199.8	210.5	3.0	-2.7	-1.3	16.3	10.7
228+00		400	900	400	167.9	167.1	165.1	168.3	181.0	178.9	-0.8	-2.0	3.2	12.7	-2.1
232+00		409	900	400	169.2	171.7	164.3	170.9	180.6	168.5	2.5	-7.4	6.5	9.8	-12.1
236+00		407	1100	400	159.9	163.8	160.6	164.5	175.2	163.7	3.9	-3.1	3.8	10.7	-11.5
240+00		392	1200	400	150.2	157.0	154.7	157.3	173.7	172.7	6.8	-2.3	2.6	16.4	-1.0
244+00		348	1200	400	148.4	160.3	163.2	171.5	186.5	197.8	11.9	2.9	8.3	15.0	11.3
248+00		327	1000	400	103.7	110.6	135.7	143.8	144.6	137.0	6.9	25.0	8.1	0.9	-7.6
252+00		120	1000	0	109.2	111.6	124.0	137.7	146.4	144.6	2.4	12.4	13.7	8.7	-1.8

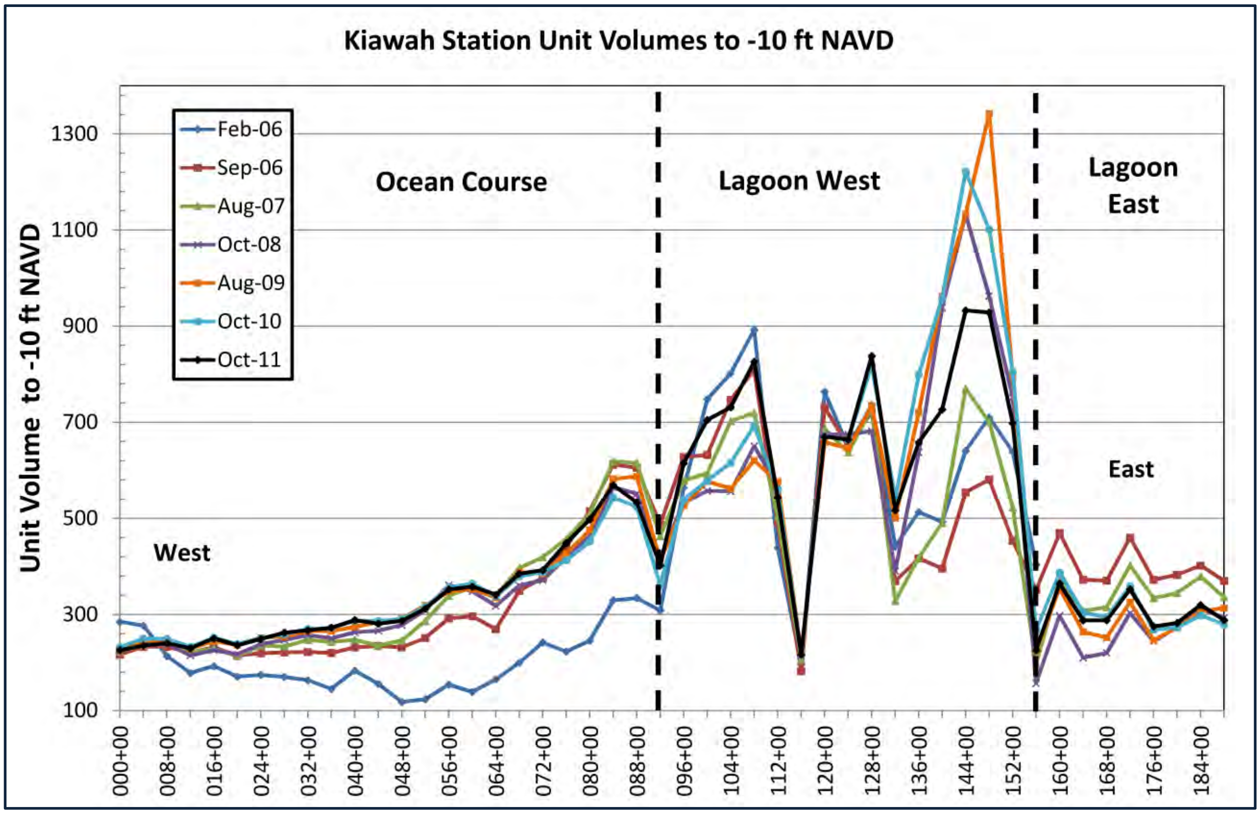


FIGURE 4.13. Unit volumes at the east end of Kiawah Island since February 2006. The restoration project was completed in the summer of 2006. A shoal-bypass event occurring between 2007 and 2010 led to significant accretion between stations 132+00 and 152+00. Stations 112+00 and 116+00 are not full sections due to a turn in the baseline and thus have lower unit-volumes than adjacent stations.

FIGURE 4.14. Boundary for the West Lagoon Reach used to compute beach volumes for the present report. Elevation models were produced for surveys between 2006 and 2011 and total beach volume within the boundary was calculated to -10 ft NAVD.

The Stono Inlet Reach (Fig 4.15) spans ~6,000 ft from the eastern extreme of the island (station 192+00) to Penny's Creek (station 252+00). This reach lost ~18,000 cy (3.0 cy/ft) of sand from October 2010 to October 2011. Since September 2006, this reach has generally been accreting, gaining an average of ~10,000 cy per year between 2006 and 2010. With the current erosion, the reach presently contains ~23,000 cy (3.8 cy/ft) more sand than the September 2006 condition. There were no discernible patterns of erosion within the reach. Individual stations ranged from 33.2 cy/ft accretion to 27.7 cy/ft erosion. Dunes are narrow between stations 192+00 and 208+00, and continued erosion of this area will eventually result in dune loss and overwash into the marsh. Near station 196+00, roughly 60 ft separate the marsh from the October 2011 escarpment (Fig 4.16).

FIGURE 4.15. Oblique aerial photo of the Stono Inlet Reach taken April 2011. The 1989 shoreline was positioned at the most seaward tree-line visible in the image. Since then, shoal-bypass events have led to natural accretion along the northeastern end of the island.

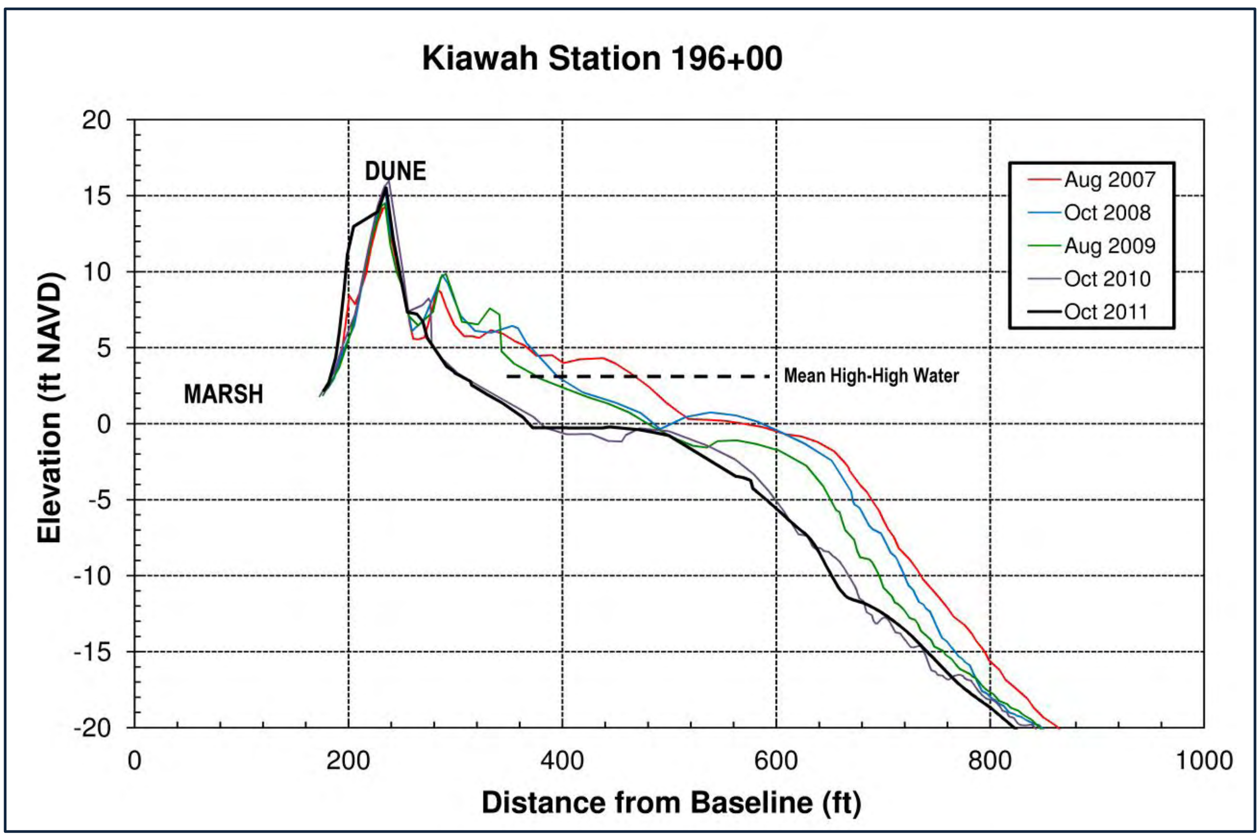


FIGURE 4.16. Beach profiles from Station 196+00, near the southern end of the Stono Inlet reach. Here, only ~60 feet of dune separate the ocean from the marsh-filled east lagoon.

The East Lagoon Reach encompasses the shoreline length between stations 160+00 and 192+00 (Fig 4.17). This corresponds to 3,200 ft of shore fronting the marsh-filled eastern lagoon. Its western boundary is situated near the constructed flushing channel for the 2006 project (arrow). Prior to 2009, the reach had eroded significantly as sand moved to the south-west (in the lee of the approaching shoal). The eastern edge of the shoal attached in 2009, and the reach began to accrete (gaining 57,000 cy between 2008 and 2009). The reach continued to accrete at a similar rate from 2009 to 2010, gaining 51,400 cy (18.4 cy/ft). Over the past year (October 2010 to October 2011), the reach remained stable, gaining only 640 cy (0.2 cy/ft). Due to spreading of shoal sand, erosion dominated the southern end of the reach, while the north end accreted. The excess sand introduced by the shoal is moving north into Stono Inlet, contributing to the accretion in the northern end of the reach and stability of the Stono Inlet Reach.

Despite erosion in the southern portion of the reach, dune growth is continuing and no stations show signs of berm overtopping (washover into the lagoon) during storm events. Extensive areas of sparsely vegetated and mostly flat berm are present at the southern end of the reach (Fig 4.18).

FIGURE 4.17. Oblique aerial image of the East Lagoon Reach taken April 2011. The southern end of this reach (bottom of image) has eroded as sand added during the "2007" shoal-bypass event is spreading to adjacent areas. Arrow marks location of the 2006 constructed flushing channel.

FIGURE 4.18. Panoramic image of the West Lagoon Reach, taken in October 2011. A narrow dune field separates the marsh filled lagoon from the ocean at the north end of the reach (Photos by S Traynum).

The West Lagoon Reach extends ~6,800 ft between stations 92+00 and 160+00. It includes a large washover outer berm, extensive intertidal sand flats, and the flushing channel for the lagoon system (Fig 4.19a–c). This reach has been heavily influenced by the recent shoal-bypass event, which attached at the eastern end of the reach in 2009–2010. The shoal attached from the south, forming a perturbation in the shoreline extending to the south at the eastern end of the lagoon (see Fig 4.1). Following attachment, sand eroded from this perturbation, spreading to the east and west. The result of this process is significant and rapid fluctuation in the shoreline position and in sand volume.

Since 2006 (post-project condition), the West Lagoon Reach has gained ~670,000 cy (105 cy/ft) of sand. The majority of this gain is a result of the "2007" shoal-bypass event. Net volume changes since 2006 include a loss of ~127,000 cy (20 cy/ft) over the past year. Erosion has dominated the eastern portion of the reach since 2010, where spreading of shoal sand resulted in recession of the shoreline roughly 700 ft at station 144+00 (cf — Fig 4.2) and ~450 ft at station 136+00 (Fig 4.20). This dramatic change was countered by seaward growth of the shoreline at the western end of the reach, where the shoreline grew ~500 ft seaward over the past year at station 108+00 (Fig 4.20).

The flushing channel of the lagoon remained in a similar position as in October 2010, with the main inlet throat near station 124+00. The seaward end of the channel meanders along the active beach, generally migrating west and periodically relocating via breaches through the berm to the east. Evidence of old meanders can be seen in aerial imagery (Fig 4.21).

FIGURE 4.19a. Oblique aerial image of the Wast Lagoon Reach taken April 2011. The throat of the flushing channel has remained stable over the past year while the seaward end meandered across the active beach face.

FIGURE 4.19b. Station 148+00 looking west in October 2011.

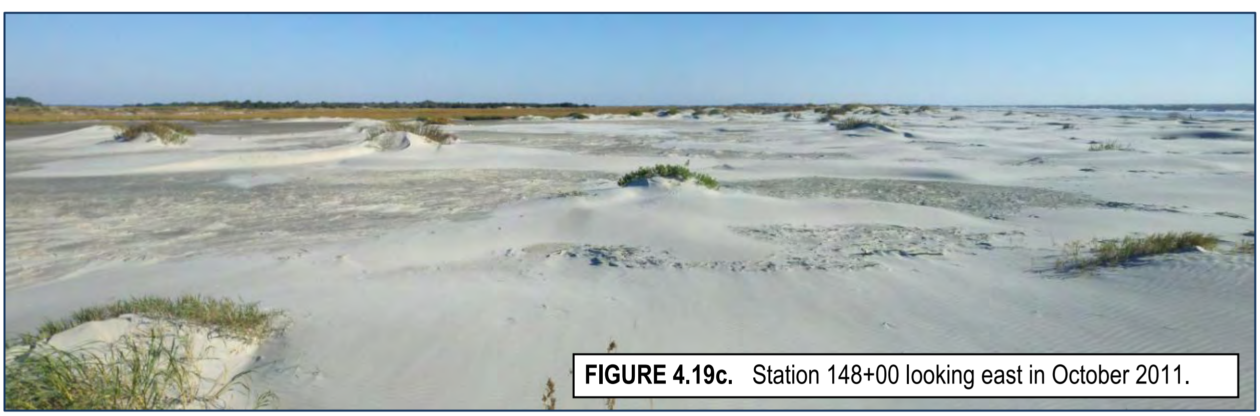


FIGURE 4.19c. Station 148+00 looking east in October 2011.

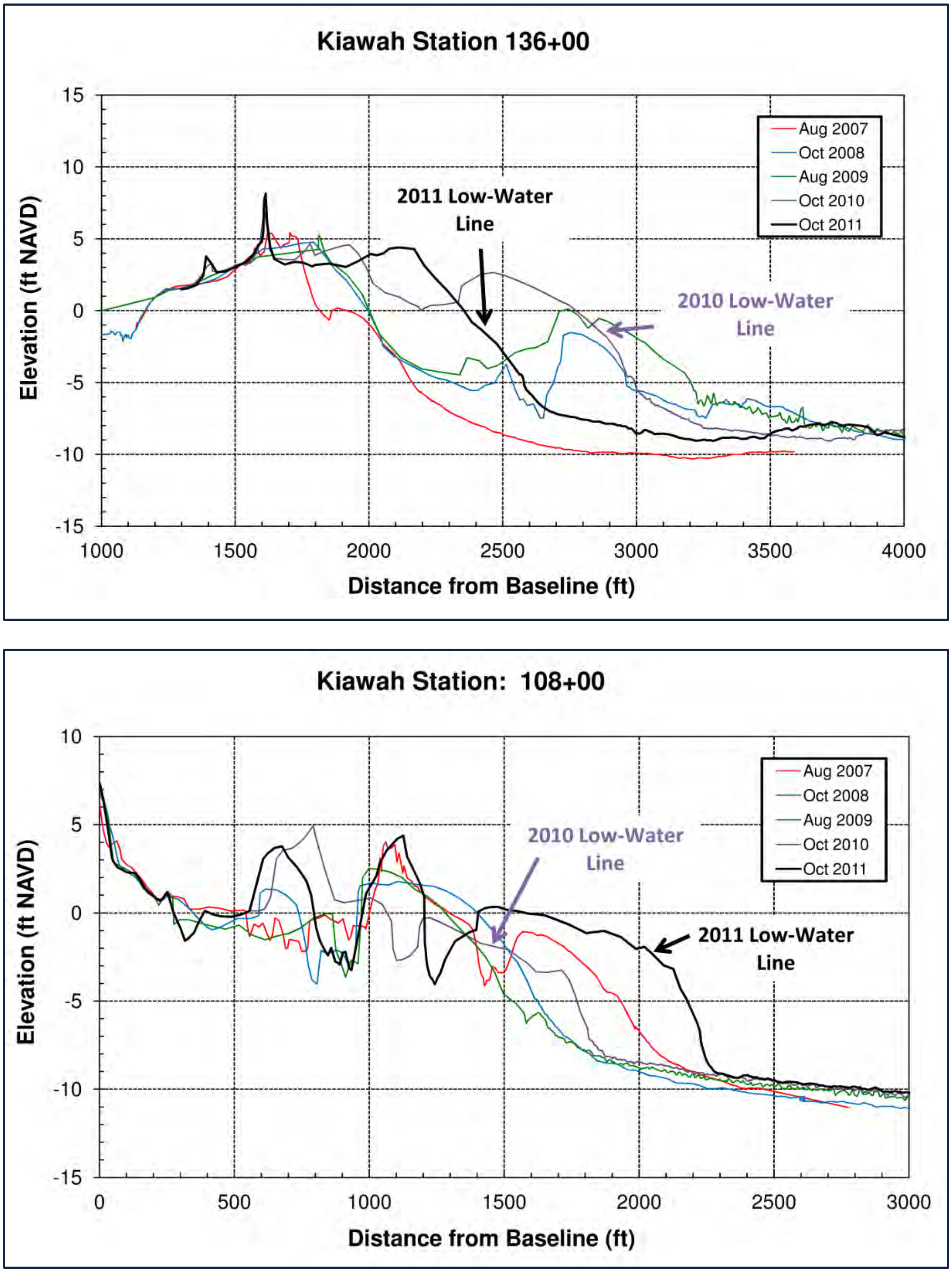


FIGURE 4.20. Profiles from Stations 136+00 (upper) and 108+00 (lower) showing shoreline changes resulting from spreading of sand added during the 2007 shoal bypass event. At Station 136+00 (see Figure 4.2 for location), the beach eroded by ~500 ft, while the beach at the low-tide line accreted a similar distance at station 108+00.

There is presently little evidence of the "2007" shoal remaining at the eastern end. The shoreline is less concave at the west lagoon than last year and is in better equilibrium with the wave climate. A small pond remains near station 132+00, just landward of the outer berm. Figure 4.20 (see also Fig 4.2) shows changes in the beach in response to the shoal migration, attachment, and spreading.

Aerial imagery shows that a new shoal is emerging south of the project area roughly 2,200 ft offshore of the southern foreland of the island (Fig 4.21). This will likely be the next shoal that attaches to the beach. No estimate of the sand volume within the new shoal can be made with the available data; however, it appears to be of a similar scale as the "2007" shoal event. Since this is the first year that the shoal has been observed, the rate of migration is unknown. CSE expects this shoal to migrate landward over the next few years. Future surveys should monitor the shoal's position, volume, and migration rate.

FIGURE 4.21. October 2011 aerial image of the eastern end of Kiawah Island showing an incipient shoal ~2,200 ft offshore of the southern foreland of the island. Over the next few years, this shoal will likely migrate onshore and attach to the beach.

The Ocean Course Reach is the most westward reach in the project area. This transition zone, between the washover/lagoon reaches in the project area and the developed sections of Kiawah Island, contains a more typical beach profile away from the influence of Stono Inlet. Comparative profiles are, therefore, more applicable for estimating volume changes at specific locations. The reach spans 9,200 ft of shoreline, fronting the Ocean Course from station 0+00 (OCRM 2735) to station 92+00 (Fig 4.22). It received the majority of the nourishment fill in the 2006 project.

Since the 2006 restoration project, the Ocean Course Reach has gained ~211,650 cy (23 cy/ft) of sand, including ~37,000 cy (4.0 cy/ft) over the past year. This represents an average annual accretion rate of 4.5 cy/ft/yr. From 2009 to 2010, the eastern portion of the reach was erosional, while the western portion was accretional. An opposite trend was observed from 2010 to 2011. The eastern 2,800 ft of shoreline (stations 64+00 to 92+00) gained an average of 21.1 cy/ft over the past year, while the western end of the reach (station 0+00 to 64+00) lost an average of 3.7 cy/ft.

FIGURE 4.22. April 2011 oblique aerial image of the Ocean Course Reach.

The lagoon flushing channel is responsible for the change in shoreline position over the last few years. From 2007 to 2010, the channel migrated from the center of the lagoon to the west. This caused erosion of the eastern portion of the Ocean Course Reach as the channel encroached on the closure dike. In 2010, the channel naturally relocated to the east, eliminating the cause of erosion in the area of the old channel. Coupled with excess sand spreading from the “2007” shoal event, the site of the old channel has accreted while still supplying sand to downcoast areas of Kiawah Island.

Table 4.3 summarizes the beach volume changes to −10 ft NAVD along Kiawah Island by reach. Figure 4.23 illustrates yearly volume trends (average unit volume) for the monitoring reaches. Overall, the eastern end (stations 0+00 through 252+00) lost 107,600 cy (4.4 cy/ft) of sand over the past year. Total volume change at the eastern end since September 2006 (post-construction) is a net gain of ~645,370 cy (26.4 cy/ft), the majority of which is associated with the 2007 shoal-attachment event.

TABLE 4.3. Beach volume and volume changes for monitoring reaches between September 2006 and October 2011.

Total Volumes By Reach (cy)									
	Length	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	2010 - 2011 Change (cy)	Sep '06 to Oct '11 Change
Kiawah Spit	5,658	-	1,912,078	1,910,518	1,964,689	2,033,925	2,006,821	-27,104	*12,1847
West Beach	11,822	-	3,000,715	2,955,334	3,019,453	3,033,680	3,035,303	1,623	*32,965
Turtle Point	13,694	-	3,738,343	3,737,489	3,798,014	3,787,476	3,783,587	-3,889	*49,133
Ocean Course	9,200	2,826,752	3,002,193	2,926,952	3,039,062	3,001,382	3,038,404	37,022	211,652
Lagoon West**	6,400	2,765,941	2,750,232	3,191,207	3,406,176	3,563,070	3,435,843	-127,227	669,902
Lagoon East	2,800	1,111,151	974,045	742,925	799,929	851,360	852,003	642	-259,148
Stono Inlet	6,000	976,048	988,853	999,150	994,414	1,017,032	999,013	-18,019	22,964
	East End Total	*7,679,892*	*7,715,322*	*7,860,233*	*8,239,580*	*8,432,844*	*8,325,262*	*-107,582*	*645,370*
	Island Total	-	*16,366,458*	*16,463,574*	*17,021,736*	*17,287,926*	*17,150,973*	*-136,953*	**784,515*

Unit Volumes By Reach (cy/ft)									
	Length	Sep-06	Aug-07	Oct-08	Aug-09	Oct-10	Oct-11	2010 - 2011 Change (cy)	Sep '06 to Oct '11 Change
Kiawah Spit	5,658	-	337.9	337.7	347.2	359.5	354.7	-4.8	*21.6
West Beach	11,822	-	253.8	250.0	255.4	256.6	256.8	0.1	*2.8
Turtle Point	13,694	-	273.0	272.9	277.3	276.6	276.3	-0.3	*3.6
Ocean Course	9,200	307.3	326.3	318.1	330.3	326.2	330.3	4.0	23.0
Lagoon West	6,400	432.2	429.7	498.6	532.2	556.7	536.9	-19.9	104.7
Lagoon East	2,800	396.8	347.9	265.3	285.7	304.1	304.3	0.2	-92.6
Stono Inlet	6,000	162.7	164.8	166.5	165.7	169.5	166.5	-3.0	3.8
	East End Total	*314.7*	*316.2*	*322.1*	*337.7*	*345.6*	*341.2*	*-4.4*	*26.4*
	Island Total	-	*294.5*	*296.2*	*306.3*	*311.1*	*308.6*	*-2.5*	*14.1*

* August 2007 to October 2011 change

** Volume computed via digital elevation model

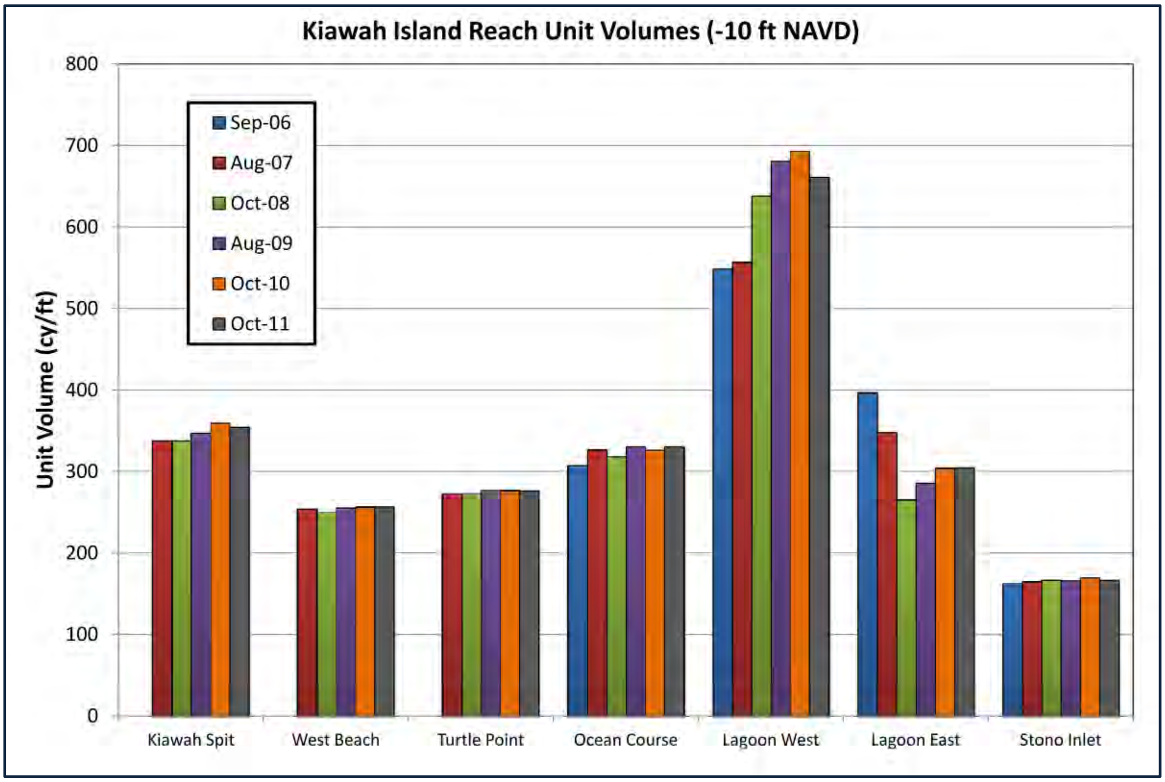


FIGURE 4.23. Annual unit volume by reach since September 2006. The East End project encompasses Ocean Course and Lagoon West. Highest volumes occur along Lagoon West, the principal shoal attachment zone along Kiawah Island.

4.4 Downcoast Reaches

The present monitoring data for reaches downcoast of the East End project area were compared to 1999 and 2006–2010 data. Profiles in these areas use OCRM monuments as benchmarks, which are typically spaced between 1,000 ft and 2,000 ft apart. CSE has collected data at certain downcoast stations since the early 1980s. Historically, the West Beach Reach has been stable, while the Turtle Point Reach and Kiawah Spit Reach have been accretional. Profiles are given in Appendix A.

At several of the downcoast stations, the 1999 profile lines terminate before reaching −10 ft NAVD. At these stations, volumes were computed to −6 ft NAVD, then adjusted by a factor of 1.95 to produce a representative volume to −10 ft. This scale factor was computed from volume analysis of 1999 profiles which extended to −10 ft NAVD. The importance of collecting and analyzing data to the depth of closure is evident in the volume changes between 2010 and 2011.

In 2011, a significant underwater bar was present at most of the profiles in the downcoast reaches. Most of the sand volume associated with the bar was positioned vertically between −6 ft and −10 ft NAVD. Thus, volume change calculations to −6 ft NAVD miss the volume in the bar and do not provide a full accounting of beach condition. For example, at station 2695, the unit volume change to −6 ft NAVD (low-tide wading depth) was −4.7 cy/ft. However, the volume change between −6 ft and −10 ft NAVD was +11.7 cy/ft, yielding a more realistic total volume change of +7.0 cy/ft. While the underwater volumes in bars may not provide immediate benefit to the visible beach, they indicate the likelihood of future beach buildup. Future monitoring should strive for a full accounting of sand volumes into deeper water because the resulting data provide the most objective picture of beach condition.

Figure 4.24 shows unit volumes for each station in the downcoast reaches. It is apparent that the present condition along the majority of the beach is much healthier than it was in 1999. Only at station 2675 does the current condition have less volume than in 1999. Overall, the downcoast reaches have gained 1.36 million cubic yards of sand since 1999, equivalent to an average annual accretion rate of 3.5 cy/ft per year over the ~6-mile length of beach. Over the past year, the downcoast beach was generally stable, losing a total of ~29,400 cy (0.9 cy/ft) of sand. The majority of sand was lost from the eastern half of the Turtle Point Reach and from the Kiawah Spit Reach.

The Turtle Point Reach (Fig 4.25) extends 13,694 ft between OCRM 2684 (~100 ft east of the Sanctuary) to station 0+00 (west boundary of the 2006 project area). Between 2010 and 2011, the length of beach between stations 2705 and 2730 lost a total of 37,200 cy while the beach between stations 2685 and 2705 gained 33,300 cy. The total volume loss for the reach was ~3,900 cy or only 0.3 cy/ft. The Turtle Point Reach shows a gain of 3.3 cy/ft compared to the 2007 condition and a gain of 38.2 cy/ft compared to the 1999 condition. All profiles in the Turtle Point Reach show dune growth and seaward expansion of the berm since 1999.

The West Beach Reach spans 11,822 ft from OCRM 2630 (Beachwalker Park) to OCRM 2685 (~1,000 ft east of the Sanctuary). Historically, this reach has been the most erosional of any portion of Kiawah Island (CSE 1999), though properties are sufficiently setback to allow for a substantial vegetated buffer between the ocean and the structures (Fig 4.26).

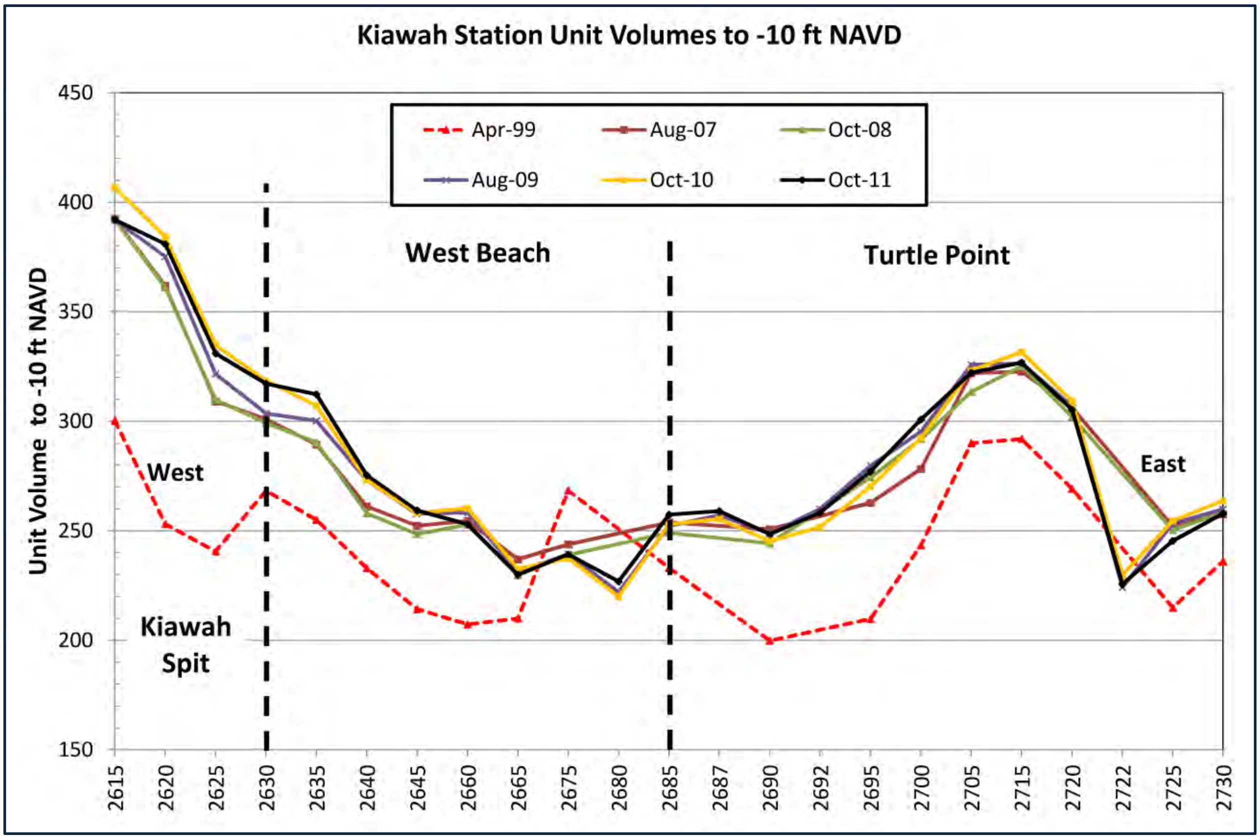


FIGURE 4.24 Unit volumes for stations in the downcoast reaches. Overall, these stations have accreted since 1999 as a result of sand inputs at the east end of the island.

FIGURE 4.25. April 2011 aerial image of the Turtle Point Reach. A new line of shrub vegetation (typically waxed myrtle) can be seen propagating between sparsely vegetated foredunes in the lower third of the photo.

FIGURE 4.26. April 2011 aerial image of the West Beach Reach.

Similar to the Turtle Point Reach, the West Beach Reach was generally stable from October 2010 to October 2011, gaining ~1,600 cy (0.1 cy/ft) of sand over that time. Volume change at individual stations ranged from −7.3 cy/ft (erosion) to +6.9 cy/ft (accretion) with erosion present in the center of the reach (OCRM stations 2660 and 2665) and the westernmost station (OCRM 2630 near Beachwalker Park). The West Beach Reach has gained 3.3 cy/ft since September 2006 and 24.4 cy/ft since 1999. This represents an average annual accretion of 2.0 cy/ft/yr over the past 12.5 years.

The Kiawah Spit Reach (Fig 4.27) encompasses the downcoast end of the island. It acts as a collection site for sand transported by longshore currents from upcoast areas. As wave action transports sand to the west, it feeds the spit, causing growth into Captain Sams Inlet and forcing the inlet to migrate toward Seabrook Island. This 5,658-ft reach lost ~27,100 cy (4.8 cy/ft) of sand between October 2010 and October 2011 (to −10 ft NAVD), which is abnormal for this area. Erosion was most severe at station 2615, which lost 14.6 cy/ft. The volume calculation does not include the portion of the beach west of station 2615 to Captain Sams Inlet. This downcoast area has accumulated sand as the inlet migrates toward Seabrook Island. The Kiawah Spit Reach has gained ~95,000 cy since 2007 and ~546,000 cy (7.7 cy/ft per year) since 1999.

FIGURE 4.27. April 2011 aerial image of the Kiawah Spit Reach.

Island-wide, Kiawah lost ~137,000 cy (2.5 cy/ft) between October 2010 and October 2011. Including the erosion observed over the past year, the island has gained ~785,000 cy (14.1 cy/ft), since 2007, which is an annual gain of 3.3 cy/ft per year over the ~10 mile beach.

5.0 SUMMARY OF FINDINGS

The fifth annual survey following the 2006 east end beach restoration project shows that the eastern end of Kiawah Island is continuing to evolve as anticipated with infilling of the lagoon and marsh propagation within the lagoon. The outer shoreline continues to change rapidly in response to sediment supply and wave action. The most obvious change over the past year was erosion of the “2007” shoal-bypass attachment site at the southern foreland (prominent bulge marking the terminus of the Stono Inlet delta). This was balanced by accretion in adjacent areas and expansion of the active beach in the west lagoon.

Marsh vegetation has continued to propagate, and lower elevation areas continue to gain sand and transition into higher elevation habitats (eg — intertidal habitat transitions into marsh or washover, and washover transitions into dune habitat). The throat of the lagoon flushing channel remained in a similar location from 2010 to 2011, though the seaward end of the channel meandered across the active beach, periodically migrating west then recutting further east. The eastern end lost a total of ~186,000 cy (7.6 cy/ft) from October 2010 to October 2011.

A principal goal of the 2006 east end beach restoration project was to maintain washover habitat within the new, barrier island-lagoon complex formed by the shoal-bypassing events. Within the control area of 636 acres, washover habitat increased from 46.8 acres before the project to 62.4 acres after construction. Washover area continued to increase, reaching a maximum of 93.6 acres by August 2009. From August 2009 to October 2010, the washover area decreased by ~14 acres; however, over the past year, washover increased by 2.7 acres, leaving it ~75 percent greater than pre-project conditions.

Sand volume changes over the past year show that the beach west of the 2006 project area was generally stable to accretional with the exception of Kiawah Spit, which lost 4.8 cy/ft of sand. The Western Lagoon Reach showed highly variable erosion and accretion, due to spreading of sand from the recent shoal attachment site. The East Lagoon Reach and Stono Inlet Reach were fairly stable from 2010 to 2011. Overall, the island lost ~137,000 cy (2.5 cy/ft) of sand over the past year (~79 percent of which was lost at the eastern end); however, due to the “2007” shoal-bypass event, the island has gained ~785,000 cy (14.1 cy/ft) of sand since August 2007.

The results reported herein represent the final condition survey and habitat mapping effort required under permits for the 2006 project. It will likely be necessary to modify future monitoring designs and eliminate portions of the lagoon system that have become inaccessible due to marsh propagation. Elevations in these areas (and thus impacts to beach volumes) remain fairly constant as long as the beach does not encroach on the marsh. It may be advantageous to reduce the number of profile lines in the project area and increase the number of lines in downcoast areas to offer a more consistent analysis of beach changes along the entire shoreline.

CSE recommends periodic surveys of the ebb-tidal delta of Stono Inlet to locate the position and determine the extent of offshore shoals over time, as these shoals are the source of sand for Kiawah Island and are responsible for the island's history of accretion.

Kiawah Island represents one of the healthiest beaches along the U.S. East Coast and offers an unparalleled example of the accretionary dynamics which maintain mixed-energy barrier islands. While monitoring of any sort entails some cost, its value lies in prediction of localized problems such as the events that led to the 2006 project.

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