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OREGON BEACH SHORELINE MAPPING AND ANALYSIS PROGRAM: QUANTIFYING SHORT- TO LONG-TERM BEACH AND SHORELINE CHANGES IN THE GOLD BEACH, NESIKA BEACH, AND NETARTS LITTORAL CELLS, CURRY AND TILLAMOOK COUNTIES, OREGON

TECHNICAL REPORT TO THE OREGON DEPARTMENT OF LAND CONSERVATION AND DEVELOPMENT

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Cover photograph: Looking north along the coastal bluffs of Nesika Beach, Curry County. Erosion of the Nesika Beach bluffs reflects some of the highest rates of coastal retreat observed on the Oregon coast. (Photo by J. C. Allan, DOGAMI.)

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EXECUTIVE SUMMARY

This report describes the procedures used to establish new beach observation sites along the Gold Beach, Nesika Beach, and Netarts littoral cells on the Oregon coast. On the basis of these efforts, a total of 21 beach profile sites were established in the Gold Beach littoral cell, which extends from Cape Sebastian in the south to Otter Point in the north. An additional 14 profile sites were established in the Nesika Beach cell, just north of the Gold Beach cell. On the north coast in Tillamook County, 24 beach profile sites were established in the Netarts littoral cell. In addition to real-time kinematic (RTK) differential Global Positioning System (RTK-DGPS) surveys of 59 new beach profile sites, analyses were undertaken to compare these results to surveys carried out using airborne lidar. In each cell, new tidal datum-based shorelines were measured and compared against both recent historical (lidar) shorelines and older historical shorelines (e.g., 1920s, 1950s, and 1960s era). Our beach monitoring efforts completed thus far have identified the following large-scale beach responses:

Gold Beach

- Erosion is occurring immediately north and south of the Rogue River jetties, while much of the shore south of Hunter Creek remains relatively unchanged when compared to historical shoreline information.
- Significant erosion has occurred adjacent to Hunter Creek due to northward migration of the creek coupled with ocean wave attack. This recent phase of erosion now threatens several homes built adjacent to the creek and ocean. Analyses of aerial photos and lidar data indicate that the response has occurred as recently as in 1985 and hence is not unique. We speculate that the recent northward migration may be due to the occurrence of the 2009-2010 El Niño, which likely shifted significant volumes of sand along the beach to the north, preventing Hunter Creek from draining out along its more typical westerly or southwesterly course. In the absence of high flows to punch an outlet, the creek simply began to migrate northward.
- At the north end of the littoral cell (north of the community of Rogue Shores) the beach has been gaining sand, which has resulted in seaward progradation of the shore.

Nesika Beach

- Significant erosion is occurring along the coastal bluffs that front the community of Nesika Beach. As indicated in Figure 23, the mean change in the toe of the bluffs between 1967 and 2008 was determined to be -15.4 m (-50.5 ft), with a standard deviation (σ) of ±7.1 m; ±1σ[1] about the mean gives an erosion range of -8.3 to -22.5 m (-27.2 to -73.8 ft). The total excursion over which the shoreline has varied was found to range from +2.4 m to -30 m (+7.9 to -98.4 ft).
- Estimates of the bluff erosion rate indicate that the bluffs are receding at an average rate of -0.38 m/year (-1.25 ft/year); mean ±1σ gives an erosion range of -0.20 to -0.55 m/year (-0.66 to -1.8 ft/year). These values are slightly lower than the erosion rates determined by Priest and others (2004), who identified an average erosion rate of ~-0.58 m/yr (-1.9 ft/yr).
- Recent mapping (2011) of the bluff toe and top indicates little erosion has occurred along the bluff top since the lidar was flown in 2008. For the most part, this finding applies to measurements of the bluff toe. However, in a few discrete shore sections, we observed some 2 to 3 m (6.6 to 9.8 ft) of additional retreat, causing the bluffs to become oversteepened in those areas.
- At the north end of the cell the beaches are actively advancing (prograding) seaward.

Netarts

- Analyses of historical shorelines indicate that the beach along Netarts Spit was in its most accreted state in the 1920s and 1960s.
- Since the 1960s, and particularly in the last decade, coastal erosion has come to dominate the overall response along essentially the full length of the spit. Lidar data derived changes in the position of the dune toe between 1997 and 2009 indicate a mean net retreat of -21.8 m (-71.5 ft) (Figure 26, left); the mean ±1σ gives an erosion range of -13 to -30.6 m (-42.7 to -100.4 ft) since 1997, while the absolute range of measured response varied from +4.4 m to -35.9 m (+14.6 to -117.8 ft).
- The estimate of the mean erosion rate for the past decade is -2.0 m/year (mean ±1σ indicates that 68.2% of the variability ranges from -1.2 to -2.8 m/year [-3.9 to -9.2 ft/year]) (Figure 26, right). This reflects the highest erosion rate presently known for the dune-backed beaches on the Oregon coast.
- Unless conditions change soon, continued erosion along Netarts Spit will lead to spit breaching and could eventually impact bay hydrodynamics.
- In the north adjacent to the community of Oceanside, the beach appears to be in a state of quasi-equilibrium, responding to periodic shifts in sediment to the north due to effects from El Niño winter storms, followed by reversals where the sand is shifted back to the south by storm waves.
- Shoreline measurements undertaken between Happy Camp and Oceanside appear to capture the effects of the 2009-2010 El Niño, which caused the bay mouth to migrate northward, significantly lowering sand elevations in front of the Capes landslide and eventually removing a large sand wedge that had accumulated north of the mouth to Netarts Bay.

1 ±1σ equates to 68.2% of all measured values and provides a good measure of the typical range of responses along a given shore.

INTRODUCTION

Over the past century the Oregon coast has undergone several periods of major coastal erosion in which the mean shoreline position retreated landward, encroaching on homes built atop dunes and coastal bluffs and, in several cases, destroying homes. The most notable of these events occurred in 1934 and 1939 (Cooper, 1958); 1958, 1960, and 1967 (Dicken and others, 1961; Stembridge, 1975); the winters of 1972-1973 and 1982-1983 (Komar, 1997); 1997-1998 and 1999 (Allan and others, 2003); and most recently in December 2007 (Allan and Hart, 2008). Of these, it is generally thought that the winter of 1938-1939, and specifically a storm in January 1939, was probably the worst on record (Paul Komar, personal communication, 2006) as it resulted in extensive coast-wide erosion (e.g., Netarts Spit was breached at several locations), along with the flooding inundation of several communities (e.g., Seaside, Cannon Beach, Rockaway, and Waldport), as ocean waves accompanied high water levels (Cooper, 1958; Stembridge, 1975). Although the effects of the January 1939 storm were captured in the 1939 suite of aerial photographs flown by the U.S. Army Corps of Engineers (USACE), the absence of orthrectification for these photos makes it difficult to interpret the true extent of the storm's impact on the coast.

An assessment of how the beaches of Oregon respond to storms could not be fully documented until the late 1990s, when a joint venture between the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA) used light detection and ranging (lidar) technology to measure the topography of U.S. coastal beaches. On the Oregon coast the results of such surveys have been published in several papers (Allan and Hart, 2005; Allan and Komar, 2005; Allan and others, 2003, 2004; Revell and others, 2002). However, although lidar provides an unprecedented amount of quantitative information that can be used to assess beach morphodynamics, on the Oregon coast such data sets have been collected infrequently (1997, 1998, 2002 [NOAA/USGS/NASA]; 2008/2009 [DOGAMI]; and most recently in 2010 [USACE]); given the present high costs, the expectation is that lidar will be flown only approximately every five years. As a result, the temporal scale of the lidar surveys is presently insufficient to adequately characterize the short-term and to a lesser extent the long-term trends of beaches.

The purpose of this report is to describe the results of an expansion to the Oregon Beach and Shoreline Mapping Analysis Program (OBSMAP), which now includes new GPS and lidar observational data derived for three sites on the southern Oregon coast (Gold Beach, Rogue Shores, and Nesika Beach) and one new network on the northern Oregon coast along the Netarts littoral cell in Tillamook County. The OBSMAP network is maintained by the Oregon Department of Geology and Mineral Industries (DOGAMI) with funding from the Northwest Association of Networked Ocean Observing System (NANOOS) and the Department of Land Conservation and Development Agency (DLCD). The overarching goal of the OBSMAP effort is to develop a comprehensive beach observation program capable of providing high-quality quantitative data on the response of Oregon's beaches at temporal and spatial scales that are of most value to coastal resource managers and the public at large. Such data have been further supplemented through analyses of lidar data measured along the Oregon coast and are now beginning to yield important insights on how the beaches of Oregon respond to storms, El Niños, and climate change.

MANAGEMENT NEEDS AND MONITORING OBJECTIVES

Management of beaches and dunes in Oregon falls under the jurisdiction of the Oregon Parks and Recreation Department (OPRD), the Coastal Management Program of DLCD and local jurisdictions through their comprehensive plans and land-use ordinances. OPRD has jurisdiction over the active beach up to the statutory vegetation line (surveyed in 1967) or the existing vegetation line, whichever is located most landward, and thereby controls the permitting of structures used to protect ocean shore property. DLCD works with the planning departments of local jurisdictions to preserve Oregon's beaches and dunes by ensuring that they apply the standards for siting development as required by specific statewide planning goals that are incorporated into local comprehensive plans. The department provides technical assistance to local jurisdictions in the form of model ordinances, as well as support for improved and updated mapping and inventories.

Permitting of new ocean shore development by state and local jurisdictions is based on the best available knowledge and, in some cases, site investigations of specific locations. Although information collected through these efforts meets the standards required by agencies, at times the information is piecemeal and does not always reflect an adequate understanding of the processes affecting the property for making sound decisions (i.e., site-specific studies on dune-backed beaches tend to be too narrowly focused, effectively ignoring issues that may influence the site at larger spatial or longer time scales). Specifically, the information presented often does not fully take into account the high-magnitude episodic nature of North Pacific extratropical storms, the long-term processes that may impact the property, the manner in which proposed alterations might affect the system, or the effect those alterations could have on adjacent properties. State and local agencies are therefore relegated to making decisions about ocean shore development with only a partial understanding of potential impacts. Those decisions affect not only the relative level of risk posed to that development but also the long-term integrity of ocean shore resources and a variety of public recreational assets. Improved baseline data and analysis of beach morphodynamics will enable state agencies and local governments and the geotechnical community to better predict future shoreline positions and will provide the quantitative basis for establishing scientifically defensible coastal-hazard setback lines.

New baseline data repeated at appropriate time intervals (e.g., seasonal to annual surveys) and spatial scales (hundreds to thousands of meters) in conjunction with periodic detailed topographic information derived from lidar and ground surveys will together help coastal managers resolve short- and long-term specific planning issues by providing an improved understanding of the following:

- The spatial and temporal responses of beaches to major winter storms in the Pacific Northwest (PNW) and to climate events such as El Niños and La Niñas.
- The time scales required for beach recovery following major winter storms, El Niños, or from persistent El Niño conditions that characterize the warm phase of the Pacific Decadal Oscillation. Under the present climatic regime and given uncertainties over future climate conditions, an important question is how long does it take for beaches to fully recover following a major storm(s)?
- What are the long-term implications of climate change to Oregon's beaches as a result of increased storminess, larger storm wave heights (and hence greater wave energy), changes to the predominant tracks of the storms, and sea level rise?

Other important questions that may be addressed from repeated ongoing monitoring of Oregon beaches include:

- What are the cumulative effects of the increasing storm wave heights, increasing armoring of shorelines, and possible accelerating sea level rise on erosion rate predictions for bluffs and dunes? Is past practice of using historical data (e.g., aerial photos, ground surveys) to predict future shoreline or bluff toe/top locations defensible? If not, what quantitative approach needs to take its place? Can a numerically based model be developed that adequately handles all of the forcing that affects coastal change in the PNW?
- How can we improve on existing process/response models so they adequately account for the erosion of PNW beaches? Present models were developed mainly for East Coast wave and sediment transport conditions rather than for the significantly different conditions in the PNW. The wave climate in the PNW is far more severe and, unlike the unidirectional longshore movement of beach sediment typical of the U.S. East and Gulf coasts, Oregon's beach sand oscillates from south to north, winter to summer, within its headland-bounded littoral cells.
- What are the spatial and temporal morphological characteristics of rip embayments on PNW beaches? What are the "hotspot" erosion impacts of rip embay-

ments on dunes and beaches? How often do these rip embayments occur at a particular site on the coast and what is the long-term effect on bluff erosion rates?

- How has the morphology of Oregon's beaches changed since the 1960s (i.e., when the coastline was last surveyed)?
- The loss of large volumes of sediment from several littoral cells on the northern Oregon coast in recent years (e.g., Netarts and Rockaway) raises the obvious questions: why are they eroding, where has the sand gone, and will it return?

Integral to answering many of these questions and for making informed decisions based on technically sound and legally defensible information is an understanding of the scales of morphodynamic variability within the coastal zone. Comprehensive beach monitoring programs have enhanced decision-making in the coastal zones of populous states such as Florida (Leadon and others, 2001), South Carolina (Gayes and others, 2001), Texas (Morton, 1997), Washington state (Ruggiero and others, 2000), and in the United Kingdom where the U.K. Government recently endorsed the expansion of a pilot beach and bluff monitoring to extend around the bulk of the English coastline (Bradbury, 2007). These programs typically include collection of topographic and bathymetric surveys, remote sensing of shoreline positions (aerial photography or lidar), and measurements of environmental processes such as currents, waves, and sediment transport. Over time such data sets prove critical for calibrating predictive models of shoreline change, designing shore-protection measures, and determining regional sediment budgets (Gayes and others, 2001).

The general purpose of this study is to continue to document the response of Oregon's beaches using real-time kinematic (RTK) differential Global Positioning System (RTK-DGPS) technology. Although the OBSMAP program now spans several littoral cells, this report will focus primarily on the measured responses in the Gold Beach, Nesika, and Netarts littoral cells. The specific tasks associated with completing this ongoing study include the following:

The specific tasks associated with completing this goal include the following:

1. Establish a comprehensive shoreline observation network along the Gold Beach and Nesika Beach shorelines (southern Oregon coast, Figure 1) and Netarts (North coast, Figure 2) littoral cells. The proposed network will consist of:

   Gold Beach:

   i. At least 20 beach profile stations located approximately 1 km apart in the Gold Beach littoral cell, which extends from Cape Sebastian in the south to Euchre Creek in the north;

   ii. Undertake semi-detailed mapping of existing bluff-top (toe) positions along Nesika Beach to provide current estimates of how the bluffs are changing. Undertake comparisons with historical shoreline (e.g., 1967) and aerial photograph information to establish rates of coastal change;

   Netarts Spit:

   iii. At least 12 beach profile stations located approximately 1 km apart in the Netarts littoral cell, which extends from Cape Lookout State Park to Oceanside in the north;

   iv. For both sites, undertake reconnaissance trips to identify appropriate sites for the establishment of permanently monumented GPS survey benchmarks; where available we will use existing National Geodetic Survey monuments. Install the monuments consistent with existing approaches used elsewhere along the Oregon coast and undertake surveys to establish their precise locations and elevations. These monuments will provide GPS control for the established survey network;

   v. Where available, integrate existing lidar data with the GPS surveys to extend the time series of measured beach and bluff changes.

2. Undertake Mean Higher High Water (MHHW) tidal based shoreline surveys on the same days as the beach profile measurements are carried out.
3. Maintain and update the existing OBSMAP[2] and NANOOS[3] websites. Continue to develop new data products that may be of value to coastal resource managers, and to improve the readability and usability of the website;
4. Disseminate beach state/change data and products among coastal managers and regulatory authorities in appropriate formats. Specific products produced as part of this monitoring effort include the measured beach profile responses (including information on normal range of variability), and the response of the beach at specific contour intervals. For the purposes of this study, we use the 6.0-m (20 ft) and 5.0-m (16 ft) contour changes to account for changes that may be occurring adjacent to the dune toe (i.e., caused predominantly by storms, El Niños, and long-term shoreline responses), while the 3.0-m (10 ft) contour

2 http://www.oregongeology.org/nanoos1/index.htm

3 http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Beaches-Mapping

reflects those changes near the Mean Higher High Water (MHHW) line (i.e., the seasonal to interannual to longer term changes);

5. Produce a report documenting the methods used to establish GPS survey control, RTK-DGPS surveys, and where available lidar topographic changes.

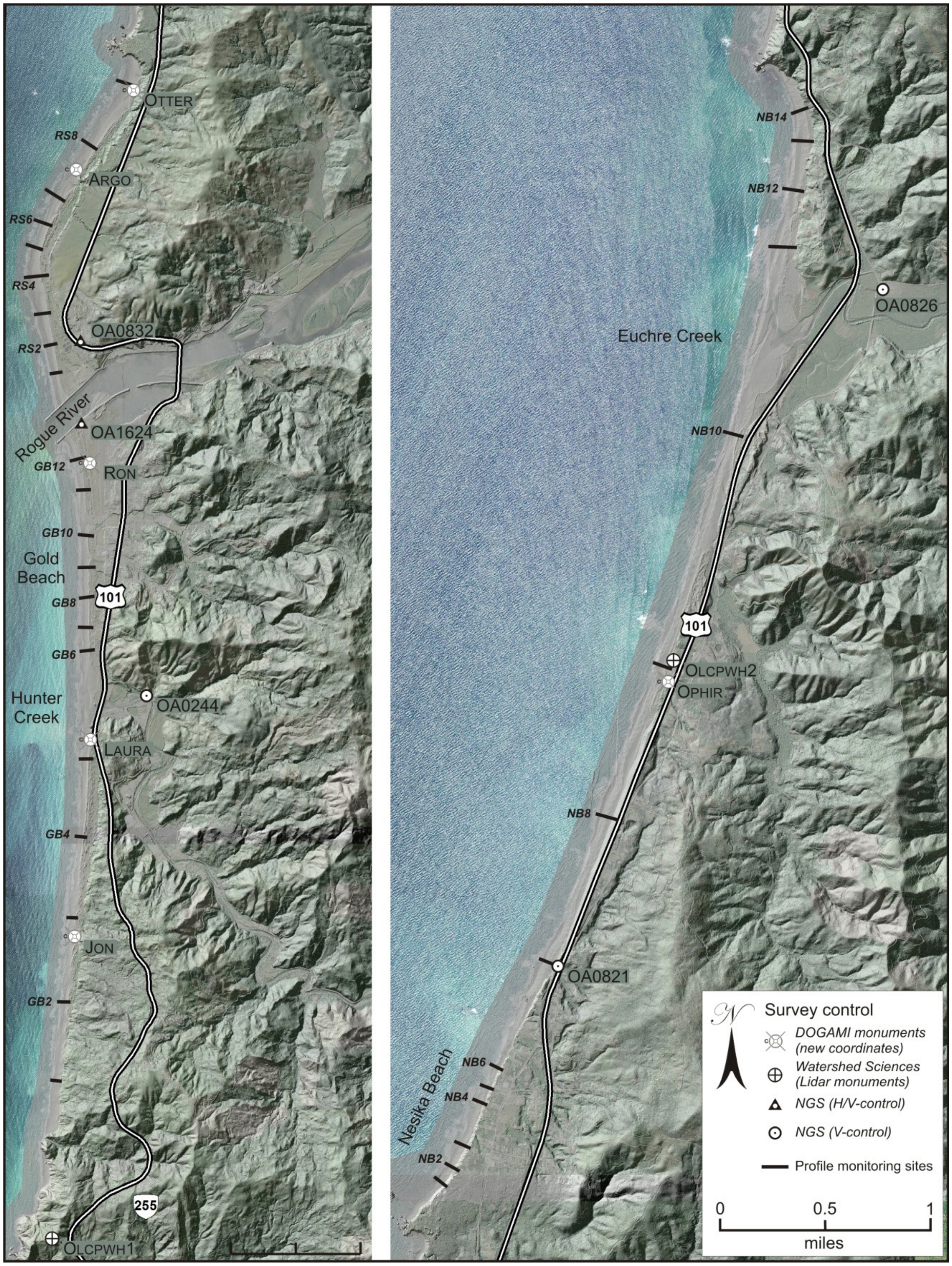

Figure 1. Location map of the Gold Beach littoral cell and Nesika Beach littoral cell shoreline monitoring stations established on the southern Oregon coast and overlaid on a 2009 basemap of lidar combined with orthoimagery.

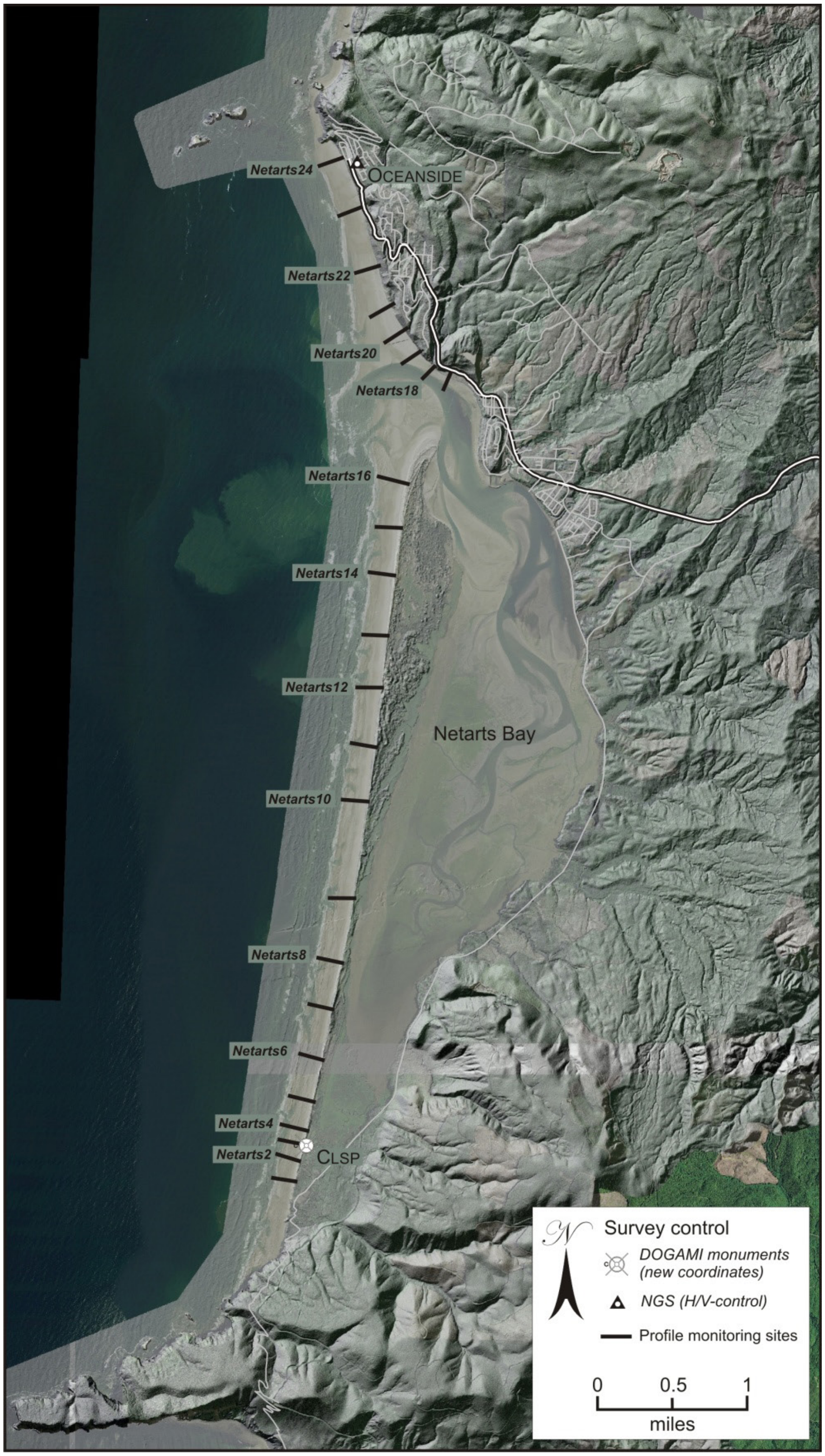

Figure 2. Location map of the Netarts littoral cell shoreline monitoring stations established on the northern Oregon coast and overlaid on a basemap of 2009 lidar and orthoimagery.

STUDY AREA

The Oregon coast is approximately 560 km (360 miles) long and can be broadly characterized as consisting of long stretches of sandy beaches bounded by resistant headlands. These types of systems are referred to as littoral cells and include both a cross-shore and a longshore extent. There are at least 18 major littoral cells identified on the Oregon coast, with the majority of the shoreline (72%) consisting of either dune- or bluff-backed sandy beaches, while the remaining 28% of shore is a mixture of rocky shores, mixed sand and gravel beaches, and coarse-grained (gravel) beaches. Most of the beaches of Oregon are backed by sea cliffs that have eroded into Tertiary mudstones and siltstones, in places capped by Pleistocene terrace sands (one-hundred thousand to one-million-year old uplifted beaches and dunes), while along low-lying stretches of coast the beaches are backed by modern active sand dunes or are part of barrier spits that have developed across estuaries and bays.

Oregon's beaches generally have limited sand sources and simple sediment budgets. In a study of the beach-sand mineralogies along the northern and south-central Oregon coast, Clemens and Komar (1988) found that the sand on most beaches was derived from three sources:

- the Klamath Mountains in southern Oregon and northern California;
- the Coast Range mountains backing most of the coast; and,
- the Columbia River to the north.

It was concluded, however, that those sources cannot supply sand to the littoral cells at present due to the numerous headlands, the sand instead having been carried onshore by beach migration under rising sea levels over the last 3,000 to 5,000 years. Current observations of coastal shoreline and bluff changes suggest that there are only limited quantities of modern sand being added to the beaches, and this varies considerably from cell to cell. Erosion of the coastal bluffs, primarily those containing Pleistocene dune and beach sands, represents a major sand source for some beaches, although the cliffs are eroding at rates typically less than 0.3 m/yr (0.1 ft/yr) (Priest and others, 1993) so the quantities are likely small. Little of the sediment transported down the major rivers reaches the ocean beaches, because most of it is deposited in estuaries (Komar, 1997). It is more likely that the estuaries are sinks of beach sand, demonstrated by studies of sediment accumulation in Oregon's bays and estuaries (Clemens and Komar, 1988; Komar and others, 2004). Nearly all sand presently derived from the Columbia River is transported northward to the Washington coast (Sherwood and others, 1990).

Gold Beach

Gold Beach is located midway along the Gold Beach littoral cell (Figure 1) on the central Curry County coast. The littoral cell likely forms two subcells, which include the shore south of the Rogue River and the area to its north. The southern subcell is approximately 9.7 km (6.1 mi) long, extending from the Rogue River mouth to Cape Sebastian in the south, and includes the town of Gold Beach along its northern section. The second subcell is approximately 4.7 km (2.7 mi) long, extending from the Rogue River to Otter Point in the north, and includes the community of Rogue Shores. Although sediments probably bypass the Rogue River jetties, thus enabling sand exchange between the two subcells, it is unlikely that sediments are entering the cell in the south (i.e., coming around Cape Sebastian). It is possible that sediments leak around Otter Point and supply the beaches to the north. If this is occurring, the absence of significant beach development north of Otter Point suggests that the volume leaking round the headland is probably very small. For almost its entire length the beaches are backed by a foredune of varying dimensions, with remnant sea cliffs located further landward of the dunes, particularly along the shore north of the Rogue River.

The geomorphology of the Gold Beach littoral cell (Figure 1) can be broadly classified into three contrasting beach types:

- South of Hunter Creek, beach sediments reflect a mixture of sand and gravel (southern end) to essentially a coarse to medium sand beach nearer Hunter Creek. In the south the beach face is steeply sloping, with the waves breaking directly on the beach face across a narrow surf zone. Due to the dynamic and dangerous nature of these types of beaches, beach surveys were not extended into the surf zone. With progress to the north the slope of the beach decreases.
- North of Hunter Creek, beach sediments reflect a mixture of coarse to medium sand, while the low tide intertidal zone is characterized by numerous gravels (fine gravels to cobble size particles). This section of the beach face is generally characterized by much lower beach slopes.
- North of the Rogue River, the beach changes from coarse sediments with some gravels in the south to essentially a fine to medium sand beach in the north. In both areas the beach face is gently sloping, while the surf zone is much wider and is characterized by multiple sand bars.

Due to the range of grain sizes, the morphology of the beach along the Gold Beach cell broadly ranges from being steep and reflective to an intermediate category beach state using the classification of Wright and Short (1983). In general, the steep reflective state characterizes much of the southern half of the Gold Beach cell and is typified by a narrow surf zone so the waves tend to break close to shore, often on a plunge step, where they immediately develop into strong swash up the beach face. As a result, reflective beaches lose very little wave energy during shoaling; the bulk of their energy is expended during the breaking process and directly on the beach face. In contrast, dissipative beaches in the Wright and Short (1983) classification make up much of the Oregon coast and are characterized by low sloping morphologies and wide surf zones, so that most of the wave energy is dissipated across the surf prior to reaching the beach face. This latter beach type typifies the beach north of the Rogue River. Intermediate beach states as occurs at various sites in the Gold Beach cell have a range of morphologies, including the tendency to develop strong seaward-flowing rip currents that can locally erode back the beach to from an embayment.

Figure 3 shows the changes in the shoreline morphology at the mouth of the Rogue River, which has been strongly influenced by the construction of jetties in 1960. Following their construction, the beach rapidly accreted, causing the shoreline to prograde some 152 m (500 ft) seaward on the north side, while shoreline advance south of the Rogue reached as much as 200 m (655 ft) nearest to the jetty. According to Priest and others (2004), the shoreline reached as much as 270 m (885 ft) seaward of its 1928 position by the early 1980s but has not accreted greatly since that time. In contrast, erosion appears to have dominated the shoreline response north of the north jetty, with the beach having eroded by some 60 m (200 ft) since the late 1960s (Figure 3), while changes to the south reflect a net loss of about 10 m (33 ft) since the late 1960s.

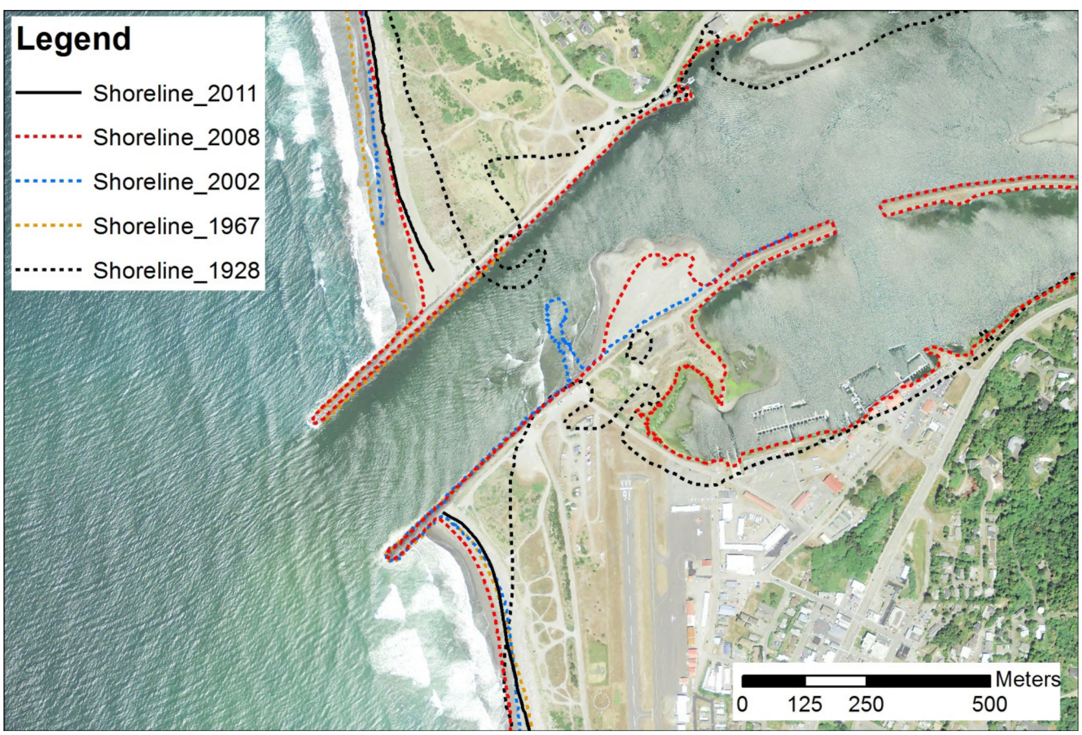

Figure 3. Shoreline changes at the mouth of the Rogue River due to jetty construction.

Nesika Beach

The Nesika Beach littoral cell extends from a point located just south of the town of Nesika Beach to Sisters Rocks, located just north of the Ophir River. Along much of the shore the beach is backed by prominent cliffs of Pleistocene marine terrace deposits (horizontally bedded sand in the uppermost part of the bluff) overlying sheared Jurassic sedimentary rocks (mudstone and sandstones) that are presently being rapidly eroded. Estimates of erosion by Priest and others (2004) indicate that the Nesika Beach bluffs are eroding at a rate of ~0.58 m/yr (-1.9 ft/yr), which represent some of the highest bluff toe erosion rates measured so far on the Oregon coast (e.g., compare to Allan and Priest [2001] and Priest and Allan [2004]). The geomorphology of the Nesika Beach cell can be broadly classified into three contrasting beach types:

- At Nesika Beach, beach sediments are generally fine grained, while the back of the beach may be nominally protected by a lag of cobbles to boulders. The beach face is predominantly gently sloping and is interspersed with rock outcrops and offshore reefs.
- Between Nesika Beach and Ophir Creek, beach sediments coarsen significantly becoming more mixed sand and gravel. As a result, the beach slope is generally steep, while the waves tend to break directly on the beach face.
- North of Ophir, beach sediments become finer grained and the slopes of the beach decrease, while the nearshore surf zone widens significantly.

Netarts

The Netarts littoral cell located on the northern Oregon coast in Tillamook County is approximately 15 km (9 mi) long and is bounded by resistant basaltic headlands in the south (Cape Lookout) and north (Cape Meares). The beaches within this cell are composed predominantly of fine sand and are characterized by low slopes (~2.3°), so they are fully dissipative in the morphodynamics classification of Wright and Short (1983). Along the southern 4 km (2.4 mi) of Netarts Spit, a narrow (10 to 15 m wide [33 to 50 ft]) gravel beach backs the otherwise sandy beach, with the crest of the gravel beach ranging in elevations from 6 to 7 m NAVD88. Along much of its shore, Netarts Spit forms a barrier beach that provides protection to Netarts Bay from large ocean waves. In the north, the bay mouth is unmodified, and its position varies significantly depending on the prevailing wave approach. In the far north is the community of Oceanside. There, the beaches remain highly dissipative, but are also backed by a cobble beach that serves to further protect the marine terrace that ultimately backs the beach north of the mouth of Netarts Bay.

BEACH PROCESSES

Beaches composed of loose sediments are among the most dynamic and changeable of all landforms, responding to a myriad of complex variables that reflect the interaction of processes that drive coastal change (waves, currents, and tides), and the underlying geological and geomorphological characteristics of the beaches (sediment grain size, shoreline orientation, beach width, sand supply and losses, etc.). These multiple factors have a threefold role in contributing to the morphology and position of the beach:

- Promoting the supply of sediments to the coast for beach construction;
- Transferring sediments through the system; and ultimately,
- Removing sediments through the process of erosion.

Because beaches are composed of loose material, they are able to respond and adjust their morphology rapidly in intervals of time ranging from seconds to days to years (Figure 4) in response to individual storm events, enhanced periods of storm activity, and increased water levels (e.g., the 1982-1983 and 1997-1998 El Niños).

Beginning with the 1997-1998 El Niño, the Oregon coast experienced a series of 20 unusually severe storms in which the deep-water significant wave heights exceeded 6 m (20 ft) for 9 hours or longer (Allan and Komar, 2000, 2002b). Prior to the 1997-1998 winter the largest number of major storms experienced in a single season was 10 to 12, which occurred in the early 1980s (1982–1986). Furthermore, from wave data up through 1996, researchers (Ruggiero and others, 1996) had calculated the 100-year storm waves to be around 10 m (33 ft) for the Oregon coast. However, an event on November 19-20, 1997, exceeded that projection, and wave conditions were far worse the following winter, 1998-1999, when 22 major storms occurred, four of which generated deep-water significant wave heights over 10 m—the largest generated wave heights of 14.1 m (47 ft). When wave energy of this magnitude (approximately proportional to the square of the wave height) is expended on the low sloping beaches characteristic of the Oregon coast, especially at times of elevated ocean water levels, these storms have the potential for creating extreme hazards to developments in foredunes and atop sea cliffs backing the beaches. For example, the cumulative impact of these recent extreme storms along the Neskowin and Netarts littoral cells in Tillamook County resulted in the foredune retreating landward by on average 11.5 m (38 ft) to 15.6 m (49 ft), respectively, and as much as 55 m (180 ft) in some locations,

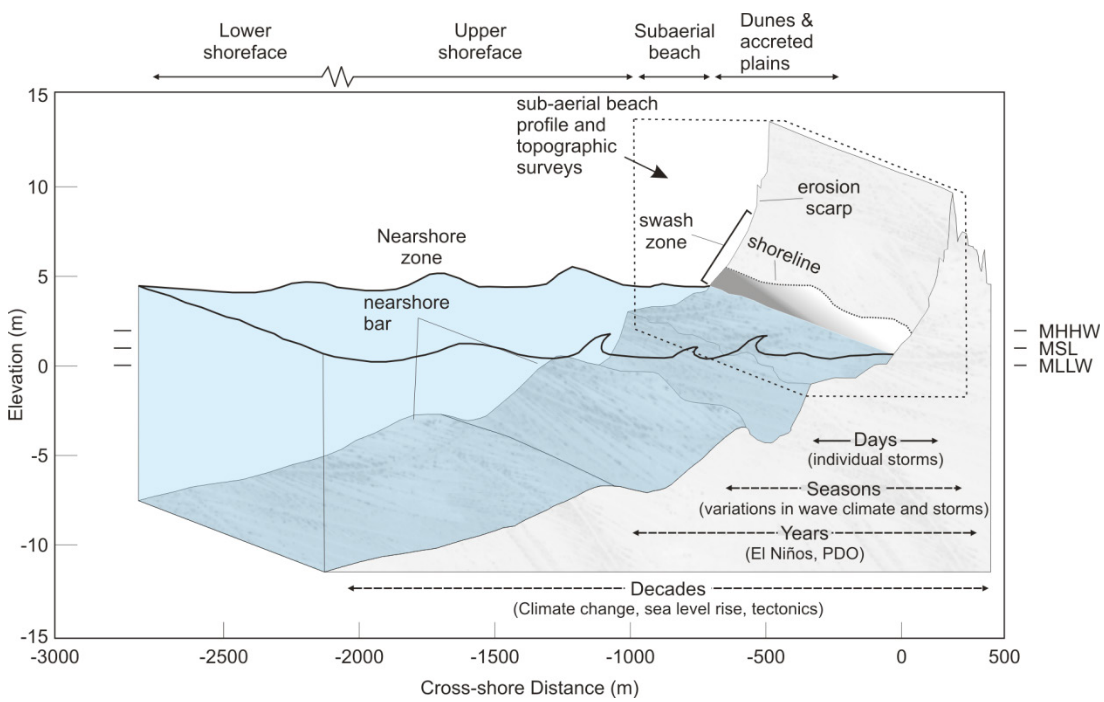

Figure 4. Conceptual model of beach and shoreline changes that occur over various temporal and spatial scales. Dashed box indicates the portion of beach measured as part of the Oregon Beach and Shoreline Mapping and Analysis Program (after Ruggiero and Voigt, 2000).

damaging properties fronting the eroding shore (Allan and others, 2004). In response to the erosion, property owners have resorted to the placement of riprap to safeguard their properties. Following the erosion there is usually a period lasting several years to a few decades during which the dunes rebuild, until later they are eroded by another storm (Allan and others, 2003). How long this process takes is not known for the Oregon coast. However, what is known is that, to date, many beaches throughout Tillamook County remain in a degraded state and hence continue to be highly susceptible to a repeat of the extreme winter storms of the late 1990s.

Longer-term adjustments of the beaches may also result from changes in sediment supply or mean sea level. However, attempts to quantify these processes suggest that erosion due to rising sea level is considerably lower compared with the effects of individual storms or from storms-in-series.

Sediment transport

Sediment transport in the littoral zone can be divided between the movement of sediments that is directed in primarily onshore-offshore directions (cross-shore sediment transport) and the movement of sediments parallel to the beach (longshore transport). The latter is especially significant when waves approach the shore at an angle as they then generate stronger currents confined to a narrow zone landward of the breaker zone and can be responsible for the movement of substantial volumes of sand along the shore, including significant quantities of gravels and cobbles.

Along the Oregon coast the role of longshore currents is especially important due to a seasonal variation in the direction of wave approach between the summer and winter (Figure 5A). During a "normal year," summer waves, driven by north to northwesterly winds, approach the coast from the northwest, transporting large volumes of sand and fine gravel toward the southern ends of the cells and also landward, causing the dry portion of the beach to build out. In contrast, during the winter the arrival of large waves from the southwest results in a reversal in the net sediment transport direction, which is now directed toward the north, as well as a cutting back of the the dry summer beach by moving the sand back offshore (Figure 5A). Over several "normal" years there can be an equilibrium such that the net sediment transport is close to zero (i.e., there is no net long-term buildup (accretion) of sediment at either end of the littoral cell) (Komar, 1986).

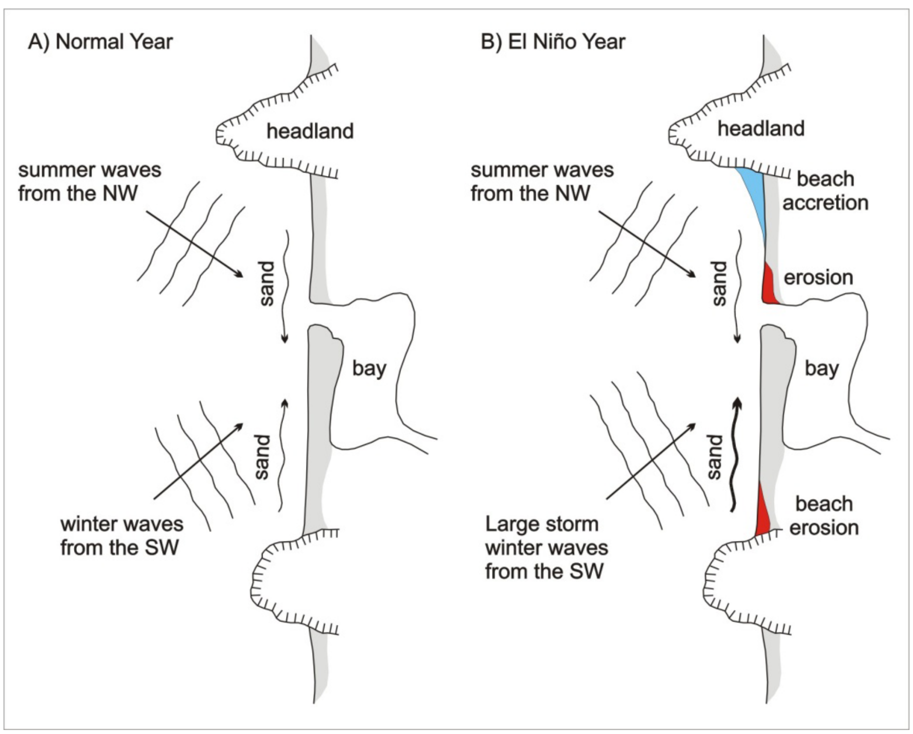

Figure 5. Alongshore-seasonal movement of beach sediments on the Oregon coast for A) a typical year and B) an El Niño year (after Komar, 1998).

The volume and direction of sand and gravel transported along Oregon's littoral cells may be augmented due to the periodic occurrence of an El Niño. El Niños typically occur at intervals of 5 to 6 years, but may recur on 2- to 7-year cycles. In the past two decades there have been seven El Niños, with the 1982-1983 and 1997-1998 events the strongest on record. The period between 1990 and 1995 was characterized by persistent El Niño conditions, the longest on record (Trenberth, 1999). The 1982-1983 and 1997-1998 El Niños were particularly significant events, producing some of the most extreme erosion on the Oregon coast (Allan and Komar, 2002b; Allan and others, 2003; Komar, 1986, 1998; Revell and others, 2002).

El Niños impact Oregon's beaches in a variety of ways, most notably by elevating the mean water levels that cause the measured tides to be much higher than usual. Under normal conditions the Oregon coast experiences a seasonal variation in its monthly mean water levels. During summer, water levels tend to be lowest, a result of coastal upwelling that produces cold, dense water, which depresses water levels along the coast. With the onset of winter the upwelling process breaks down and ocean temperatures are much warmer; thermal expansion causes the level of the sea to be elevated by some 0.2 m (0.6 ft), with the highest water levels occurring in December and January (Allan and others, 2003). During an El Niño, however, ocean temperatures are further enhanced due to the release of a warm pool of ocean water that emanates from the tropics. The arrival of this warm pool along the Oregon coast during the winter further elevates the ocean surface by an additional 0.3 m (1 ft). Thus, an El Niño may produce an increase in winter water levels by as much as 0.5 m (1.6 ft), greatly enhancing the capacity of waves to erode beaches and backshore properties during those months.

Aside from changes to the mean water levels along the coast, during an El Niño there is also a southward displacement of the storm tracks so they mainly cross the coast of central California (Seymour, 1996). As a result, storm waves reach the Oregon coast from a more southwesterly quadrant, creating an abnormally large northward transport of sand within its littoral cells. This creates "hotspot" erosion at the southern ends of the cells, north of the bounding headlands and also north of migrating inlets, shown conceptually in Figure 5B. The opposite response is found south of the headlands, where the northward displaced sand accumulates, causing the coast there to locally advance seaward (Figure 5B).

METHODOLOGY

Monitoring two-dimensional beach profiles over time provides an important means of understanding the morphodynamics of beaches and the processes that influence the net volumetric gains or losses of sediment (Morton and others, 1993; Ruggiero and Voigt, 2000). Beach monitoring is capable of revealing a variety of information concerning short-term trends in beach stability, such as the seasonal response of a beach to the prevailing wave energy, responses due to individual storms, or hotspot erosion associated with rip embayments. Over sufficiently long periods, beach monitoring can educe important insights about the long-term response of a particular coast, such as its progradation (seaward advance of the mean shoreline) or recession (landward retreat), attributed to variations in sediment supply, storminess, human impacts, and ultimately as a result of a progressive increase in mean sea level.

Beach profiles that are nominally orientated perpendicular to the shoreline can be surveyed using a variety of approaches, including a simple graduated rod and chain, surveying level and staff, total station theodolite and reflective prism, lidar, and real-time kinematic (RTK) differential Global Positioning System (RTK-DGPS) technology.

Traditional techniques such as leveling instruments and total stations are capable of providing accurate representations of the morphology of a beach but are demanding in terms of time and effort. For example, typical surveys undertaken with a total station theodolite require anywhere from 30 to 60 minutes to complete, which reduces the capacity of the surveyor to develop a spatially dense profile network. At the other end of the spectrum, high-resolution topographic surveys derived from lidar are ideal for capturing the three-dimensional state of the beach over an extended length of coast within a day; other forms of lidar technology are now being used to measure nearshore bathymetry but are dependent on water clarity. However, the technology remains expensive and is impractical along small segments of shore. More importantly, the high cost of lidar limits the temporal resolution of the surveys and hence the ability of the end-user to understand short-term changes in beach morphology (Bernstein and others, 2003). Within this range of technologies the application of RTK-

DGPS for surveying the morphology of both the subaerial and subaqueous portions of the beach has effectively become the accepted standard (Bernstein and others, 2003; Morton and others, 1993; Ruggiero and others, 2005; Ruggiero and Voigt, 2000).

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations, originally developed by the Department of Defense. In its simplest form, GPS can be thought of as triangulation with the GPS satellites acting as reference points, enabling users to calculate their position to within several meters (e.g., by using off-the-shelf handheld units [note the vertical error is typically about twice the horizontal error]), while survey-grade GPS units are capable of providing positional and elevation measurements that are accurate to a centimeter.

At least four satellites are needed mathematically to determine exact position, although more satellites are generally available. The process is complicated because all GPS receivers are subject to errors that can significantly degrade the accuracy of the derived position. These errors include the GPS satellite orbit and clock drift plus signal delays caused by the atmosphere and ionosphere and multipath effects (where the signals bounce off features and create a messy signal). For example, handheld autonomous receivers have positional accuracies that are typically less than about 10 m (<~30 ft) but can be improved to less than 5 m (<~15 ft) by using the Wide Area Augmentation System (WAAS). This latter system is essentially a form of differential correction that accounts for the above errors, which is then broadcast through one of two geostationary satellites to WAAS-enabled GPS receivers.

Greater survey accuracies are achieved with differential GPS (DGPS) by using two or more GPS receivers to simultaneously track the same satellites. This enables comparisons to be made between two sets of observations (Figure 6). One receiver is typically located over a known reference point (Figure 6), and the position of an unknown point is determined relative to the reference point. With the more sophisticated 24-channel dual-frequency RTK-DGPS receivers, positional accuracies can be improved to the subcentimeter level when operating in static mode and to within a few centimeters when in RTK mode (i.e., as the rover GPS is moved about).

Survey benchmarks

Fieldwork to establish a survey control network in the Gold Beach, Nesika Beach, and Netarts littoral cells was undertaken in January/February (Curry County) and May 2011 (Tillamook County). Procedures for installing the survey benchmarks are similar to the approach used by (Allan and Hart, 2007).

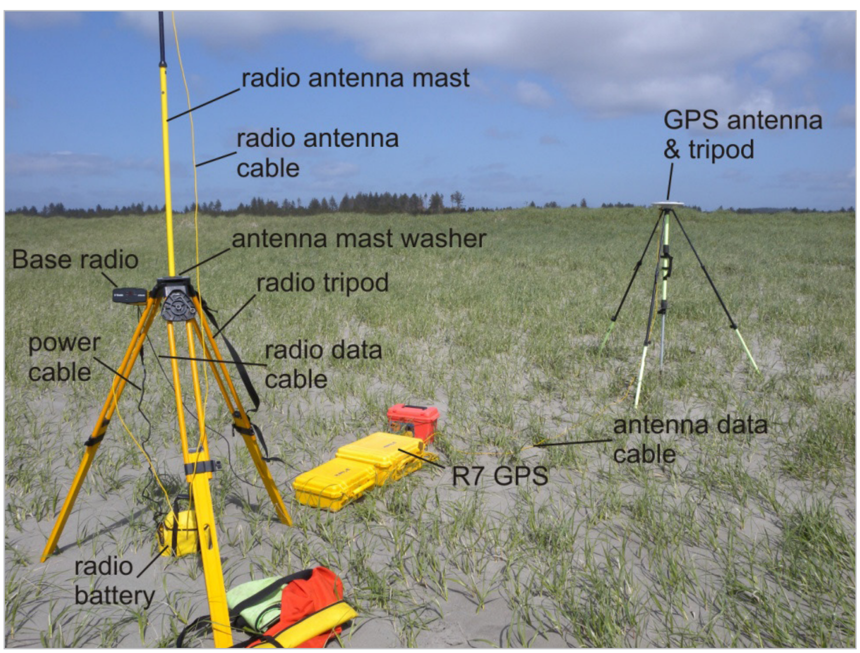

Figure 6. The Trimble R7 base station antenna in operation on the Clatsop Plains. Corrected GPS position and elevation information are transmitted by an HPB450 Pacific Crest radio to the R8 GPS rover unit.

Gold Beach monitoring network

Locations for permanently monumented benchmarks were initially identified in a Geographical Information System (GIS). Ground-truthing of the benchmark sites was undertaken in late January 2011 to finalize the benchmark locations and to ensure that the sites would have an unobstructed exposure to the sky. Benchmarks were installed by using one of these methods:

- 2.5-ft-deep holes were first dug. Aluminum sectional rods (Figure 7A) were hammered approximately 12 to 24 ft into the ground and were topped with a 2.5-inch aluminum cap. The ends of the rods and caps were subsequently concreted in place (Figure 7B); or,
- 5-inch-deep holes were drilled into rock outcrops (Figure 8A). The holes were filled with a fast-setting epoxy resin, in which a brass survey cap was inserted (Figure 8B).

All survey caps are stamped with an Oregon Department of Geology designation and a unique site label. In total, six new survey monuments were installed in the Gold Beach (five sites: RON, JON, LAURA, OTTER PT, and ARGO) and Nesika Beach (one site: CLSP) littoral cells (Figure 1).

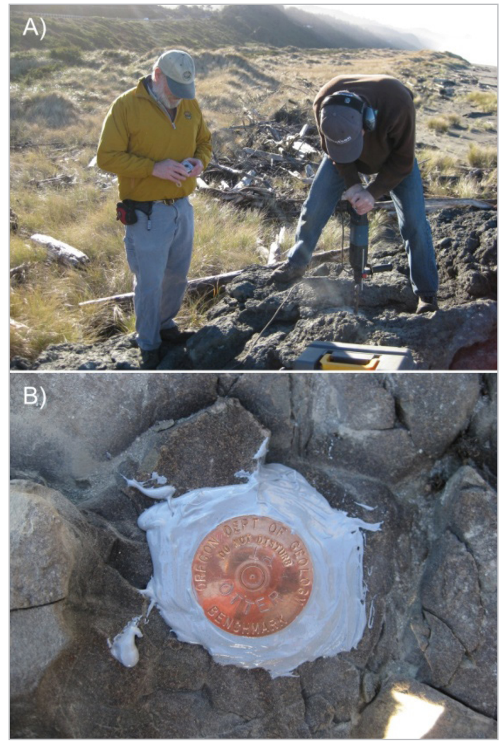

Figure 8. A) Drilling a benchmark site at Kissing Rock, south of Hunter Creek, Gold Beach. B) The Otter Point benchmark glued in place with a heavy duty epoxy resin.

Figure 7. A) Installation of sectional aluminum rod topped by a 2.5-inch aluminum cap. B) The sectional rod and cap concreted in place.

Precise coordinates and elevations were determined for the benchmarks by using several GPS units, which included a Trimble® 5700, 5800, R7, and R8. The GPS antenna was mounted on fixed-height (2.0 m [~6.5 ft]) survey rods or GPS tripods and located over each monument to establish precise survey control. Surveys of the new monuments were then undertaken and typically involved occupation times of at least 2 hours or more. The measured GPS data were submitted to the Online Positioning User Service (OPUS) maintained by the National Geodetic Survey (NGS; http://www.ngs.noaa.gov/OPUS/). OPUS provides a simplified way to access high-accuracy National Spatial Reference System (NSRS) coordinates using a network of continuously operating GPS reference stations (CORS, http://www.ngs.noaa.gov/CORS/). In order to use OPUS, static GPS measurements are typically made using a fixed-height tripod for periods of 2 hours or greater. OPUS returns a solution report with positional accuracy confidence intervals for adjusted coordinates and elevations for the observed point. In all cases the coordinate system used was Oregon State Plane (southern zone for Curry County and northern zone for Tillamook County), while the vertical datum was relative to the North American Vertical Datum of 1988 (NAVD88). Additional checking was performed by occupying several other benchmarks in the areas including OLCPWH1 and OLCPWH2 (installed by Watershed Sciences limited for the purposes of lidar survey control) and four NGS survey monuments (OA0244, OA1624, OA0826, and OA0821). Table 1 lists the derived coordinates and elevations determined for DOGAMI survey benchmarks. In all cases, the *xyz* difference between the coordinates and elevations derived using the OPUS solutions and post-processing against selected monuments yielded mean *xy* errors on the order of 0.002 m (±0.004 m) and 0.001 m (± 0.003 m), respectively, while the mean *z* error was determined to be 0.009 m (±0.019 m). The largest error (0.058 m) determined from a comparison of a single OPUS solution versus coordinates derived from a local site calibration was associated with the *z* value determined for the monument JON. It is not immediately clear as to the cause of this error. One possible fix is to undertake a network adjustment, which would allow the errors of this particular site (and others within the survey network) to be spread among the other survey monuments. However, given the relatively long occupation of this particular site (just under 4 hours), we chose to base the final coordinates on the OPUS solution. As additional observations are undertaken at this site in the future, it can be expected that this error will be reduced.

Netarts monitoring network

In contrast to the Gold Beach monitoring network, only one new benchmark (CLSP located in Cape Lookout State Park at the south end of the Netarts littoral cell; Figure 2), was established for the Netarts cell. To provide survey control, we used CLSP and two existing NGS monuments: OCEANSIDE, located at the north end of the cell in the community of Oceanside; and PRAIRIE, located to the east adjacent to Highway 101 and just south of the turnoff to the Tillamook airport.

Prior to establishing the beach and shoreline monitoring network in the Netarts cell, the three benchmarks were separately occupied for several hours in a manner similar to the approach described above for the Gold Beach area. The measured GPS data were submitted to the NGS OPUS for online processing. Results from OPUS and post-processing in the Trimble Business Center (TBC) GPS software were then used to establish a local coordinate system (a site calibration file) for the Netarts cell and the final derived coordinates, which are presented in Table 2. As can be seen from Table 2, overall the GPS results are very good.

Beach profile surveying

After survey monuments were established in the Gold Beach and Netarts cells, beach cross-sections were established along each of the littoral cells. Figure 1 shows the general layout of the final Gold Beach and Nesika Beach survey network, which consists of 12 profile sites between Cape Sebastian and the Rogue River, 9 sites located north of the Rogue River and south of Otter Point, and 14 sites from Nesika Beach to the just north of the Ophir Creek. Figure 2 shows the final monitoring network established in the Netarts cell, which consists of 24 sites.

Surveying of beach profiles began on January 26 (Gold Beach area) and May 23 (Netarts) using a Trimble® R7/R8 total station GPS. This system consists of a GPS base station (R7 unit), Zephyr™ Geodetic antenna, HPB450 base radio, and R8 "rover." The R7 base station was mounted on a fixed height (2.0 m [~6.5 ft]) tripod and located over a known survey monument ("RON" in the Gold Beach cell and "CLSP" in the Netarts cell) followed by a site calibration on various benchmarks to precisely establish a local coordinate system (Figure 9). This step is critical in order to eliminate various survey errors. For example, Trimble reports that the R7/R8 GPS system has horizontal errors of approximately ±1 cm + 1 ppm (parts per million × the baseline length) and ±2 cm in the vertical (Trimble, 2011).

Table 1. Survey benchmark coordinates and elevations for the Gold Beach, Oregon area* established using National Geodetic Survey Online Positioning User Service (OPUS) solutions.

Benchmark	Survey Date	Occupation Length (m)	Northing m)	Easting (m)	Elevation (m)	rms (m)	Method
RON	1/20/2011	~ 6 h 47 min	0.000	0.001	0.000	0.010	OPUS
	1/26/2011	~ 8 h 40 min	0.002	0.003	0.005	0.009	OPUS
	1/27/2011	~ 8 h 15 min	−0.001	−0.001	0.003	0.009	OPUS
	2/15/2011	~10 h	−0.001	−0.004	−0.008	0.011	OPUS
		Final	**90801.941**	**1176979.766**	**7.132**	**0.010**	
LAURA	1/26/2011	~ 4 h 51 min	0.009	0.000	0.019		OPUS and post-processed
		Final	**87355.238**	**1176983.056**	**9.284**	**0.010**	
JON	1/26/2011	~ 3 h 44 min	0.011	0.006	0.058		OPUS and post-processed
		Final	**84908.711**	**1176790.557**	**6.879**	**0.011**	
OTTER PT	1/27/2011	~ 3 h 51 min	0.000	0.000	0.014		OPUS and post-processed
		Final	**95447.084**	**1177520.533**	**5.851**	**0.011**	
OPHIR	1/28/2011	~ 2 h 10 min	−0.001	−0.001	−0.002	0.013	OPUS
	2/16/2011	~ 10 h 8 min	0.001	0.002	0.001	0.013	OPUS
	2/17/2011	~4 h	0.000	0.000	0.001	0.010	OPUS
		Average	**103909.429**	**1179707.203**	**12.080**	**0.012**	

In all cases, final coordinates were determined from the OPUS solutions. Reported errors are relative to the final derived coordinates, which may have involved both OPUS solutions and post-processed derivations.

*Coordinates for the ARGO site located north of the Rogue River are not reported here due to an error in the data.

Table 2. Survey benchmark coordinates and elevations for the Netarts, Oregon area established using National Geodetic Survey Online Positioning User Service (OPUS) solutions.

Benchmark	Survey Date	Occupation Length	Northing (m)	Easting (m)	Elevation (m)	rms (m)	Method
CLSP	5/18/2011	~ 5 h 43 min	0.004	0.008	0.007	0.013	OPUS
	5/23/2011	~ 7 h 46 min	−0.019	0.003	−0.008	0.013	OPUS
	5/25/2011	~ 5 h 6 min	0.014	0.006	0.000	0.016	OPUS
		Final	**194592.790**	**2228287.190**	**4.792**	**0.014**	
OCEANSIDE	5/18/2011	~ 2 h 10 min	−0.016	−0.003	0.122*		OPUS versus post-processed
		Final	**205112.210**	**2228840.680**	**37.609**	**0.016**	
PRAIRIE	5/18/2011	~ 2 h 15 min	−0.016	0.007	0.003		OPUS versus post-processed
		Final	**200302.483**	**2239922.133**	**4.514**	**0.016**	

In all cases, final coordinates were determined from averaging of the OPUS solutions. Reported errors are relative to the final derived coordinates, which may have involved both OPUS solutions and post-processed derivations.

*The OPUS solution for the OCEANSIDE benchmark was found to be higher by 0.12 m when compared with a separate derivation, whereby the GPS ephemeris data were downloaded and post processed in Trimble Business Center (TBC). In addition, an earlier GPS survey undertaken by the NGS indicated that their result more closely approximated our separate TBC derivation. As a result, we used the coordinate results from the TBC analyses rather than the OPUS solution for the OCEANSIDE benchmark.

These errors may be compounded by other factors such as poor satellite geometry, multipath, and poor atmospheric conditions, combining to increase the total error to several centimeters. Thus, the site calibration process is critical in order to minimize these uncertainties (Ruggiero and others, 2005).

After local site calibration was completed, cross-shore beach profiles were surveyed with the R8 GPS rover unit mounted on a backpack (Figure 10). This process was typically undertaken during low tide. The approach was to walk a straight line from the landward edge of the primary dune, over the dune crest (Figure 10, left), down the beach face, and out into the ocean to approximately wading depth (Figure 10, right) by navigating along a predetermined line perpendicular to the shoreline and displayed on a handheld Trimble TSC2 computer, connected to the R8 rover. The computer shows the position of the operator relative to the survey line and indicates the deviation of the GPS operator from the line. The horizontal variability during the survey is generally minor, typically less than about ±0.25 m either side of the line, which results in negligible vertical uncertainties due to the relatively uniform nature of beaches characteristic of much of the Oregon coast (Ruggiero and others, 2005). From our previous research at numerous sites along the Oregon coast, this method of surveying can reliably detect elevation changes on the order of 4 to 5 cm, that is, well below normal seasonal change in beach elevation, which typically varies from 1 to 2 m (3 to 6 ft) (Allan and Hart, 2007, 2008).

Figure 9. Static GPS occupations were used as part of a site calibration on selected benchmarks to derive a local coordinate system in the Gold Beach and Netarts area. GPS site calibration procedures involved occupying a benchmark for 180 epochs (typically at least 3 minutes or longer) and then processing the data in Trimble Business Center (TBC) software. Example here is of the Trimble R8 receiver located on National Geodetic Survey monument OA0832 just north of the Rogue River, with geologist Laura Stimely standing by.

Figure 10. Beach profile surveys being undertaken using a Trimble R8 GPS rover mounted on a backpack.

The collected GPS data were processed using the Trimble Business Center suite of software. The first stage involves a re-examination of the site calibration undertaken on the TSC2 computer. A three-parameter least-squares fit was then applied to adjust all data points collected during the survey to the local coordinate system established for the particular study area in order to reduce any errors that may have occurred as a result of the GPS units. The reduced profile data were then exported for analysis.

Where available and to supplement the GPS beach survey data in order to extend the time series, light detection and ranging (lidar) data measured by the USGS/NASA/NOAA in October 1997 (pre 1997-1998 El Niño), April 1998 (post 1997-1998 El Niño), 2002 (post extreme 1998-1999 winter season), and the most recent lidar flights undertaken by DOGAMI in 2008 (south coast) and 2009 (north coast) were also analyzed. Each of these data sets was separately processed, gridded, and analyzed in a GIS (e.g., Esri ArcGIS™), enabling their integration into the beach profile data set.

Analysis of the beach survey data involved several stages. The data were first imported into MATLAB®[4] using a customized script. A least-squares linear regression was then fit to the profile data. The purpose of this script is to examine the reduced data and eliminate data points that exceed a ±0.5 m threshold either side of the predetermined profile line. The data is then exported into an Microsoft Excel® database for archiving purposes. A second MATLAB script uses the Excel profile database to plot the latest survey data (relative to the earlier surveys) and outputs the generated figure as a Portable Network Graphics file. A third script examines the profile data and quantifies the changes that have occurred at selected contour elevations; for this study temporal trends are developed for all contours between the 1-m and 6-m elevations and for all available data. Finally, the reduced contour data are plotted against time and exported as Portable Network Graphics files for additional analysis. After data analysis, the graphic images are displayed on the OBSMAP[5] and NANOOS[6] websites for online viewing.

Shoreline changes

Although beach profiles provide important information about the cross-shore and to some degree the longshore response of the beach as a result of variations in the incident wave energy, nearshore currents, tides, and sediment supply, it is also necessary to understand the alongshore variability in shoreline response that may reflect the development of large morphodynamic features such as rip embayments, beach cusps, and alongshore transport of sediment. To complement the beach profile surveys initiated in the Gold Beach and Netarts cells, surveys of a tidal datum-based shoreline were also undertaken. For the purposes of this study we used the Mean Higher High Water (MHHW) tidal datum measured at the Port Orford tide gauge, located at an elevation of 2.07 m NAVD88, as a shoreline proxy for the Gold Beach and Nesika Beach surveys; in the Netarts cell we used a shoreline proxy located at an elevation of 2.32 m NAVD88. Measurement of the shoreline was undertaken by mounting the rover R8 GPS on top of an ATV and driving two lines above and below the MHHW contour in order to bracket the shoreline. The GPS data were then gridded in MATLAB in order to extract the appropriate tidal datum-based shoreline proxy.

In addition to contemporary datum-based shorelines, historical shoreline positions were compiled in a GIS. These latter data sets were originally mapped by early National Ocean Service (NOS) surveyors for select periods on the Oregon coast including the 1920s, 1950s, and 1970s. In addition, Ruggiero and others (in press) are presently completing a study of long-term trends of coastal change for the Pacific Northwest coasts of Oregon and Washington. In this latter study, Ruggiero and colleagues digitally orthorectified a suite of aerial photographs flown in 1967 along the Oregon coast, ultimately deriving a 1967 shoreline for the entire coast. Finally, we also use available lidar data to derive contemporary datum-based shorelines for each of the study areas.

4 Computer programming languages.

5 http://www.oregongeology.com/sub/nanoos1/index.htm

6 http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Beaches-Mapping

RESULTS

A variety of approaches may be used to view and analyze the morphology of the beach measured by the RTK-DGPS surveys. This includes the traditional approach of simply examining the temporal and spatial variability of graphed beach profiles. Other approaches include examining the changes at specific contour elevations (also known as excursion distance analysis or EDA), undertaking volumetric calculations, or examining alongshore changes.

Beach profiles provide the most important information concerning the spatial variability in the shape of a beach section over time. The information derived from repeated surveys provides a measure of the response of the beach to variations in the wave energy (e.g., winter versus summer wave conditions), which is reflected in accretion of the beach during the summer and erosion in winter. These data may also contain important information on how the beach responds to major storms, such as during the extreme 1997-1998 and 1998-1999 winters, including dune or bluff erosion (i.e., how much dune or bluff retreat occurred), data that are extremely useful when designating hazard zones along the coast. Given the short period in which beach changes in the Gold Beach, Nesika Beach, and Netarts cells have been monitored, information derived from lidar topographic surveys has been used to supplement the beach monitoring data. This addition extends the data set back to at least September 2002 (south coast) and October 1997 (north coast). Along the Gold Beach and Nesika Beach cells, airborne lidar data were obtained in September 2002, summer 2008, and most recently in late summer 2010. Additional lidar data for the Netarts cell includes that from flights undertaken in October 1997 (pre-El Niño) and April 1998 (post El Niño). When combined, the lidar and RTK-DGPS data provide 9 years of information on beach changes on the southern Oregon coast and 14 years of information on beach changes on the northern Oregon coast. Plots from the analyzed lidar and RTK-DGPS data sets have been uploaded to the NANOOS beach and shoreline monitoring web portal[7] for rapid dissemination.

7 http://www.nanoos.org/nvs/nvs.php?section=NVS-Products-Beaches-Mapping

Gold Beach

Figure 11 present results from analyses of various historical shorelines, while Figure 12 presents the results of the beach surveys and lidar analyses for four representative transect sites located in the southern Gold Beach subcell (Figure 1). Shorelines have been defined by using standardized procedures that include the mean high water line as defined by early National Ocean Service (NOS) Topographic "T" sheet surveys of shorelines along the U.S. coastline, the wet-dry sand line in aerial photographs, and MHHW lidar-derived datum-based shorelines (e.g., Allan and others, 2003; Moore, 2000; Shalowitz, 1964). Several characteristics are worth noting about the shoreline changes depicted in Figure 11:

- The beach immediately (up to ~2 km [1.2 miles]) north of Cape Sebastian (Figure 11A) has clearly gained sand and over time has resulted in the shoreline advancing seaward by some 50 to 80 m (164 to 262 ft);
- Immediately south of Hunter Creek (Figure 11B) the beach initially eroded (retreated) landward between 1928 and 1967. However, since the 1960s, the beach and shoreline have been aggrading, while the shoreline has prograded (advanced) seaward by ~60 m (197 ft), such that today the shoreline follows closely its original location as defined in 1928;
- North of Hunter Creek (Figure 11C), a similar response can be seen with the beach having initially eroded landward between 1928 and 1967. Since 1967 the shoreline had advanced seaward and by 1985 had reached its most accreted state ~100 to 130 m (328 to 426 ft) west of the 1967 shoreline. However, since 1985 the shoreline has eroded landward by some 60 m (197 ft) and is presently located either near its original 1928 location, or is just seaward of the 1928 shoreline; and,
- Adjacent to the south Rogue River jetty (Figure 11D), the shoreline appears to have reached its most accreted state in the mid-1980s, with considerable sand having built up against the south jetty, and since then has been in a predominantly erosional phase, with the shoreline having retreated landward by ~60 to 90 m (197 to 295 ft). Today, the shoreline is close to its original 1967 location.

Figure 11. Shoreline changes south of the Rogue River. The plates progress left to right from Cape Sebastian in the south to Hunter Creek (top of B) to the Rogue River.

The plots (GB1 and GB4 in Figure 12) indicate that beach aggradation and dune growth have been occurring south of Hunter Creek since the 2002 lidar data were flown (Figures 12 and 13A). However, during the past decade the beach and shoreline data appear to suggest that the beach in general is in a state of equilibrium and, as a result, is neither

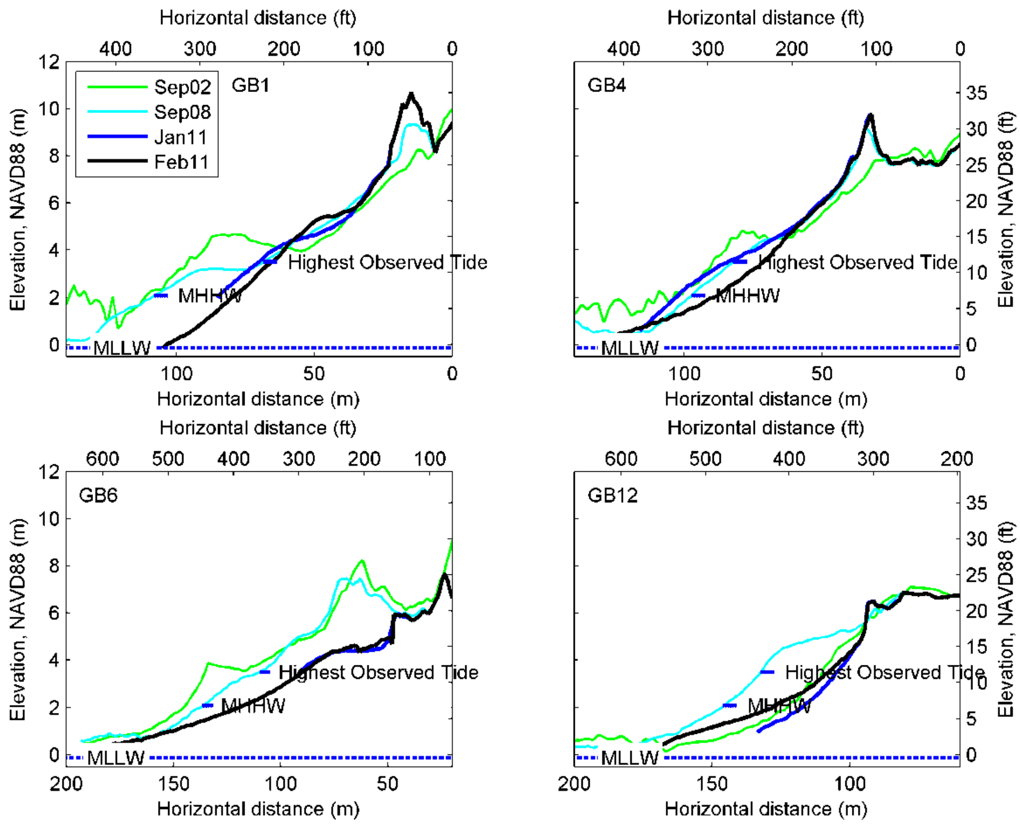

Figure 12. Profile changes identified in the Gold Beach subcell (Cape Sebastian to Rogue River). Transect locations are identified in Figure 1.

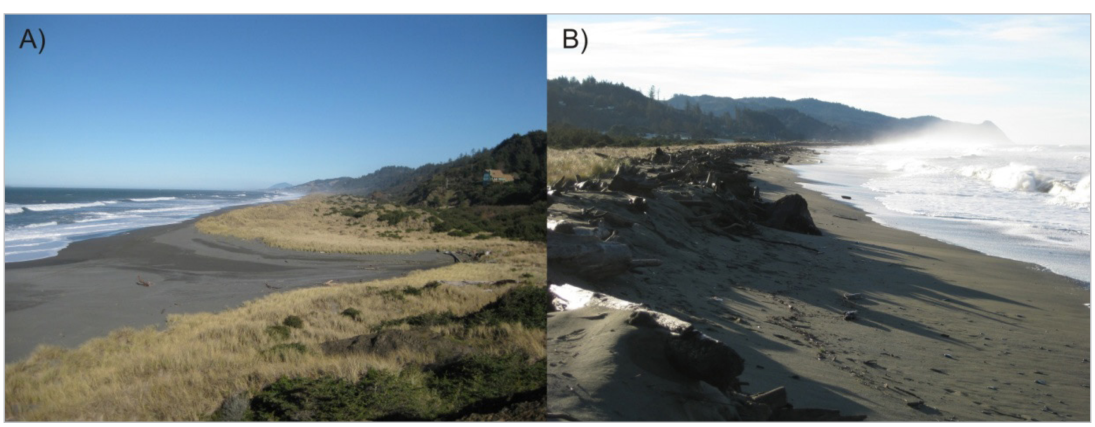

Figure 13. Contrasting beach and dune morphologies in the southern portion of the Gold Beach littoral cell. A) Development of a well vegetated dune. The original 1967 shoreline position is probably depicted in A by the transition from the darker green brush line to the region dominated by dune grasses, while the low dune elevations west of the brush line indicate that the beach prograded rapidly. B) Erosion now appears to be dominating beach response immediately south of the Rogue jetty.

advancing nor retreating. This would further suggest that current rates of sediment supply are probably negligible relative to the erosive forces of waves and currents, which serve to erode and redistribute those sediments both in the cross-shore (i.e., offshore to form bars) and alongshore directions. North of Hunter Creek, dune crest elevations are generally much lower when compared with the beaches to the south of Hunter Creek, averaging some 7 to 8 m (23 to 26 ft) in elevation. In addition, with progress toward the south Rogue jetty there is clear evidence that much of this shore is presently being eroded (Figures 11D and 13B). More detailed site-specific information characterizing the individual profile sites can be found on the NANOOS beach and shoreline mapping website.

Hunter Creek shoreline and channel patterns

Figure 14 documents river channel changes adjacent to Hunter Creek, just south of the town of Gold Beach. As can be seen in the figure, Hunter Creek periodically experiences large shoreline excursions that may vary spatially by as much as ~1 km from its most northern position defined in a 1985 aerial image, to its southernmost position, which typically abuts Kissing Rock. These variations are driven to a large degree by a combination of riverine discharge versus the accumulation and migration of sand at the mouth of the creek due to variations in wave approach angles that drive longshore currents and ultimately alongshore sediment transport. The latter process serves to cause sand build-up around the creek mouth and, as these sediments build and shift about, the creek channel is deflected accordingly. Although it is not immediately clear from the 1985 aerial photo why the channel was so far north, it is interesting to note that the northern position of the creek occurred two years after the major 1982-1983 El Niño. It is well documented that El Niños result in significant alongshore shifts in sediment; the southern ends of littoral cells typically experience significant erosion, while the northern ends of the cell tend to gain sediments causing the shoreline to prograde. Associated with this sand migration, El Niños also tend to produce a northward shift in the position of the mouths of estuaries and rivers (e.g., Komar, 1986, 1998; Allan and others, 2003), responses that are entirely consistent with the observed changes at Hunter Creek. In addition, it is interesting to note that the analyses of the 1985 shoreline described above revealed that the beach north of Hunter Creek was located some 30 to 55 m (98 to 180 ft) west of the shore's present position. This would suggest that the 1982-1983 El Niño probably contributed to a substantial alongshore shift in the beach sediments that likely contributed to its overall 1985 migration to the north.

Due to its northern position and high flows, the river eroded landward into a bank located immediately west of Highway 101, where it formed an erosion scarp that is depicted in a 1994 orthorectified image of the coast (Figure 14); this latter feature is also clearly documented in the 2008 lidar data flown by DOGAMI and matches perfectly the location of the scarp in 1994. Examination of earlier aerial imagery obtained in 1951, 1977, and 1980 tends to reinforce the perception that the erosion scarp was indeed caused by the 1985 northward migration of Hunter Creek. Although no additional photos between 1985 and 1994 have been found, given the proximity of the erosion scarp to the flood channel in 1985, one can speculate that erosion of the bank continued for some time after the 1985 event due to ongoing influences associated with the river, as well as from erosion from waves, which were now able to swash across the eroded channel attacking the back of the beach. As can be seen in Figure 14, by 1994 Hunter Creek had shifted back to the south, where it continued to fluctuate between its southern limit and a few hundred meters north of the bridge.

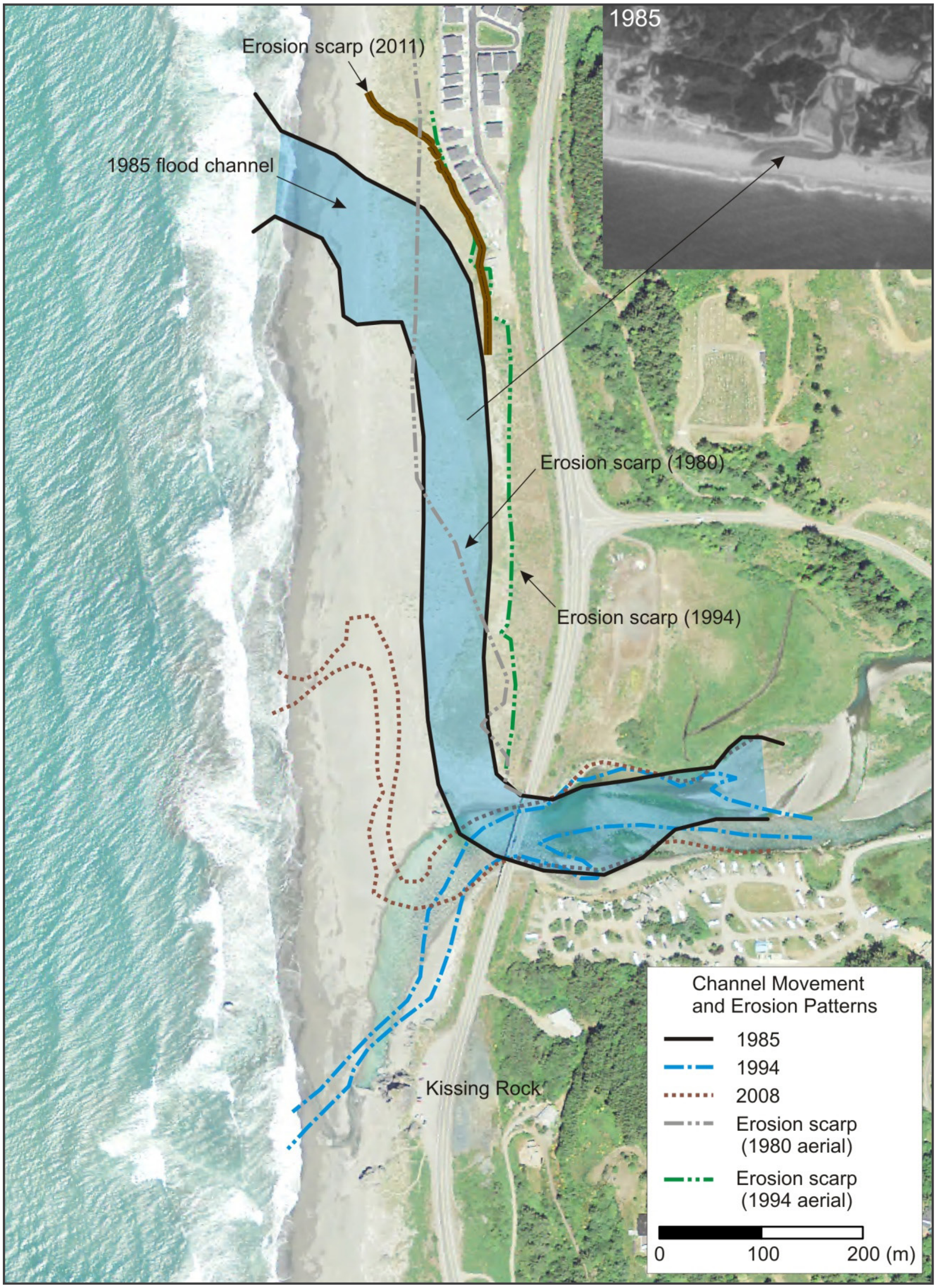

Figure 14. Hunter Creek channel migration patterns in 1985, 1994, and 2008.

Recently, however, in early spring 2010, the creek once again shifted back to the north (Figure 15), exposing a series of groynes constructed by ODOT. These groynes were installed sometime in the late 1980s, presumably to protect U.S. Highway 101 by deflecting the creek away from the road, and having been installed in response to the 1985 erosion event. As can be seen in Figure 14, the northern most position of the creek channel (brown line) was measured in January 2011 with the aid of RTK-DGPS. As can be seen in Figures 14 and 15, migration of Hunter Creek this time resulted in the river migrating farther north and eroding landward, eventually reaching several homes that had been constructed close to the beach and immediately adjacent to the original erosion scarp documented in the 1994 orthophoto. As a result of this recent phase of erosion, home owners mobilized rapidly to mitigate the problem by constructing a riprap revetment in front of their properties (Figure 16). While the problem stemmed originally from the movement of the channel, the lowering of the elevation of the beach throughout this area enabled waves to easily crest the beach and erode the bank, on top of which the homes had been built.

Figure 15. In early spring 2010, Hunter Creek migrated so far northward that it began to erode the toe of several homes constructed immediately adjacent to the creek and beach. Note the locations of at least two of the groynes, which are depicted by the two prominent horns at the back of the beach around mid-photo. (Photo taken on April 9, 2011; courtesy of Ron Sonneville, geotechncal consultant, Terrafirma Building, Inc.)

Figure 16. Homeowners placed riprap to mitigate erosion caused by a combination of Hunter Creek riverine channel erosion and wave runup and overtopping of the barrier beach. Photo shows DOGAMI geologist Laura Stimely surveying the toe of the erosion scarp.

Rogue Shores beach and shoreline patterns

Coastal shoreline changes for the northern Gold Beach subcell (Rogue River to Otter Point) are presented in Figure 17. From these patterns three broad responses are apparent:

- The beach and shoreline north of the Rogue River are presently eroding and have been retreating since at least the mid 1960s. The erosion extends at least 1.6 km (1 mile) north of the Rogue River, with the greatest shoreline retreat (~85 m [279 ft]) adjacent to the jetty.
- Adjacent to the community of Rogue Shores the beach appears to be a hinge point, separating the erosion in the south from accretion to the north.
- North of Rogue Shores the beach is actively accreting and prograding, with the shoreline having advanced seaward by about 50–80 m (164–262 ft).

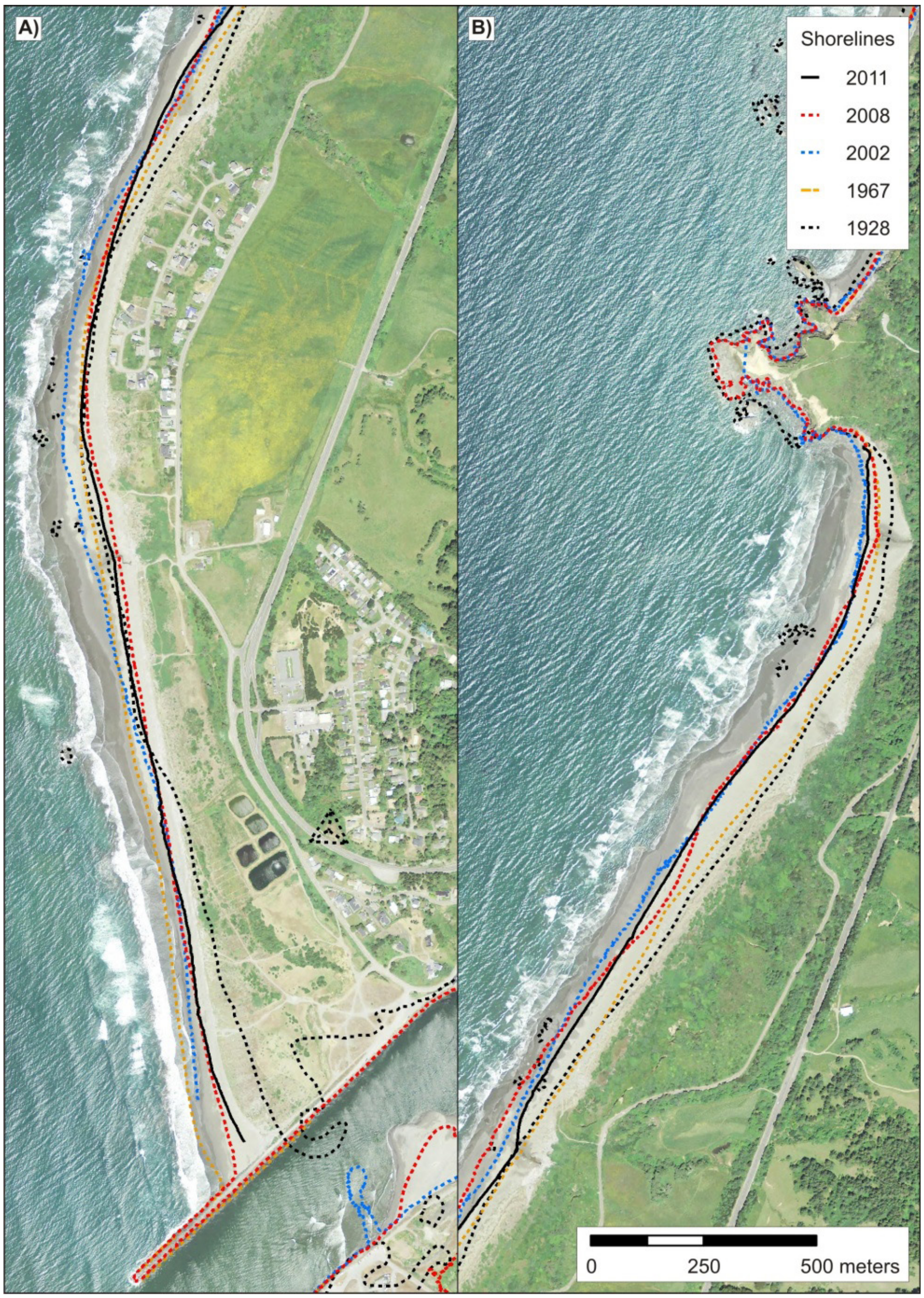

Figure 17. Shoreline changes in the northern Gold Beach subcell (Rogue River to Otter Point), including the community of Rogue Shores. The plates progress left to right from the Rogue River in the south to Otter Point in the north.

Figure 18 presents a synthesis of the lidar and RTK-DGPS beach survey results. The patterns depicted in the figure reinforce the overall shoreline responses described above, with erosion dominating the southern portion of the subcell (e.g., the RS1 and RS3 beach profiles in Figure 18), whereby the dune face has cut back some 10 m (33 ft) since 2002. Conversely, the northern profiles (RS6 and RS8) indicate that the dunes are actively aggrading.

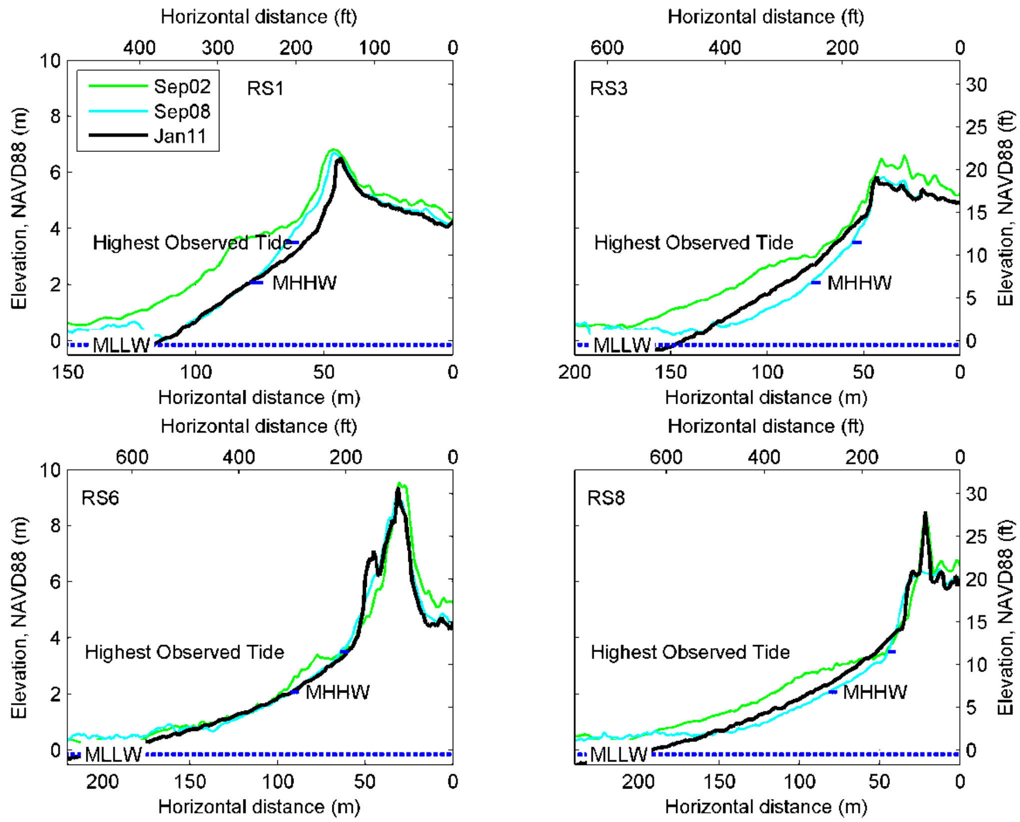

Figure 18. Profile changes identified in the northern Gold Beach subcell (Rogue River to Otter Point). Transect locations are identified in Figure 1.

Nesika Beach

Coastal shoreline changes for the Nesika Beach littoral cell (Nesika to Sisters Rocks) are presented in Figure 19. From these patterns three broad responses are apparent:

- The beach and shoreline in front of the community of Nesika Beach is presently eroding and has been retreating since at least the late 1920s. The area of greatest erosion extends at least 1.4 km (0.9 mile) from the southern end of the cell, with the shoreline

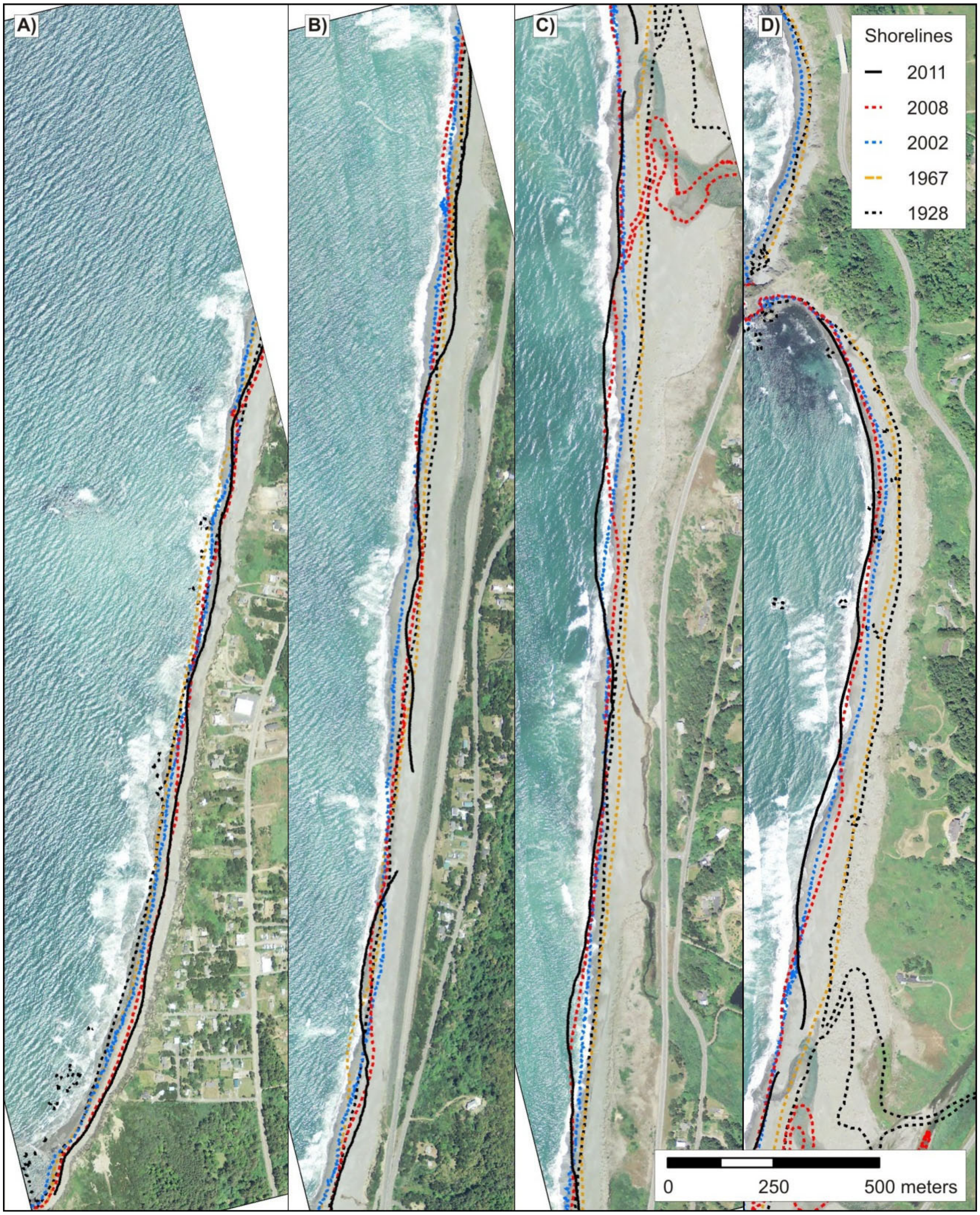

Figure 19. Shoreline changes in the Nesika Beach littoral cell. The plates progress left to right from Nesika Beach in the south to Sisters Rock in the north (top of D).

having retreated by as much as ~50 m [160 ft]) since the late 1920s. Erosion of the bluffs extends at least another 1 km (0.6 mi) to the north for a total of 2.4 km (1.5 mi) north of the south end of the cell.

- North of the community of Nesika and about 1.2 km (0.75 mi) south of the Ophir Creek, the shorelines fluctuate considerably, with little to no evidence of a prevailing trend (Figure 19B). However, as can be seen from the 2011 shoreline, this portion of the coast is strongly influenced by rip embayments. For example, the break in the 2011 shoreline depicted in Figure 19B reflects the formation of a large rip (Figure 20) that extended to the base of the riprap that presently protects U.S. Highway 101, enabling waves at the time to directly attack the toe of the revetment.
- Just south of the Ophir Creek to Sisters Rocks, the shoreline is presently in an accreted state, with the mean shoreline located some 50 m to as much as 100 m (160 to 325 ft) seaward of the 1967 shoreline (Figures 19C and 19D), suggesting that this portion of the cell is actively prograding seaward.

Figure 20. Development of a rip embayment adjacent to U.S. Highway 101 allows waves to directly attack the toe of the revetment. The photo was taken at low tide on February 16, 2011.

Figures 21 and 22 provide more detailed views of the erosion of the coastal bluffs along the Nesika Beach shore in order to derive more detailed estimates of the erosion patterns along this shore (Figure 23). Mapping was undertaken for two distinct areas:

- The toe of the bluff was mapped using 1967 orthorectified aerial imagery. The mapping was accomplished by identifying distinct breaks between the top of the beach and the active vegetation line. A similar approach was carried out using 2009 orthorectified aerial images, coupled with high-resolution lidar data flown by DOGAMI in 2008. Additional measurements were made in February 2011 by using detailed RTK-DGPS mapping, which was achieved by mapping the toe of the bluff with the GPS mounted on a backpack.

Figure 21. Bluff toe changes at Nesika Beach, Oregon between 1967 and 2008.

- The top of the bluff was mapped using the 2008 lidar data and field-based mapping of selected sites carried out with the GPS equipment. The former was accomplished in GIS by looking for distinct (sharp) breaks in the slope contours (i.e., the bluff and backslope geomorphology). In contrast, the latter was achieved by carefully locating the GPS along the edge of the bluff top. No attempt was made to map the top of the bluff from the 1967 aerial imagery due to the difficulties associated with this process.

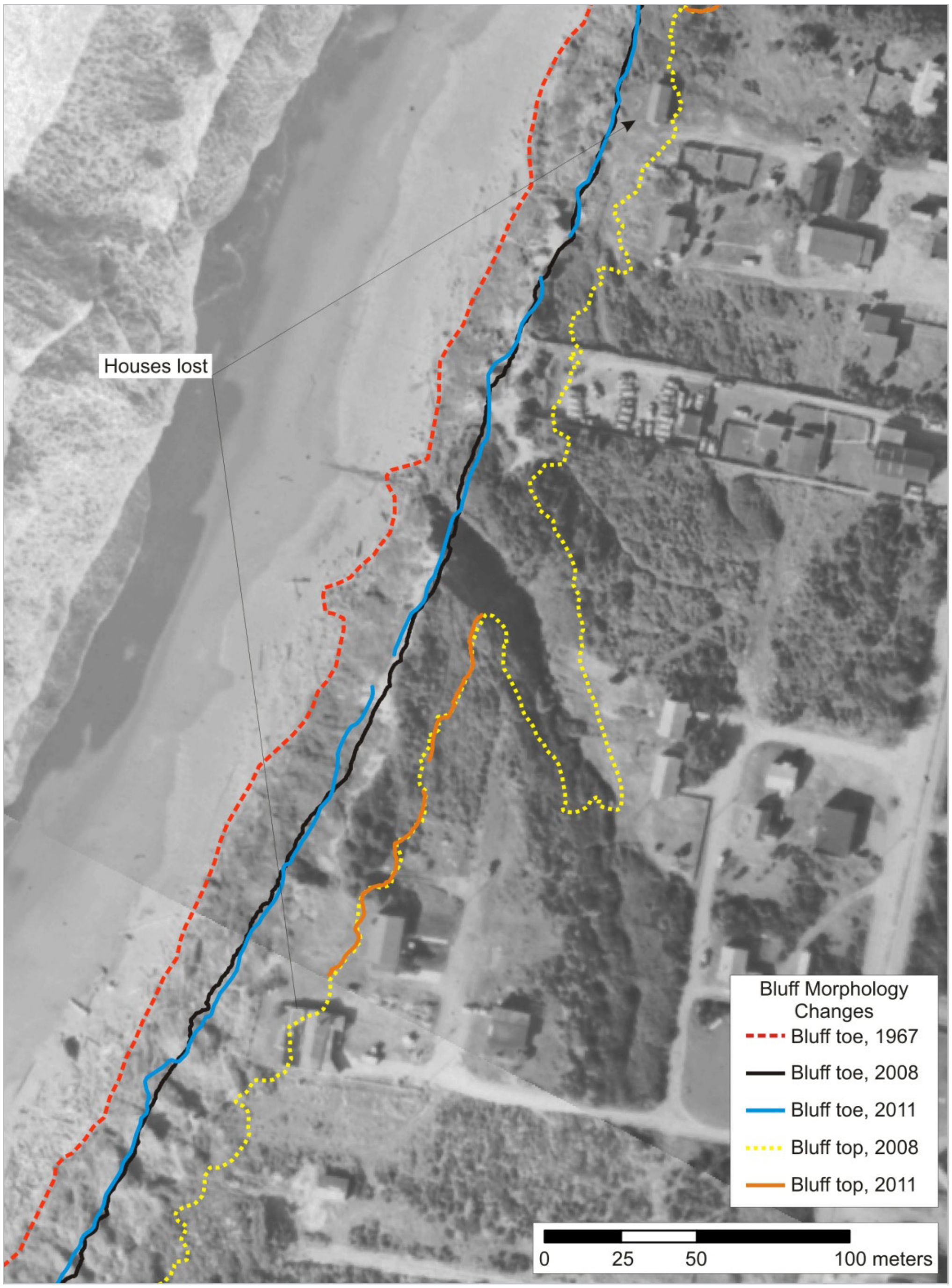

Figure 22. Close-up view of geomorphic changes (bluff toe and top) along a portion of the Nesika Beach shore depicted on a 1967 orthorectified image. Note the two homes identified in the 1967 aerial images that have been lost due to retreat of the bluffs.

As depicted in Figure 23 (left plot), the mean change in the toe of the bluffs between 1967 and 2008 was determined to be -15.4 m (-50.5 ft), with a standard deviation (σ) of ±7.1 m; ±1σ[8] about the mean gives an erosion range of -8.3 to -22.5 m (-27.2 to -73.8 ft), while the total range was found to vary from +2.4 m to -30 m (+7.9 to -98.4 ft). This equates to an average bluff-retreat rate of -0.38 m/yr (-1.25 ft/yr), while ±1σ about the mean gives a range of -0.20 to -0.55 m/yr (-0.66 to -1.8 ft/yr). These values are slightly lower than the erosion rates determined by Priest and others (2004), who identified an average erosion rate of ~0.58 m/yr (-1.9 ft/yr). As can be seen from Figure 22, our recent mapping of the bluff toe and bluff top reveal that the erosion along the bluff top has changed little since the lidar was flown in 2008. Nevertheless, a few discrete sections of shore have experienced some 2 to 3 m (6.6 to 9.8 ft) of additional retreat, causing the bluffs to become oversteepened in those areas. The absence of significant shorewide changes in recent years along the Nesika bluffs is probably not surprising given the relatively mild winters of the past few years, with generally nominal wave activity (particularly when compared to storm wave runup during the late 1990s) and hence generally lower wave runup and wave impact along the toe of the bluffs. Despite this, it is very clear that this section of coast remains highly vulnerable to wave attack, such that the next period of heightened storm wave activity will almost certainly re-invigorate bluff toe erosion, which will lead to oversteepening of the bluffs and their eventual collapse and retreat. As Priest and others (2004) concluded, the Nesika Beach shore continues to be characterized by some of the highest bluff toe erosion rates measured thus far on the Oregon coast (e.g., compare to Allan and Priest, 2001; Priest and Allan, 2004), and care must be taken when sitting new development along the bluffs to provide appropriate set-back from the edge of the bluffs.

8 ±1σ equates to 68.2% of all measured values and provides a good measure of the typical range of responses along a given shore.

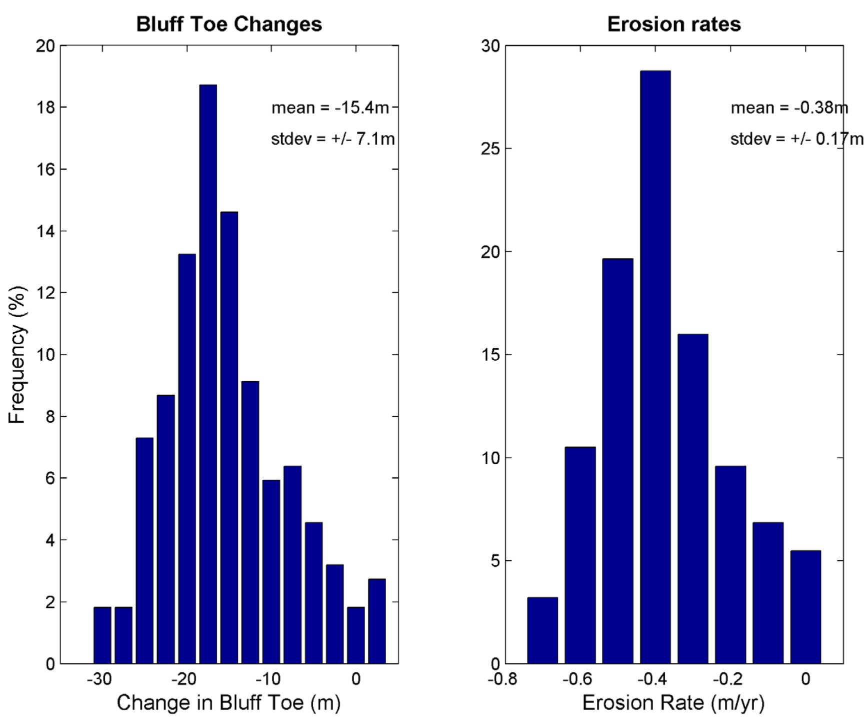

Figure 23. Histograms showing the net change in the position of the toe between 1967 and 2008 (left) and the calculated erosion rates (right).

Finally, Figure 24 depicts four representative transects that are part of the broader (14 sites) beach monitoring network established in the Nesika Beach littoral cell to document the cross-shore beach profile response and the alongshore shoreline changes. The results presented in Figure 23 further reinforce the overall trends and patterns described above: significant bluff erosion and retreat in the south (e.g., profiles NS2 and NS6), while north of Ophir Creek (e.g., NS 14) the beach and shoreline is actively aggrading vertically, coupled with seaward progradation of the shore. In contrast, the intermediate profiles (e.g., NS9) remain in a state of near equilibrium, characterized by considerable cross-shore and alongshore movement in sand volume. Furthermore, these latter profile sites serve to highlight the large vertical and horizontal changes characteristic of mixed sand and gravel beaches.

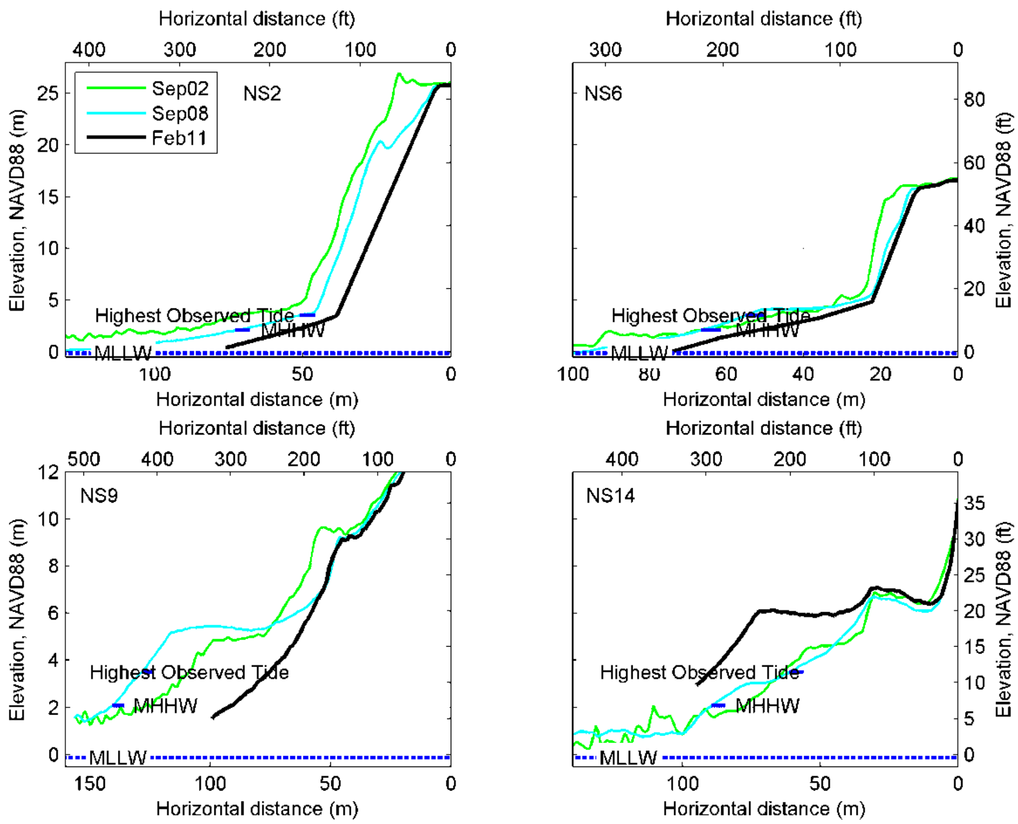

Figure 24. Profile changes identified in the Nesika Beach littoral cell (Nesika Beach to Sisters Rocks). Transect locations are identified in Figure 1.

Netarts

Final locations for the Netarts littoral cell beach monitoring network are depicted in Figure 2, which consists of a total of 24 sites (16 along Netarts Spit and an additional 8 between Happy Camp and Oceanside). All beach profile data plots are presently accessible on the NANOOS beaches and shoreline monitoring web portal.

Figure 25 presents results from various shorelines determined for Netarts Spit for the period 1920–2011. These data have been derived from a combination of historical NOS T-sheets, orthorectified imagery, lidar data, and RTK_DGPS surveys of the beach. From these results a variety of broad responses can be observed:

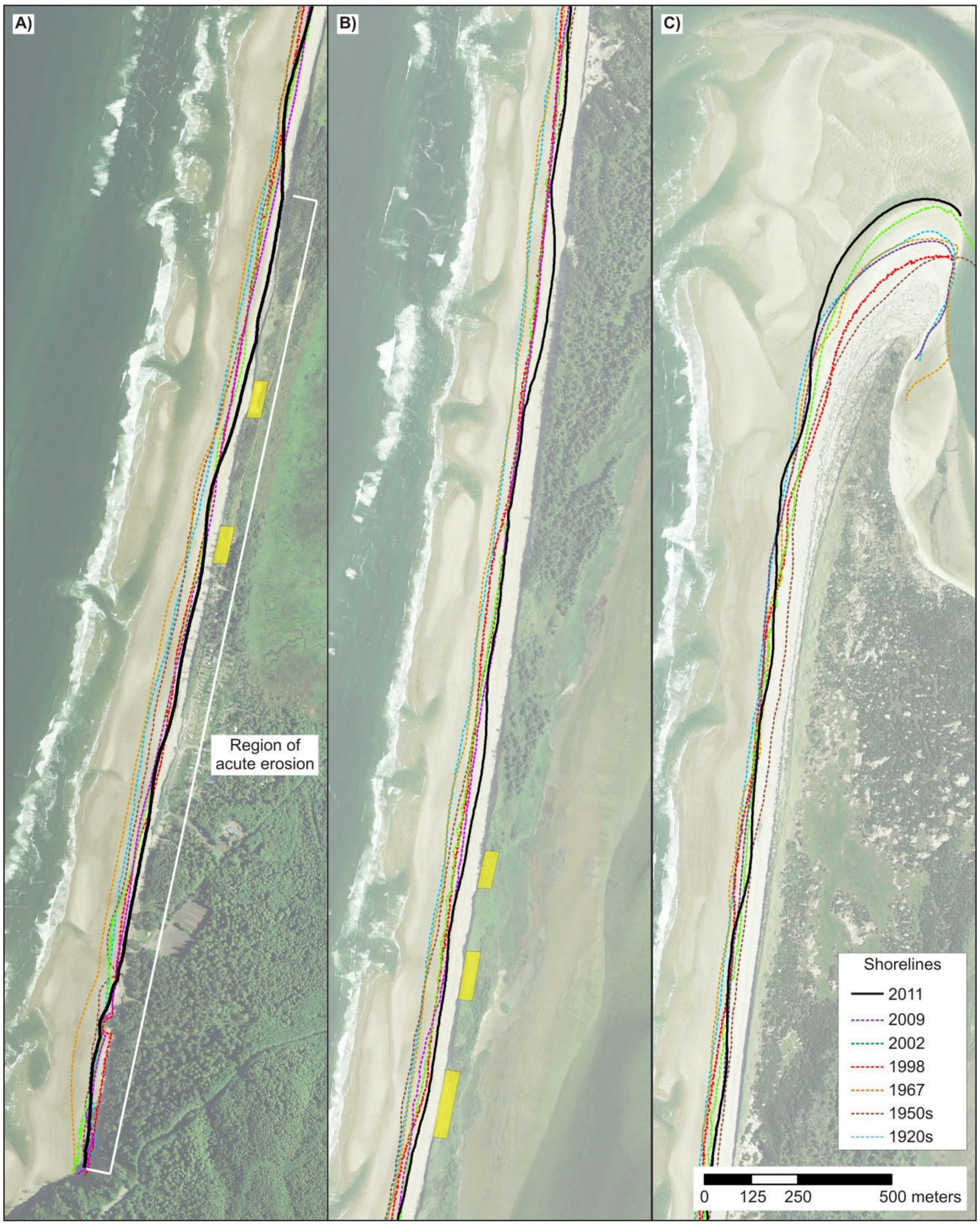

Figure 25. Shoreline changes along Netarts Spit. The plates progress left to right from Cape Lookout State Park in the south to the mouth of Netarts Bay in the north (top of C). Yellow polygons indicate impending spit breach locations.

- Along Netarts Spit the 1920s era and 1967 shorelines indicate a period of time when the spit was in its most accreted state; thus the shoreline was generally located in its most seaward position.
- Since 1967, the southern two thirds of Netarts Spit has entered a strongly erosional phase that has resulted in considerable shoreline retreat, with the mean shoreline having eroded landward in many places by as much as 70 m (230 ft). Erosion is now acute immediately north of Cape Lookout, extending some 2.7 km to its north, encompassing all of Cape Lookout State Park (CLSP).
- Beginning in the early 1980s, erosion in the south end of the Netarts littoral cell accelerated due to the onset of the 1982-1983 El Niño; erosion has been compounded in the last decade by several major storms between 1997 and 1999 (Allan and others, 2006; Allan and Komar, 2002b; Komar, 1986, 1998). In 1999, the Oregon State Parks and Recreation Department responded to the erosion by constructing a dynamic revetment to protect the park from further wave erosion and flood inundation (Allan and Komar, 2002a).
- Erosion has continued throughout the past decade, primarily in response to large storm waves coupled with high tides that have resulted in extremely rapid shoreline retreat. Figure 26 presents results from an analysis of the change in position of the dune toe from 1997 to 2009. From previous analyses of Oregon beach morphologies (Allan and Hart, 2005), the dune toe was found to be typically located at an elevation of ~6 m (19.8 ft). Using this elevation, we extracted the position of the dune toe in 1997, 1998, 2002, and 2009

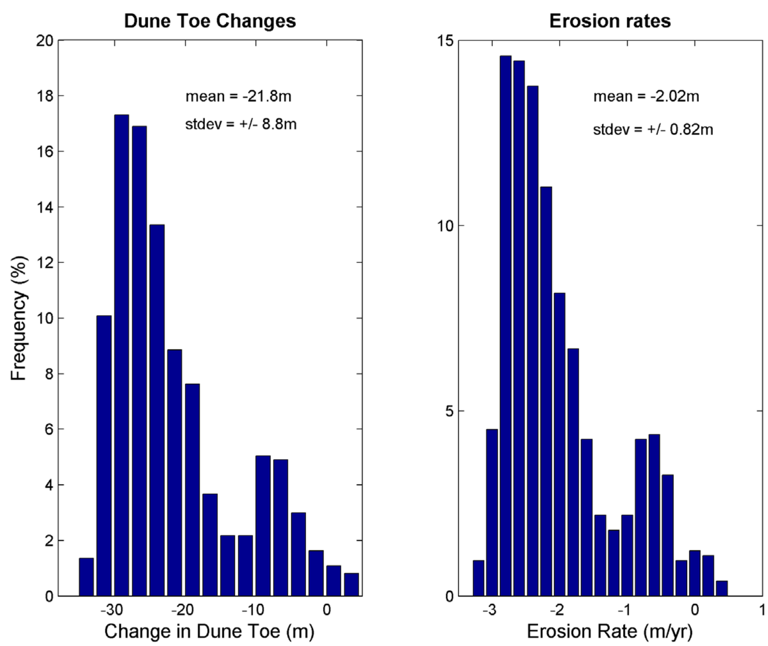

Figure 26. Histograms showing the net change in the position of the dune toe along Netarts Spit (6-m [19.7 ft] contour elevation) from 1997 to 2009 (left), and calculated erosion rates for the past decade (right).

at 10-m increments along the length of the spit (e.g., Figure 27) using the Digital Shoreline Analysis System (DSAS) developed by Thieler and others (2009). Using this approach, we calculated the amount of dune toe change from 1997 to 2009 (Figure 26, left) and an erosion rate (Figure 26, right). As can be seen from Figure 26 (left), the mean change reflects a net retreat of -21.8 m (-71.5 ft), the mean ±1σ gives an erosion range of -13 m to -30.6 m (-42.7 ft to -100.4 ft) since 1997, while the absolute range of measured responses varies from +4.4 m to -35.9 m (+14.6 ft to -117.8 ft). This equates to a mean erosion rate (Figure 26, right) for the past decade of -2.0 m/yr (mean ±1σ gives an erosion range of -1.2 to -2.8 m/yr [-3.9 to -9.2 ft/yr]). This is the highest erosion rate presently known for dune-backed beaches on the Oregon coast.

- Aside from storm waves, additional factors such as the development of rip embayments have helped to accelerate erosion along discrete sections of the spit, contributing to highly focused areas of erosion. On the basis of current trends, several sections of Netarts Spit are now close to being breached (yellow boxes in Figure 25); this could happen in the next major storm or in the next few winters.
- Shoreline analyses indicate that the spit tip has prograded northward in recent years. Nevertheless, the position and spatial size of the spit tip continues to fluctuate, responding to both major erosional events (e.g., the 1997-1998 El Niño) and the recent period of aggradation. Without a detailed understanding of the nearshore beach morphology, one can only speculate where the sand is going. However, there is strong evidence to suggest that a significant volume of sand has moved north, where it now forms an extensive shoal at the mouth of Netarts Bay, and farther north toward Oceanside.

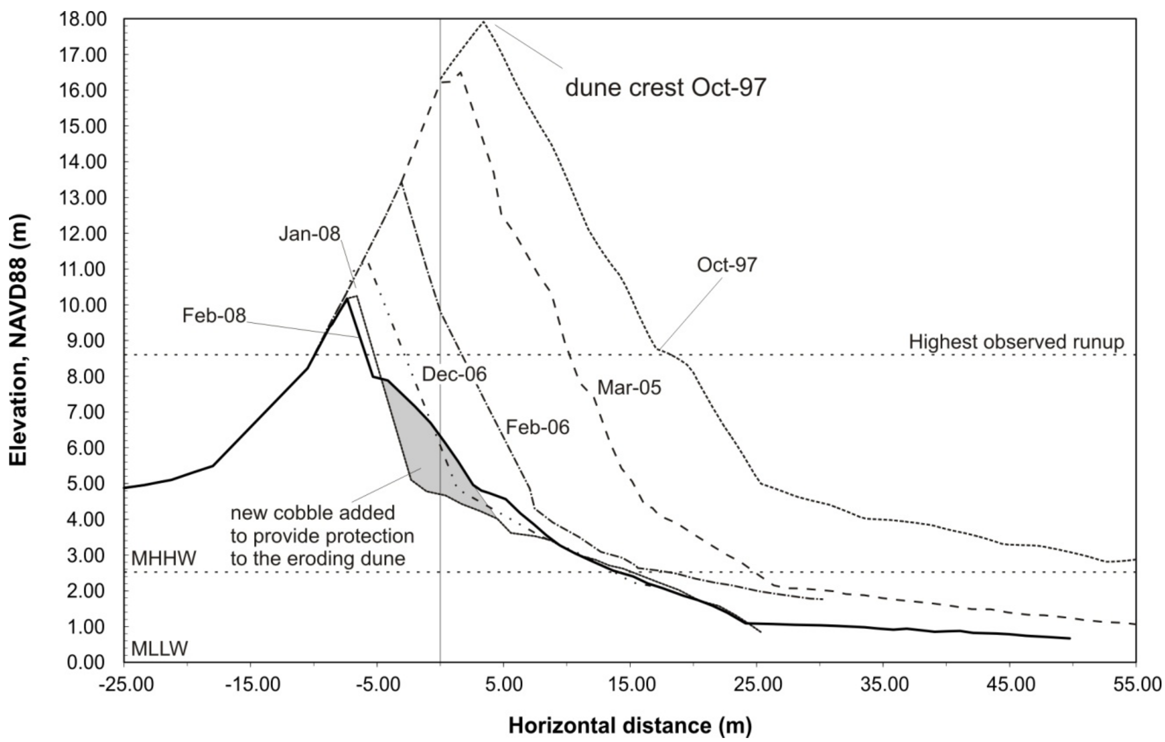

Figure 27. Dune erosion at Cape Lookout State Park measured at the Netarts 5 beach profile site for the period 1997 to 2008 (Allan and others, 2009). Erosion reached a critical stage in January 2008. The Oregon State Parks and Recreation Department (OPRD) responded by placing a few thousand cubic yards of cobble on the upper beach face to provide some protection to the dune. OPRD also installed a sewer septic drain field behind the dune.

Figure 28 presents four representative examples of the profile changes that have taken place over the past decade, as determined from both lidar data and our most recent survey of the beach, which was completed in May 2011. The locations of the transects can be determined from Figure 3. The patterns of change depicted in Figure 28 are entirely consistent with the descriptions presented above. Erosion has been very significant along virtually the entire length of the spit, while the northernmost profile (Netarts 16) is the only site characterized by active beach and dune aggradation and shoreline advance. This latter response probably reflects the alongshore transport of sand from the southern eroding end of the spit to the north. In the south, erosion is presently being controlled between the Netarts 2 and Netarts 5 beach profile sites by a dynamic revetment (cobble beach) and artificial dune (e.g., (Allan and others, 2005; Allan and Komar, 2002a; Komar and Allan, 2010).

Figure 29 present the results from the shoreline compilation and analyses north of the mouth to Netarts Bay, while Figure 30 presents examples of selected beach profile sites. Several interesting patterns, apparent in Figure 29, reflect geomorphic patterns characteristic of much broader shoreline changes taking place in the Netarts littoral cell. These include:

- The position of the shorelines in the 1920s and 1950s were generally located in their most landward position (i.e., closest to the bluffs that back this entire stretch of shore from Happy Camp to Oceanside).
- With the occurrence of the 1997-1998 El Niño, the mouth of Netarts Bay migrated northward (Allan and Priest, 2001), where it pushed up against the toe of the Capes landslide, undermining the toe of the slide. As a result of this process, instability issues occurred along the headwall of the slide, where homes had been constructed. The cause of the instability can be attributed to the northward migration of the bay mouth, a typical El Niño response, which produced a deeper section of water immediately offshore from the slide. This

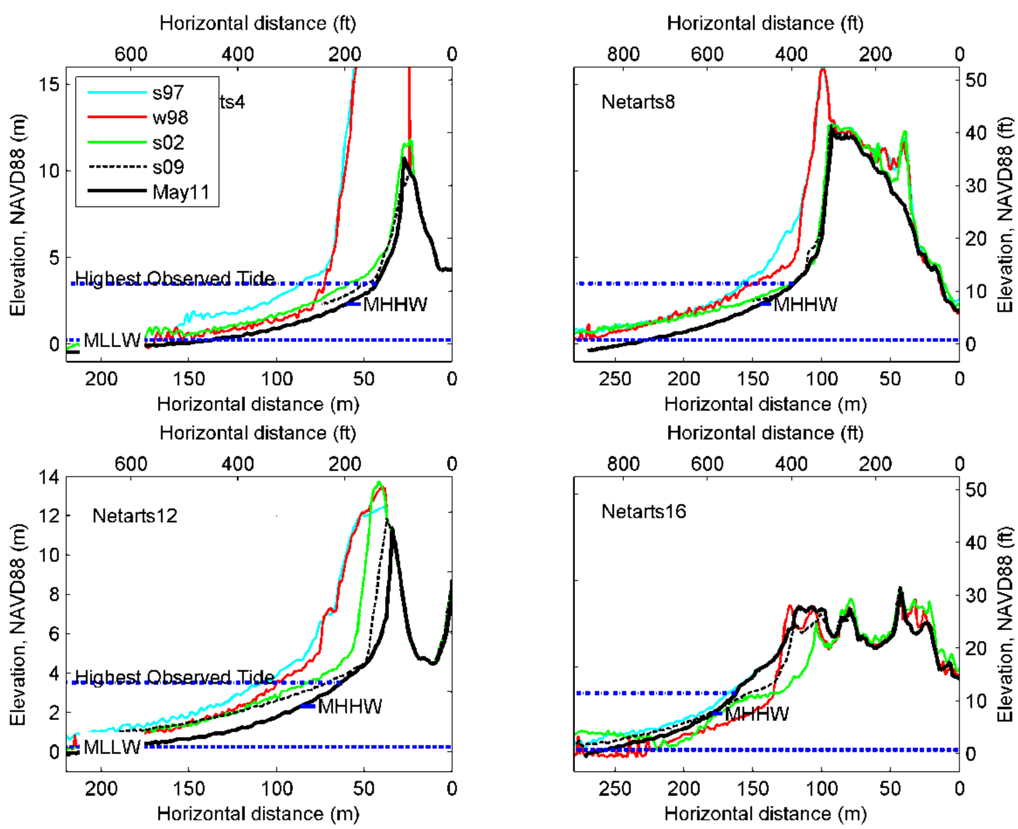

Figure 28. Selected beach profiles identified along Netarts Spit. Transect locations are identified in Figure 2.

enabled storm waves to break close to the beach and enhanced the erosion process. Additional beach erosion occurred over the 1998-1999 winter, which was characterized by even larger storm waves. Eventually, several houses had to be abandoned. The recent phase of Capes erosion as documented here is not unique; similar erosion has occurred in the past (Allan and Priest, 2001). For example, Figure 29 indicates that the shoreline position has been located close to the toe of the slide on at least two previous occasions (1920s and 1950s), with the 1997-1998 El Niño shoreline having reached its most landward extent immediately in front of the landslide toe. With a return to El Niño conditions in the 2009-2010 winter, the 2011 survey appears to have captured the same response, albeit one year after the event, with the bay mouth having again migrated northward to push up against the toe of the landslide. This recent change did not result in any significant erosion of the backshore, which is probably due to the fact that the 2009-2010 winter was relatively mild in the Pacific Northwest (Barnard and others, 2011). Further evidence suggesting that the of the 2009-2010 El Niño played a significant role in bay mouth migration and the shoreline changes is most apparent when one compares the dramatic change in the position of the shore between summer 2009 and the May 2011 survey (Figure 29).

- Farther north and near Oceanside the 1920s and 1950s era shorelines reveal the presence of an extremely narrow beach in the vicinity of Oceanside. This suggests a period of extensive erosion during those years. In contrast, the position of the shoreline in 2009 indicates a wide sandy beach that is probably a function of the recent period of erosion along the spit and the subsequent redistribution of sediment offshore and to the north where it has accumulated.

Figure 29. Shoreline changes north of Netarts Bay, adjacent to the communities of Oceanside and Happy Camp.

Finally, Figure 30 presents four examples of representative beach profiles measured between Happy Camp and Oceanside. Overall, these results highlight the erosion that took place immediately adjacent to the Capes landslide (e.g., Netarts 20) and the relative stability of the bluff to the north of the landslide (particularly when compared to the Netarts 24 profile in Oceanside). Of interest and as noted above, survey results appear to have captured the effects of the most recent 2009-2010 El Niño winter (depicted by the large vertical changes that took place between 2009 and 2011 at the Netarts 20 and 21 profile sites). These conditions resulted in the removal of an extensive sand wedge up to 4 m (13.1 ft) thick that had accumulated along the toe of the Capes landslide and to its north. While it is certainly possible some of this response could be attributed to recent wave erosion (i.e., beach measurement occurred in mid-spring 2011), the fact that the 2010-2011 winter was relatively mild and characterized by few storms would suggest that the May 2011 survey results were probably more likely due to the 2009-2010 El Niño winter shifting the bay mouth to the north, allowing waves to break close to the shore and thus eroding the beach.

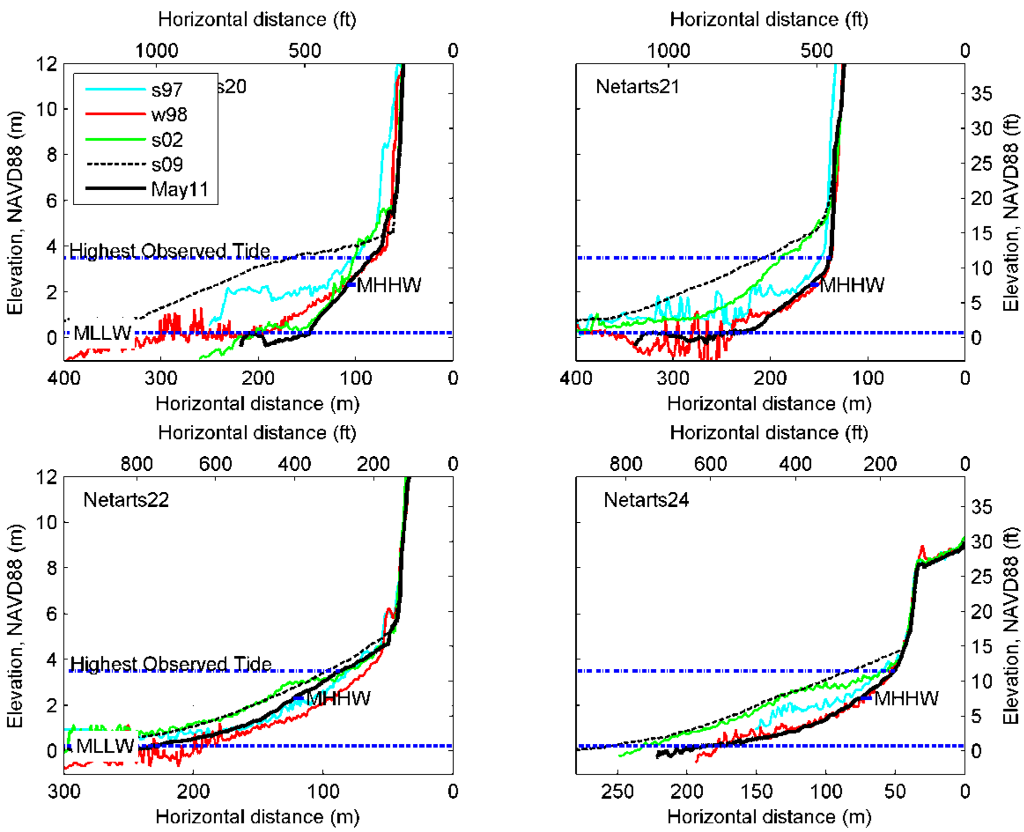

Figure 30. Selected beach profiles located between Netarts Bay and Oceanside. Transect locations are identified in Figure 2.

CONCLUSIONS

This report describes and documents the establishment of a beach and shoreline monitoring program in two littoral cells (Gold Beach and Nesika Beach) on the southern Oregon coast and in the Netarts littoral cell on the northern Oregon coast. This effort enhances the Oregon Beach Shoreline and Mapping Analysis Program (OBSMAP) maintained by the Oregon Department of Geology and Mineral Industries (DOGAMI) and provides additional information to coastal managers about the variability of coastal response in other areas on the Oregon coast. The overall objective of such a monitoring program is to document the response of Oregon's beaches to both short-term climate variability (e.g., El Niños, extreme storms) and longer-term effects associated with earth's changing climate (e.g., increasing wave heights, changes to the storm tracks, and sea level rise) that will influence the stability or instability of Oregon's beaches over the next century. Understanding the wide range of responses characteristic of the Oregon coast is critical for effectively managing the public beach both today and into the future.

Beach monitoring undertaken as part of the OBSMAP effort is based on repeated high-accuracy surveys of selected beach profiles using a Trimble R7/R8 real-time kinematic (RTK) differential Global Positioning System (RTK-DGPS), mounted on either a backpack or on an ATV vehicle. The OBSMAP monitoring network presently consists of 119 active beach monitoring sites:

- 6 sites along the Clatsop Plains (Seaside to the mouth of the Columbia River);
- 25 sites along the Rockaway littoral cell (Cape Meares to Neahkahnie Mountain);
- 15 sites in the Neskowin cell (Cascade Head to Cape Kiwanda);
- 15 sites in the Beverly Beach cell (Yaquina Head to Otter Rock); and,
- 58 sites in the Newport littoral cell (Yachats to Yaquina Head).

In addition, DOGAMI periodically maintains numerous other monitoring sites that are maintained on an ad hoc basis.

This report describes the procedures used to establish new beach observation sites along the Gold Beach, Nesika Beach, and Netarts littoral cells. From these efforts, a total of 21 beach profile sites were established in the Gold Beach littoral cell, which extends from Cape Sebastian in the south to Otter Point in the north. An additional 14 profile sites were established in the Nesika beach cell, just north of the Gold Beach cell. On the north coast in Tillamook County, 24 beach profile sites were established in the Netarts littoral cell. In addition to RTK_DGPS surveys of 59 new beach profile sites, analyses were also undertaken to compare these results to surveys carried out using airborne lidar. In each cell, new tidal datum-based shorelines were measured and compared against recent historical (lidar) shorelines as well as older, historical shorelines (e.g. 1920s, 1950s, and 1960s era shorelines). Our beach monitoring efforts completed thus far have identified the following large-scale beach responses:

Gold Beach

- In the Gold Beach cell, erosion is occurring immediately north and south of the Rogue River jetties, while much of the shore south of Hunter Creek remains relatively unchanged when compared to historical shoreline information.
- Significant erosion has occurred adjacent to Hunter Creek, due to the northward migration of the creek coupled with ocean wave attack. This recent phase of erosion now threatens several homes built adjacent to the creek and ocean. Analyses of aerial photos and lidar data indicate that the recent response has occurred as recently as in 1985 and hence is not unique. The recent northward migration may be due to the occurrence of the 2009-2010 El Niño, which likely shifted significant volumes of sand along the beach to the north, preventing Hunter Creek from draining out along its more typical westerly or southwesterly course. In the absence of high flows to punch an outlet, the creek simply began to migrate northward.
- At the north end of the littoral cell (north of the community of Rogue Shores) the beach has been gaining sand, which has resulted in seaward progradation of the shore.

Nesika Beach

- Significant erosion is occurring along the coastal bluffs that front the community of Nesika Beach. As indicated in Figure 23, the mean change in the toe of the bluffs between 1967 and 2008 was determined to be -15.4 m (-50.5 ft), with a standard deviation (σ) of ±7.1 m; ±1σ about the mean gives an erosion range of -8.3 to -22.5 m (-27.2 to -73.8 ft). The total excursion over which the shoreline has varied was found to range from +2.4 m to -30 m (+7.9 to -98.4 ft).
- Estimates of the bluff erosion rate indicate that the bluffs are receding at an average rate of -0.38 m/year

(-1.25 ft/year); mean ±1σ gives an erosion range of -0.20 to -0.55 m/year (-0.66 to -1.8 ft/year). These values are slightly lower than the erosion rates determined by Priest and others (2004), who identified an average erosion rate of ~0.58 m/yr (-1.9 ft/yr).

- Recent mapping (2011) of the bluff toe and top indicates little erosion has occurred along the bluff top since the lidar was flown in 2008. For the most part, this finding applies to measurements of the bluff toe. However, in a few discrete shore sections, we observed some 2 to 3 m (6.6 to 9.8 ft) of additional retreat, causing the bluffs to become oversteepened in those areas.
- At the north end of the cell the beaches are actively advancing (prograding) seaward.

Netarts

- Analyses of historical shorelines indicate that the beach along Netarts Spit was in its most accreted state in the 1920s and 1960s.
- Since the 1960s, and particularly in the last decade, coastal erosion has come to dominate the overall response along essentially the full length of the spit. Lidar data derived changes in the position of the dune toe between 1997 and 2009 indicate a mean net retreat of -21.8 m (-71.5 ft) (Figure 26, left); the mean ±1σ gives an erosion range of -13 to -30.6 m (-42.7 to -100.4 ft) since 1997, while the absolute range of measured response varied from +4.4 m to -35.9 m (+14.6 to -117.8 ft).
- The estimate of the mean erosion rate for the past decade is -2.0 m/year (mean ±1σ indicates that 68.2% of the variability ranges from -1.2 to -2.8 m/year [-3.9 to -9.2 ft/year]) (Figure 26, right). This reflects the highest erosion rate presently known for the dune-backed beaches on the Oregon coast.
- Unless conditions change soon, continued erosion along Netarts Spit will lead to spit breaching and could eventually impact bay hydrodynamics.
- In the north adjacent to the community of Oceanside, the beach appears to be in a state of quasi-equilibrium, responding to periodic shifts in sediment to the north due to effects from El Niño winter storms, followed by reversals where the sand is shifted back to the south by storm waves.
- Shoreline measurements undertaken between Happy Camp and Oceanside appear to capture the effects of the 2009-2010 El Niño, which caused the bay mouth to migrate northward, significantly lowering sand elevations in front of the Capes landslide and eventually removing a large sand wedge that had accumulated north of the mouth to Netarts Bay.

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