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Brad Avy, State Geologist

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TEMPORAL AND SPATIAL CHANGES IN COASTAL MORPHOLOGY, TILLAMOOK COUNTY, OREGON

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2020

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DISCLAIMER

Cover photograph: Contemporary and historical dune development at Pacific City, Tillamook County. Photo taken by E. Harris, August 12, 2011.

WHAT'S IN THIS REPORT?

New lidar based mapping along the Tillamook County coast provides updated spatial extents of beaches and dunes that may be subject to existing and future storm-induced wave erosion, runup, overtopping, and coastal flooding. Side-by-side maps of the spatial extent of beaches and dunes in 1975 and now show changes that have taken place. These data will help communities implement Oregon Statewide Planning Goal 18: Beaches and Dunes.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

See the digital publication folder for files.
Geodatabase is Esri® version 10.1 format. Metadata is embedded in the geodatabase and is also provided as a separate .xml format file.

tillamook_dune_geodb.gdb:

Feature dataset: dune_polygons

feature classes:

BeachesandDunes_orcoast_original (polygon)
BeachesandDunes_revised_tillamook_2020 (polygon)

Beaches & Dunes 2020.lyr – layer file providing symbology for the feature class *BeachesandDunes_revised_tillamook_2020*

ABSTRACT

The objective of this study was to produce updated information on the spatial extent of beaches and dunes in Tillamook County that may be subject to existing and future storm-induced wave erosion, runup, overtopping, and coastal flooding. These data are of importance to the Department of Land Conservation and Development and the seven coastal counties of Oregon in order to implement Statewide Planning Goal 18: Beaches and Dunes.

Oregon Statewide Planning Goal 18 requires local jurisdictions adopt a beach and dune overlay zone in their comprehensive plan, which may be used to manage development on or near beaches and dunes. Regional mapping of the coastal geomorphology of the Oregon coast to define the extent of its beaches and dunes was originally undertaken between 1972 and 1975 by the U.S. Department of Agriculture Soil Conservation Service (USDA, 1975). However, in the intervening 45 years, much has changed on the coast. Of particular importance has been the proliferation of European beach grasses that have helped stabilize many coastal dune systems, while many areas of the Tillamook County coastline have experienced significant erosion, especially since the late 1970s. In addition, new technologies such as lidar are now providing unprecedented levels of detail, enabling scientists to more accurately map the spatial extents of both the contemporary and historical foredune systems. These three factors combined necessitate that the USDA (1975) overlay zone be updated to reflect contemporary conditions. As a result of the updated mapping, our analyses indicate the following broad-scale changes:

- Overall, areas defined as open sand (OS) have decreased by about ~67% since the 1970s, from 2,335 acres to 767 acres. Most of this change can be directly attributed to anthropogenic effects, particularly the introduction of European beach grass (*Ammophila arenaria*) as well as stabilization from shore pine (*Pinus contorta*) and other native plant species.
- Areas subject to existing coastal hazards, which include active foredunes (FDA) and, new in 2020, reactivated foredunes (FDR), indicate an overall slight increase in their spatial extent. However, within discrete sections of the littoral cells, some areas have experienced significant loss of active foredunes, including the Rockaway Beach area, followed by Nestucca Spit and Nehalem Spit.
- Areas classified as recently stabilized foredune (FD) have seen a significant expansion (~45% increase) in spatial coverage, increasing from ~287 acres in the 1970s to ~522 acres in 2020. Consistent with the changes seen on active foredunes, the increase in stabilized foredunes can be attributed to the proliferation of dune grasses and other native trees and shrubs.

1.0 INTRODUCTION

The Oregon Department of Land Conservation and Development (DLCD) and Tillamook County Department of Community Development commissioned the Oregon Department of Geology and Mineral Industries (DOGAMI) to undertake detailed mapping of beach and dune features in Tillamook County. The purpose for such mapping is to produce updated information on the extent of the contemporary beach and foredune system that may be subject to future storm-induced erosion, runup, overtopping, and coastal flooding. These data are of importance to DLCD and the county in order to improve implementation of Statewide Planning Goal 18: Beaches and Dunes (https://www.oregon.gov/lcd/OP/Pages/Goal-18.aspx). Specifically, Oregon Statewide Planning Goal 18 requires that local jurisdictions adopt a beach and dune overlay zone in their comprehensive plan, which may be used to manage development on or near such features.

Regional mapping of the beaches and dunes of the Oregon coast was originally undertaken between 1972 and 1975 by the U.S. Department of Agriculture Soil Conservation Service (U.S. Department of Agriculture Soil Conservation Service [USDA], 1975). However, much has changed along the Oregon coast over the past 45 years, so the original maps are both inaccurate and importantly lack sufficient resolution to support current land use planning efforts. Some of the largest changes to have taken place along the coast include:

- The rapid expansion of European beach grass (*Ammophila arenaria*), which has helped to stabilize many dune systems;
- Encroachment of human development into foredune areas;
- Dune management activities such as foredune grading and planting;
- Changes in beach and dune morphology due to either coastal erosion or accretion;
- Construction of coastal engineering used to mitigate erosion hazards; and,
- Shoreline changes at the mouths of estuaries controlled by jetties.

Accordingly, the purpose of this project is to produce modern maps of beach and dune features along the Tillamook County coastline, defined in a geographical information system (GIS) and informed by historical and contemporary aerial photographs, airborne lidar, coastal erosion and FEMA flood modeling (Allan and others, 2015), and recent coastal change analyses and monitoring undertaken along the beaches of the county (Allan and Priest, 2001; Allan and Hart, 2007, 2008; Allan and others, 2009; Allan and Harris, 2012). Although the geospatial data used today to define the various mapping units are much improved, the original USDA (1975) nomenclature consisting of 12 core mapping units is retained, and in some cases is modified or refined. Finally, it is recognized that the six other Oregon coastal counties face similar challenges with beach and dune overlays that are presently outdated. Accordingly, the mapping and accompanying report undertaken for Tillamook County may be used as a framework for similar mapping of beaches and dunes in these coastal counties.

2.0 COASTAL GEOLOGY AND GEOMORPHOLOGY

Tillamook County is located on the northwest Oregon coast, between latitudes 45° 45′ 49.49″ N (Cape Falcon) and 45° 3′ 54.88″ N (Cascade Head), and longitudes 124° 1′ 15.57″ W and 123° 17′ 59.88″ W (**Figure 1**). The terrain varies from low-elevation sandy beaches and dunes on the coast to elevations over 1,000 m (e.g., Rogers Peak reaches 3,706 ft [1,130 m]) farther inland. The coastal strip is approximately 65 miles (104 km) in length and varies in its geomorphology from broad, low-sloping sandy beaches backed by dunes, to beaches backed by engineered structures, cobble and boulder beaches adjacent to the headlands, and cliff shorelines (Allan and others, 2015). In these areas sand entrained by wind is carried up into the dunes where the sand becomes trapped by plants (primarily beach grass). Where vegetation is absent or sparsely present, the dunes are able to drift in response to the prevailing wind direction. In some areas, the drifting dune sand can become a nuisance as the sand accumulates in and around coastal properties, while in other areas the migrating dune may engulf buildings, contributing to their eventual destruction (Komar, 1997).

The formation of dunes is dependent on three simple requirements:

- A sufficient supply of sediment;
- A prevailing wind. Wind speed is especially important as strong winds entrain and mobilize sediments across the beach and carry sand up into the developing dunes. Wind direction is also important as it governs the types of dunes that could develop; and,
- Obstacles to trap the sand such as woody debris, vegetation, and micro-topography.

Where sediment supply is sufficient, dunes provide effective coastal protection and at a significantly lower cost when compared with coastal engineering structures (Woodhouse, 1978). Along the Tillamook County shoreline, the bulk of the coastline is dominated by barrier spits, backed by dunes of varying ages. In recent decades, however, parts of the coast have experienced significant coastal erosion, requiring the construction of coastal engineering in order to mitigate the erosion hazards (e.g., Neskowin, Pacific City, and Rockaway Beach).

Prominent headlands formed of resistant basalt (e.g., Cascade Head, Cape Meares, Cape Lookout, and Neahkahnie Mountain) provide natural barriers to alongshore sediment transport (Komar, 1997), effectively dividing the Tillamook County coastline into four littoral cells (**Figure 1**). These are:

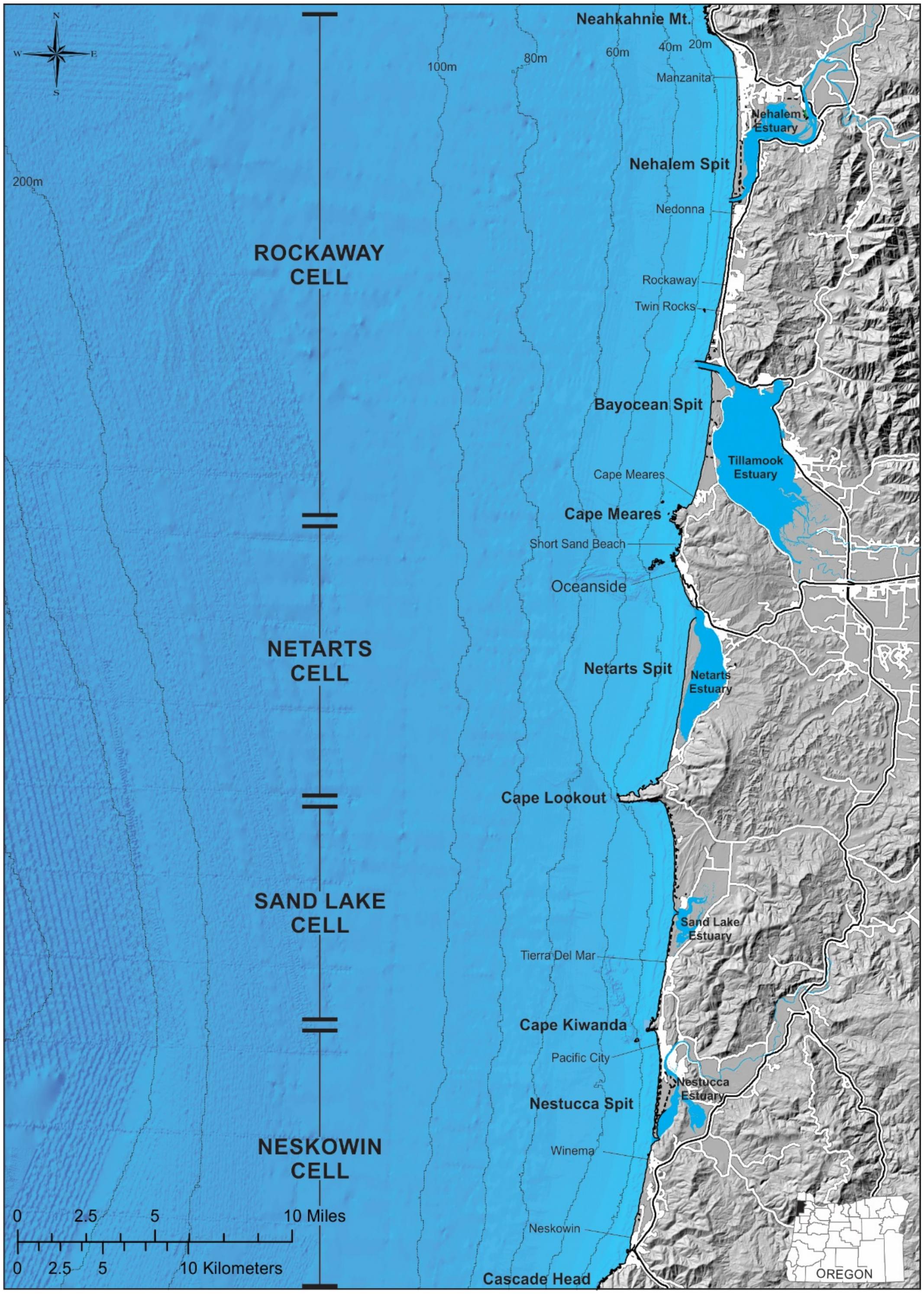
- Neskowin (~ 8.9 miles [14.3 km]), extends from Cascade Head to Cape Kiwanda;
- Sand Lake (~ 8.2 miles [13.2 km]), extends from Cape Kiwanda north to Cape Lookout;
- Netarts (~ 9.9 miles [15.9 km]), extends from Cape Lookout to Cape Meares; and,
- Rockaway (~ 17.5 miles [28.2 km]), extends from Cape Meares to Neahkahnie Mountain in the north.

Each of these cells is further divided into a series of subcells due to the presence of five estuaries (from south to north: Nestucca, Sand Lake, Netarts, Tillamook, Nehalem), two of which (Tillamook and Nehalem) are stabilized by prominent jetties (**Figure 1**). The county also is characterized by several major rivers (Nestucca, Nehalem, Miami, Tillamook, Trask, Kilchis, and Wilson Rivers) that terminate in the estuaries. Due to their generally low flows and the terrain they are eroding, these rivers carry little beach sediment out to the open coast but instead deposit most of their sediment in the estuaries (Clemens and Komar, 1988). Hence, the beaches of Tillamook County receive very little sediment along the coast today other than from erosion of the backshore.

2.1 Local Geology

The predominant geologic unit along coastal Tillamook County consists of latest Holocene beach sand present along the full length of the coastline (Cooper, 1958). Interspersed between the sand are invasive basalt bodies of the Miocene Columbia River basalt, such as Neahkahnie Mountain at the northern end of the county coastline, and flows of Columbia River Basalt that form the prominent headlands such as at Cape Meares and Cape Lookout (Schlicker and others 1972; Wells and others, 1994, 1995; Smith and Roe, 2015). These latter rocks are described as fine grained. In all cases, rockfalls and landslides in these latter units are actively providing new material (gravel and cobbles) to the beaches, albeit at relatively slow rates. These failures contribute to the formation of extensive cobble and boulder berms, which accumulate along their northern/southern flanks, where beaches have merged up against the headlands (Allan and others, 2006).

Figure 1. Location map of the Tillamook County coastline, including key place names.



South of Cape Lookout and north of the Sand Lake estuary, part of the beach is backed by bluffs, which have an average height of 24 m (Allan and Harris, 2012) and consist of medium-grained sandstone and interbedded siltstone of the Astoria Formation. Adjacent to the bluffs, sand dune sheets have accreted and ramped up against the marine terraces, before spilling over and inundating large areas in landward of the bluffs. Astoria Formation sandstone and siltstone also characterize the geology of Cape Kiwanda, adjacent to Pacific City. Eocene-Oligocene basaltic sandstone of the Alsea Formation is also prominent along a small section of the coast adjacent to Porter Point, located just south of the Nestucca estuary mouth. These sediments are massive basaltic sandstone that is predominantly fine to medium grained (Schlicker and others, 1972; Wells and others, 1994, 1995; Smith and Roe, 2015).

The contemporary beach and dune system characteristic of Tillamook County is, in geologic terms, young, having begun to form around 5,000–7,000 years ago, as the rate of post-glacial sea level rise slowed as it approached its current level (Komar, 1997). At this stage the prominent headlands would have begun to interrupt sediment transport, leading to the formation of barrier spits and beaches within the headland-bounded littoral cells.

Much of the beach sand present on the beaches of Oregon consists of grains of quartz and feldspar. The beaches also contain small amounts of heavier minerals (e.g., garnet, hypersthene, augite, and hornblende), which can be traced to various sediment sources along the Pacific Northwest coast (Clemens and Komar, 1988). Concentrations of augite, a product of erosion of the volcanic rocks present throughout the county, are especially abundant along the Tillamook County coast. This suggests that at the time, rivers and streams were carrying these sediments out to the coast where they mixed with other sediments. It is possible that concentrations of augite likely increased during the past 150 years as human settlement accelerated, leading to increased deforestation (Peterson and others, 1984; Komar and others, 2004), which correspondingly contributed to increased sediment loads in the various rivers. However, although some of these sediments reached the open coast, the bulk of the sediments are retained in the estuaries due to generally low discharge levels characteristic of the rivers (Komar and others, 2004).

Prior to the 1940s, many of the barrier spits were devoid of significant vegetation. With the introduction of European beach grass (*Ammophila arenaria*) in the early 1900s and its subsequent proliferation along the Oregon coast, the dunes and barrier spits eventually stabilized. The product today is an extensive foredune system, which consists of large “stable” dunes containing significant volumes of sand. Accompanying the stabilization of the dunes, humans have settled on them, building in the most desirable locations, typically on the most seaward foredune.

3.0 METHODOLOGY

An initial meeting was held with DLCD staff to discuss the overall study approach. This included evaluating the existing Beach and Dune Overlay Zone in a geographical information system (GIS), developed by DLCD from the original 1975 mapping. These data were used to establish the baseline on which the updated GIS layer was developed. **Table 1** identifies the key beach and dune classifications that are used in the revised mapping, including their accompanying DLCD classification where applicable, and derived originally from USDA (1975). In addition, we define six new classifications in **Table 1**, including:

- Artificial Active Foredune (AFDA) – An artificial foredune constructed from geotextile sand bags and planted with dune grass. This category is unique to Cape Lookout State Park where such a structure was constructed;
- Reactivated foredune (FDR) – In several areas the existing foredune has been:

1. completely removed such that coastal processes are presently eroding into the previously stabilized foredune (FD); and,
2. extreme total water levels are expected to inundate portions of the backshore (e.g., FD or DS) landward of the active foredune (FDA). The latter results are based on the work of Allan and others (2015).

- Coastal Landslides (LD) – Derived from coastal landslide mapping undertaken by Allan and Priest (2001), as well as more recent landslide failures observed and documented by the author;
- Fluvial and Estuarine Deposits (FED) – Defined from geologic mapping undertaken by Wells and others (1994) and compiled in the Oregon Geologic Database Compilation (OGDC-6; Smith and Roe, 2015). The OGDC is a digital geologic map and database covering the entire state and depicting the best available geologic mapping in any location;
- Coastal Lakes (LK) from e.g., ; and,
- Wetland (WL) – These data stem from the National Wetlands Inventory (https://www.fws.gov/wetlands/) compiled by the U.S. Fish and Wildlife Service (USFWS).

These latter classifications simply help to better define additional geographic and geologic features evident along the Tillamook County coastline but not explicitly addressed by USDA (1975). Definitions of the original mapping nomenclature are described by USDA (1975) and are not repeated here.

Table 1. Beach and dune overlay zone nomenclature (after USDA, 1975).

Associated Dune Category	Inventory Classification	DLCD Classification	Mapping Unit
Active Beach and Foredune	beach	Beach	B
	active foredune	Foredune, Active	FDA
	active dune hummocks	Hummocks, Active	H
Recently Stabilized Dunes	recently stabilized foredune	Foredune, Conditionally Stable	FD
	inland foredune		IFD
	dune complex	Dune Complex	DC
	younger stabilized dunes	Dune, Younger Stabilized	DS
Older Stabilized Dunes	older stabilized dunes	Dune, Older Stabilized	ODS
Inland Dunes	open dune sand	Dune, Active/Dune, Parabolic	OS
	open dune sand conditionally stable	Dune, Conditional Stable	OSC
	active inland dune	Dune, Active	AID
Interdune Forms	wet interdune	Interdune	W
	wet deflation plain	Deflation Plain	WDP
	wet mountain front		WMF
Estuary	wet surge plain		WSP
	wet flood plain		WFP
Other	coastal terrace		CT
	New:		
	artificial active foredune		AFDA
	reactivated foredune (subject to erosion/flooding)		FDR
	coastal landslide		LD
	fluvial and estuarine deposits		FED
	lake		LK
	wetland		WL

3.1 Previous Coastal Hazard Studies

Because the foundation of the Beach and Dune Overlay Zone reflects those areas subject to active coastal change (either erosion or accretion), and/or may be impacted by storm wave runup, overtopping, and flooding, the revised mapping undertaken here was strongly guided by existing information available from a number of recent coastal investigations. These include coastal erosion hazard studies (Allan and Priest, 2001; Stimely and Allan, 2014), beach and shoreline monitoring efforts undertaken along the Tillamook County coastline (Allan and Hart, 2007, 2008) and continuing (e.g., http://nvs.nanoos.org/BeachMapping), analyses of lidar data (Allan and Harris, 2012), and recently completed geomorphic, erosion analyses, coastal flood modeling, and mapping (Allan and others, 2015).

3.2 Lidar

Beach and dune morphology was mapped for this study largely from light radar (lidar) data collected by DOGAMI in 2009. Lidar is a remote sensing technique consisting of x, y, and z values of land topography that are derived using a laser ranging system and geo-located using an onboard Real-Time Kinematic Differential Global Positioning System (RTK-DGPS). The lidar data have a vertical accuracy of ~0.1 m (0.3 ft), while the horizontal accuracy is ~1 m (3 ft). Because lidar collected by DOGAMI consisted of multiple laser returns, processing of these data enabled the production of bare-earth rasters of the ground surface; i.e., the vegetation was able to be stripped off, leaving just the ground elevation.

Analyses of these data were previously undertaken by Allan and Harris (2012) in order to define various beach, dune, and bluff morphological characteristics (e.g., tidal-datum based shorelines, cross-sections, and a variety of geomorphic features including the beach-dune toe, foredune toe, dune crest, dune heal, bluff toe, and bluff crest). These data were subsequently refined and updated by Allan and others (2015). Additional information concerning post-2009 beach and shoreline changes were determined from lidar collected in 2016 on behalf of the USGS, from recent observations of beach profile and shoreline changes measured using RTK-DGPS by DOGAMI staff (e.g., http://nvs.nanoos.org/BeachMapping), and from modern aerial images of the coastline.

3.3 Aerial Imagery

Although lidar is the foundation on which the geomorphic mapping is based, valuable geomorphic information may also be gleaned from analyses of repeat aerial photographic imagery of the coast collected over the last century.

The earliest compilation of aerial photographs of Oregon coast was undertaken in 1939 by the U.S. Army Corps of Engineers. Unfortunately, the images are simply stereo (pairs) images that have never been rubber-sheeted or ortho-rectified. Orthorectification is an approach used to process imagery in order to account for optical distortions (e.g., tilt or relief) with the goal of yielding an image that is planimetrically correct that is fixed to a geospatial coordinate system, enabling the data to be viewed and analyzed in GIS.

In order to rubber-sheet the images, the 1939 aerial photographs were added to ArcGIS and processed using the Georeferencing suite of tools. This is accomplished by identifying common ground control points (e.g., road junctions, bridges, buildings, rock outcrops) that can be identified in the 1939 images and in contemporary (1994, 2000, 2004, 2009, 2014, 2016) orthorectified images (or lidar) collected for the State of Oregon. Using this approach, twenty-six 1939 photos were able to be georeferenced for Tillamook County, enabling comparisons to be made against modern images of the coastline and from lidar. These data were extremely useful for understanding early historical changes in the morphology of the barrier spits, including the proliferation of dune grasses on the dunes and their subsequent stabilization of the dunes.

Imagery acquired by the Oregon Department of Transportation (ODOT) in 1967 (Ruggiero and others, 2013) was also examined. These aerial photographs extend along the entire coast of Oregon and reflect a collection of 1,611 photographs along roughly 50 to 60 flight paths for the open ocean beaches (no bays). The photographs were taken at 1:6,000 scale, such that 1 inch on the photograph is 500 ft (152 m) on the ground. The images were originally processed and orthorectified for DOGAMI by the Washington Department of Ecology using Leica Photogrammetry Suite, controlled by a digital elevation model developed from 2002 lidar data.

3.4 Wet Interdunes

The USDA (1975) beach and dune mapping identified many areas among the dunes as either *Wet Deflation Plain*, *Wet Mountain Front*, or *Wet Interdune*. These sites reflect areas characterized by high water tables such that the areas are either underwater or are seasonally covered in water. In the large majority of cases, these classifications are analogous to areas delineated as "wetland." To that end, the USFWS National Wetland Inventory[1] was downloaded for Oregon and examined in a GIS. Identified wetlands were added to the revised beach and dune overlay.

3.5 Estuary Shoreline and Storm Flood Water Level

The USDA (1975) beach and dune mapping include two additional geospatial attributes defined as the *Wet Surge Plain* and *Wet Flood Plain*. The *Wet Surge Plain* was defined by USDA (1975) as the area between the lowest and highest tides within an estuary and delineated as the drift line; no additional explanation is provided as to how the drift line was identified, such as from aerial imagery or early National Ocean Service (NOS) topographic "T" Sheets. The *Wet Flood Plain* is essentially that area that can be reasonably expected to be inundated under a flood condition. Again, no specific information is provided that describes how it was mapped.

For the purposes of the revised mapping, a more refined approach involved adopting a tidal datum-based shoreline and then extrapolating the defined tidal shorelines from lidar. For the *Wet Surge Plain*, we used an elevation of 7.9 ft (2.4 m, relative to NAVD88), which equates to the Mean Higher High Water (MHHW) tidal datum defined for the Garibaldi tide gauge station by NOAA NOS. The NOS defines MHHW as "the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch"[2] and is a reasonable approximation for the *Wet Surge Plain*. For the *Wet Flood Plain*, we used an elevation of 11.5 ft (3.5 m, relative to NAVD88), which equates to the highest observed tidal elevation at the same gauge. This latter elevation reflects a storm flood, whereby the elevated water levels are a function of the combined effects of high tide, plus a storm surge component, plus riverine flooding. In both cases, contours for the predefined elevations were extracted from 2009 DOGAMI lidar data.

In a number of areas, changes in the configuration of the estuary have occurred since the lidar data were collected in 2009, necessitating a need to adjust the boundary of the *Wet Surge Plain*. This was achieved by using recently collected digital ortho imagery (e.g., 2016) to evaluate any spatial changes that may have ensued in the estuary shoreline between 2009 and 2016.

[1] https://www.fws.gov/wetlands/Data/State-Downloads.html
[2] https://tidesandcurrents.noaa.gov/datum_options.html

4.0 RESULTS

The primary results associated with this latest mapping effort is contained in an Esri geodatabase "tillamook_dune_geodb.gdb". The feature dataset file "BeachesandDunes_revised_tillamook_2020" contains the updated geospatial information and includes the following key attributes: "Codes", "Feature", "Feature_2", "Notes", "Coastal_hazard", and "Cell". This contrasts with the original geospatial overlay, which only included information specific to the codes and feature class. In the updated overlay, 'Codes' and 'Features' are identical to information included in the original mapping. "Feature_2" includes secondary information relating to the feature class (e.g., younger/older deposits, wet (due to ocean flooding) etc.). The "Notes" attribute includes additional information about the respective feature (e.g., pre or post-jetty foredunes) or source information (e.g., landslide data from Allan and Priest (2001) or from field observations). The "Coastal_hazard" attribute includes specific hazard information unique to that feature, including whether it is subject to current wave erosion, runup, overwash and inundation processes, or may be impacted in the near future. Finally, the "Cell" attribute categorizes the geomorphic units by littoral cell or subcell.

Here we will briefly describe and summarize some of the key changes that have taken place along the Tillamook County ocean shore. The approach taken is to focus initially on broad scale changes that can be observed in the landscape, followed by a series of brief qualitative descriptions of changes identified within each littoral cell identified in **Figure 1**.

4.1 Countywide Beach and Dune Changes

Figure 2 presents pie charts depicting changes in the coastal geomorphology of Tillamook County from the 1970s to the present. Data inputs used to generate the pie charts are derived from the change in surface area of the respective geomorphic unit over time; note that USDA (1975) defined "Beach" for only Nehalem and Bayocean Spit and ignored the other areas. The overall focus of **Figure 2** is a subset of the suite of USDA classifications identified in **Table 1**, with emphasis on those geomorphic units closest to the beach and as such directly dependent on coastal and aeolian processes for their formation and evolution. These units include the active foredune (FDA), reactivated foredune (FDR, new in 2020), recently stabilized foredune (FD), dune complexes (DC), hummocks (H), and areas characterized as having open sand (OS). The reason for focusing on these specific units is that they are of greatest significance under Goal 18. The values listed for each pie in **Figure 2** reflect the acreage associated with the six units used here, while the proportions of each pie graphic are based on the sum of the combined acreage of the six units. Thus, Figure 2's significance is less about the actual proportions (which may be of interest), and more about the degree of change that has taken place from one time period to the next. **Table 2** includes cell specific information of the actual change in acreage over the time period for each unit, and expressed as a summary total for the entire county; results shown in Table 2 reflect a smaller subset of the suite of units defined in **Table 1**.

As can be seen in **Figure 2** (left), a significant portion of the county coastline in the 1970s was classified as open sand (totaling ~2,335 acres [9.5 km^2]), while the amount of active and stabilized foredune were ~685 and 287 acres respectively. Hummocky terrain and dune complex (essentially a complex mix of different units) made up comparably smaller portions of the county coastline. As a result of anthropogenic effects associated with dune planting (especially *Ammophila arenaria*) and the proliferation of shore pine (*Pinus contorta*) and other coastal shrubs and trees since the 1970s, there has been a significant decrease in the amount of open sand present throughout the county. Overall, **Figure 2** (right) indicates the open sand class has decreased by 67% to ~767 acres in 2020. The bulk of this reflects a shift toward these areas now being reclassified as younger stabilized dunes (DS). Of interest, although the total area of active foredune (FDA) remains essentially unchanged for the entire county (**Figure 2**), changes within individual subcells indicate some loss (Table 2). For example, Rockaway Beach is characterized by the largest decrease in active foredunes (−61 acres), followed by Nestucca Spit and Nehalem Spit. Losses in the Rockaway Beach area are compounded by the fact that previously stabilized dune areas are now being actively eroded into reactivated foredune (FDR), or are subject to wave runup, overtopping, and inundation during extreme storms. Conversely, the proliferation of beach grass (and other anthropogenic effects) throughout the county has resulted in an expansion in recently stabilized foredune (FD), which have seen an increase of ~82%. Similarly, the expansion of dune hummocks (H) and dune complex (DC) throughout the county can be attributed to anthropogenic effects associated with jetty construction (e.g., Bayocean Spit tip) or rehabilitation (e.g., both sides of Nehalem Bay mouth), which resulted in rapid seaward progradation of the shoreline, limiting foredune development in those areas, until such time as the rate of advance slowed and approached equilibrium. In other areas, hummock terrain can be linked with spit breaching such as on Nestucca Spit and mid-way along Bayocean Spit.

Figure 2. Pie charts depicting Tillamook County countywide changes over time for select coastal geomorphic units. Values shown for each pie reflect the acreage of that unit. Note: totals for the 1970s (3,588 acres) and for 2020 (2,656 acres) differ by ~930 acres.

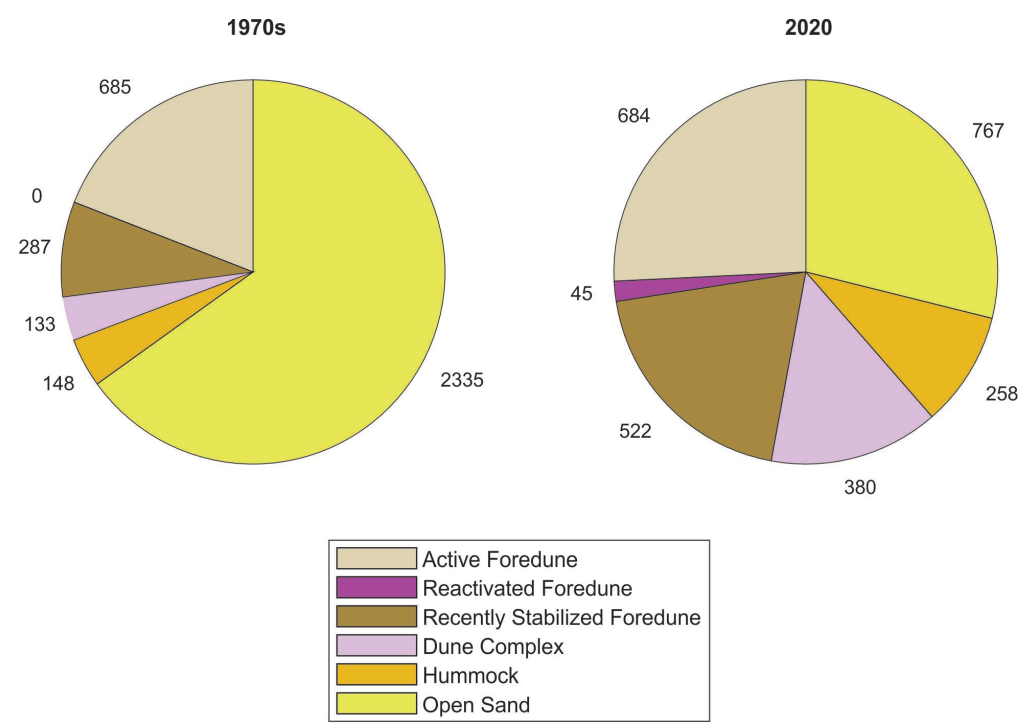


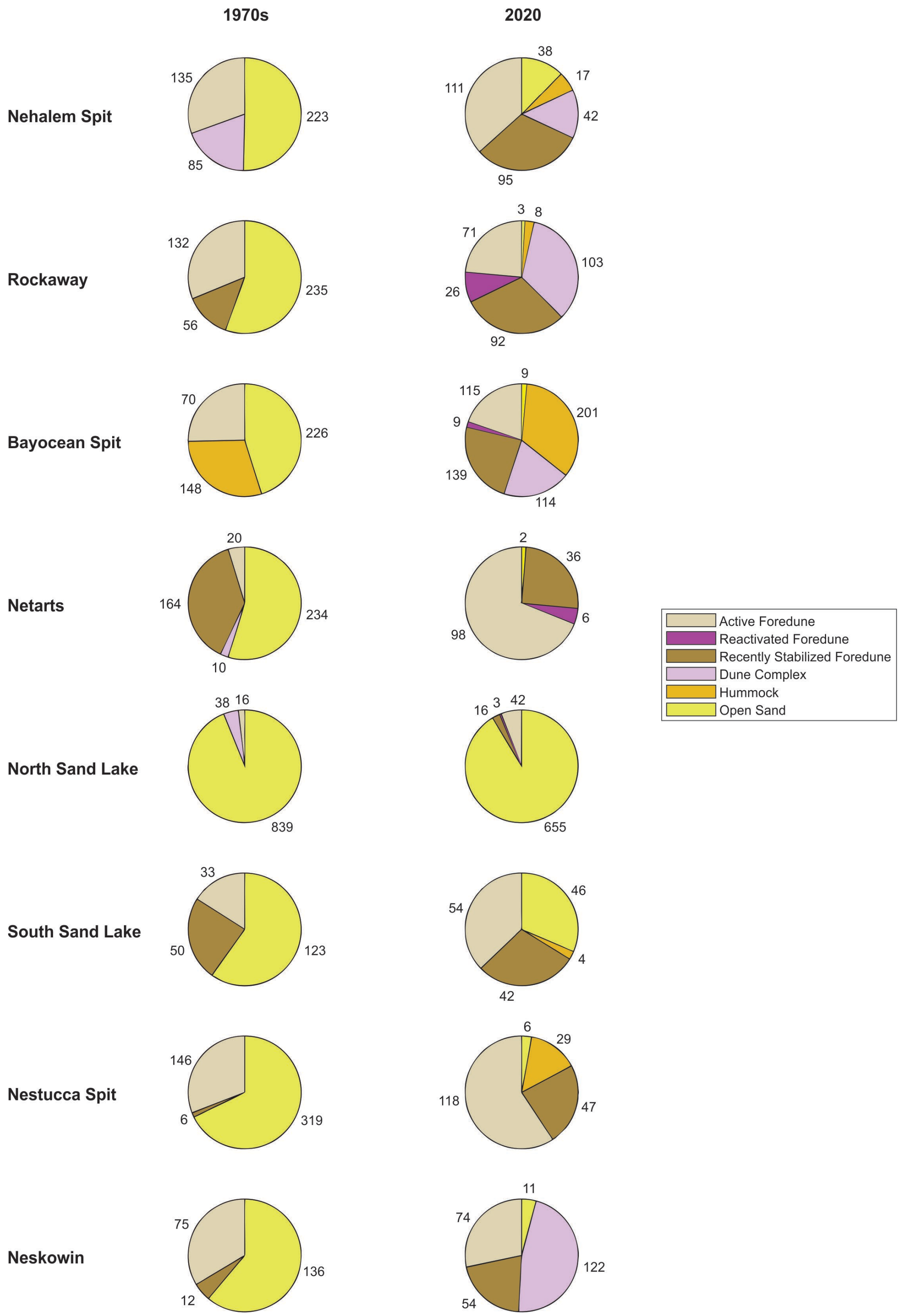
Table 2. Change in acreage of various coastal geomorphic units identified in Tillamook County from the 1970s to 2020.

Code	Description	Nehalem Spit	Rockaway	Bayocean Spit	Netarts Spit	North Sand Lake	South Sand Lake	Nestucca Spit	Neskowin	Total
B	Beach	161.1	367.7	214.0	370.0	253.7	280.2	199.6	268.3	2,114.6
FDA	Active Foredune	−24.3	−61.1	−11.6	77.8	26.1	21.1	−27.3	−1.1	−0.4
FDR	Reactivated Foredune	0	26.4	9.1	6.4	3.3	0	0	0	45.2
FD	Recently Stabilized Foredune	95.4	35.8	139.1	−127.5	16.2	−7.8	40.9	42.5	234.6
DC	Dune Complex	−42.2	102.7	113.5	−9.9	−38.1	0	0	121.7	247.6
H	Hummocks	17.1	8.1	52.5	0	0	3.5	28.5	0	109.6
DS	Younger Stabilized Dunes	275.3	625.2	−141.7	126.4	237.7	-20.9	−18.2	1.4	1,085.0
OS	Open Sand	−185.5	−232.3	−217.6	−232.7	−183.7	−77.4	−313.1	−125.6	−1,567.9
W	Interdune	−193.8	0	3.8	−54.1	−521.9	0	0	0	−766.0
WDF	Wet Deflation Plain	0	−73.2	−48.1	38.5	0	18.0	−179.3	0	−244.3
WMF	Wet Mountain Front	−29.6	−129.3	0	−59.3	−195.7	−82.0	−69.9	−147.9	−713.7
WL	Wetland	123.2	339.7	164.1	157.7	690.3	93.9	219.8	272.7	2,061.4

4.2 Nehalem Spit

Figure 3 presents summary pie charts of the same six geomorphic units identified in **Figure 2**, but now broken down according to each subcell; values provided are the actual unit acres, while summary changes are provided in **Table 2**. **Figure 4** presents a map showing the complete suite of geomorphic units based on the original mapping (left) compared with present-day conditions (right). Overall, the area designated as active foredune has decreased by 18% (~24 acres) since the 1970s. Much of this change reflects improvements in base map accuracy due to the use of lidar data, coupled with improved geomorphic designation of the primary frontal dune and modeling of the erosion, wave runup, and inundation extents (Allan and others 2015). The jetties at the mouth of Nehalem Bay were originally constructed between 1916 and 1918 and later rehabilitated in the early 1980s (Lizarraga-Arciniega and Komar, 1975). Following construction of the jetties, Nehalem Spit advanced seaward. However, the shoreline did not straighten and tended to recurve landward near the jetties; the latter is evident in the curvilinear nature of the dunes near the spit tip (**Figure 4**). The reason for this was because the jetties were constructed low and quite porous, allowing sand to migrate across the jetty and into the estuary.

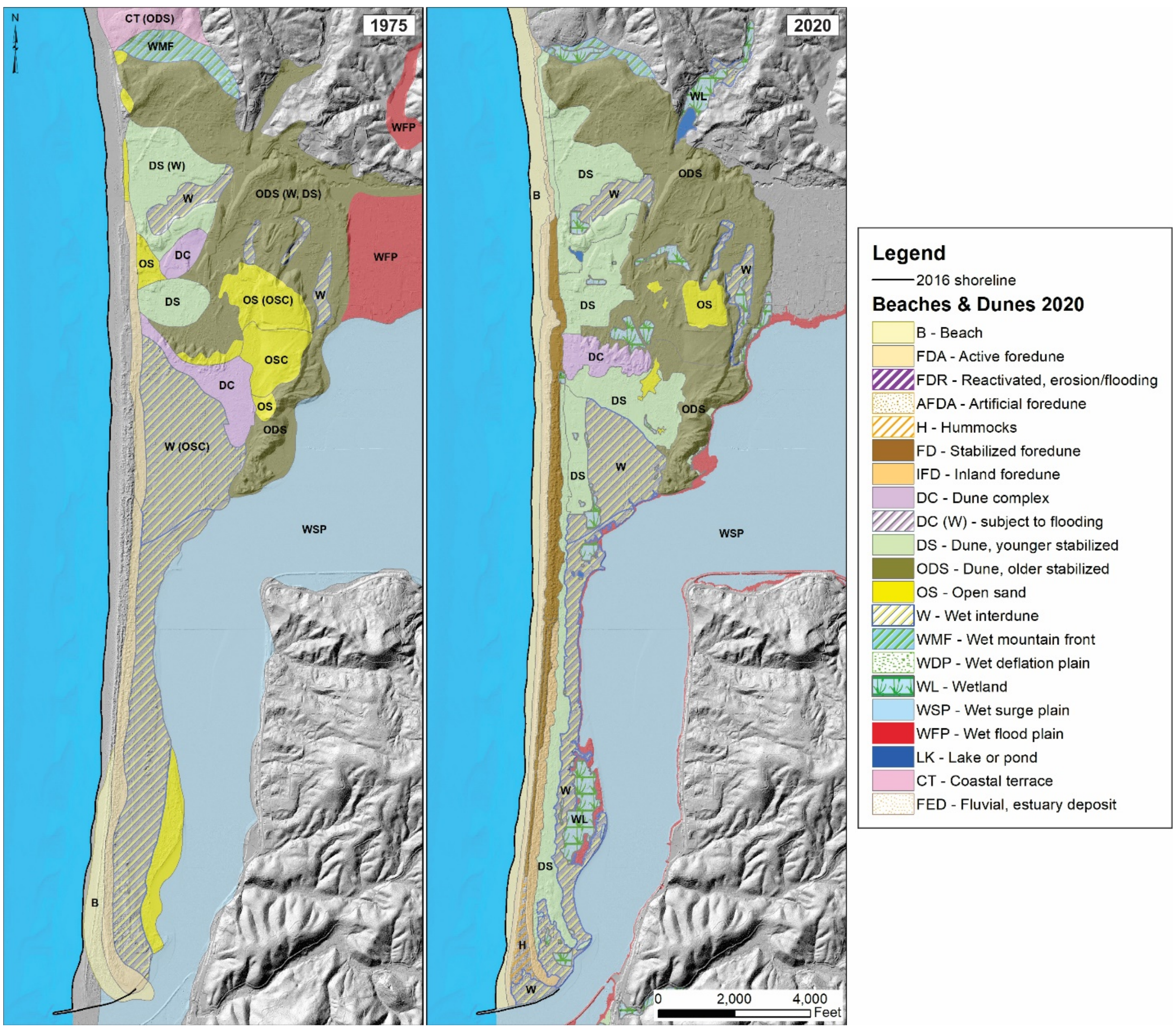
Figure 3. Pie charts depicting coastal geomorphic unit changes defined for each Tillamook County subcell. Values shown for each pie reflect acres of land, drawn from Table 2. Pie proportions are a function of the combined value of the six units presented in the figure, and their sums are not necessarily the same from 1970 to 2020.



With rehabilitation of the jetties in the 1980s, the beach stabilized and advanced seaward, leading to the formation of an entirely new active foredune system, while resulting in stabilization of the previously active foredune. Hence, evident from both Figure 3 and 4 is the appearance of the stabilized foredune designation (FD), which is now present along two thirds of the spit. Lidar mapping has also helped refine the number of foredunes present on the spit, which now reflect at least four sequences of development, with the most landward extent (DS) probably reflecting the pre-jetty position of the beach and dune.

Other notable features along Nehalem Spit include the reduction in areas designated as open dune sand (OS), and the presence of hummock terrain near the estuary mouth and between the present-day active foredune and an inland foredune. Refinements in both the wet surge plain and wet flood plain better characterize those areas impacted by daily tides as well as high water events.

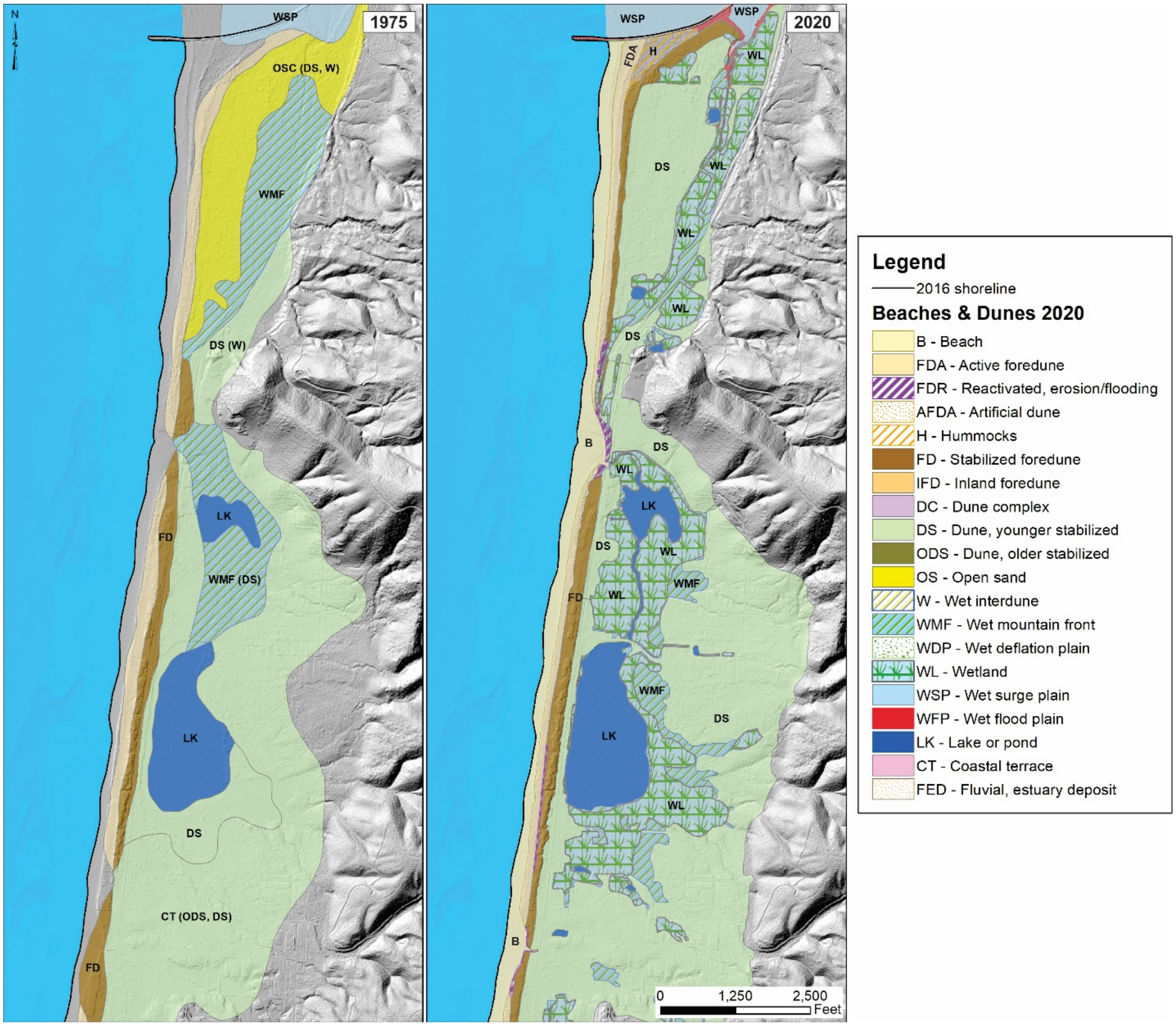
Figure 4. Beach and dune geomorphic mapping classifications for Nehalem Spit. (*left*) original USDA (1975), (*right*) updated version.



4.3 Rockaway Beach

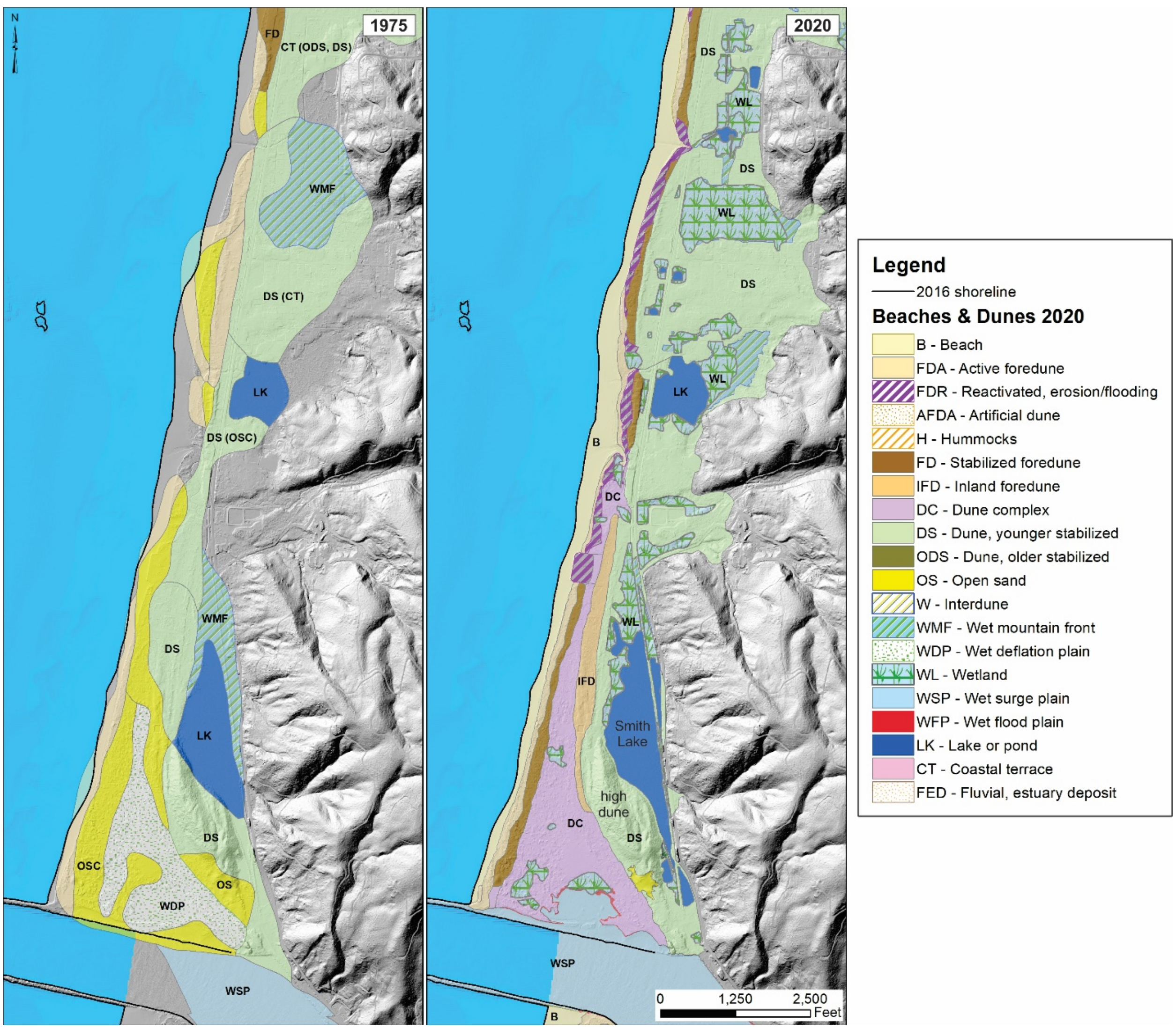
Figure 5 and **Figure 6** present maps showing the suite of coastal geomorphic units based on the original mapping (left) compared with present-day conditions (right) for the Rockaway Beach and the Twin Rocks areas. Beginning with Rockaway, the most obvious changes have occurred in the north adjacent to the mouth of Nehalem Bay where previous areas of open sand (**Figure 5**, left) have since been stabilized (**Figure 5**, right). As noted in section 4.2 for Nehalem Spit, these changes reflect improvements to the jetty undertaken in the early 1980s, which caused the shoreline to build seaward. As can be seen in **Figure 4** and **Figure 5**, associated with this advance was stabilization of the previous foredune and the formation of a new active foredune seaward of it. In fact, our analyses reveal a more contiguous foredune system today compared with the 1970s. Of interest also is the inclusion of a new geomorphic unit (FDR) that reflects erosion into the former stabilized foredune. This new class is especially prevalent along the Rockaway Beach and Twin Rocks shoreline and is reflective of the fact that this area has been undergoing significant erosion since at least 1997. The erosion is especially acute at Manhattan Beach wayside near the north central area of **Figure 5**, such that it has all but eliminated portions of the previous active foredune. To the south, development has encroached onto the dune, and much of the Rockaway Beach area today is now engineered (i.e., riprap) as a result of erosion effects that have occurred since 1997 (Allan and Hart, 2008; Allan and others, 2009). Other notable changes include the proliferation of wetland-designated areas throughout the area, which are found concentrated in areas defined previously as wet mountain front or wet interdunes (i.e., areas subject to high water tables and periodic standing water).

Figure 5. Beach and dune geomorphic mapping classifications for Rockaway Beach. (*left*) original USDA (1975), (*right*) updated version.



Between Twin Rocks and the mouth of Tillamook Bay, areas designated as open sand have now been virtually eliminated, the exception being a small designated area of high dune by Smith Lake, near Barview (**Figure 6**). Erosion hazards have also increased along most of the shore to the point where it is now considered to be chronic, such that the previous active foredune has been eliminated in a number of areas (FDR). As a result, erosion is continuing and is now cutting landward into older dune features that formed both prior to and immediately following jetty construction (completed in 1917) at the mouth of Tillamook Bay. Finally, a large area defined previously as a wet deflation plain (**Figure 6**, left) has been redefined as dune complex (**Figure 6**, right) since this feature can be attributed entirely to coastal nearshore processes that resulted in rapid beach and shoreline advance following construction of the north Tillamook jetty (Komar, 1997), as opposed to wind-dominated processes.

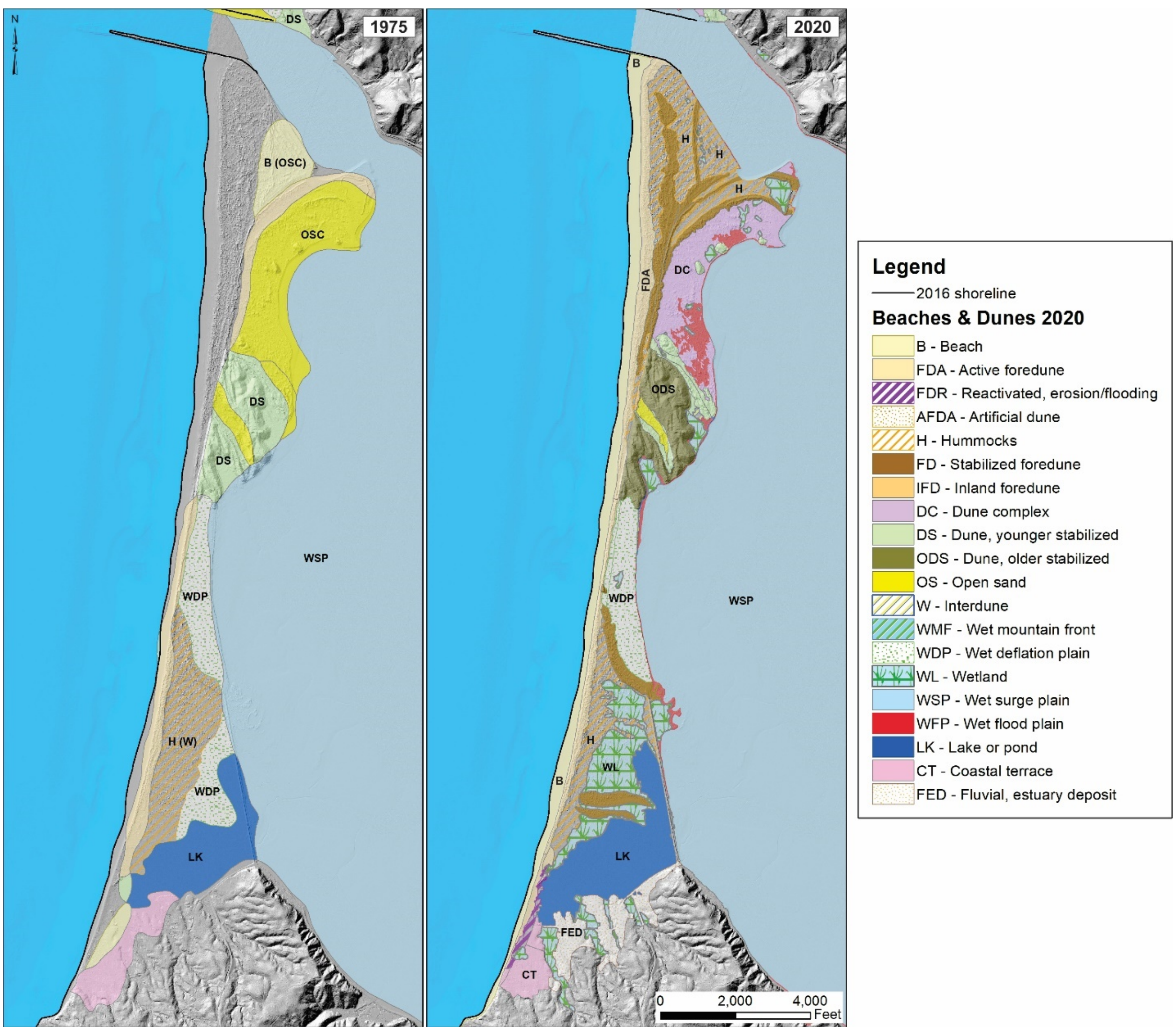
Figure 6. Beach and dune geomorphic mapping classifications for Twin Rocks. (*left*) original USDA (1975), (*right*) updated version.



4.4 Bayocean Spit

Figure 7 shows changes in the suite of coastal geomorphic units based on the original mapping (left) compared with present-day conditions (right) for Bayocean Spit. Several interesting features are apparent from the updated mapping. For context, the original mapping would have occurred prior to completion of the south Tillamook Jetty, which was finished in 1974. Hence, along the spit tip one can see evidence of varying stages of foredune development that occurred as the jetty was being built, with the shoreline transitioning from a curvilinear shape at the tip, to a more linear feature as sand aggraded against the jetty as it was being built. As can be seen from **Figure 7**, there is evidence of at least two stabilized foredunes (FD) that run parallel to the existing active foredune (FDA). Between these dunes is an area of hummock terrain, indicative of the rapid pace in which the shoreline advanced, followed by a period of slower growth, enabling the foredune to begin developing.

Figure 7. Beach and dune geomorphic mapping classifications for Bayocean Spit. (*left*) original USDA (1975), (*right*) updated version.



Immediately south of the pre-jetty spit tip is a large area of open sand conditional (OSC, **Figure 7**, *left*) that has since been stabilized by dune grasses, shore pine, and other coastal shrubs. This section has been redefined as a dune complex because it is still evolving toward a stabilized younger dune state. A section of parabolic dunes in the north central portion of the spit previously classified as younger stabilized dune (DS) has been redefined as older stabilized dune (ODS); the original distinction between the two units is largely based on soil development. However, this section is almost certainly much older than originally identified by the USDA (1975) with extensive forest and soil development (evident in early 1939 photos of the area) and observed by Cooper (1958), such that calling it a younger stabilized dune (DS) would be inconsistent with other ODS designations used by the USDA (1975) elsewhere. Moreover, (Cooper, 1958) speculated on the longevity of these dune features noting that they have almost certainly been around for a long time given the size of the dune features and their persistence in having survived any potential shifts in the location of the estuary mouth, which likely has remained in the north. Evident also in **Figure 7** (left), is that at the time of mapping USDA (1975) did not identify an active foredune in front of the older dunes, suggesting that this site was probably experiencing intense erosion, essentially truncating the dunes.

The erosion of Bayocean Spit is especially well documented, culminating with the spit breaching in the late 1940s (Komar, 1997; Allan and Priest, 2001). The cause of the erosion was entirely due to construction of the north Tillamook jetty (completed in October 1917), which interrupted the natural supply of sediment. During the construction phase, changes in the inlet channel and the adjacent shorelines soon became evident. North of Tillamook Bay, sand accumulated rapidly and the shoreline advanced seaward at a rate almost equal to the speed at which the jetty was being constructed (Komar 1997). Between 1914 and 1927, the coastline just north of the jetty advanced seaward some 975 m (3,200 ft). However, by 1920 the rate of sand accumulation on the north side of the jetty had slowed, so that the position of the shoreline was much the same as it is today. In the south, the shoreline near Cape Meares retreated some 200 m (650 ft). The erosion was particularly severe between 1927 and 1953, with the mean shoreline retreating at a rate of ~ 2.4 to 3 m/yr (~8 to 10 ft/yr), culminating with the cutting away of a 1,220 m (4,000 ft) section of the spit on November 13, 1952, breaching the spit. The geomorphic evidence of the breach is clear in our updated geomorphic mapping (**Figure 7**, *right*). As can be seen in the south-central portion of the spit, curved stabilized foredunes (FD) are evident in the landscape, while the bulk of the area between the relict foredunes is characterized by hummock terrain and/or wetlands. In the far south, adjacent to Cape Meares, portions of this area are subject to wave overtopping and inundation of the backshore (FDR), while much of the terrain above the community is characterized by active landsliding.

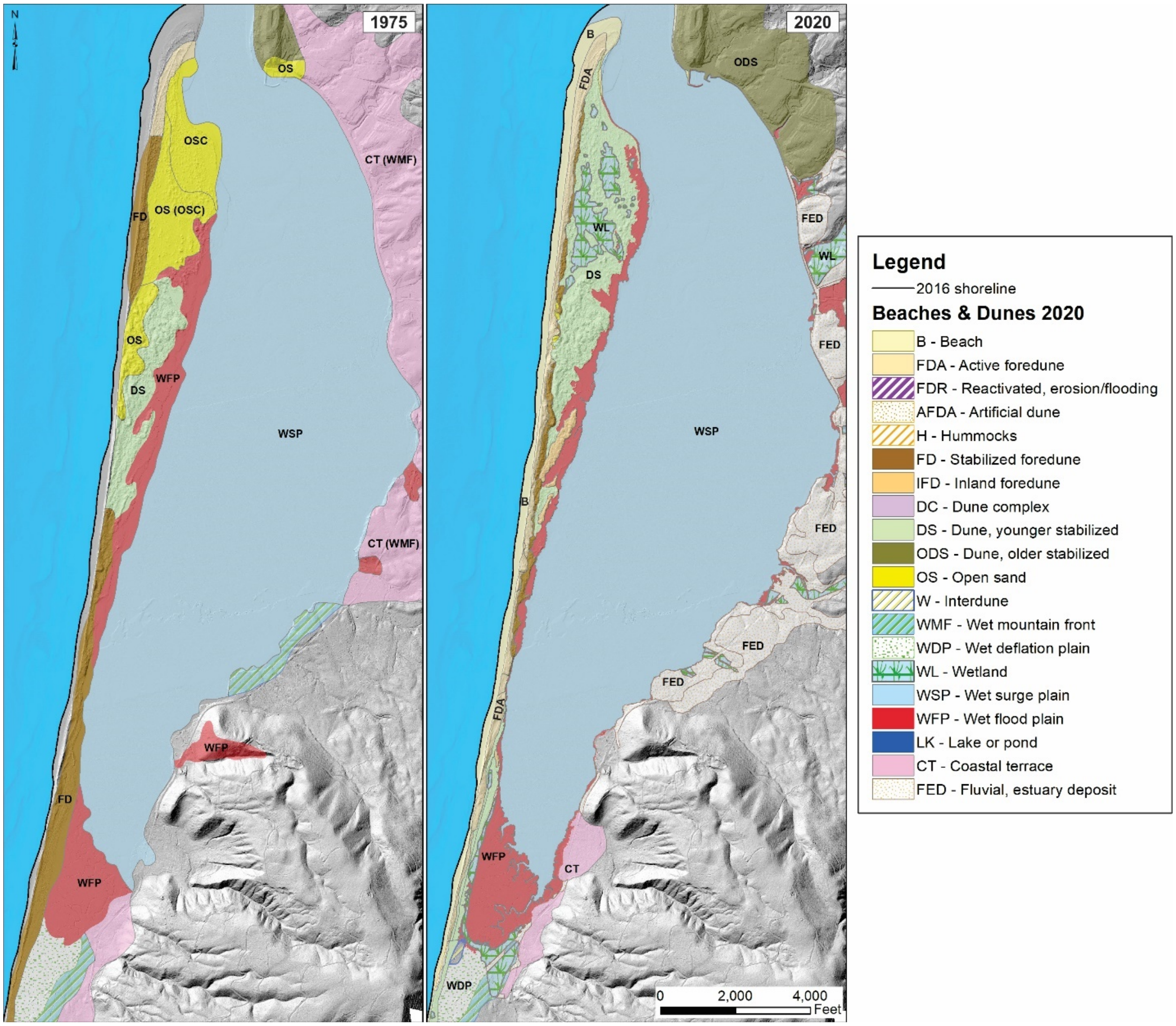
Finally, it is worth noting that the degree of the post-jetty changes identified in **Figure 7** (right) is indicative of the speed at which the entire spit adjusted and eventually stabilized. This process began to occur almost immediately after construction on the south Tillamook Bay jetty started. As a result, conditions today now reflect an extensive active foredune system that effectively developed over a very short period. Ongoing beach monitoring by the author indicates that the southern half of the spit is largely stable (neither eroding nor accreting), while the northern half of the spit is presently accreting at rates of ~0.6 to ~1 m (2-3 ft) per year[3].

[3] http://nvs.nanoos.org/BeachMapping?action=oiw:beach_mapping_point:bay06:plots:trends (after Allan and Hart, 2008)

4.5 Netarts Spit

Updated mapping of the beaches and dunes along Netarts Spit is presented in **Figure 8**. Consistent with other areas, the most notable change reflects the stabilization of open sand areas and their conversion to younger stabilized dunes. This change reflects a decrease in the total acreage of open sand areas by 232.7 acres (**Table 2** and **Figure 3**). Apparent also are changes in the large areas defined as stabilized foredune (FD), evident in **Figure 8** (left), much of which has been redefined as active foredune (FDA, **Figure 8** [right]). While we don't disagree with the original interpretation, it is puzzling that the USDA (1975) did not map any active foredune along the spit other than a small area near the spit tip. Finally, it is worth mentioning that prior to the 1980s, Netarts Spit may have been stable. However, since the 1980s the spit has experienced some of the fastest rates of erosion in the county, which has continued to the present (Komar, 1986, 1998; Allan and others, 2006). The culmination of the erosion occurred at the south end of the cell at Cape Lookout State Park, where Oregon State Parks constructed an artificial foredune to mitigate the erosion.

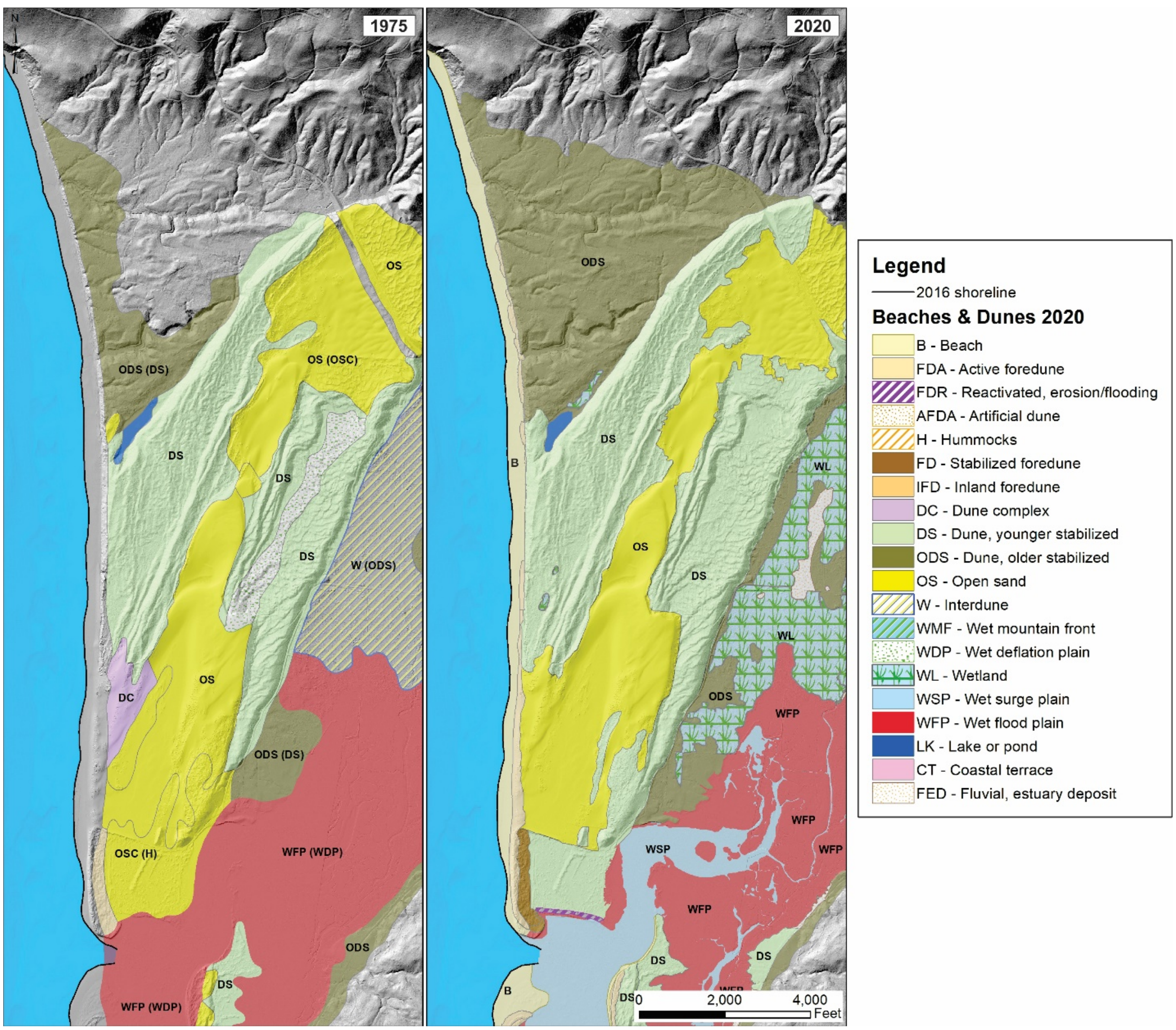
Figure 8. Beach and dune geomorphic mapping classifications for Netarts Spit. (*left*) original USDA (1975), (*right*) updated version.



4.6 Northern Sand Lake

Updated mapping of the beaches and dunes along the northern half of the Sand Lake littoral cell is presented in **Figure 9**. The main refinements to the latest mapping include designations of the active foredune (where applicable), improvements to the wet flood zone and wet surge plain, and updates to the extent of open sand in the area. Of the four littoral cells in Tillamook County, the Sand Lake cell has the largest area of open sand remaining, the bulk of which is located in the northern half of the cell (**Figure 9**). However, since the 1970s, open sand in this area has decreased by about 22%, from a high of 839 acres to ~655 acres today (**Table 2** and **Figure 3**). Much of this reflects the stabilization of areas in the south, adjacent to the estuary, and to a lesser extent in the northeast. A small area in the south adjacent to the estuary has been mapped as reactivated foredune (FDR) and is presently being eroded into by ocean waves from the southwest. Areas of older stabilized dunes (ODS) in the north have expanded significantly based on the mapping of Wells and others (1994).

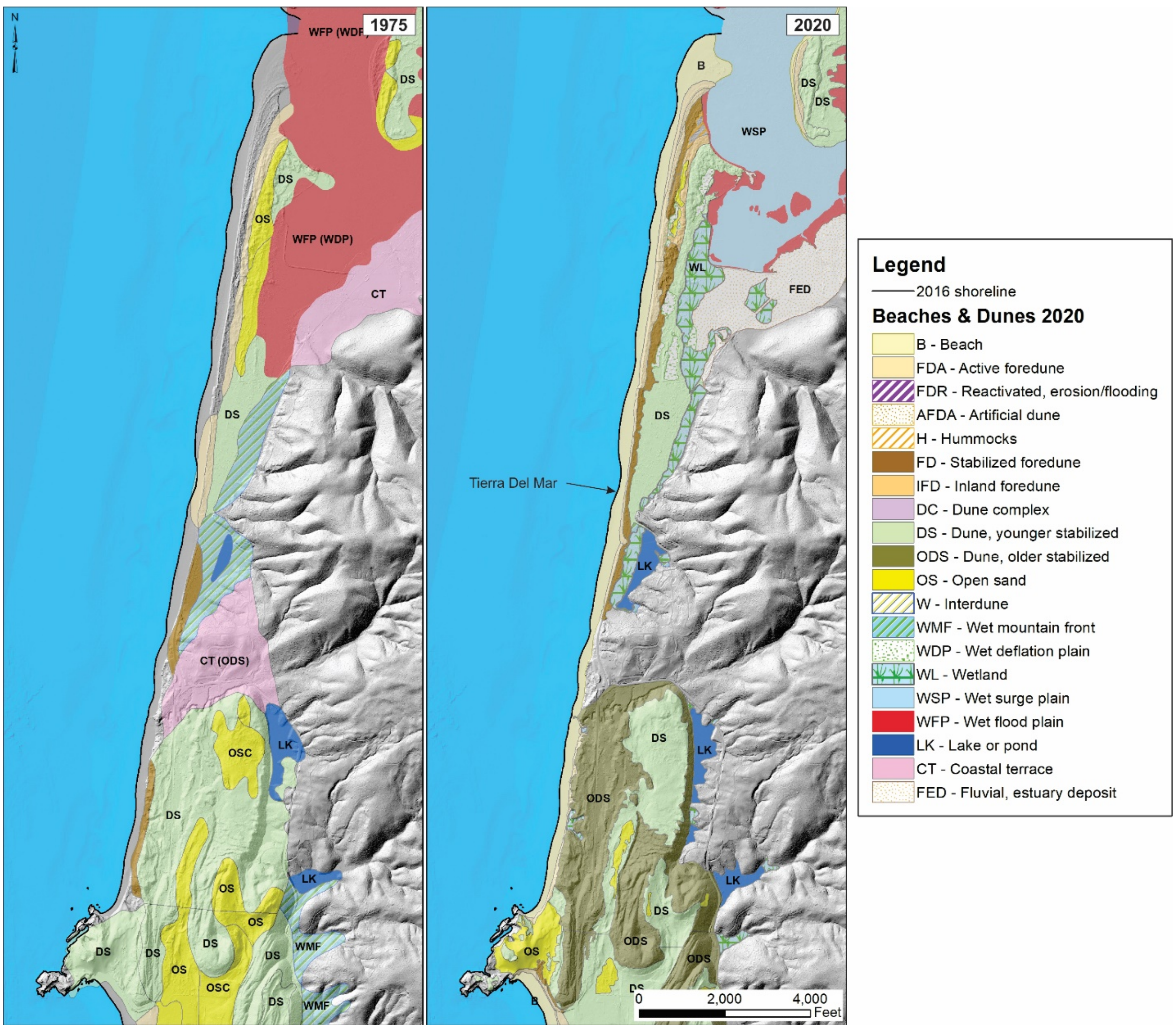
Figure 9. Beach and dune geomorphic mapping classifications for northern Sand Lake. (*left*) original USDA (1975), (*right*) updated version.



4.7 South Sand Lake

Figure 10 shows changes in the suite of coastal geomorphic units based on the original mapping (left) compared with present-day conditions (right) for the southern half of the Sand Lake littoral cell. Our updated mapping indicates that areas designated as open sand (OS) have been reduced by ~63% since the 1970s (**Figure 3**). The bulk of these changes occurred north of Tierra De Mar out on the spit, and in the south, just north of Pacific City. Stabilized foredunes (FD) have contracted slightly, while active foredunes have expanded by ~64%. Other notable changes include the inclusion of fluvial/estuarine deposits (mapped by Wells and others [1994]) located adjacent to the estuary, and the reclassification of areas designated as younger stabilized dunes (DS) to older stabilized dunes (ODS) based on an evaluation of 1939 aerial photos of the area. Finally, refinements to the wet surge plain and wet flood plain indicate more realistic tidal effects, along with flood potential (**Figure 10**).

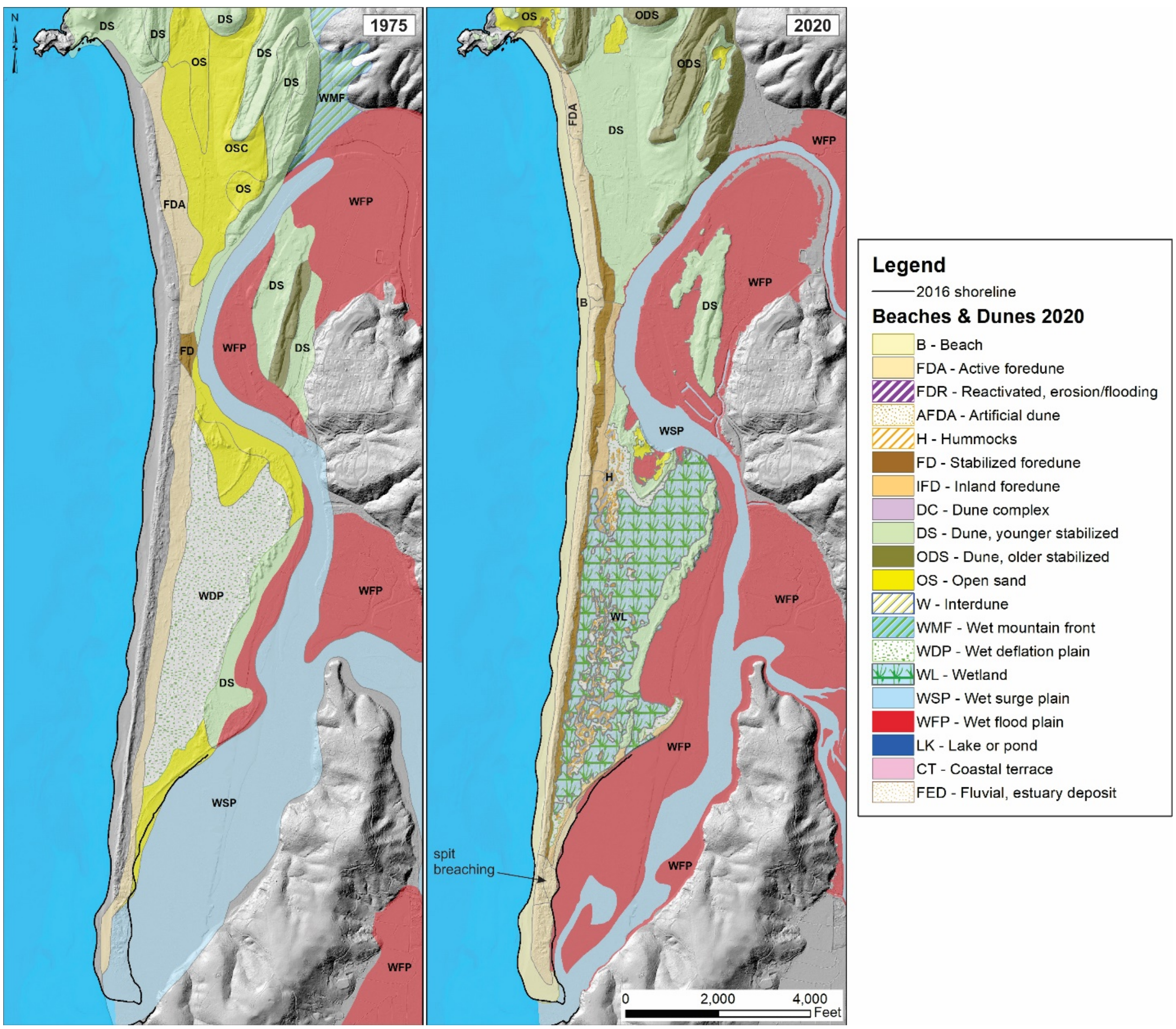
Figure 10. Beach and dune geomorphic mapping classifications for southern Sand Lake. (*left*) original USDA (1975), (*right*) updated version.



4.8 Nestucca Spit

Updated mapping of the beaches and dunes along Nestucca Spit is presented in **Figure 11**. As can be seen from the figure, the largest change since the 1970s is the dramatic reduction in areas defined as having open sand, the bulk of which was concentrated in the north, near Cape Kiwanda. Thus, while the area of open sand has contracted, the updated mapping indicates that much of this has been converted to younger stabilized dunes (DS). Refinements to the active foredune area indicate that it has contracted by about 29%, while stabilized foredunes (FD) have expanded substantially. Near the spit tip, evidence of spit breaching that took place in 1978 remains evident in the landscape today. Finally, the large area defined as wet deflation plain has been re-designated as a mixture of wetland (WL, USFWS National Wetland Inventory), hummock terrain, and wet deflation plain.

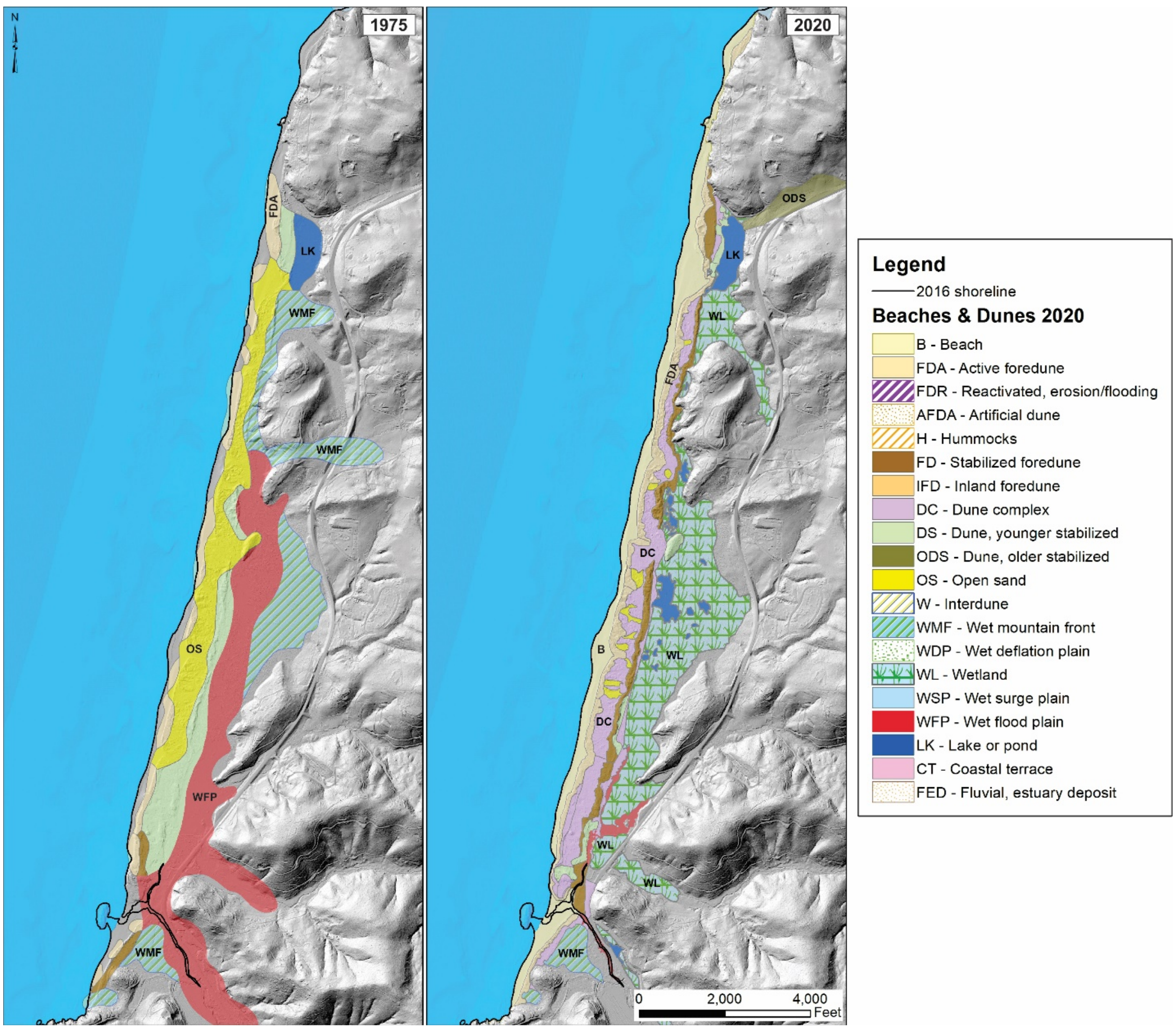
Figure 11. Beach and dune geomorphic mapping classifications for Nestucca Spit and Pacific City. (*left*) original USDA (1975), (*right*) updated version.



4.9 Neskowin

Figure 12 shows changes in the suite of coastal geomorphic units based on the original mapping (left) compared with present-day conditions (right) for the Neskowin area. Consistent with other areas in Tillamook County, the largest change reflects the overall decrease (98%) in areas characterized as open sand. The remaining pockets of open sand are largely confined to areas where dune blowouts have occurred, due to aeolian and/or wave runup-inundation processes. Consistent with the decrease in open sand areas has been a shift toward stabilized foredunes, which are now spread along the length of the Neskowin shoreline. Because the area landward of the foredune exhibits a complex history with many factors contributing to its overall development, it is designated dune complex (DC). Finally, with refinements in the wet flood plain toward using a tidal datum-based shoreline, the wet flood plain in 2020 is significantly smaller when compared with the area mapped in the 1970s.

Figure 12. Beach and dune geomorphic mapping classifications for Neskowin. (*left*) original USDA (1975), (*right*) updated version.



5.0 CONCLUSION

The objective of this pilot beach and dune mapping study has been to produce updated information on the spatial extent of the beach and foredune system in Tillamook County that may be subject to existing and future storm-induced wave erosion, runup, overtopping, and coastal flooding. These data are of importance to DLCD and the coastal counties of Oregon in order to improve implementation of Statewide Planning Goal 18: Beaches and Dunes. Specifically, Oregon Statewide Planning Goal 18 requires that local jurisdictions adopt a beach and dune overlay zone in their comprehensive plan, which may be used to manage development on or near such features. Regional mapping of the original beaches and dunes overlay zone of the Oregon coast was undertaken between 1972 and 1975 by the U.S. Department of Agriculture Soil Conservation Service (USDA, 1975). However, much has changed on the Oregon coast, requiring that the USDA (1975) overlay zone be updated to reflect current conditions. As noted throughout this report, some of the largest changes to have taken place along the coast include:

- The rapid expansion of European beach grass (*A. arenaria*), which has helped to stabilize many dune systems;
- Encroachment of human development into foredune areas;
- Dune management activities such as foredune grading and planting;
- Changes in beach and dune morphology due to either coastal erosion or accretion;
- Construction of coastal engineering used to mitigate erosion hazards; and,
- Shoreline changes at the mouths of estuaries controlled by jetties.

Although the updated beaches and dune overlay zone maintains the core classification structure developed originally by the USDA (1975), it does include several new classes that address changes in the coastal geomorphology of Tillamook County. Importantly, the geospatial attributes associated with the GIS are now much refined, so that they account for comments and notes made by the author and include specific references to their susceptibility to coastal hazards.

Analyses presented here clearly demonstrate the transformation of the coast over the past 45 years. Of particular note has been the overall reduction in areas defined as open sand (OS), which has decreased by ~67% since the 1970s. Most of this change can be directly attributed to anthropogenic effects, particularly the introduction of European beach grass (*Ammophila arenaria*) as well as stabilization from shore Pine (*Pinus contorta*) and other native plant species. Although the bulk of this transformation can be attributed to a shift toward younger stabilized dunes (DS), the expansion of areas defined as active foredune (FDA) and stabilized foredunes (FD) is a testament to the role humans have played in driving these changes.

6.0 ACKNOWLEDGMENTS

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