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BEACHES AND DUNES OF CLATSOP COUNTY, OREGON: 1975 TO 2022

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WHAT'S IN THIS REPORT?

New lidar-based mapping along the Clatsop County coast provides updated spatial extents of beach and dune features exposed to existing and future storm-induced wave erosion, runup, overtopping, and coastal flooding. Side-by-side comparisons between 1975 and the latest mapping of beach and dune feature highlight important spatial changes in coastal geomorphology that have taken place.

Cover photo: Aerial view looking south over the Clatsop Plains toward Gearhart, Seaside, and Tillamook Head. The left edge of the image reflect a sequence of eroded marine terraces. The Clatsop Plains (central photo) consist of a sequence of dunes that have formed over the past ~4,000 years. Broad expanse of dune grasses between the seaward line of buildings and the sandy beach, is the approximate position of the coastline in the 1870s. Photo taken by L. Gabel, August 12, 2011.

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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 10.7 format. Metadata is embedded in the geodatabase and is also provided as a separate .xml format file.

Clatsop_Dune_Mapping_Original.gdb:
Feature class: O*riginal_Dune_mapping_Clatsop* (polygon)
Clatsop_Dune_Mapping_Revised_2025.gdb:
Feature class: *Beaches_and_Dunes* (polygon)

Layer file providing symbology for the feature class
Clatsop_Beaches&Dunes_Original.lyrx
Clatsop_Beaches&Dunes_2025.lyrx

UNITS OF MEASUREMENT

The intended audience for this report includes both the general public and scientists. Therefore, we selected U.S. Customary units as the primary units; SI (International System) Metric units are included in paratheses. A conversion table for U.S. Customary units to SI (International System) Metric units is included for easier conversion where needed.

U.S. Customary Units to SI (International System) Metric

	Original Units	Conversion Equation	To Obtain
length:	inch (in)	in × 2.54	centimeter (cm)
	foot (ft)	ft × 0.305	meter (m)
	yard (yd)	yd × 0.914	meter (m)
	mile (mi)	mi × 1.609	kilometer (km)
area:	acres (ac)	ac × 0.405	hectares (ha)*
volume:	cubic ft (ft^3)	ft^3 × 0.028	cubic meter (m^3)

*Hectares are a non-SI metric unit.

EXECUTIVE SUMMARY

The objective of this study was to produce updated information on the spatial extent of beach and dune geomorphology in Clatsop County, Oregon, 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 (DLCD) and the seven coastal counties of Oregon in order to implement Statewide Planning Goal 18: Beaches and Dunes (Goal 18 (DLCD, 2024)). Goal 18 requires local jurisdictions to adopt a beach and dune overlay zone in their comprehensive plan that may be used to manage development on or near beaches and dunes.

Between 1972 and 1975, the U.S. Department of Agriculture (USDA) Soil Conservation Service conducted regional mapping of Oregon's coastal geomorphology to define the extent of its beaches and dunes (USDA, 1975). However, in the intervening 50 years, much has changed on the coast. Of particular importance has been the proliferation of European and American beach grasses that have helped to stabilize the coastal foredune. In contrast, Clatsop Spit (north of the Peter Iredale shipwreck) is presently experiencing significant erosion that is likely due to long-term changes in the Columbia River sediment beach budget. In addition, new technologies such as light detection and ranging data (lidar) and aerial imagery are now providing unprecedented levels of detail about the elevation and shape of the ground surface, enabling scientists to map the spatial extents of both the contemporary and historical foredune systems more accurately. These factors combined necessitate that the USDA (1975) mapping be updated to reflect contemporary conditions. As a result of the updated mapping, our analyses indicate the following broad-scale changes:

- Areas classified as active foredune (FDA) and recently stabilized foredunes (FD) increased by 1,095% and 54%, respectively, in Clatsop County.
- Recently stabilized dune (DS) and open sand (OS) areas make up a negligible (0.23%) proportion of the Clatsop County geomorphological mapping.
- Areas mapped as inland foredune (IFD) increased significantly (472%) from 700 acres (28 ha) in 1975 to 4,007 acres (1,621 ha) in 2024; most of this change occurred on the Clatsop Plains.
- Interdune areas have also increased in Clatsop County (45%) from 420 acres (170 ha) in 1975 compared with 2,182 acres (883 ha) in 2024; most of this change occurred on the Clatsop Plains.
- Areas mapped as dune complex (DC) decreased by 68% since 1975. Much of this change can be explained by our improved mapping of contemporary and historical foredunes, interdune areas, and the designation of wetland (WL) areas in Clatsop County.

1.0 INTRODUCTION

The Oregon Department of Land Conservation and Development (DLCD) and Oregon Department of Geology and Mineral Industries (DOGAMI) are collaborating through a National Oceanic and Atmospheric Administration (NOAA) Project of Special Merit study to undertake detailed mapping of beach and dune features along the Oregon Coast. The objective of this report is to describe and document recent (post-1975) changes in beach and dune areas along the Clatsop County coastline (**Figure 1-1**) that may be subject to future storm-induced erosion, runup, overtopping, and coastal flooding. A secondary objective is to map the spatial distribution of unique coastal geomorphological and eolian features in coastal Clatsop County. These data are of importance to DLCD and the county in order to improve implementation of Oregon Statewide Planning Goal 18 (DLCD, 2024). Specifically, Goal 18 requires that local jurisdictions adopt a beach and dune overlay zone in their comprehensive plan that 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 USDA Soil Conservation Service (USDA, 1975). The purpose of this mapping was to:

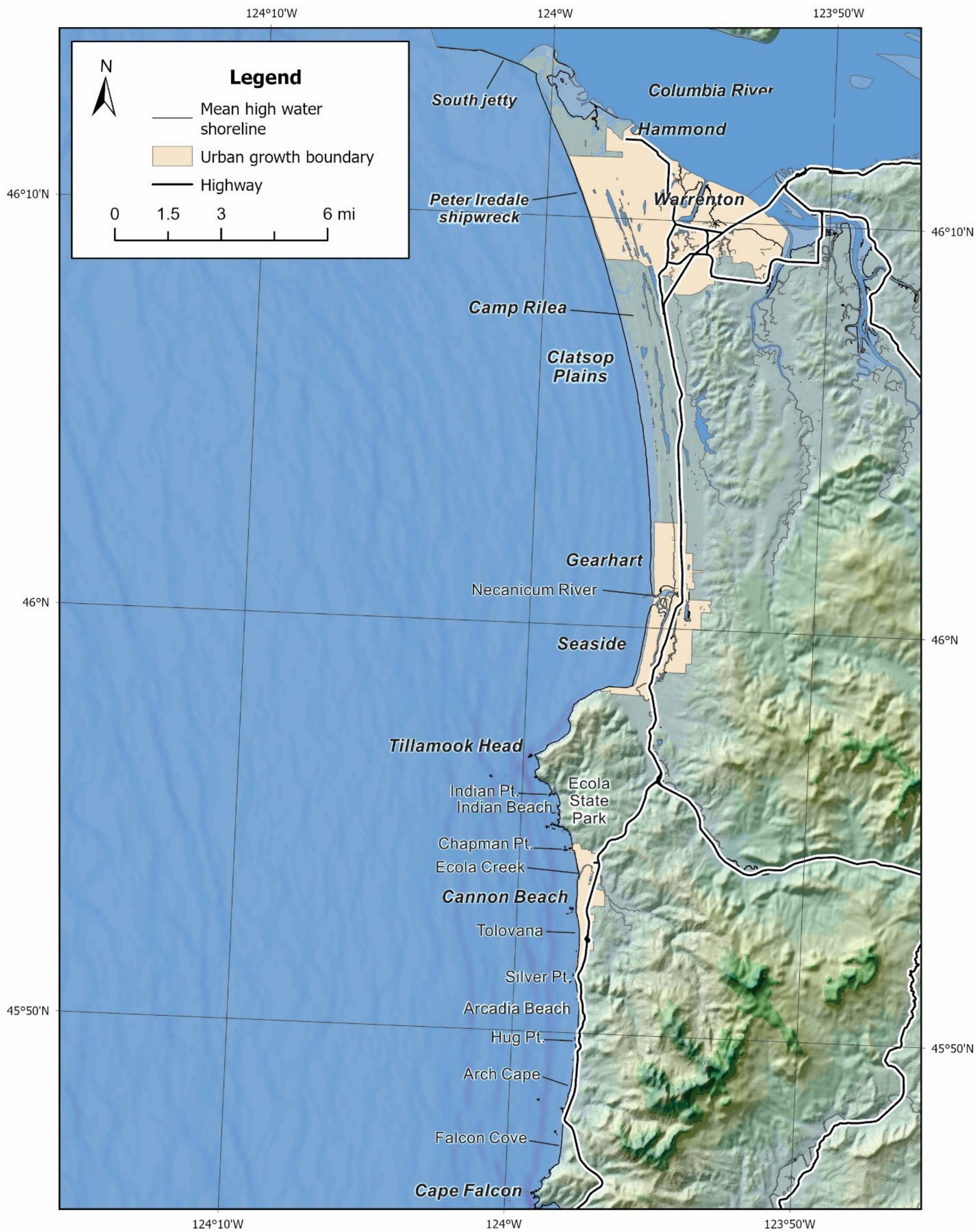
1. Produce inventory resource maps of beaches, sand dunes, and interdune areas along the Oregon Coast
2. Explain components of the inventory
3. Present illustrations and tables summarizing the various mapping dune units
4. Provide interpretations of the map units and their potential use characteristics

The mapping was undertaken using stereoscopic investigations of available aerial imagery, accompanied by extensive fieldwork (USDA, 1975).

Over the past 50 years, much has changed in the landscape along the Oregon Coast, while technologies such as lidar and aerial imagery enable us to visualize the ground surface in unprecedented detail. Accordingly, the original maps are both out of date and lack sufficient spatial resolution to resolve and support current land use planning efforts. Some of the largest changes to have taken place along the Clatsop County coast include:

- The rapid expansion of European beach grass (*Ammophila arenaria*) has helped to stabilize many dune systems along the Oregon Coast while fundamentally changing the morphology of the dunes (Allan and Priest, 2001; Allan and others, 2009; Zarnetske and others, 2012)
- Shoreline changes at the mouth of the Columbia River (Lizarraga-Arciniega and Komar, 1975; Kaminsky and others, 2010)
- Encroachment of human development into foredune and other flood-prone areas (Allan and others, 2009; Allan and others, 2015)
- Dune management activities such as foredune grading and planting
- Long-term changes in beach and dune morphology due to coastal erosion and/or accretion (Ruggiero and others, 2013; Burgette and others, 2023)
- Construction of coastal engineering to mitigate erosion hazards

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



This report presents summary information and modern maps of beach and dune features along the Clatsop County coastline, defined in a geographical information system (GIS) and informed by historical and contemporary aerial photographs (e.g., 1939, 1967, and 1998 to 2022), airborne lidar (multiple lidar collections since 1997), coastal erosion mapping (Allan and Priest, 2001; Witter and others, 2009; Kaminsky and others, 2010; Kaminsky and others, 2022), FEMA flood modeling (Allan and others, 2015), recent (1997 to 2016) coastal change analyses derived from lidar data (Burgette and others, 2023), and coastal change monitoring (Allan and others, 2018). Comprehensive dune mapping by Cooper (1958), Woxell (1998), Reckendorf and others (2001), and Peterson and others (2010) to map and date Pleistocene and Holocene dunes on the Oregon Coast were also evaluated, and, where applicable, used here. Geologic mapping of the Clatsop Plains by Schlicker and others (1972) and Niem and Niem (1985) provided an important foundation to the updated geomorphic mapping presented in this report and accompanying GIS data. 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 were retained, and in some cases modified or refined.

2.0 COASTAL GEOLOGY AND GEOMORPHOLOGY

Clatsop County is located on the northern Oregon Coast, between latitudes 46°15′33.16″ N (Columbia River) and 45°46′59.24″ N (Cape Falcon), and longitudes 123°59′50.64″ W and 123°21′47.55″ W (**Figure 1-1**). The terrain varies from low-elevation sandy beaches and dunes at the coast to elevations higher than 2,950 ft (900 m) inland. In the north, the county is bounded by the Columbia River, which is the fourth largest river by discharge in the United States. Prior to the construction of the jetties in the late 1800s and implementation of discharge control in the 1960s, the Columbia River system transported large volumes of sediment to the coast, which directly contributed to the growth and evolution of the Clatsop Plains and southern Washington Coast beaches. Farther south, smaller streams such as the Necanicum River (Seaside) and Ecola Creek at Cannon Beach flow out of the coast range. Both streams have generally low flow and the terrain into which they are downcutting yields very little sediment that would contribute to the beach sediment budget. Hence, there is little to no significant source of sediment to the coast today other than from erosion of the backshore. This is especially true of the coast south of Tillamook Head, which includes Cannon Beach, Arch Cape, and Falcon Cove.

2.1 Geology

The geology of Clatsop County can be broadly characterized as being comprised of three predominant lithologic units: late-Holocene sandy beaches and dunes, marine terraces formed in mudstone and sandstone, and basalt headlands.

Along the outer coast, the predominant geologic units consist of late-Holocene sandy beaches backed by prominent dunes and boulder-cobble beaches that make up the bulk of the coastline. Of these, the extensive dune ridges that compose the Clatsop Plains are the most prominent. Woxell (1998) dated the landward edge of these dunes where they abut against marine terraces; they identified an age of about 4,000 years before present (YBP). Hence, the Clatsop Plains reflect aggradation and progradation of beach sand that spans less than 4,000 years. Areas of highland east of Seaside and Gearhart consist of marine terraces that have eroded into Astoria Formation (Miocene Age) mudstone. Farther north, marine terraces east of Camp Rilea reflect erosion into the Smuggler Cove Formation (Oligocene Age) tuffaceous claystone and siltstone (Niem and Niem, 1985).

South of Seaside (**Figure 1-1**), Tillamook Head consists of intrusive Grande Ronde Basalt (lower Miocene) that abuts against Smuggler Cove Formation mudstone. The latter underlies the northern side of Tillamook Head (Witter and others, 2009). Extensive landsliding is evident across much of the headland but is particularly prevalent adjacent to the coast (Burns and others, 2024). Witter and others (2009) speculated that much of the landsliding on the north side of the headland was probably due to the intrusion of the basalt dikes into the mudstone, which reduced its overall strength and competency. Extensive landsliding along the western extent of the headland is probably due to the presence of tall sea cliffs, where colluvium sediments mantle the basalt, at or near their angle of repose, forming rockfalls and large block slides (Witter and others, 2009). The landslide detritus, consisting of boulders and cobbles, has accumulated along the shoreline where it is exposed to wave action and longshore currents. These processes further redistribute the sediments, winnowing away the finer sediments, eventually forming late-Holocene boulder and gravel beaches.

North of Cannon Beach at Ecola State Park (**Figure 1-1**), complex landsliding is prevalent throughout the park, affecting both road access as well as facilities within the park (Burns and others, 2025). The local geology consists of intrusive basalt dikes that form near vertical sea cliffs (e.g., Indian Point and Chapman Point) separated by weaker Astoria Formation sandstone and siltstone (Witter and others, 2009; Niem and Niem, 1985). The cliffs range in height from 33 ft to >410 ft (10 m to >125 m). The Ecola State Park cliffs transition to a prominent dune system that has formed on the north side of Ecola Creek and south of Chapman Point (**Figure 1-1**).

North of Proposal Rock and south of Ecola Creek (Cannon Beach), the shoreline is largely dominated by late-Pleistocene (<125 thousand years) terrace deposits that transition to middle- to lower-Miocene (~14.5 to 15.5 million year old) Astoria Formation mudstone at Tolovana (Niem and Niem, 1985). The sediments are characterized by well-cemented fluvial gravels, massive beach sand, and poorly bedded mud with fossil shells from estuarine environments (Witter and others, 2009). In many areas, low cliffs along the seaward margin of the terrace are protected from storm wave erosion by a ramp of dune sand and as a result they are well vegetated suggesting that the cliffs have been stable for some time. Nevertheless, the shoreline has also been stabilized by a large number of coastal engineering structures that were constructed in the 1970s and 1980s. The need for such structures suggests a period of higher erosion rates at the time of their installation.

Between Silver Point and Hug Point (**Figure 1-1**), the shore can be characterized as consisting of unstable cliffs, 10 ft to 50 ft (3 m to 15 m) in height, with several major active landslides. The geology in this area is mostly Astoria Formation (middle- to lower-Miocene) sandstone/mudstone units, interspersed with Pleistocene terrace deposits (e.g., in the vicinity of Arcadia Beach), while in the south near Hug Point, exposures of Angora Peak sandstone form prominent cliffs. The community of Arch Cape occupies a broad coastal terrace with few active landslides impacting relatively low (<33 ft (<10 m) high) cliffs. The entire shoreline is naturally armored by a gravel beach that is periodically is covered with sand during summer months.

Falcon Cove is a crescent-shaped beach located between Arch Cape and Cape Falcon (**Figure 1-1**). The small beach community of Falcon Cove that overlooks Cove Beach faces the most severe erosion and landslide hazards among coastal communities in southern Clatsop County. More than 65% of the coastal cliffs backing Falcon Cove show evidence of active or prehistoric mass movement (Witter and others, 2009). Deposits that compose these cliffs are inferred to reflect mostly late-Pleistocene rock-avalanche deposits.

2.2 Coastal Geomorphology

The Clatsop County coastline is 35.4 mi (56.9 km) in length (**Figure 1-1**) and varies in its geomorphology from wide sandy beaches backed by broad dunes (Clatsop Plains), cobble and boulder beaches (Tillamook Head), and bluff backed shorelines (e.g., Tolovana, Arch Cape and Falcon Cove) in southern Clatsop (Allan and others, 2015). Within the study area, Tillamook Head provides a natural barrier to alongshore sediment transport (Clemens and Komar 1998, Komar, 1997), effectively dividing the Clatsop County coastline into two dominant littoral cells within which sediment transport is constrained (**Figure 1-1**). These include:

- Cannon Beach Cell (~10 mi (~16 km)) extends from Falcon Cove in the south to Tillamook Head in the north.
- Columbia River Cell (~115 mi (~ 185 km)) extends from Tillamook Head north to Pt. Grenville on the Washington coast.

2.2.1 Sediment Sources and Budgets

The formation of beaches and dunes is dependent on three requirements: a sufficient supply of sediment, a prevailing wind, and obstacles to trap the sand such as woody debris, vegetation, and microtopography. The speed and direction of the wind is especially important. Strong winds (>9.7 knots (>4.9 m/s)) are capable of entraining and mobilizing dry sand (Bauer and others, 1990), which are then transported across the beach and upslope into the developing dunes or onto older marine terraces where the sand becomes trapped by plants; stronger winds >29 knots (>15 m/s) are required to entrain wet sand (Bauer and others, 1990). The removal of sand onto marine terraces by wind processes constitutes a net loss of sediment from the littoral system. Where vegetation is absent or sparse, the dunes drift about in response to the prevailing wind, where they form a variety of aeolian landforms, including transverse, parabolic, and longitudinal dunes. Accordingly, wind direction is critically important, as it governs the types of dunes that could develop.

Whether a shoreline is eroding or accreting is dependent on the budget of sediments within the littoral system and reflects a balance between sediment inputs and losses (Komar, 1998). Sediment inputs may be derived from a variety of potential sources, including the erosion of coastal bluffs and dunes, longshore sediment transport, as well as from major river systems such as the Columbia River. Sediment may be removed or lost from the littoral system through a variety of mechanisms, including anthropogenic extraction of sand (e.g., dredging within the Columbia River navigation channel), the erosion of sediment from beaches, sediment removal into deeper water in response to extreme storm waves, and, in the long term, because of sea level rise. Where net sediment inputs exceed losses, beach and dune aggradation may occur and the coast will tend to advance seaward. Conversely, where sediment losses exceed inputs, the coastline retreats. Hence, in areas subject to a net gain in sediment, the development of broad beaches and dunes tends to provide natural and effective coastal protection, and at a significantly lower cost when compared with coastal engineering structures (Woodhouse, 1978; Komar, 1998).

The Columbia River is the major river system that bounds the northern end of Clatsop County and has historically supplied sediment to the Clatsop Plains and southwest Washington coastline. South of Tillamook Head, the county is drained by several small creeks, including Ecola Creek and Arch Cape Creek. Ecola Creek reaches the coast at Cannon Beach, while the latter is located at Arch Cape (**Figure 1-1**). However, due to their negligible river flow volumes, neither creek contributes much beach sand to the coastal environment. Therefore, only the Columbia River has the potential to carry relatively large amounts of sediment to the coast in the study area.

Much of the sand present on the beaches of Oregon consists of grains of quartz and feldspar, with smaller quantities of heavier minerals, including pink garnet, hypersthene, hornblende, and augite (Clemens and Komar, 1988). In Clatsop County, significant concentrations of augite and hornblende are likely due to erosion into Astoria Formation sandstone that makes up much of the marine terraces in the Cannon Beach/Tolovana area. This suggests that at the time of deposition, rivers and streams were actively carrying these sediments out to the coast where they mixed with other sediments. The garnet in the beach sand is sourced from the Klamath Mountains in southern Oregon/northern California (Clemens and Komar, 1988). North of Tillamook Head, the contemporary Clatsop Plain beach contains large concentrations of hypersthene, which is likely sourced from weathering and erosion of Columbia River basalts.

2.2.2 Late-Holocene Evolution of Clatsop County Beaches

The contemporary beach and dune system of Clatsop County is young in geologic terms, having begun to form ~4,000 to 5,000 years ago when the rate of postglacial sea level rise slowed and it approached its current level (Komar, 1997; Woxell, 1998; Peterson and others, 2010). As the ocean neared its present level, 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.

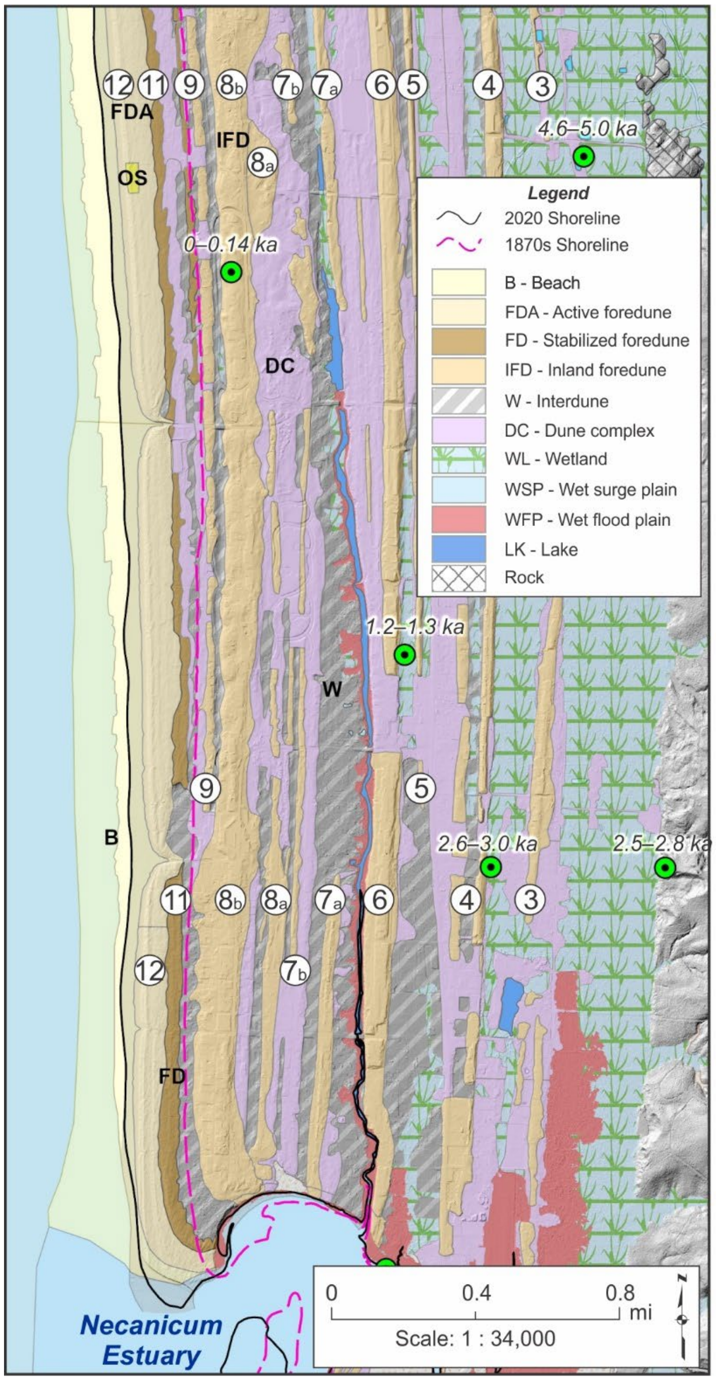
Figure 2-1 presents a geomorphological map of the late-Holocene evolution of the southern Clatsop Plains (Gearhart area). Included in the figure are various carbon 14 (^{14}C) dates (green circles) compiled by Peterson and others (2010), the 1870s and modern-day shorelines, and at least 12 sequences of foredunes mapped as part of this study, with the youngest foredune (12) reflecting the contemporary environment today. Along the right-hand margin of **Figure 2-1** (in gray) are marine terraces, fronted by a sea cliff. A ^{14}C date taken near the eastern edge of the Clatsop Plains and just seaward of the marine terraces (above the legend) indicates an age of 4,600 to 5,000 years. A younger (~2,500–2,800 years) ^{14}C date located east of Gearhart is a basal peat deposit that postdates the formation of the Clatsop Plains (i.e., is younger). A third date sampled at an archeological site known as Palm Rose (not shown on **Figure 2-1**) located southeast of Seaside has a date of ~4,000 years (Woxell, 1998), consistent with our understanding of the late-Holocene evolution of the Clatsop Plains.

As can be seen in **Figure 2-1**, we identify more than 12 independent foredunes that characterize the development of the Clatsop Plains over the past 5,000 years. Foredunes (1) and (2) are not identified at this location but are present farther north along the central to northern Clatsop Plains. A ^{14}C date between foredunes (3) and (4), an interdune area 0.4 mi (0.6) km west of the sea cliffs, indicates an age of ~2,600 to 3,000 years (**Figure 2-1**). Farther seaward, ^{14}C dating of an interdune area between foredunes (5) and (6) indicates ages of about 1,200 to 1,300 years. Dating of foredune (8b) gives an age of <140 years, which places it close to the 1870s era shoreline. Foredune (9) probably characterizes the prejetty condition (**Figure 2-1**), while foredune (11) postdates jetty construction and foredune (12) represents the contemporary foredune system.

Historically, the primary source of sediment to the Clatsop Plains and southwest Washington Coast has been the Columbia River, which was estimated to have supplied ~26.2 million yd^3/yr (20 million m^3/yr) of sediment (Gelfenbaum and others, 1999). Of this, an estimated 19.6 million yd^3/yr (15 million m^3/yr) of sediment was removed from the estuary and transported offshore where it accumulated on the continental shelf and as beaches along the coast of Oregon and Washington. These supply rates are for the total sediment load, including sand, silt, and clay.

South of Tillamook Head in the Cannon Beach cell, the beaches have experienced significantly less accretion due to having very limited sediment sources. Dating of *in situ* tree trunks, periodically exposed out on the beach, suggest forests existed in the intertidal region adjacent to Arch Cape ~4,000 years ago (Hart and Peterson, 2007). This is indicative of the relatively young age of beaches within the Cannon Beach littoral cell.

Figure 2-1. Late-Holocene evolution of the Clatsop Plains. ***Note:*** **Numbered circles denote unique foredune sequences (*this work*). Green circles indicate radiocarbon dates from Peterson and others (2010).**



2.2.3 Post-1880s Geomorphic Changes on the Clatsop Plains

Since the late 1800s, anthropogenic effects have significantly altered the sediment budget of the Columbia River littoral cell and resulted in changes on the Clatsop Plains. These anthropogenic effects include the following:

- Construction of jetties at the estuary mouth essentially controlled the natural migration of the mouth of the Columbia River, resulting in deeper channels and a broader, shallower intertidal region to form within the estuary. Completion of the two main jetties was accomplished by 1917.
- Construction of pile dikes along upriver channels have been used to control flow velocities and sedimentation patterns.
- Construction of 11 major and more than 200 smaller dams in the Columbia and Willamette River watersheds have reduced the supply of sand to the lower estuary and ultimately the coastal beaches.
- A decrease in the peak Columbia River flow since the mid-1960s has reduced the river's ability to transport sediment, particularly out of the lower estuary (Sherwood and others, 1990).
- Dredging and disposal practices. Dredging of the entrance channels began in 1903.
- Proliferation of nonnative dune grasses.

Together, these changes are thought to be a major cause of recent erosion problems observed on Clatsop Spit and the Southwest Washington coast (Sherwood and others, 1990; Gelfenbaum and others, 1999; Kaminsky and others, 2010).

Table 2.1 presents a summary of sand supply rates for the past 120 years, estimated using a sediment rating curve for the Columbia River (Gelfenbaum and others, 1999). Evident in the table is the dramatic decrease in sand supplied to the coastal system, from an estimated 5.6 million yd^3/yr (4.3 million m^3/yr) between 1878–1935 (prior to significant flow modification by the construction of dams) to 1.8 million yd^3/yr (1.4 million m^3/yr) for the period 1958–1997. This represents a decrease in the sand supply by a factor of three during historical times (Gelfenbaum and others, 1999). Furthermore, estimates by the U. S. Army Corps of Engineers (USACE) indicate that only about 0.79 million yd^3/yr (0.6 million m^3/yr) of sand is supplied by the Columbia River under conditions today. The secular decrease in the supply of sand to the coast represents a significant shift in the overall equilibrium of the system.

Table 2.1. Estimates of total sediment and sand volume yields for the Columbia River for pre-dam and post-dam construction (Gelfenbaum and others, 1999).

	Period	Total Sediment Volumes	Sand Supply Volumes
Pre-dam construction	1878–1934	11.4 million yd^3/yr (8.7 million m^3/yr)	5.6 million yd^3/yr (4.3 million m^3/yr)
Post-dam construction	1934–1958	—	3.4 million yd^3/yr (2.6 million m^3/yr)
Significant flow modification after mid-1960s	1958–1997	5.6 million yd^3/yr (4.3 million m^3/yr)	1.8 million yd^3/yr (1.4 million m^3/yr)

The geomorphic changes in the Columbia River system over the past 140 years are most obvious at the mouth of the Columbia River, where construction of jetties caused the coastline to initially prograde seaward. Following construction of the Columbia River south jetty in 1902, Clatsop Spit grew northward by about 2.9 mi (4.6 km) during a period of 50 years. A likely source of the sand that accumulated along Clatsop Spit was due to changes in the Columbia River inlet, which resulted in the development of shoals along the north side of the south jetty, and possibly from erosion of the mid-continental shelf region offshore from the Clatsop Plains (Lockett, 1963; Sherwood and others, 1990). Analyses by Gelfenbaum and others (2001) indicated that between the 1870s and 1926 the mid-continental shelf region and the inlet mouth lost about 476 million yd^3 (364 million m^3) of sand.

Between 1926 and the 1950s, the northern end of Clatsop Spit eroded by some 650 ft to 820 ft (200 m to 250 m). This is probably related to ongoing erosion of the mid-continental shelf region offshore from Clatsop Spit, the product of reduced sand supplies from the Columbia River, and possible dredging and disposal practices that commenced in the river. Furthermore, it is also likely that modifications made to the jetties during the 1930s may also account for some of the shoreline erosion. Much of the eroded sand was displaced either seaward or was transported northward (Lockett, 1963; Sherwood and others, 1990; Gelfenbaum and others, 2001). In particular, the erosion of the outer tidal area provided a large amount of sediment to the littoral system north of the Columbia River, which contributed to significant beach accretion on the Washington Coast, along the Long Beach Peninsula and sedimentation in Willapa Bay. On the central and southern parts of the Clatsop Plains on the Oregon Coast, the shoreline prograded seaward, gaining about 78 million yd^3 (60 million m^3) of sand throughout this period.

Between the 1950s and early 1990s, the rate of erosion along Clatsop Spit stabilized to some degree. However, recent analyses using lidar, aerial photography, and beach surveys indicate that the northern Clatsop Plains has continued to experience erosion over the past three decades (Ruggiero and Voigt, 2000; Allan and Hart, 2008; Allan and others, 2023). In contrast, progradation of the shoreline continues to dominate the beach and dunes south of Camp Rilea (**Figure 1-1**). Because of ongoing erosion offshore from Clatsop Spit and erosion adjacent to the spit tip, the USACE became concerned in early 2000 that part of the south jetty may eventually be undermined through toe erosion. In addition, the northern tip of Clatsop Spit is narrow, approximately 1300 ft–2300 ft (400 m–700 m) wide, such that there were concerns that this section of the spit could eventually be breached, potentially forming a second river mouth. Given that such an event had occurred previously in 1928–1929 (Allan and Gabel, 2016), the USACE implemented a regional sediment management plan to begin placing some of the dredged Columbia River sediments in the nearshore offshore Clatsop Spit and north of the Columbia River north jetty (Greenwood and others, 2011) with the expectation that these sediments would eventually move onshore to renourish the beaches. More recently, the USACE constructed a dynamic revetment cobble beach adjacent to the south jetty root to mitigate an erosion problem there (Allan and others, 2023).

2.2.4 Dune Grasses

Clatsop County beaches and dunes have also been significantly affected by the introduction of European beach grass (*Ammophila arenaria*) and a nonnative American dune grass introduced from the U.S. East Coast (*Ammophila breviligulata*). *Ammophila arenaria* was first introduced in the Coos Bay area in 1905 and later the Clatsop Plains in 1935 (OCZMA, 1979). *Ammophila breviligulata* was introduced into the Warrenton area in 1935 (Hacker and others, 1935). Dune plantings in the Cannon Beach littoral cell are thought to have occurred in the 1950s, with major plantings in northern Cannon Beach in the 1960s. Both plant species quickly proliferated along the Oregon Coast, eventually producing the densely vegetated continuous foredune ridges characteristic of the coast today. Cooper (1958) noted that the introduction of both grass species has resulted in the most profound changes to the morphology and size of dunes on the Oregon Coast.

Prior to their introduction, much of the Oregon Coast was dominated by broad low-lying dunes, generally devoid of beach grass. The dunes were unconstrained and shifted in response to predominant wind directions (OCZMA, 1979). However, with the introduction of dune grasses during the last century, and particularly in the 1950s to 1970s when dune grass plantings accelerated, the dunes stabilized rapidly, and their form began to change. For example, Lund (1973 in OCZMA, 1979) noted that areas of open, active sand on the south-central Oregon Coast narrowed by almost 50% within 30 years. Thus, the present-day foredune systems now consist of large, stable dunes containing significant volumes of sand. With the stabilization of the dunes, humans have settled on them, typically building in the most desirable locations, typically on the most seaward foredune or along the edges of cliffs.

2.3 Contemporary Patterns of Change in Clatsop County

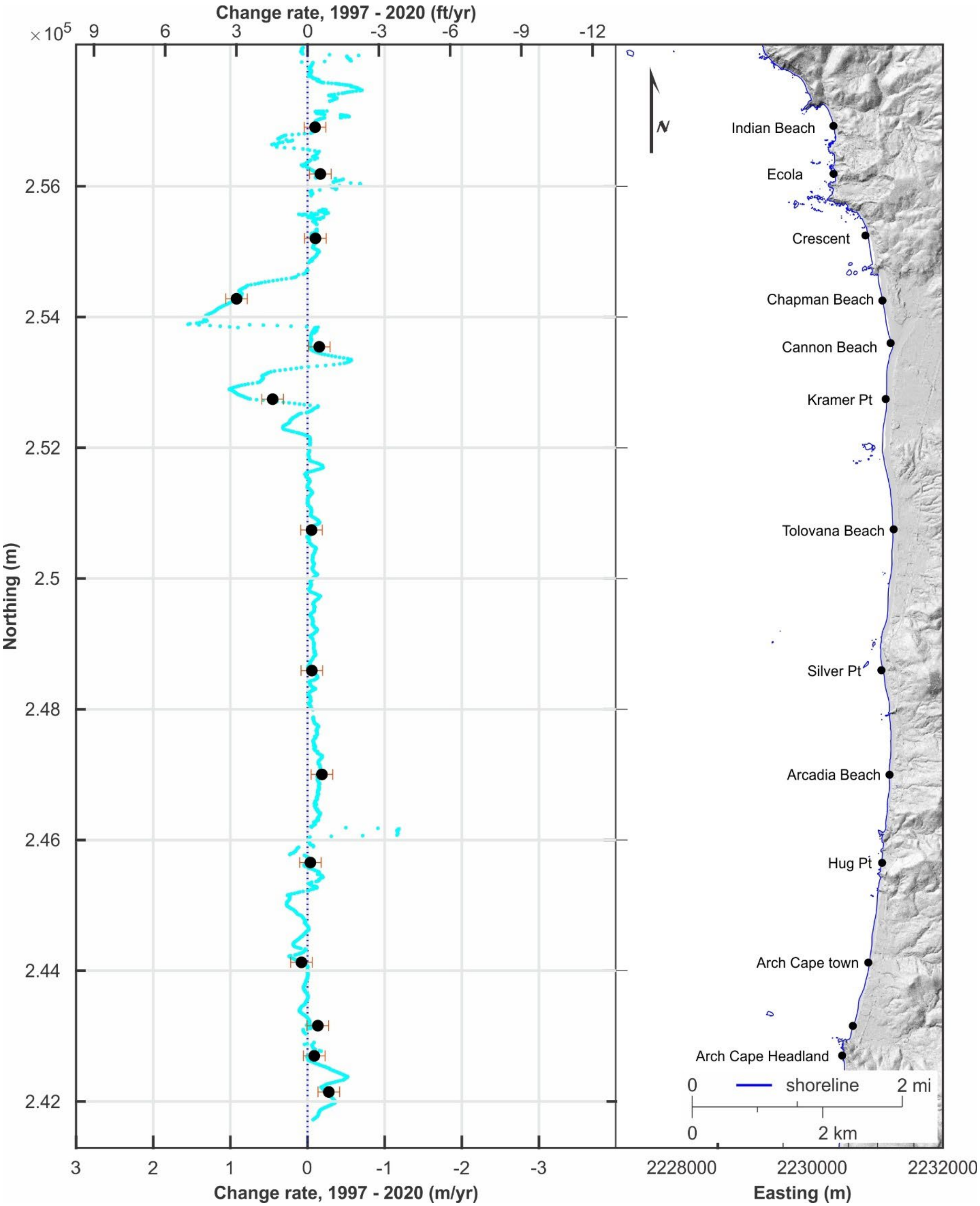
Figure 2-2 and **Figure 2-3** depict coastal changes in Clatsop County derived from lidar measurements made between 1997 and 2020. The changes shown in both figures are measured near the bluff/dune toe at an elevation of 20 ft (6 m). Additional details documenting our overall lidar processing approach are described in Burgette and others (2023). Here, we briefly summarize the main components.

For this analysis, we used lidar data collected in 1997, 1998, 2002, 2009, 2014, 2016, and 2020. The data were downloaded from the NOAA Coastal Service Center and gridded using ArcGIS Pro. The pre-2016 lidar was gridded using a 3-ft (1-m) cell size, and 1.6-ft (0.5-m) grid cell for the 2016 and 2020 lidar. Although the 3-ft (1-m) grid resolution used in the pre-2008 lidar likely pushes the point density limits of those earlier flights, they are probably not unreasonable for the generally low-sloping beaches of the Oregon Coast. Contours of interest were then extracted (e.g., Mean Higher High Water (MHHW), 16.4 ft (5 m), 20 ft (6 m)) and visually checked. The latter was accomplished by comparing the contours against lidar hillshades to identify spurious noise that can be attributed to a combination of insufficient points or spikes in the lidar returns. Noise in the contours was subsequently removed by either clipping out portions of the lines or deleting select vertices.

The contours were processed using the Digital Shoreline Analysis System Version 6 (DSAS) tool developed by the U.S. Geological Survey (Himmelstoss and others, 2018). DSAS is a standalone tool that enables a user to calculate rate-of-change statistics from a time series of vector shoreline positions. Version 6 of DSAS requires the user to specify a baseline (from which change measurements can be defined) and the historical shorelines in a GIS. These data are then output as a GeoJSON file that is read by DSAS. Within the DSAS tool, the user can then cast transects, perform rate calculations, and evaluate the statistical data necessary to assess the reliability of the change-rate calculations. For the purposes of this study, we chose to cast transects spaced 33 ft (10 m) apart for the entire coast. The change-rate calculations can then be converted back to GIS for viewing or further analyzed using software such as Matlab.

Beginning south of the Arch Cape Headland (**Figure 2-2**), the coastal response indicates mainly erosion, varying from ~-0.4 ft/yr to -1 ft/yr (~-0.1 m/yr to -0.3 m/yr). The pattern of erosion decreases slightly to ~-0.2 ft/yr to -0.66 ft/yr (~-0.05 m/yr to -0.2 m/year) between Arch Cape and Cannon Beach. With the exception of Falcon Cove, these results demonstrate that erosion rates along most of the Cannon Beach littoral cell are relatively low. North of Ecola Creek near Chapman Point, the shoreline is advancing seaward at a rate of 3 ft/yr to 5 ft/yr (~1.0 m/yr to 1.5 m/yr). Allan and others (2018) noted that this section of the coast gained approximately 294,400 yd^3 (225,100 m^3) of sediment between 1997 and 2016, largely due to alongshore sediment transport.

Figure 2-2. Coastal change rates and patterns for the period 1997 to 2020 for the Cannon Beach littoral cell, Clatsop County. Cyan points reflect a 164 ft (50 m) smoothing of the individual transect rates while the black circles (with brown uncertainty bars) depict the mean change for the identified study reach (*right*). Negative values indicate erosion, while positive values indicate accretion. Figure includes both English and metric units.



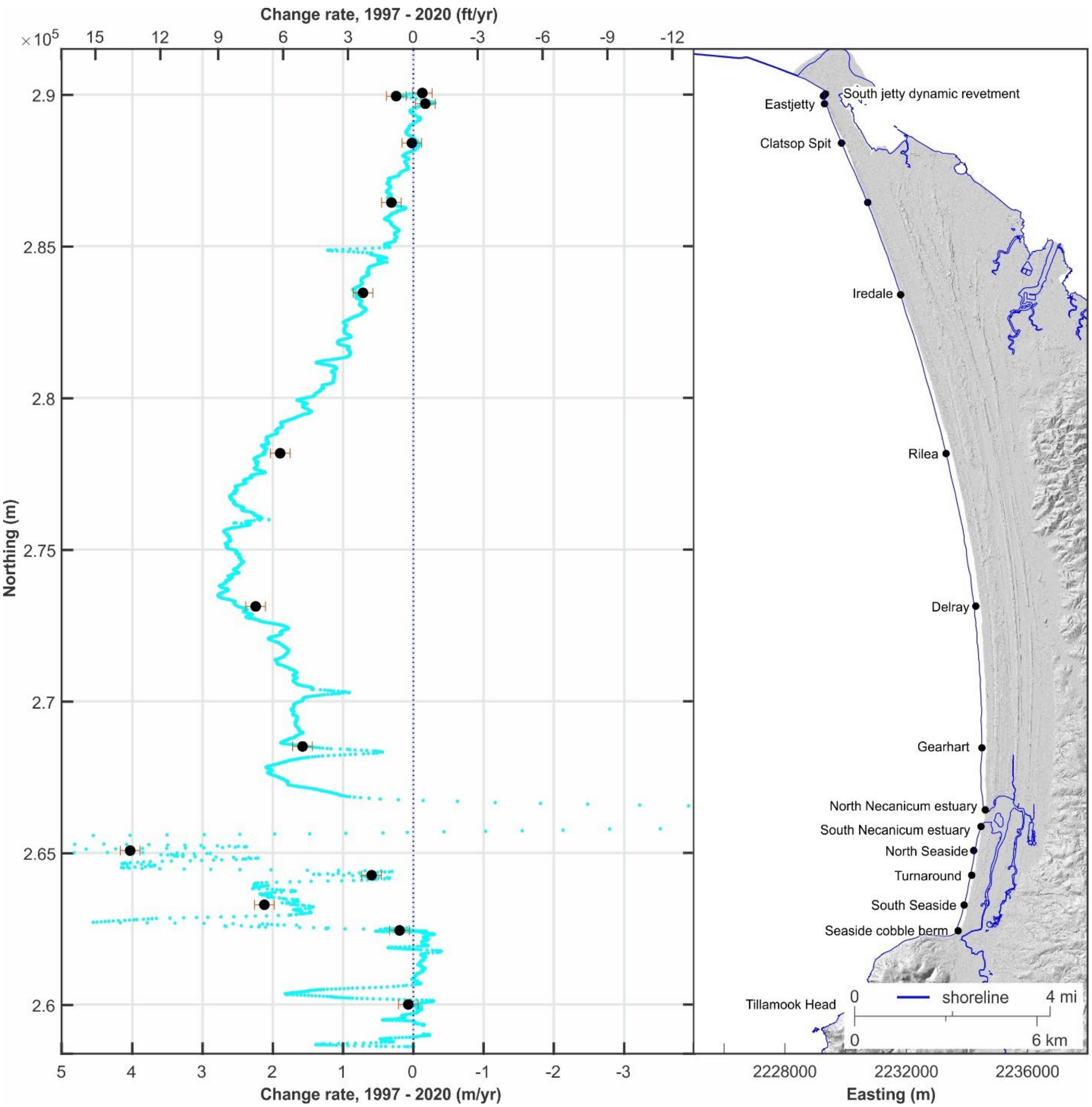
In the Columbia River littoral cell (**Figure 2-3**), the coastal response is overwhelmingly dominated by accretion. Around Tillamook Head, the pattern of change varies from gradual erosion (~-0.4 ft/yr (~-0.1 m/yr)) to a few isolated areas where large influxes of sediment have enabled the shoreline to advance at rates of 3 ft/yr to 6 ft/yr (1 m/yr to 2 m/yr) seaward significantly. The progradation rates reflect sediment input from major landslides occurring around the headland. At Seaside, our analyses indicate that the dunes are advancing seaward at rates of 3 ft/yr to 16 ft/yr (1 m/yr to 5 m/yr), with the highest accretion rates occurring just south of the Necanicum estuary.

On both sides of the Necanicum estuary, erosion dominates the shoreline response, with both sides of the estuary mouth having retreated more than 330 ft (100 m) since 1997 (**Figure 2-3**); this equates to an erosion rate of ~-16 ft/yr (~-5 m/yr). Along the Clatsop Plains, **Figure 2-3** indicates that accretion is occurring along most of the shoreline. The rate of accretion progressively increases northward from the Necanicum estuary to its peak (~8 ft/yr (~2.5 m/yr)) near Delray (**Figure 2-3**), where it then subsequently decreases with progress north along the Clatsop Plains. Near the south jetty and Clatsop Spit, the foredune switches mainly to erosion. Some of this erosion is presently being mitigated by the construction of a dynamic revetment adjacent to the south jetty root (Allan and others, 2016). Nevertheless, recent monitoring of the area south of the dynamic revetment by the authors, indicates that the foredune along Clatsop Spit started actively eroding[1] again in 2022, with the foredune having cut back 66 ft (20 m) in two years. The degree of erosion presently taking place along Clatsop Spit is likely to result in the foredune being breached in the next few years.

In summary, the contemporary beaches of southern Clatsop County are thought to receive little riverine sediment at the open coast today; most of the sediment input is likely derived from erosion of select backshore areas along the coastline. Significant beach sand accumulation is taking place north of Ecola Creek in Cannon Beach, likely in response to alongshore sediment transport. On the Clatsop Plains, accretion dominates much of the coastal response, with rates of accretion ranging from 3 ft/yr to 10 ft/yr (1 m/yr to 3 m/yr) on average, while some of the largest variations in both erosion and accretion can be observed adjacent to the Necanicum estuary mouth. Accretion observed on the Clatsop Plains is likely the result of jetty construction at the mouth of the Columbia River.

[1] https://www.oregon.gov/dogami/nanoos/data/img/lg/CR_usace1_EDA.png?v=6.3.2411211305

Figure 2-3. Coastal change rates and patterns for the period 1997 to 2020 for the Columbia River littoral cell, Clatsop County. Cyan points reflect a 164 ft (50 m) smoothing of the individual transect rates while the black circles (with brown uncertainty bars) depict the mean change for the identified study reach (*right*). Negative values indicate erosion, while positive values indicate accretion. Figure includes both English and metric units.



3.0 METHODS

Our approach to mapping beaches and dunes in Clatsop County closely follows similar work undertaken in Tillamook County (Allan, 2020)) and Coos County (Allan and others, 2024). We used GIS to evaluate the existing beach and dune overlay zones compiled by DLCD from the original USDA (1975) mapping. These data were used to establish the baseline on which the updated GIS layer was developed. **Table 3-1** identifies the key beach and dune classifications developed by the USDA (1975) that were retained in our updated mapping. **Table 3-1** also includes the accompanying DLCD classification (where applicable). Allan (2020) defined six new classifications that are included in **Table 3-1**:

- Artificial Active Foredune (AFDA) – An artificial foredune constructed from geotextile sandbags and planted with dune grass. This category is not relevant in Clatsop County.
- Reactivated foredune (FDR) – These include areas where coastal processes are presently eroding into the previously stabilized foredune (FD). We identify one site north of Ecola Creek that falls into this category.
- Coastal Landslides (LD)
- Fluvial and Estuarine Deposits (FED) – Defined from geologic mapping compiled in the digital Oregon Geologic Database Compilation (OGDC-7) (Franczyk and others, 2020), and from lidar mapping presented as part of this report
- Coastal Lakes (LK)
- Wetlands (WL) – These data were derived from the National Wetlands Inventory (https://www.fws.gov/wetlands/) compiled by the U.S. Fish and Wildlife Service (USFWS).

In addition to the above, we developed several classifications from our Coos County mapping (Allan and others, 2024). These include:

- Coastal terrace (CT) – Although we retain the original coastal terrace classification (CT), we have expanded this to better define different coastal terrace groups (e.g., CT, CT2, CT3, and CT4), where feasible, based on previous geological mapping and age dating.
- Inland dunes (IDN) – These sites reflect dune features that have formed inland from the coast, without any prior assumptions on how they formed.
- Pond (POND) – We include a pond designation to capture smaller water bodies, particularly those water features that are probably ephemeral in nature.
- Rock (ROCK) – We include a 'rock' designation to depict those areas characterized by sea stacks, resistant rocks (e.g., basalt outcrops) and various marine geologic units (e.g., mudstone/sandstone).

These latter classifications help to better define additional geographic and geologic features evident along the Clatsop 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 3-1. 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/inland stabilized dune		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, CT2, CT3, CT4
	New:	—	
	Artificial active foredune	—	AFDA
	Developed areas	—	DEV
	Reactivated foredune (subject to erosion/flooding)	—	FDR
	Fluvial and estuarine deposits	—	FED
	Coastal landslide	—	LD
	Inland dunes, not related to coastal processes	—	IDN
	Lake	—	LK
	Pond	—	POND
	Rock	—	ROCK
	Jetty	—	JT
	Wetland	—	WL

3.1 Previous Coastal Hazard Studies

Because the foundation of the beach and dune overlay zone includes those areas subject to active coastal change (either erosion or accretion) and/or those areas that 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; Witter and others, 2007), recently completed geomorphic analyses and erosion analyses (Allan and others, 2008; Allan and others, 2018), coastal flood modeling (Allan and others, 2012), and mapping (Burgette and others, 2023).

3.2 Lidar

We mapped beach and dune morphology primarily from lidar data collected by DOGAMI in 2008-2009. 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 geolocated using an onboard Real-Time Kinematic Differential Global Positioning System (RTK-DGPS). The lidar data have a vertical accuracy of ~0.3 ft (~0.1 m). The horizontal accuracy is ~3 ft (~1 m). 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 others (2015) 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). Additional information concerning post-2009 beach and shoreline changes was obtained from lidar collected in 2016 by the U.S. Geological Survey, in 2020 by the USACE, and from 2022 National Agriculture Imagery Program aerial images of the coastline.

3.3 Aerial Imagery

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

The earliest compilation of aerial photographs of the Oregon Coast was undertaken in 1939 by the USACE. Unfortunately, the images are simply stereopairs that have never been rubber-sheeted or orthorectified. Orthorectification is an approach used to process imagery to account for optical distortions (e.g., tilt or relief) with the goal of yielding a planimetrically correct image that is fixed to a geospatial coordinate system, enabling the data to be viewed and analyzed in GIS. However, this process is expensive to perform and is very time intensive. Therefore, we used simple tools in GIS to rubber-sheet the images to their approximate position.

In order to rubber-sheet the images, we processed the 1939 aerial photographs using the georeferencing tools in Esri® ArcGIS. This was accomplished by identifying common ground control points (e.g., road junctions, bridges, buildings, rock outcrops) that can be seen in both the 1939 images and in contemporary (1994, 2000, 2004, 2009, 2014, 2016, 2018, 2020, and 2022) orthorectified images (or lidar). Using this approach, several 1939 photos were able to be georeferenced for Clatsop County, spanning Cannon Beach and Seaside, which enabled comparisons to be made against modern images of the coastline and 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 the 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 consist of 1,611 photographs along roughly 50 to 60 flightpaths for the open ocean beaches (no bays). The photographs were taken at 1:6,000 scale, such that 1 in (2.5 cm) on the photographs 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 (DEM) developed from 2002 lidar data.

3.4 Wet Areas

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. Therefore, we downloaded the USFWS National Wetland Inventory (USFWS, 2024) for Oregon, which were then examined in a GIS. Identified wetlands (WL) were added to the revised beach and dune overlay.

3.5 Estuary Shoreline and Storm Floodwater Level

The USDA (1975) beach and dune mapping includes 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 NOAA National Ocean Service (NOS) topographic "T" Sheets. The *wet flood plain* is essentially that area that can be reasonably expected to be inundated under flood conditions. Again, the USDA did not provide specific information as to 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 8.8 ft (2.69 m) relative to NAVD88, which equates to the mean higher high water (MHHW) tidal datum defined for the Astoria tide gauge station by NOAA NOS. The NOS (2023) defines MHHW as "the average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch (NTDE)" and is a reasonable approximation for the *wet surge plain*. The NTDE is a 19-year period used by NOAA NOS over which tide observations are taken and reduced to obtain mean values (e.g., MHHW) for various tidal datums. The current NTDE spans the period from 1983 through 2001 and is revised every 20 to 25 years to account for sea level changes (NOS 2023). For the *wet flood plain*, we used an elevation of 12.6 ft (3.84 m, relative to NAVD88), which equates to the highest-observed tidal elevation at the same gauge. This elevation indicates a storm flood, whereby the elevated water levels are a function of the combined effects of high tide, storm surge, and riverine flooding. For both the *wet surge plain* and *wet flood plain*, 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 orthoimagery (e.g., 2022) to evaluate any spatial changes that may have ensued in the estuary shoreline between 2009 and 2022.

3.6 Marine Terrace Mapping

A series of uplifted marine terraces have been mapped and described for many areas along the Oregon Coast. Detailed investigations of uplift rates and terrace ages include work undertaken by Muhs and others (1990) between Cape Blanco and Coquille Point, Coos County, Kelsey and others (1996) on the central Oregon Coast, recent work by McKenzie and others (2022) in the Newport area, and work by Padgett and others (2019) in northern California at Trinidad Head. The terraces capture the effects of global eustatic changes in sea level that is superimposed on long-term tectonic uplift and local faulting (McKenzie and others, 2022). Kelsey and others (1996) dated several of the marine terraces and identified ages of 80 ka (thousand years), 105 ka, and 125 ka, respectively. Inclusion of information on the spatial extent of marine terraces in the Clatsop County beaches and dunes updated mapping is relevant because the terraces are a major geomorphic feature in this part of the coast. Furthermore, the terraces include areas where older stabilized dunes (ODS) have formed.

To assist with delineating potential marine terraces and boundaries, we used the semi-automated classification model (SCM) approach of Bowles and Cowgill (2012). Since marine terraces are characterized by relatively low slopes (1°–6°, but may be as high as 15° as the terraces age) and relatively smooth surfaces, the SCM approach was developed to evaluate both topographic components. Hence, the goal of the SCM processing is to broadly delineate those areas characterized by both low slope and relief (Bowles and Cowgill, 2012), which may be evaluated further using more rigorous field-based mapping techniques.

For this study, we used bare-earth lidar collected by DOGAMI in 2008–2009. The data were initially regridded using a 6.0 ft (1.8 m) cell size consistent with Bowles and Cowgill (2012) and McKenzie and others (2022); a cell size of 12.0 ft (3.6 m) was also used to evaluate a smoother product. A slope map was first generated using a three by three window, producing slope values for each digital elevation model (DEM) cell. The slope map was clipped by setting all slopes >15° to null and then normalized by dividing the slope values by 15°, producing a DEM with values ranging from zero to one. Having performed the initial slope calculations, the surface roughness (standard deviation of the slope) was then determined using the same 3x3 window; note that larger values are synonymous with greater roughness. We clipped our roughness maps by setting all values >4 to null, consistent with Bowles and Cowgill (2012) and McKenzie and others (2022), and then normalized these data by dividing the values by four. Finally, the SCM was calculated by multiplying both the slope and roughness DEMs by 0.5 and then combining the results (Equation 1 in Bowles and Cowgill, 2012) to yield values that range from zero to one. Using this approach, SCM values close to zero indicate both low slope and low roughness, with values <0.3 found to most closely approximate known marine terraces (Bowles and Cowgill, 2012; McKenzie and others, 2022).

Final mapping of the marine terraces was undertaken manually, guided by the SCM approach, a hillshade image from the bare-earth DEM, orthorectified aerial images of Clatsop County, and previous geologic mapping of the area (e.g., Niem and Niem, 1985; Witter and others, 2009).

4.0 RESULTS

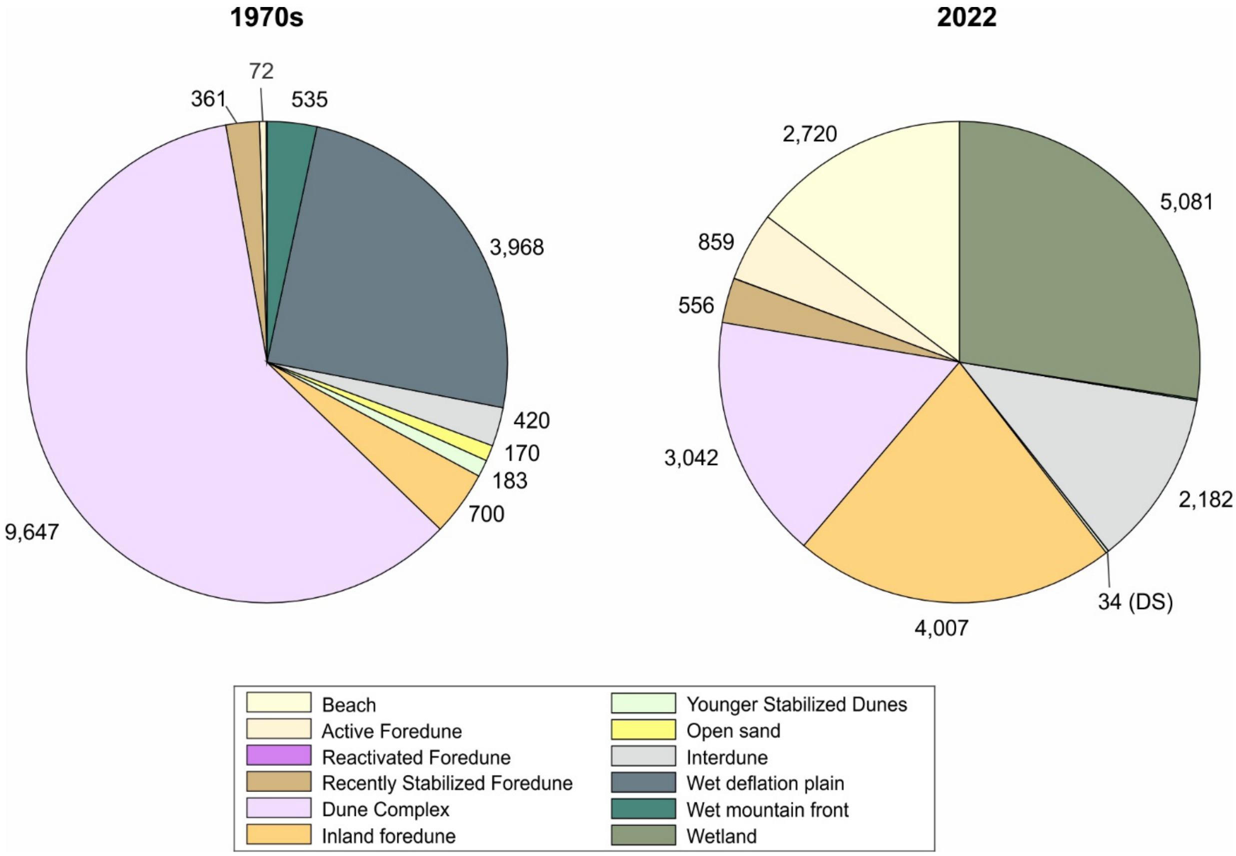
The primary results associated with this latest mapping effort are contained in an Esri geodatabase “Clatsop_Dune_Revised_2024.gdb”. The feature dataset file “Beaches_and_Dunes” contains the updated geospatial information and includes the following key attributes: “Codes”, “Feature”, “Notes”, “Notes_additional”, “Coastal_hazard”, “Location”, and “Cell”. This contrasts with the original geospatial overlay, which only included information specific to the codes and feature class. In the updated GIS, “Codes” and “Features” (**Table 3-1**) are identical to information included in the original USDA (1975) mapping. The “Notes” attribute includes generalized information about the respective feature (e.g., prejetty or postjetty foredunes), coastal geomorphic notes (e.g., former foredune), or Quaternary coastal terrace designation (e.g., x). The “Notes_additional” attribute contains secondary information that may be useful. The “Coastal_hazard” attribute includes specific hazard information unique to that feature, including whether the area is subject to existing wave erosion, runup, overwash, and inundation processes; may be impacted in the future due to sea level rise (either erosion and/or flooding) associated with climate change; or is subject to aeolian wind processes. Location names are included where relevant in the "Location" attribute. The "Cell" attribute categorizes the geomorphic units by littoral cell or subcell. Finally, source information (e.g., mapping data from Witter and others (2007) or from mapping as part of this study) is also provided in the GIS.

Here, we will briefly describe and summarize some of the key changes that have taken place along the Clatsop County 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 the Cannon Beach and Columbia River littoral cells.

4.1 Countywide Beach and Dune Changes

Figure 4-1 presents pie charts depicting changes in the coastal geomorphology of Clatsop 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 a small area at the south end of Seaside and ignored all other areas. The overall focus of **Figure 4-1** is a subset of the suite of USDA classifications identified in **Table 3-1**, 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), and recently stabilized foredune (FD). The reason for focusing on these specific units is that they are of greatest significance under Goal 18. In addition to these three core units, we also compare changes in the acreage of recently stabilized dunes (DS), areas characterized as interdune (W), deflation plain (WDF), mountain front (WMF) and wetlands (WL)) and open sand (OS). The values listed for each pie chart in **Figure 4-1** reflect the acreage associated with the 12 units used here, while the proportions of each pie graphic are based on the sum of the combined acreage of the units. Thus, **Figure 4-1**'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 to the next. **Table 4-1** 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 4-1** reflect a smaller subset of the suite of units defined in **Table 3-1**. It is important to note that the total area mapped in this study increased by ~18,477 acres (7,477 hectares (ha)) when compared with the USDA (1975) mapping. This change mainly reflects the inclusion of areas defined as beach (B), and a generic 'rock' classification to fill in gaps between the various units.

Figure 4-1. Pie charts depicting differences in mapped extents of select coastal geomorphic units between the 1970s and 2022, Clatsop County. Values shown reflect the acreage of each associated unit. Note: Total mapped areas for the 1970s (23,082 acres (9,340 ha)) and for 2024 (41,559 acres (16,818 ha)) differ by 18,477 acres (7,477 ha).



A few notable changes are worth mentioning that stand out in **Figure 4-1** and **Table 4-1**. The largest changes reflect the inclusion of areas characterized as beach (B) and the significant increase in areas classified as active foredune (FDA, 1,095%) and recently stabilized foredunes (FD, 54%). Conversely, recently stabilized dune (DS) and open sand (OS) areas decreased by 81.6% and 98%, respectively. However, it is important to note that neither of these units are prevalent in Clatsop County; they comprise about 0.23% of the total area mapped. Elsewhere our updated mapping reveals a massive increase in areas mapped as inland foredune (IFD, 700 acres (28 ha) in 1975 compared with 4,007 acres (1,621 ha) in 2024, a 472% increase), while interdune (W, 420 acres (170 ha) compared with 2,182 acres (883 ha) in 2024) areas increased by 48% (**Figure 4-1**). Both units characterize much of the Clatsop Plains geomorphic units. Lastly, it is worth noting the 68% decrease in areas classified as dune complex (DC). Much of this change can be explained in terms of our improved mapping of inland foredunes (IFD) and interdune (W) areas, as well as designation of wetlands (WL) shown in **Figure 4-1**.

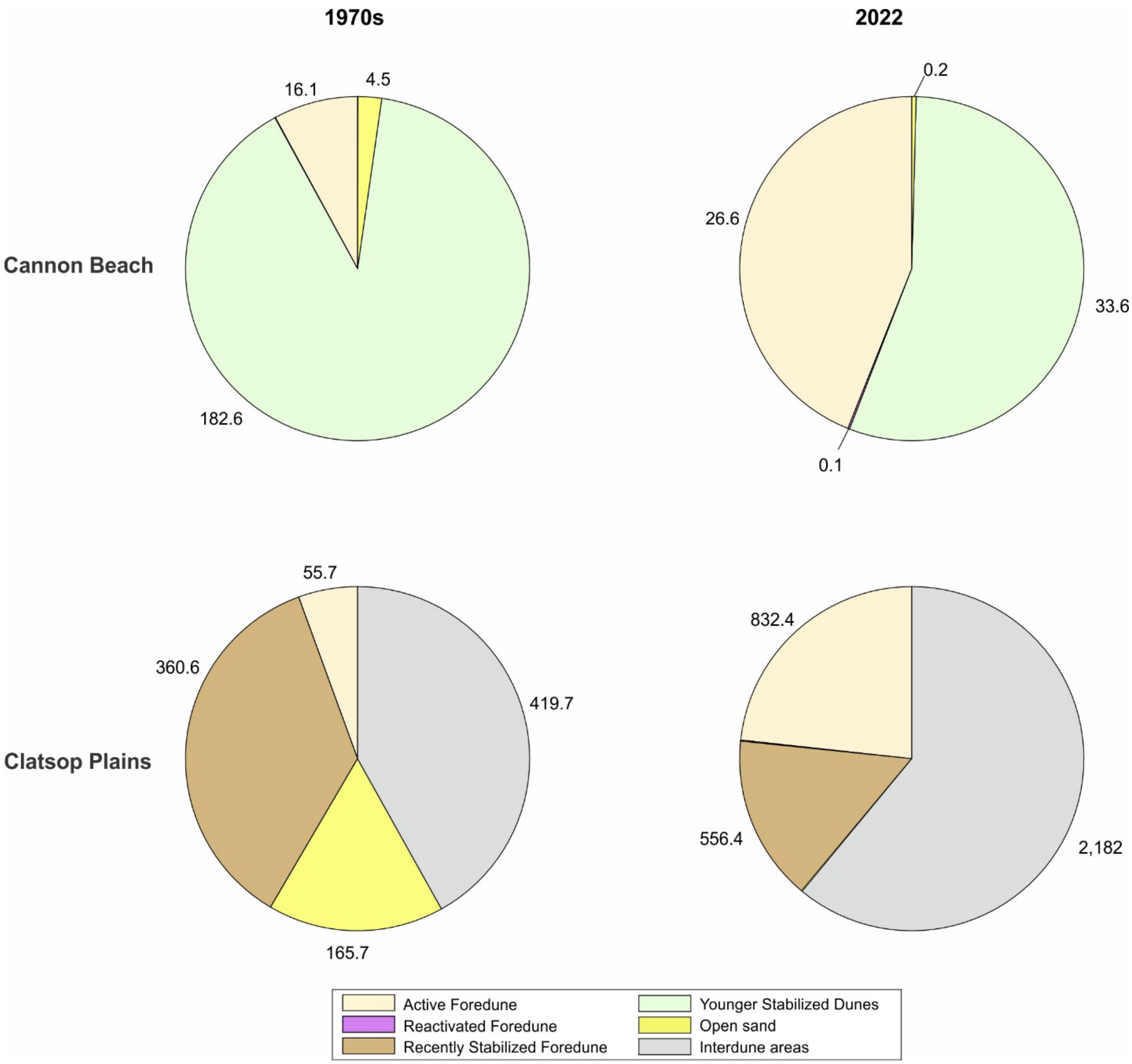
We can perform the same comparison as shown in **Figure 4-1** but now focused on the two littoral cells (**Figure 4-2**). Focusing first on the Cannon Beach cell, we observe an 82% decrease in areas characterized by younger stabilized dunes (DS) from 1975 to 2024; there are no younger stabilized dunes (DS) classified for the Clatsop Plains. Conversely, areas defined as active foredune (FDA) have increased by 65% over the past 50 years, from 16 acres (6.5 ha) to 26.6 acres (10.8 ha). Although not included in **Figure 4-2**, the rest of the Cannon Beach cell is predominantly comprised of a combination of marine terraces, various 'rock' units, and numerous landslides.

Table 4-1. Change in acreage of various coastal geomorphic units within each littoral cell and expressed as a total for Clatsop County from the 1970s to 2022.

Code	Description	Cannon Beach (Acres)	Clatsop Plains (Acres)	Total
B	Beach	836.6	1,874.3	2,711.0
FDA	Active foredune	10.5	776.7	787.2
FDR	Reactivated foredune	0.1	3.6	3.7
FD	Recently stabilized foredune	0.0	195.9	195.9
DC	Dune complex	0.0	-6,605.4	-6,605.4
H	Hummocks	0.0	3,307.6	3,307.6
DS	Younger stabilized dunes	-149.0	0.1	-149.0
OS	Open sand	-4.3	-163.0	-167.3
W	Interdune	0.0	1,762.4	1,762.4
WDP	Wet deflation plain	0.0	-3,968.4	-3,968.4
WMF	Wet mountain front	-193.9	-319.9	-513.8
WL	Wetland	336.8	4,743.7	5,080.6

In the case of the Clatsop Plains cell, **Figure 4-2** indicates that there has also been a considerable increase (419%) in areas characterized as interdune (419.7 acres to 2,182 acres (169 ha to 883 ha)). Areas defined as active foredune (AFD) have also increased (1400%) since the 1970s (56 acres (23 ha) compared with 832 acres (337 ha)). Recently stabilized foredunes (FD) have also seen a significant increase in acreage when compared with mapping undertaken in the 1970s (360 acres to 556 acres (146 ha to 225 ha)).

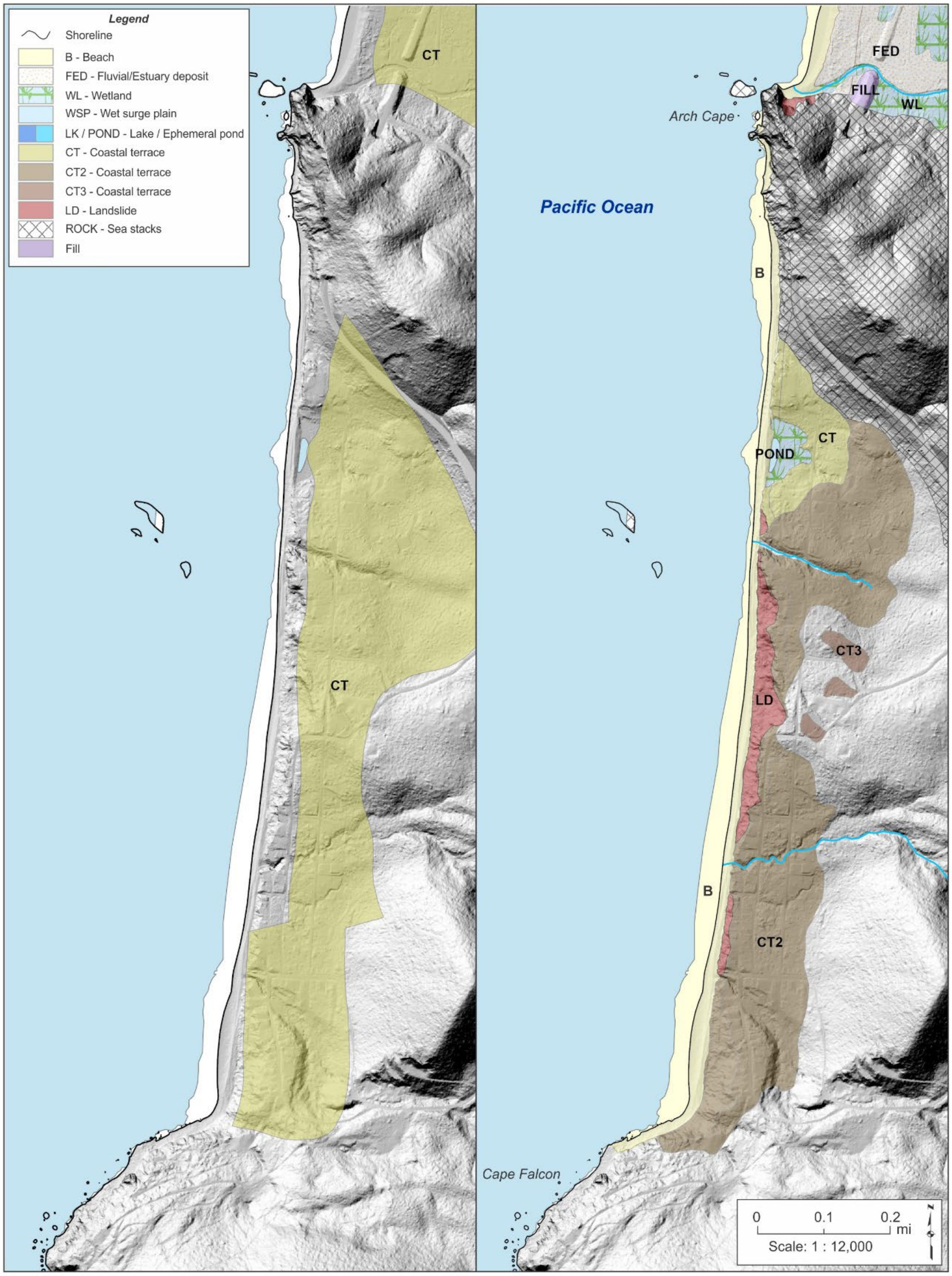
Figure 4-2. Pie charts depicting coastal geomorphic unit changes defined for both Clatsop County littoral cells. Values shown for each pie reflect acres of land, drawn from Table 4.1. Pie proportions are a function of the combined value of the six units presented in the figure.



4.2 Falcon Cove

Figure 4-3 is a map showing the suite of coastal geomorphic units based on the original USDA (1975) mapping (*left*) compared with present-day conditions (*right*) for Falcon Cove. As can be seen in the figure, the original mapping depicted this entire area as coastal terrace. The revised mapping confirms the dominance of coastal terraces throughout Falcon Cove but refines their spatial extent. In addition, the latest mapping now captures the active beach (B), coastal landslides (LD), and a small barrier beach that fronts a wetland/pond area at the northern end of the cove. Figure 4-3 also includes areas defined generically as 'rock', though this particular classification is characterized by a variety of geologic units from Tertiary mudstones and sandstones to basalt intrusions.

Figure 4-3. Beach and dune geomorphic mapping classifications for Falcon Cove. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study).



4.3 Arch Cape

The suite of coastal geomorphic units in the Arch Cape area is shown in **Figure 4-4** and compares the original mapping (*left*) with the updated mapping (*right*). Like Falcon Cove, the original 1975 mapping depicted much of this coastline as marine terrace (CT); note, the active beach (B) was not defined in the original mapping. Our latest mapping again highlights the prevalence of the coastal terrace throughout the area, consistent with the original mapping. Coastal bluffs back the beach over much of the area and these range in height from ~20 ft to 66 ft (~6 m to 20 m). At the south end of Arch Cape, the bluffs decrease in height and eventually merge with the barrier beach. The entire length of the Arch Cape shoreline is classified as a composite beach type in which the gently sloping sand beach is backed by a steep gravel berm that abuts against the bluff. As can be seen in **Figure 4-4** (*right*), the coastal terrace is interspersed with fluvial outwash deposits as well as several small landslide features. The fluvial outwash deposits are the product of historical and contemporary drainage of creeks and streams as they erode the hills surrounding Arch Cape. Within these latter deposits, wetlands (WL) have formed. **Figure 4-4** (*right*) also includes fill deposits that support State Highway 101. At the southern end of the beach, a single date of an *in situ* tree stump on the beach gives an age of ~3,980 years before present (Hart and Peterson, 2007).

4.4 Arcadia Beach

Figure 4-5 presents the updated mapping results for the area covering Hug Point, Arcadia Beach and Silver Point. Similar to Arch Cape and Falcon Cove, the original 1975 mapping depicted much of this coastline as marine terrace (CT), while the active beach (B) was not mapped. This section of beach is entirely made up of coastal bluffs that range in height from 33 ft to 164 ft in height (10 m to 50 m). Similar to Arch Cape, Arcadia Beach is dominated by a low-sloping sand beach with some cobble located at the back of the beach. However, the cobble berm in this section has much less volume when compared with Arch Cape. Several major landslides can be found along this section of shore, the most notable being the large landslide in the north at Silver Point. An excellent account of the history of this particular landslide is described in Witter and others (2009). Interspersed between the landslides are coastal terraces (CTs).

4.5 Tolovana

Changes in beach and dune mapping in the Tolovana area, located just south of Cannon Beach is presented in **Figure 4-6**. This section of shore is dominated by coastal bluffs in the south (Silver Point) and north (Proposal Rock). Between these two areas is a region characterized with mostly very low bluff heights (<18.7 ft (<5.7 m)). The entire area is highly developed and there is extensive coastal engineering along the shore, a testament to a period of time when this area was undergoing erosion. However, recent monitoring in this area suggests that much of the shoreline is presently stable. As with the coast to the south, the original 1975 geomorphic mapping depicted much of this coastline as coastal terrace (CT), while the active beach (B) was not mapped. Midway along the shoreline, the USDA (1975) mapped part of the coastline as younger stabilized dunes and older stabilized dunes. In contrast, our latest mapping depicts this entire section as a coastal terrace, consistent with observations by Witter and others (2009). Several known landslides are also mapped in the south (Silver Point) and north. Fluvial deposits can be identified in a few low-lying areas in the southern half of the Tolovana area.

Figure 4-4. Beach and dune geomorphic mapping classifications for Arch Cape. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study). Green circle indicates sample location for ^{14}C date determined by Peterson and others (2010).

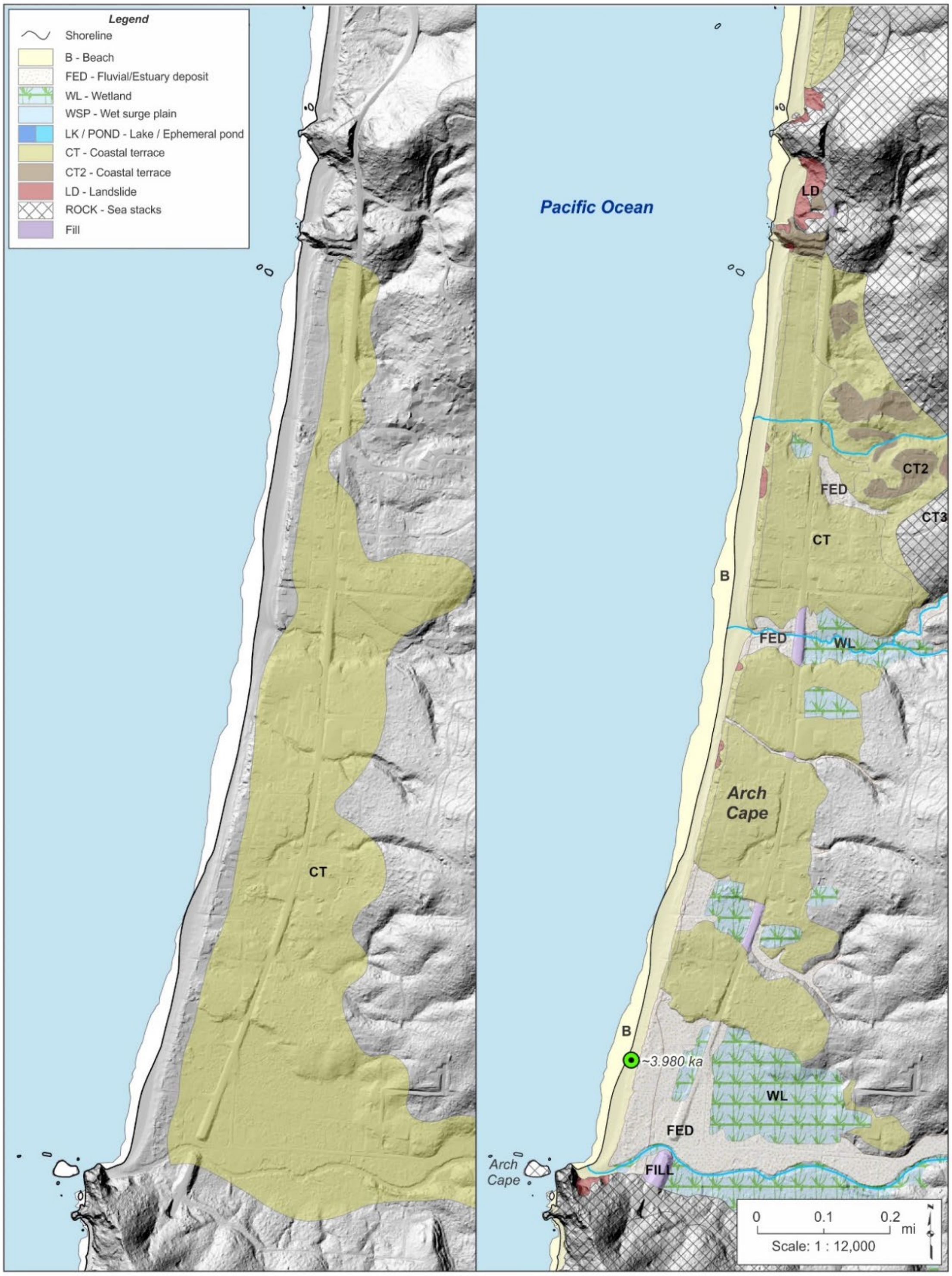


Figure 4-5. Beach and dune geomorphic mapping classifications for Arcadia Beach. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study).

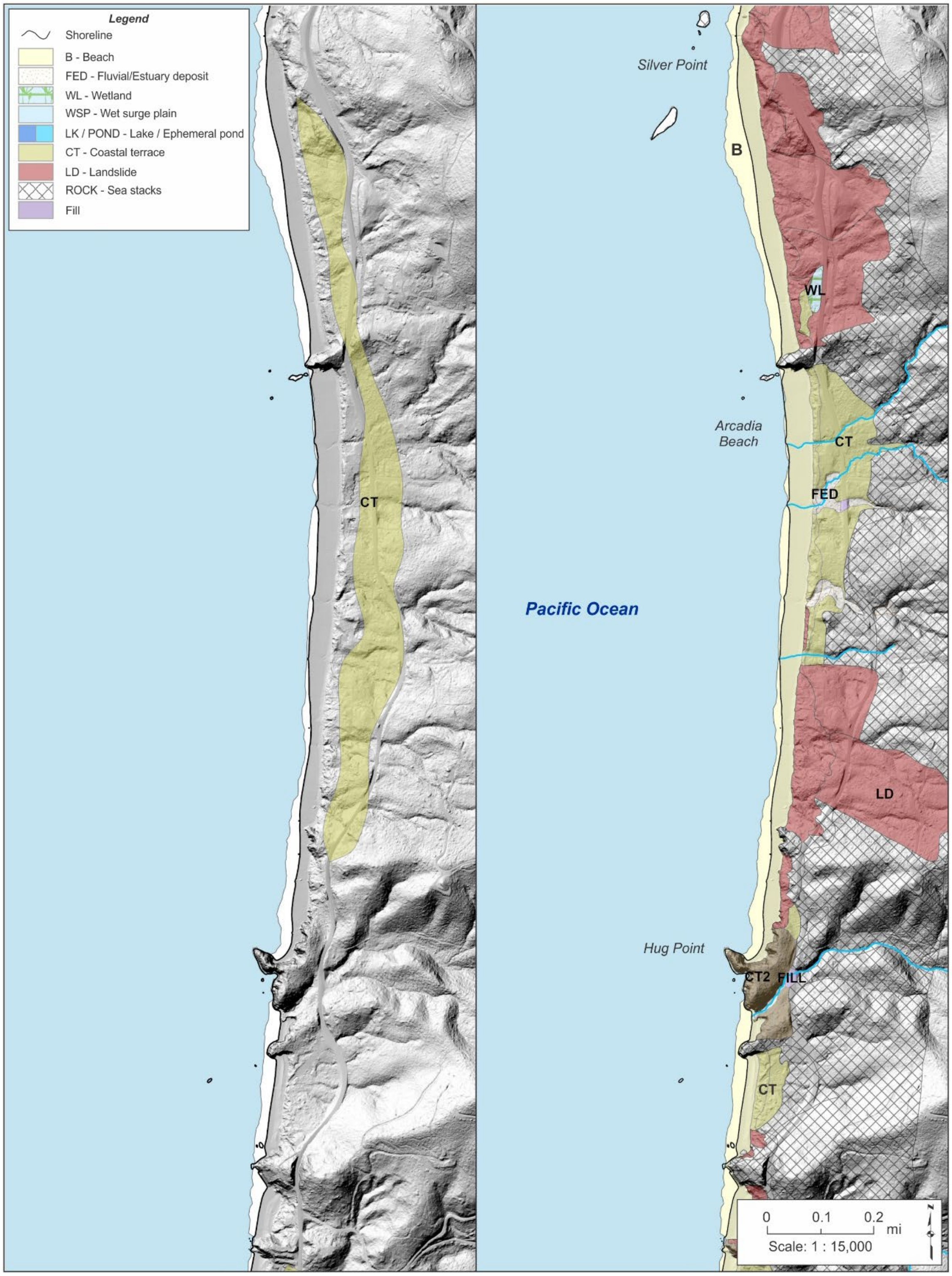
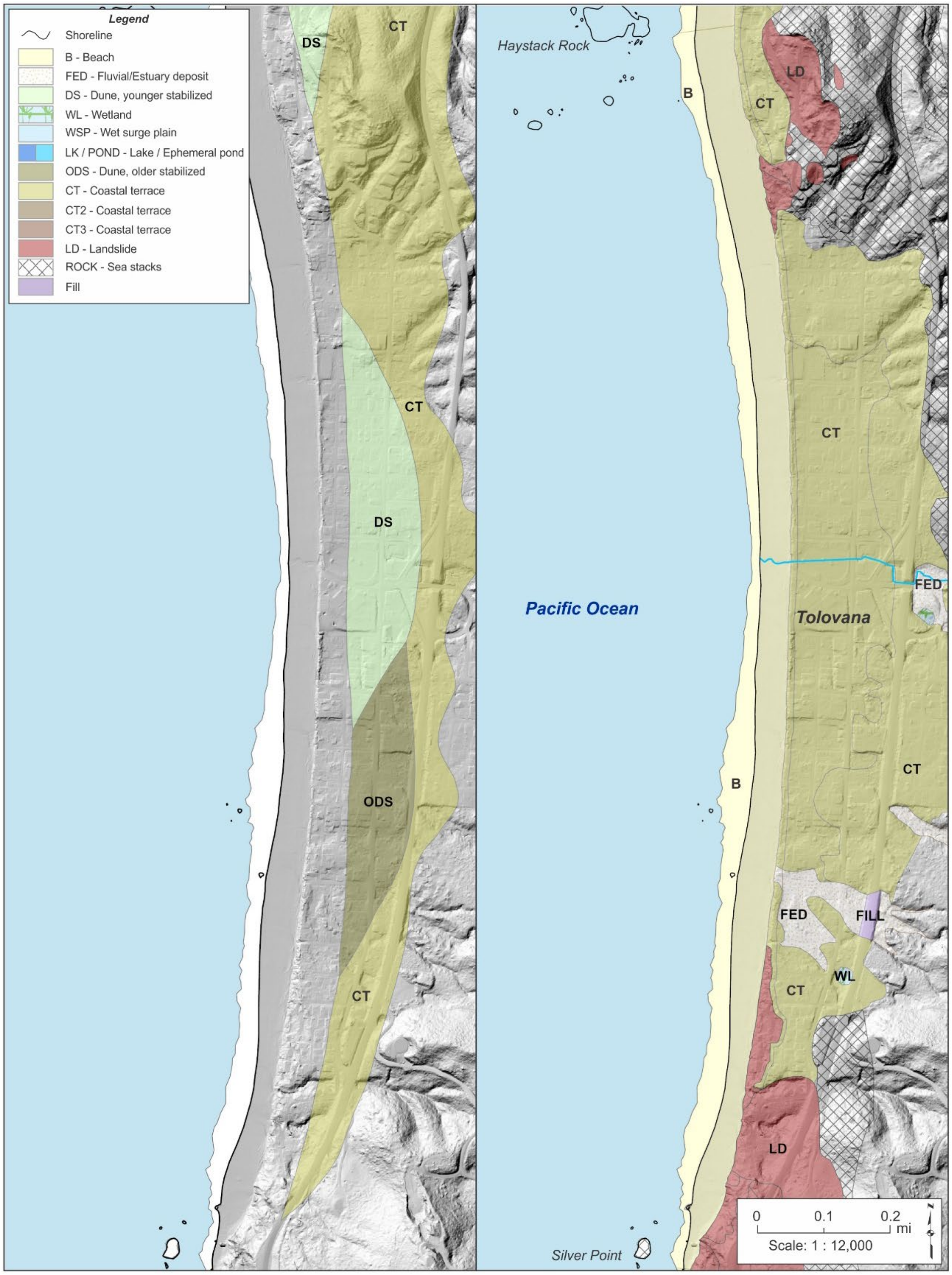


Figure 4-6. Beach and dune geomorphic mapping classifications for Tolovana. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study).



4.6 Cannon Beach

Figure 4-7 shows the suite of coastal geomorphic units based on the original USDA (1975) mapping (*left*) compared with present-day conditions (*right*) for Cannon Beach. As can be seen in the 1975 mapping, much of this shore was originally mapped as recently stabilized dunes (DS) and wet mountain front (WMF), with coastal terraces (CTs) located in the south. The latest geomorphic mapping highlights greater complexity. Much of the area originally classified as recently stabilized dune (DS) is now remapped as coastal terrace (CT). The exception is a small area of stabilized dune (DS) located near the south end of town. Downtown Cannon Beach is built entirely on fluvial-estuary deposits, the product of sediment accumulation over the past several thousand years due to erosion of the surrounding hills and the transport of these sediments down Ecola Creek. North of Ecola Creek, a prominent active foredune (FDA), recently stabilized dunes (DS) as well as fluvial deposits have developed. As described previously, Allan and others (2018) observed that the foredune north of Ecola Creek accumulated ~294,400 yd^3 (~225,100 m^3) of sediment between 1997 and 2016. A small area mapped as open sand (OS) in 1975 is now gone in our updated mapping, having been stabilized by beach grasses and shore pine. Areas subject to landsliding form the northern and southern boundaries of this section of coast.

4.7 Ecola State Park Area

Figure 4-8 shows the results of the latest geomorphic mapping for the Ecola State Park area. This entire section was not mapped by USDA (1975). However, we have included geomorphic mapping for this section of coast for completeness. The Ecola State Park area has coastal bluffs that range from 33 ft (10 m) to more than 410 ft (10 ft to more than 125 m) in height. This entire section of coast is dominated by active and potentially active landslides, interspersed with basalt outcrops.

Figure 4-7. Beach and dune geomorphic mapping classifications for Cannon Beach. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study).

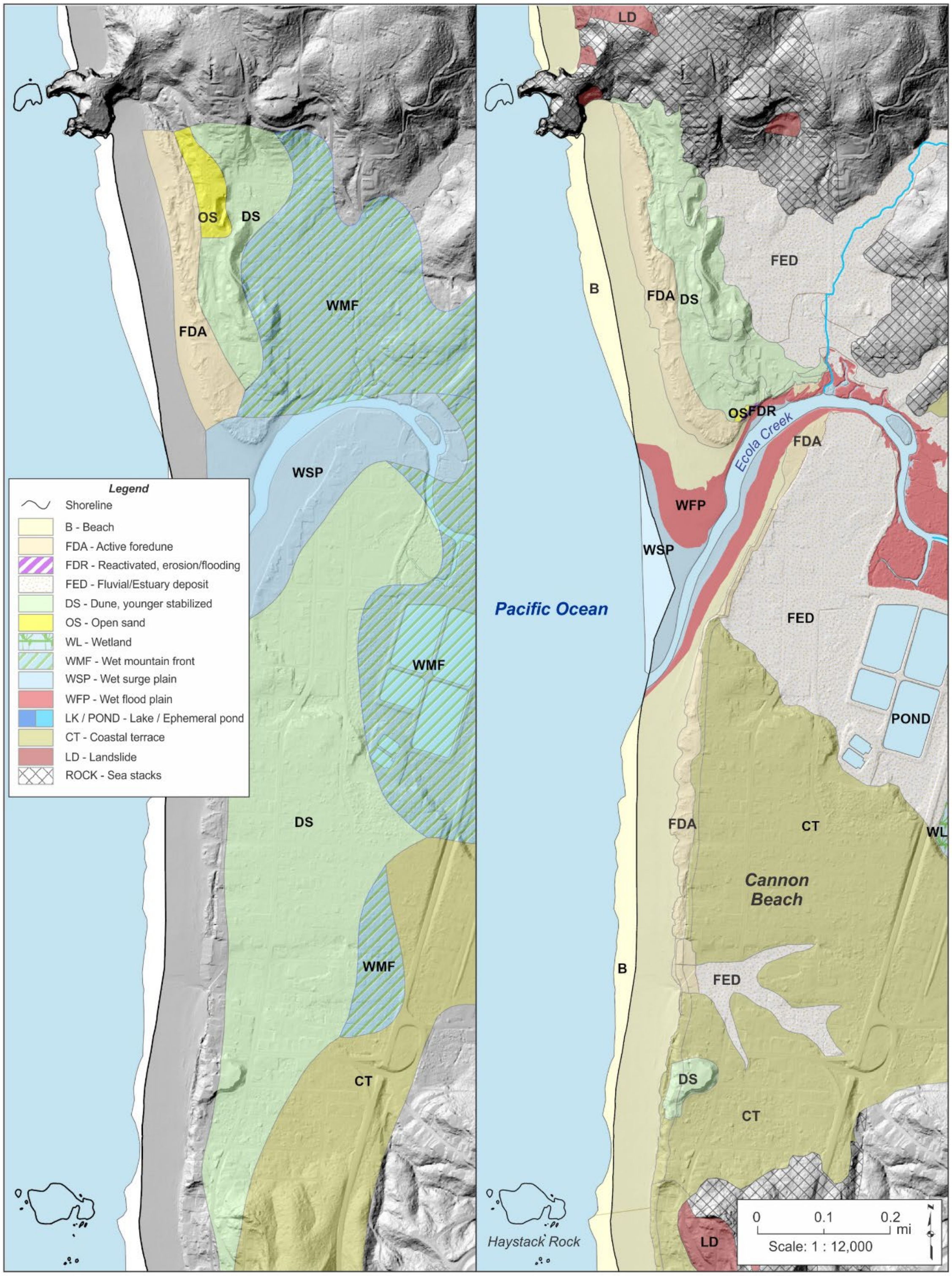
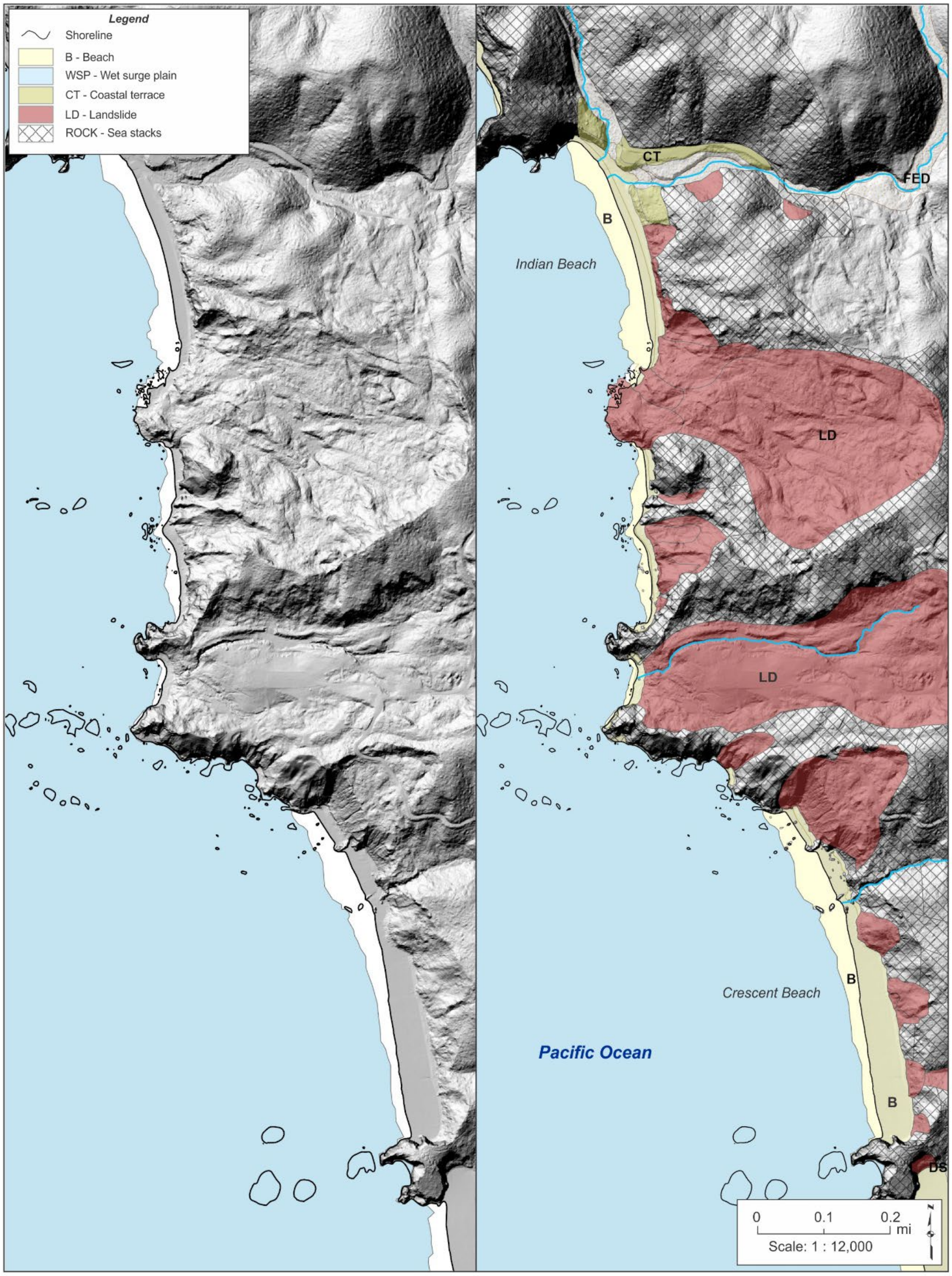


Figure 4-8. Beach and dune geomorphic mapping classifications for Ecola State Park. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study).



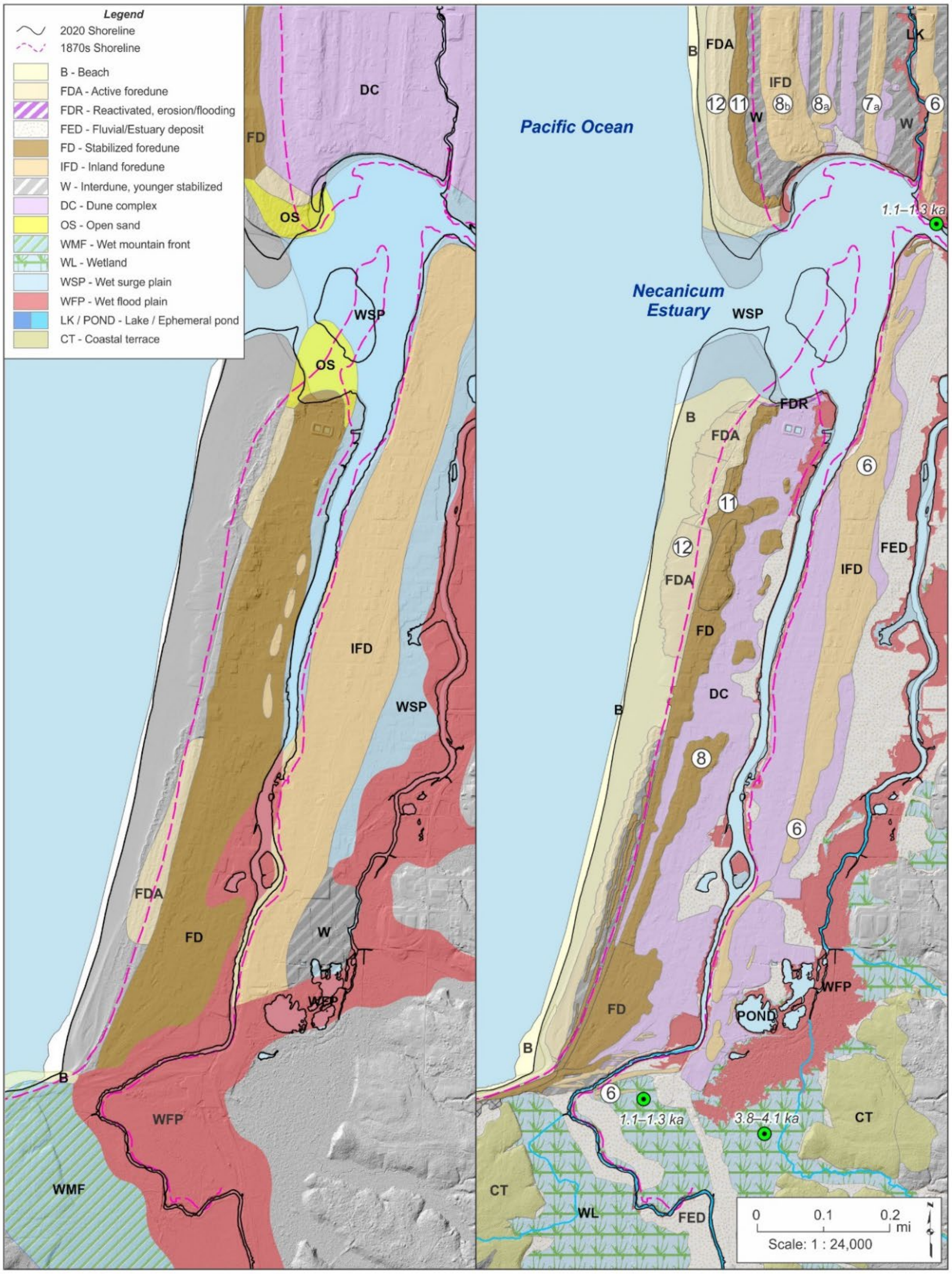
4.8 Seaside

Figure 4-9 is a map showing the suite of coastal geomorphic units based on the original USDA (1975) mapping (*left*) compared with present-day conditions (*right*) for Seaside. As can be seen in the figure, the original mapping (*left*) depicted much of downtown Seaside as being either foredune (FD) or inland foredune (IFD). Open sand (OS) was mapped at the mouth of the Necanicum estuary, while active foredunes (AFD) were confined to a few discrete sections near the southern end of town and in the north adjacent to the estuary mouth. North of the estuary in Gearhart, much of that area was mapped as dune complex (DC).

Our revised mapping (**Figure 4-9**, *right*) indicates a more complex geomorphic environment, with numerous foredune (FD), interdune (W) and wetland (WL) areas. In the ensuing sections, we identify more than 12 independent foredunes that characterize the development of the Clatsop Plains over the past 5,000 years. Each of these have been designated with a unique number in the accompanying figures, that allow for tracing of the same foredune along the length of the Clatsop Plains. An active foredune (FDA, 12) continues to aggrade and advance seaward north of the Seaside turnaround. South of the turnaround, the active foredune (FDA) is narrower than was originally mapped, but extends farther south to include Seaside 'cove,' before turning west following the cobble berm at the toe of Tillamook Head. Former foredunes (FD, 11) are evident in the mapping, located adjacent to the 1880s era shoreline; several of these are present at the south end of town, west of the 1880s shoreline. We also map an older foredune (8) that runs north-south through midtown. The remainder of Seaside west of the Necanicum River is designated dune complex (DC) (**Figure 4-9**, *right*) since this area has been extensively modified by human development, but is known to be characterized by a series of cobble berms (Witter and others, 2009).

South of Seaside (**Figure 4-9**, *right*), we map several small fingers of former foredunes (6), within fluvial-estuary deposits (FED). The fluvial-estuary deposits are the product of sediments laid down by the Necanicum River over the late Holocene. Bounding the fluvial-estuary deposits (FED) and wetlands (WL) are older (likely 80,000-year) coastal terraces (CTs) located on both sides of the Necanicum River valley (**Figure 4-9**, *right*), which constrain the lateral movement of the river system. Along the eastern bank of the Necanicum River, we identify a large former foredune (6) that likely began forming ~1,000 years ago, based on two discrete dates obtained by Peterson and others (2010). Finally, we note that our wet surge plain (WSP) and wet floodplains (WFP) are significantly better defined relative to the original USDA (1975) mapping, due to the adoption of datum-based tidal flood elevations and lidar.

Figure 4-9. Beach and dune geomorphic mapping classifications for Seaside. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study). Green circle indicates sample location for ^{14}C date determined by Peterson and others (2010). Numbered circle indicates unique foredune sequence, with #12 being the contemporary foredune and #1 being the oldest.



4.9 Gearhart

Updated coastal geomorphological mapping in the Gearhart area (southern Clatsop Plains) is presented in **Figure 4-10**. The left panel exhibits the original USDA (1975) mapping, while the right panel shows the latest mapping. Beginning with the 1975 mapping, we note that much of the southern Clatsop Plains was mapped as dune complex (DC) or wet deflation plain (WDP), with isolated pockets of open sand (OS) areas. Mapping of the active foredune (FDA) and recently stabilized foredune (FD) was confined mainly to the southern part of the area, adjacent to Gearhart, and did not extend farther north along the plains.

As can be seen in **Figure 4-10** (*right*), our updated mapping indicates a complex suite of former foredunes (IFD), separated by interdune (W) areas. The remaining geomorphological mapping units indicate either dune complex (DC) or wetlands (WL). We identify more than a dozen discrete foredune sequences that illustrate the development of the Clatsop Plains over the past 5,000 years. Of these, the youngest (contemporary) foredune is designated (12), while the oldest is (1). We include several discrete age dates obtained by Peterson and others (2010) and the 1880s era (pre-jetty) shoreline to help document the evolution of the plains. Finally, the exact chronology of dunes, as defined by the numbered sequence, remains somewhat subjective at this stage. While we can track a number of the foredunes along the length of the Clatsop Plains, (e.g., foredunes 3, 4, 6, 9, 10, 11, 12), the chronology becomes more complex in the northern plains due to the addition of many more dune sequences that both appear and disappear. These results suggest the need for further work to carefully tease out the chronology of dune development on the Clatsop Plains. Monitoring by DOGAMI indicates that the southern Clatsop Plains is presently accreting[2] at rates of ~5.6 ft/yr (~1.7 m/yr).

4.10 Central Clatsop Plains

Figure 4-11 shows the suite of coastal geomorphic units based on the original USDA (1975) mapping (*left*) compared with present-day conditions (*right*) for the central Clatsop Plains, which includes much of the area surrounding Camp Rilea. As with Gearhart, the original mapping indicates that much of this area was mapped as dune complex (DC) or wet deflation plain (WDP), with a few isolated pockets of open sand (OS) areas. Of note also is a large area of inland dunes (IFD) along the eastern edge of the Clatsop Plains (USDA, 1975).

[2] https://nvs.nanoos.org/BeachMapping?action=oiw:beach_mapping_point:delray:plots:trends

Figure 4-10. Beach and dune geomorphic mapping classifications for Gearhart. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study). Green circle indicates sample location for ^{14}C date determined by Peterson and others (2010). Numbered circle indicates unique foredune sequence, with #12 being the contemporary foredune and #1 being the oldest.

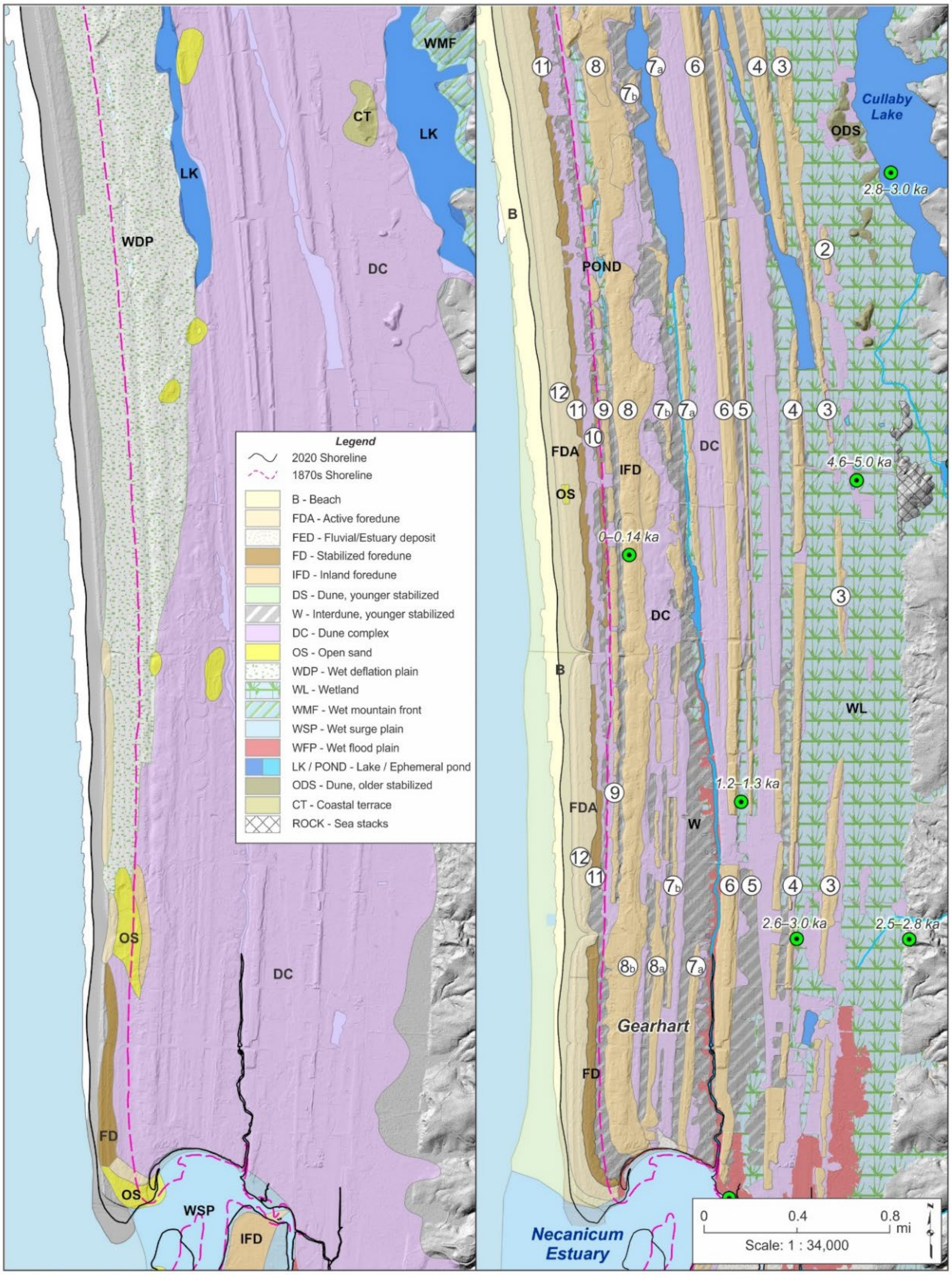


Figure 4-11 (*right*) is a northward extension of the previous map of the Gearhart area and hence reinforces the predominant geomorphic features that reflect a suite of former foredunes (IFD), separated by interdune (W) areas, dune complex (DC) or wetland (WL) areas. The eastern edge of the Clatsop Plains is bounded by a series of cliffs and coastal terraces (CTs). In this section of the Clatsop Plains, we find evidence for at least 14 foredune sequences that span the last 5,000 years. The seaward portion of the coast includes the 1880s era shoreline (magenta dashed line) as well as the contemporary (2020) shoreline (solid black line). Adjacent to the 2020 shoreline, a broad active foredune (FDA, 12) is presently developing. Monitoring by DOGAMI indicates that this central portion of the Clatsop Plains is presently accreting[3] at rates of ~8.2 ft/yr (~2.5 m/yr). East of the contemporary foredune there is evidence of at least two stabilized foredunes (11 and 10) that postdate the 1880s era shoreline. Immediately east of the 1880s era shoreline is an older foredune (9) that predates jetty construction. With eastward progress across the Clatsop Plains, we see evidence for at least 10 foredunes, with the oldest of the foredune sequence (1) located near the coastal terrace. Dating by Peterson and others (2010) east of Smith Lake at the base of the coastal terrace gives an age of ~2,900 to 3,200 years before present. In the north near Warrenton, former foredunes (e.g., 2 and 3b) begin to curve slightly toward the northeast (i.e., in the direction of the lower Columbia River estuary). These data suggest that sediment was probably being transported in a northeasterly direction into the lower Columbia River estuary at the time. These patterns are more obvious in the northern Clatsop Plains figure, described below.

4.11 Northern Clatsop Plains

Updated coastal geomorphological mapping for the northern Clatsop Plains is presented in **Figure 4-12**. Beginning with the original mapping (**Figure 4-12**, *left*), it can be seen that the bulk of the area was mapped as either dune complex (DC) or wet deflation plain (WDP), with isolated pockets of open sand (OS) areas. Interdune (W) areas also compose some of the original mapping and are located east of the 1880s era shoreline. Also evident in the original mapping is a small area of recently stabilized foredune (FD), mid-figure near the 2020 shoreline.

Figure 4-12 (*right*) presents the latest geomorphological mapping for the Clatsop Plains. Similar to the mapping discussed previously, our latest mapping highlights a more complex geological history, characterized by a suite of former foredunes (IFD) that formed over the late Holocene, separated by interdune (W), dune complex (DC) or wetland (WL) areas. In addition, we are better able to define the wet surge plain (WSP) and wet flood plain (WFP) using tidal datum-based elevations and the latest lidar. The wet flood plain (WFP) indicates the potential for flooding out on the spit and to the south of the town of Hammond. Our latest mapping highlights how the spit foredunes curve inland near their distal ends, indicative of alongshore sediment transport toward and into the lower Columbia River estuary. This pattern is further highlighted by the shape of the 1880s era (prejetty) shoreline. The significant northward and seaward growth of Clatsop Spit that followed jetty construction is especially noticeable in **Figure 4-12**, given the significant >0.4 mi-wide (>0.6 km-wide) gap between foredune (FD, 9) and the currently active foredune (AFD, 12).

[3] https://nvs.nanoos.org/BeachMapping?action=oiw:beach_mapping_point:rilea:plots:trends

Figure 4-11. Beach and dune geomorphic mapping classifications for central Clatsop Plains. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study). Green circle indicates sample location for ^{14}C date determined by Peterson and others (2010). Numbered circle indicates unique foredune sequence, with #12 being the contemporary foredune and #1 being the oldest.

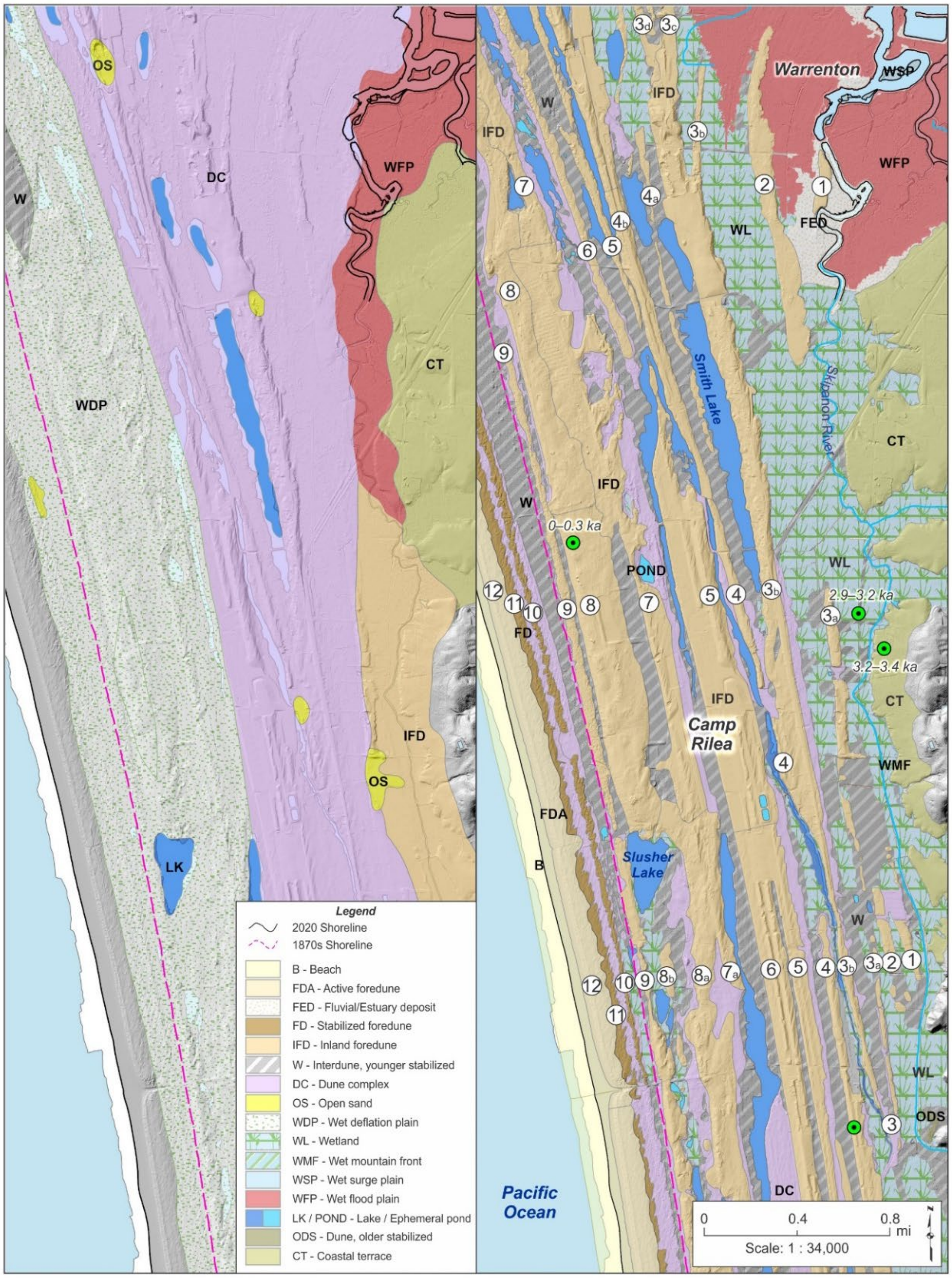


Figure 4-12. Beach and dune geomorphic mapping classifications for northern Clatsop Plains. (*left*) Original USDA (1975) mapping; (*right*) latest mapping (this study). Green circle indicates sample location for ^{14}C date determined by Peterson and others (2010). Numbered circle indicates unique foredune sequence, with #12 being the contemporary foredune and #1 being the oldest.

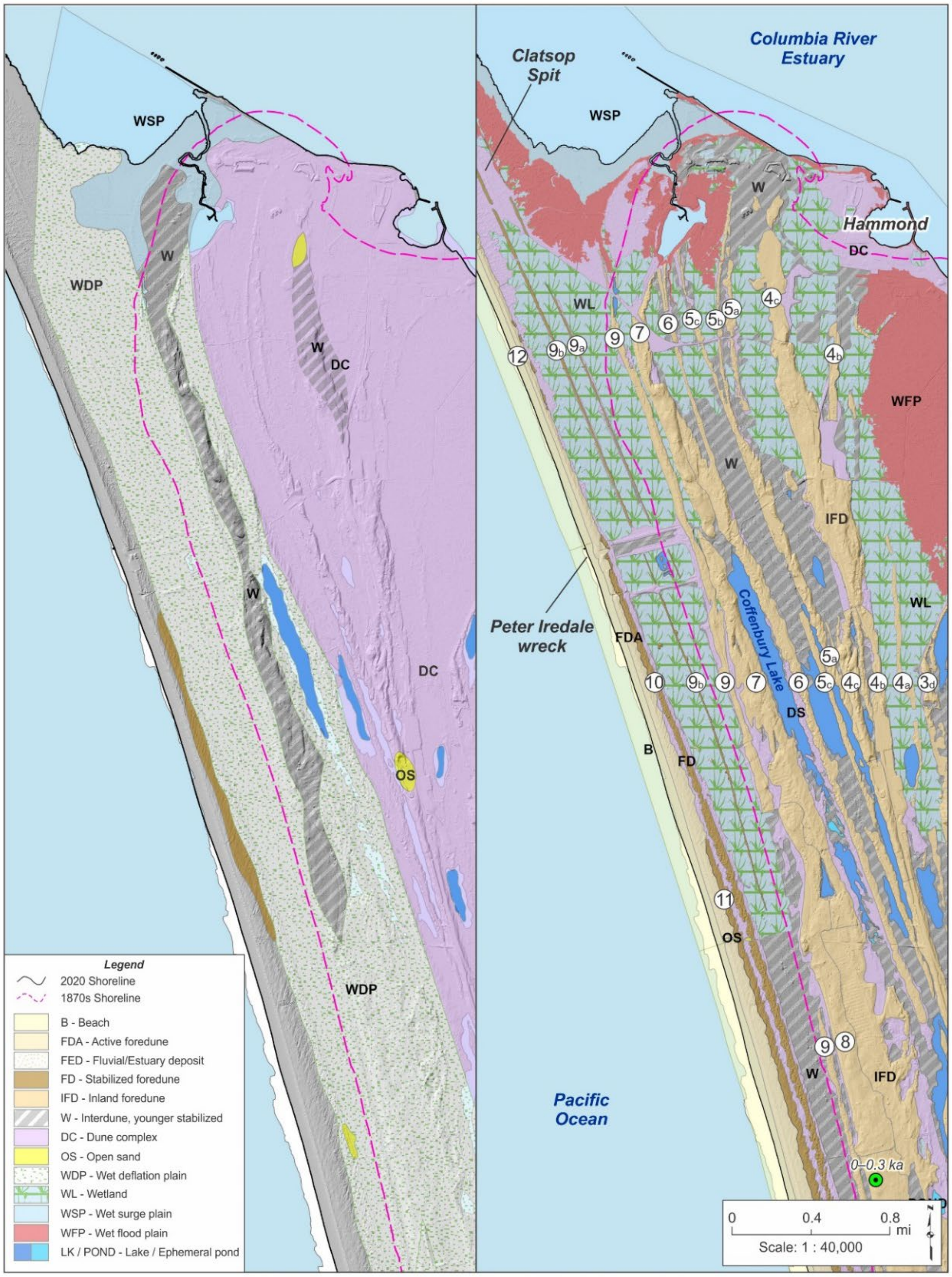


Figure 4-12 (*right*) also highlights the effects of ongoing erosion along the spit end. For example, the stabilized foredune (11) is no longer present west of Coffenbury Lake, while foredune (FD, 10) is absent north of the Peter Iredale. Instead, the northern portion of Clatsop Spit is largely made of the currently active foredune (FDA, 12), with small pockets of remnant stabilized foredune (FD, 10) in the north. We identify several narrow foredunes (highlighted as (9a and 9b)) on the spit, west of the 1880s era shoreline. These geomorphic features are narrow and have low elevations and are probably indicative of the period of time during which the Columbia River South Jetty was being constructed, such that the spit end was rapidly accreting both northward and seaward.

5.0 CONCLUSION

The objective of this beach- and dune-mapping study was to produce updated information on the spatial extent of the beach and foredune system in Clatsop 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 to improve implementation of Statewide Planning Goal 18. Specifically, 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 USDA 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 (*Ammophila arenaria*), which has helped to stabilize many dune systems
- Dune management activities such as foredune grading and planting
- Changes in beach and dune morphology due to either coastal erosion or accretion
- Shoreline changes along the Clatsop Plains due to the construction of the Columbia River jetties

The overall study approach follows the original core classification structure developed by the USDA (1975), Allan (2020) in Tillamook County, and Allan and others (2024) in Coos County. Of particular importance, our GIS mapping includes a suite of geospatial attributes that broadly characterize the susceptibility of the coastal strip to existing coastal hazards, while also noting the likely future effects of climate change along the Clatsop County coast. Finally, the GIS mapping also include numerous comments and notes made by the authors.

Analyses presented here clearly demonstrate the transformation of the Clatsop County shoreline over the past 50 years. Of note has been the significant increase in areas classified as active foredune (FDA, 1,095%) and recently stabilized foredunes (FD, 54%) since the 1970s. Most of this change can be directly attributed to recent anthropogenic effects, particularly the introduction of European beach grass (*Ammophila arenaria*) and its expansion on coastal foredunes as well as stabilization from shore pine (*Pinus contorta*) and other native plant species. In the Columbia River littoral cell, aggradation of the contemporary foredune system and progradation of the shoreline over the past 50 years is indicative of ongoing changes to the littoral system following jetty construction at the mouth of Columbia River in the early 1900s. Besides these changes, our updated mapping along the Clatsop Plains, guided by lidar, further serve to highlight the complex history of the plains over the late Holocene, beginning ~4,500 to 5,000 years ago. Given the detailed nature of the geomorphic maps produced from the Clatsop Plains and uncertainties regarding the along-coast relationship between dune sequences, their ages and geomorphic history, we recommend further work be performed to better constrain the geologic evolution of the Clatsop Plains.

6.0 ACKNOWLEDGMENTS

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