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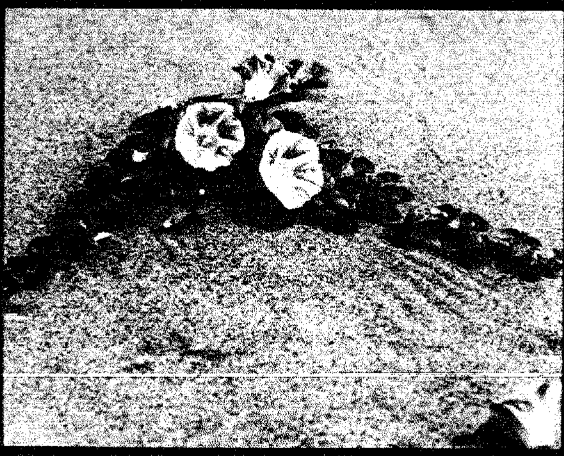
THE ECOLOGY OF PACIFIC NORTHWEST COASTAL SAND DUNES: A Community Profile



Fish and Wildlife Service
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THE ECOLOGY OF PACIFIC NORTHWEST COASTAL SAND DUNES: A COMMUNITY PROFILE

by

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PREFACE

It was just twenty years ago, in the summer of 1963, that I began my study of the Pacific Northwest coastal sand dunes. At that time ecological awareness was just beginning to creep into the national social consciousness. In the years that followed, wetlands and shorelines became the focus of widespread interest and concern. Coastal sand dunes shared in this focus from a number of perspectives. The sand dunes became increasingly valuable as real estate and as playfields for motorized recreation. They were also seen as great natural laboratories where biological and geological processes could be observed in accelerated action.

To be able to deal with these conflicting interests in something as complex as a natural ecosystem, responsible public agencies need as much information as possible. This is one of the main purposes of the community profile series of which this publication is a part. In putting together this profile, I have drawn on my many years experience with the sand dunes of the Pacific Northwest. I have also tried to locate as much of the great amount of published and unpublished material on the dunes as possible.

I have organized what I know and what I have learned from other sources into six chapters. The first gives general background information and an overview of the area under consideration: the Pacific coast from Cape Flattery, Washington, to Cape Mendocino, California. In the second I have summarized the environmental setting, emphasizing those factors involved in shaping the dune landscape. The third chapter is an attempt at a classification system for dune forms, a subject of great interest to those studying inland dunes, but not yet applied to coastal dunes. The history of the dune processes of this area and the possible future course of events is the subject of the fourth chapter. In the fifth chapter I have put down my present notions about the plant communities of the dunes. The result of an ongoing, subjective classification process based on much looking and thinking, it is not likely that the list of communities contained herein will remain stable. This does not detract from their present usefulness, however, since the shifts in view and thought are likely to be subtle and slow. This chapter also summarizes the wildlife habitats of the dunes and briefly characterizes each one. The last part of the sixth chapter on human impact emphasizes management problems--the major concerns in looking at the dunes from the viewpoint of both the biologist and the manager.

The appendices include a complete list of the dune areas (localities) in the coastal region defined above, as well as lists of characteristic plants and animals. For these latter lists I have tried to avoid making a list for the sake of listing. I have included only those plants and animals that have actually been observed in the plant communities and habitats of the dunes. For those who would like to take a detailed look at the dunes, I have included in the appendix detailed descriptions of two very different dune systems that I know very well. Visiting them would be a rewarding experience.

Credits for maps, diagrams, photographs, and tables that are not my own are given in parenthesis at the end of the figure and table captions. For each photograph I have included locality information and the date it was taken.

This description of the Pacific Northwest coastal dunes is by no means complete. In looking at something as complex as a sand dune ecosystem, every bit of data fitted into the total known picture shifts the perspective and the interpretation. It is my hope that this community profile will start or add to that experience for anyone interested in the coastal sand dunes.

A.M. Wiedemann
30 September 1983

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ACKNOWLEDGMENTS

This community profile could not have been completed in its present form without the assistance and inspiration of other people. I am especially indebted to my research assistant on this project, Pene Speaks, for her very competent help with library research and the appendix tables. Nancy Herman's drafting skills are reflected in the fine work of Figures 1, 2, 4, 5, 12, 14, 31, and appendix Figures II-1 and II-2. Art Hare of Seattle, Washington, provided a number of the aerial photographs. Just as valuable as the photographs was the experience of watching him in his work as a careful and skilled photographer. I appreciate the willingness of Ruth Wilson Jacobs and David V. McCorkle, respectively, to lend me their valuable color tranparencies of Snowy Plovers and the Oregon silverspot butterfly.

Dr. Ralph Hunter's responses to my questions and observations and his review of the chapters on dune morphology and process were very helpful. Dr. Rudolph Becking's interest in this project was much appreciated. His comments on the manuscript and the time he spent with me in the field were valuable. A critical reading of the manuscript from the non-scientist's perspective by Leslie Goldstein was most valuable. Her comments and suggestions helped improve the presentation of ideas and descriptions in many places.

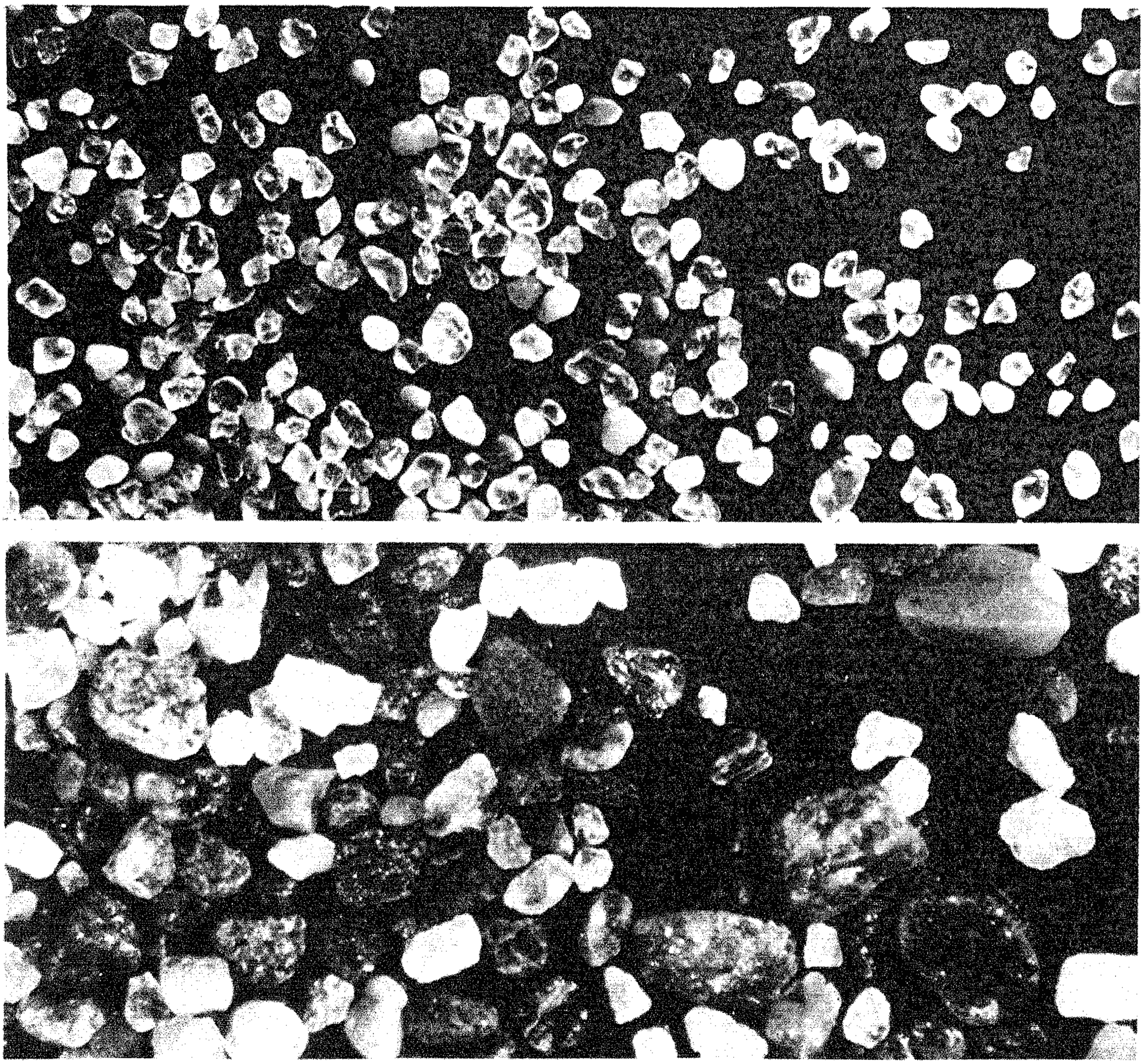
Special thanks go to the personnel at Perfect Copy, Olympia, Washington, for their work in the preparation of the final copy of the manuscript. Margie Barnard spent long hours typing the text and worked with patience and good humor on the seemingly endless appendix tables. Mary Geraci was responsible for production; her suggestions and advice on layout were much appreciated.

Preparation and publication of this community profile were supported by the U.S. Fish and Wildlife Service, and U.S. Army Corps of Engineers. I wish to thank the Project Officer, Dr. Jay F. Watson, for this opportunity, and for his interest and support.

Beyond material assistance, I wish also to acknowledge the sources of inspiration that have ultimately made it possible for me to undertake a project like this. The life and work of Dr. W.S. Cooper has been basic to my interest in the sand dunes from the very beginning. When I met him in 1965 he was past his 80th year of life and still vigorously involved in his research, writing, and other interests. We should all be so fortunate! My good friend and colleague, Dr. S.G. Herman, carefully and critically reviewed the list of vertebrate animals included in this report. More importantly, it is to him that I am indebted for my introduction to the world of birds and for an appre-

ciation of a traditional approach to natural history that emphasizes the individual as observer and recorder. The growing pile of green notebooks will be a monument to his influence in my life!

Finally, I would like to dedicate this report to Dr. W.W. "Bill" Chilcote, Professor Emeritus, Oregon State University, who introduced me to the sand dunes and who supervised my graduate work in the years that followed. It was not his style to try to indoctrinate his students in any particular school of ecological thought and methodology. Rather he encouraged them to observe and to think, to "pull up a stump" and try to see the whole picture. I have sat on many stumps in many parts of the world since that time, and have always been grateful for Bill's example and advice.



Photomicrographs of sand from two locations along the Pacific Northwest coast. Top: fine, yellowish brown sand from the open dunes of Tenmile Creek, Locality 22. Bottom: coarse, almost black sand from the beach ridge of Big Lagoon, Locality 32. (Magnification of both photographs about 20X.)

CHAPTER ONE
INTRODUCTION

Sand dunes--the very words conjure up images of vast seas of shifting sand barren of plants and hostile to human habitation. Hot, dry winds shape and arrange the sand in geometric and artistic patterns described by words such as barchan, transverse, star, blowout, dome, stringer, seif, sheet, oblique, and parabolic.

There are many areas in the world where sand dunes are a dominant feature of the landscape. Many of these areas are very large: the extremely dry interior deserts of the continental land masses such as the Sahara in Africa and the Victoria Desert in Australia. Even more numerous are the smaller, relatively narrow strips of sand along the shores of oceans and large lakes.

The climatic conditions of the sand dune areas of the world range from tropical to arctic. Precipitation also varies widely. The coastal dunes of Chile and Peru in South America receive no rain, while those along the west coast of Japan receive as much as 2,000 mm a year. Except in hot climates with extremely low rainfall, the dune landscape is not bare of vegetation. The cold, dry Taklamakan Desert in northeast China, the largest sand dune area in the world, has a sparse but noticeable cover of small shrubs. The ground between the actively moving dune crests of the Simpson Desert in Australia is well covered by grasses and shrubs. Mature, productive forests cover the extensive coastal dunes on the Bay of Biscay in France.

Because of their unique characteristics, dune areas have drawn the attention of many kinds of people. Geologists are interested in the sources of the sand and the processes involved in dune formation and movement. Zoologists and botanists study the adaptations of animals and plants to conditions that make the existence of life difficult. Engineers seek ways to control the active shifting sands. Artists attempt to record and interpret patterns and moods. People of many backgrounds are drawn by the raw, wild beauty of the dunes to see, and to feel, the forces of nature at work.

In many parts of the world coastal dune areas also attract human populations because of the proximity of the dunes to the ocean and the ease of establishing habitation on them. This is especially true in Europe. There is an extensive literature dating back to the 15th century on the description, use, and management of coastal dunes. The literature of the last 75 yrs reveals intensive research on all aspects of European dune ecology and geography.

Coastal sand dunes occur along both the Atlantic and Pacific coasts of North America. Those along the Atlantic coast are mostly broad, low, sandy plains with generally slight relief. The wind regimes are not very conducive to massive sand movement and accumulation, so that large, moving sand dunes are not frequently encountered. It is along the Pacific coast, and more especially the northern half of the Pacific coast, that the truly spectacular dune areas are found. Because of a fortuitous combination of geologic and climatic factors, no other dune area in North America offers such a range of dune forms and landscapes. Massive moving dunes of the kind characteristic of the great interior deserts are found along with dunes that are the result of sand and wind interacting with vegetation. The forests, meadows, marshes, and lakes of these dunes are the habitats of great numbers of animals and plants.

The unique dune landscape of the Pacific Northwest coast has felt the impact of human activity only in comparatively recent times. Aboriginal people used the dunes as a means of moving up and down the coast, and may have had settlements on some, especially on bays and estuaries. The first Europeans to reach the coast were attracted to the dune areas as places to establish farms and towns. In California this occurred in the early 19th century. In Washington and Oregon it was not until the 1850's that settlement became extensive. Towns developed mostly on rivers, bays, and estuaries. Agriculture was taken up on the extensive grasslands of some of the dune areas. There was some mining of the dune sands, especially in southern Oregon and northern California. A few parks were established, and rather extensive areas in some places came under the ownership of public agencies such as the U.S. Forest Service and the Bureau of Land Management. Access to the coast was limited and difficult. The coast highway in Oregon was not built until the 1930's. The Alsea River bridge was completed in 1934; the Siuslaw River bridge, in 1936. The mouth of the Columbia River was not bridged until 1966.

It was not until after World War II, the middle of the 20th century, that the coastal dunes came to be seen as a major recreational and real estate resource. Increased incomes and accessibility to motorized transport both played an important role in this. Privately owned dune areas began to undergo commercial development, primarily for vacation home communities, but also for the expansion of existing communities. The abundant water resources of the dunes were exploited. Extensive artificial stabilization programs were initiated to keep sand from filling rivers and lakes and from covering buildings and roads. Large areas were also planted to provide wildlife habitat. Recreational use increased dramatically, mostly by "off-road vehicle" enthusiasts.

This increased commercial and recreational use poses problems and concerns. The problems are related to development and construction: siting hazards, erosion, drainage, waste disposal, and aesthetics. The concerns deal with the rational use of a limited land resource, with the conservation of plants and animals, and with maintaining the natural beauty of the landscape. The coast became the focus of planners. Coastal zone management plans were mandated. Local zoning ordinances spelled out in detail what could and could not be done on beaches and dunes. An attempt was begun in the late 1950's to set aside a large dune area as a National Seashore, but this failed.

Scientific and technical information about the dune areas has been limited in scope and amount. The most comprehensive works are those of Cooper (1958, 1967) on the geomorphology of the Washington, Oregon, and California dunes; and Wiedemann (1966) on the plant ecology of the Oregon dunes. Johnson (1963) and Parker (1974) provide information on the dunes of northern California. Kumler (1963, 1969), Pinto et al. (1972), and USDA-SCS (1975) are other sources of information on the dunes. Many documents have been published that relate to specific situations or to planning and management concerns. Morgan (1980) and Fowler (1979) review this literature.

PACIFIC NORTHWEST COASTAL SAND DUNES

The coastal sand dunes described in this report lie on the northwest Pacific coast of the United States, between the Straits of Juan de Fuca (49°N) on the north and Cape Mendocino (40°N) on the south (Figure 1). This is the U.S. Northwest Pacific Coast Region (H - Level I) of the U.S. Fish and Wildlife Services's physical regionalization of coastal ecosystems of the United States and its territories (Terrell 1979; Proctor et al. 1980). Dune systems occur primarily on the Pacific Northwest subdivision of the region (H1 - Level II), but some are included in the Columbia River Estuary subdivision (H2 - Level II).

The region includes about 950 km of coastline: 264 km in Washington, 500 km in Oregon, and 186 km in California. This stretch of coast has considerable geomorphic diversity: ocean-front mountain masses, high terraces, bays and their associated spits, low terraces with sand masses, and promontories are all prominent features. The trend of the coast is slightly west of south from the Columbia River to Cape Blanco in Oregon (43°N). North of the Columbia River the trend is almost exactly south. South of Cape Blanco the trend is south-southeast.

Sand dunes are found along 82 km of coastline in Washington, 225 km in Oregon, and 92 km in California, a total of 399 km, or 42% of the total coastline. These sand dunes have formed since the last Pleistocene glaciation (discussed in chapters 2 and 4). Their landward boundary is defined by an active or stablilized ridge of unconsolidated sand which may have an incipient soil profile, but which does not show the red color of advanced chemical weathering characteristic

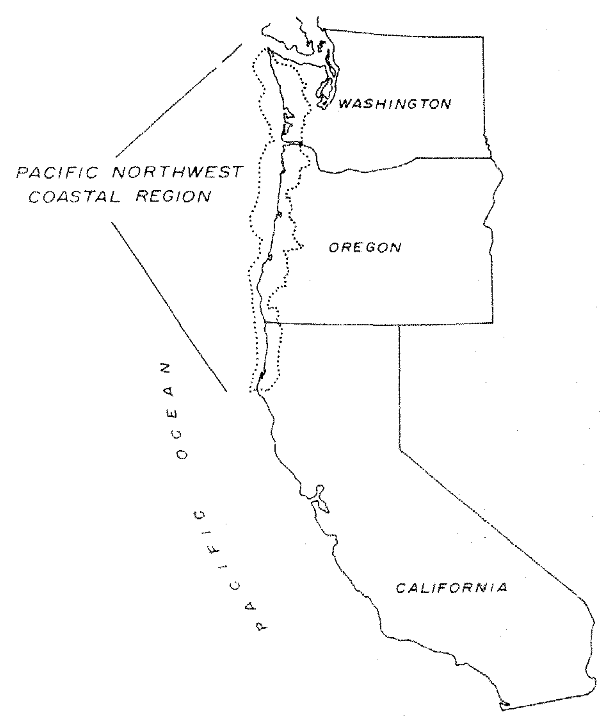


Figure 1. The location of the Pacific Northwest Coastal Region.

of older sand deposits in this area. These older deposits are the result of earlier cycles of glaciation and can be seen in highway cuts inland from the present dune activity. Although the current (post-Pleistocene) dunes advanced inland as far as 4 km in a few places, the inner margins more generally lie 1 to 2 km from the shore. In many cases, relatively narrow sand spits define the dune areas.

The sand dunes between Cape Flattery and Cape Mendocino occur both as small, isolated areas associated with bay and river mouths and as extensive areas on broad, sea-cut terraces. Cooper (1958, 1967) identified 33 "localities", some of which are distinct units, others parts of more extensive units subdivided on the basis of physiography. Cooper's locality names and numbers are retained except that his California Localities 1, 2, and 3 become Localities 31, 32, and 33 in this report. Figure 2 shows the major physiographic features and dune localities of the Pacific Northwest coast. A list of the dune localities with locations and descriptive details is included in Appendix I.

Between Cape Flattery and Copalis Head in Washington, the mountain masses come right to the sea, and there is no receptive shore on which sand can accumulate. Localities 1 to 4 are all associated with the Columbia River. Parts of each of these form spits or peninsulas across Grays Harbor, Willapa Bay, and the Columbia River estuary.

From Tillamook Head to Heceta Head on the northern Oregon coast, the dunes are all associated with rivers or bays (Localities 5 to 18). The largest areas (Localities 9 and 10) lie between Cape Lookout, a promontory extending 3 km out to sea, and the massive Cascade Head. Relatively large dune areas are also found at the mouths of the Nehalem (Locality 5), Yaquina (Locality 15), and Alsea (Locality 16) Rivers. Dunes at the outlets of creeks and small rivers, and bay spits, make up the rest of the localities.

Sand dunes extend from Heceta Head south 86 km to Coos Bay (Cape Arago) in a continuous sheet broken only by the outlets of three major rivers (the Siuslaw, Umpqua, and Coos Rivers) and a few smaller streams. Popularly called the "Coos Bay Dune Sheet", the area is subdivided into five localities (19 to 23) of more or less uniform size. The boundaries are marked by Heceta Head, the Siuslaw River, Siltcoos River, the Umpqua River, Tenmile Creek, and the Coos River. This is the most spectacular of the dune areas along the coast, and the most visited.

The dunes north and south of the Coquille river (Localities 24 to 26) extend a total distance of 23 km along the shore. In breadth, height, and mass, however, they are much less impressive than the Coos Bay dunes to the north. From Cape Blanco to the California border, the dune areas (Localities 27 to 30) are all small and associated with small rivers and creeks. In California, dunes occur only on sections of the coast that trend west of south. This is very apparent at Localities 31 and 33.

At Crescent City (Locality 31) there is a very large, but low-lying dune area. The dunes at Big Lagoon (Locality 32) are mostly a very long, narrow strip of sand spit and bay bar across a series of large bays just north of Patrick's Point. At Humboldt Bay (Locality 33), the dunes again are primarily long, narrow bay spits.

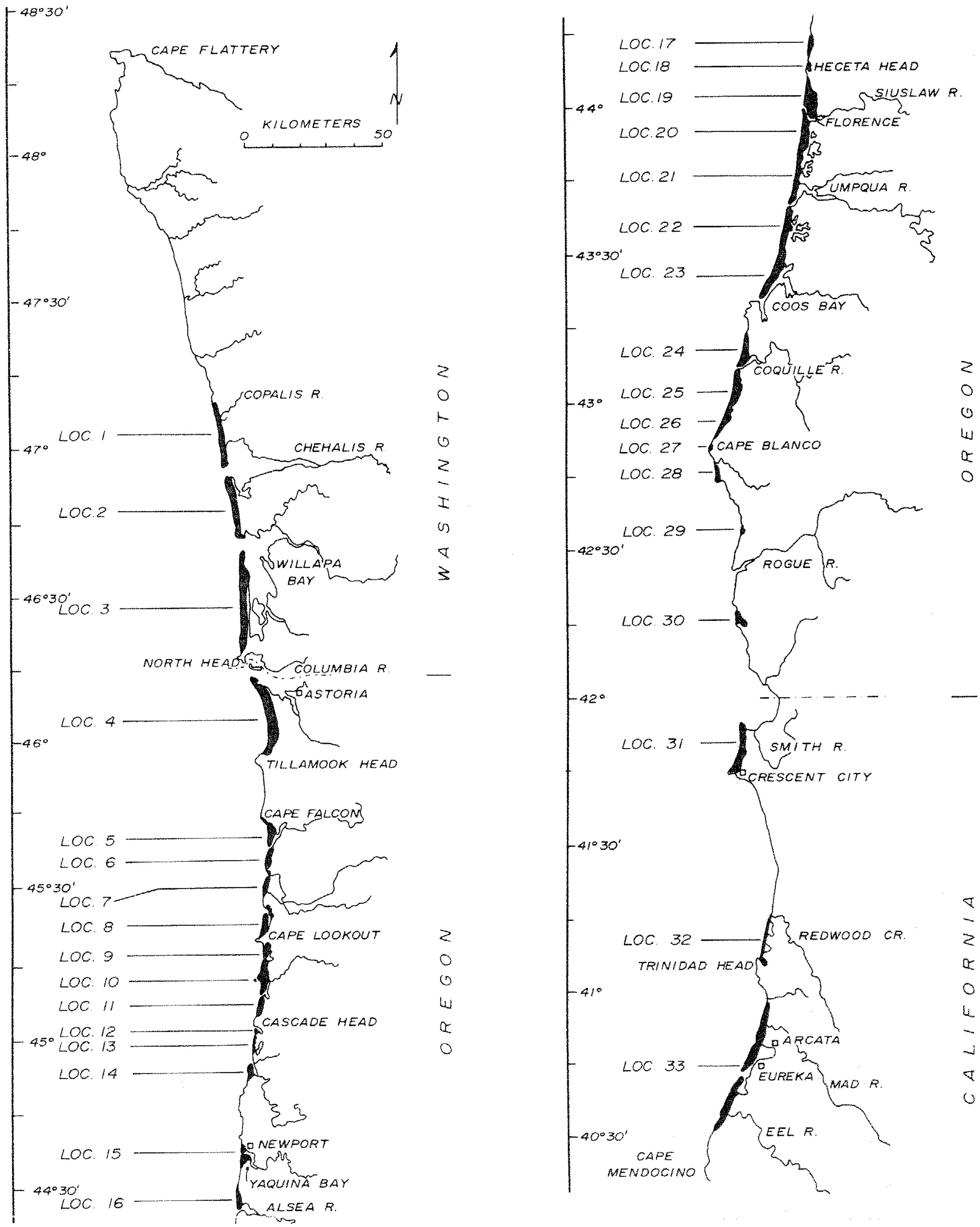


Figure 2. The sand dune localities and major land features of the Pacific Northwest Coastal Region.

Towns and cities are located along the entire length of the coast, but few are very large. The largest population centers are Astoria, Oregon (10,244), in the north; Coos Bay-North Bend, Oregon (22,019), in the center; and Eureka-Arcata, California (33,222) in the south. All of the other towns, with one exception, have populations of less than 5,000. Forest products, marine fisheries, tourism, and limited agriculture are the basic industries of the larger towns. The smaller towns rely mostly on tourism.

The entire coast is traversed by a major Federal highway, U.S. 101, its route usually within a few kilometers of the shore. Frequently the ocean is in view. Drawn by spectacular scenic views, deep-sea fishing, and an excellent system of county, State, and Federal campgrounds, tourists come to the area in great numbers during the summer season from June to August. Because of limited public transport to the coastal region, most come by automobile.

Information available to the public about the natural history of the coastal region and the dunes is extremely limited. Yocum and Dasmann (1965) provide an introduction to the Pacific coastal wildlife region. Horn (1980) and Munz (1964) describe Pacific coast wildflowers. Becking's (1982) illustrated flora of the redwood forests includes common coastal plant species of southern Oregon and northern California. Wiedemann et al. (1969) briefly describe the dune forms and provide an identification key to the most common Oregon sand dune plants.

This community profile represents an initial attempt at providing an overall picture of the Pacific Northwest coastal dunes. In addition to a description of the environment, dune forms and systems, dune processes, flora and fauna, and human impacts, it includes guides to relevant field sites (Appendix II). These sites were chosen to permit the observation of as many dune features as possible with a minimum of travel and searching.

CHAPTER 2
ENVIRONMENT

The coastal sand dune landscape is the product of geologic events that have occurred in the past and continue to the present, of wind and water movement, of sediment supply, and of the effects of vegetation. Other forces are at work also, such as soil formation, fire, and human activity, but these tend to modify the landscape rather than create its basic form.

LAND

The geologic history of the Pacific Northwest Coastal Region is complex. Three geologic provinces are included: the Olympic Mountains to the north, the Coast Ranges from central Washington to southern Oregon, and the Klamath Mountains in southern Oregon and northern California. Only brief accounts of the history of these areas will be included here. More extensive treatments can be found in Flint (1971), Emery and Milliman (1968), Franklin and Dyrness (1973), Proctor et al. (1980), and Cooper (1958, 1967).

The Olympic Mountains are made up of two volcanic belts which encircle a large interior area containing sedimentary rocks. The outer belt was formed in the Eocene, while the inner was deposited late in the Mesozoic, 100 mya (million years ago). These mountains rise to 3500 m and meet the sea in spectacular, erosion-resistant sea cliffs which have not permitted formation of the broad beaches and terraces necessary for the development of sand dunes.

The Coast Ranges extend from the Willapa Hills of Washington south to the Klamath Mountains in southern Oregon. They are characterized by Tertiary and Pleistocene sedimentary depositions and igneous intrusions. The sedimentary formations had their origin in the early Eocene, 53 mya, when a eugeosyncline[1] occupied the area from the Klamath Mountains (42°N) north to Vancouver Island and east to the present day Cascade Mountains (about 150 km inland).

The initial deposits were volcanic in origin, but by middle Eocene, 45 mya, uplift activity to the south and subsequent erosion contributed arkosic (feldspar and quartz) sands as marine deposits for a considerable distance northward. Volcanic activity persisted throughout the Eocene so that igneous materials are frequently interbedded with the sedimentary layers. By late Eocene, 37 mya, tuffaceous (volcanic origin) silts and clays began to be deposited by the streams

[1]The seaward part of a geosyncline, which is a linear downwarp in the earth's crust more than 1000 km long with thick accumulations of sediments.

and rivers flowing from the surrounding highlands. The deposition continued and increased considerably during the Oligocene and into the Miocene, 37 to 16 mya, when arkosic sands and silts were also laid down in great amounts.

During middle Miocene, vigorous volcanic activity formed many of the basaltic intrusions and headlands which remain today as erosional remnants. Toward the end of the Miocene, 7 mya, uplift began which was to form the Coast Range. This uplift reached its maximum height during the Pliocene, 7-2 mya, when peneplanation (erosional lowering and leveling) began. The erosion of the thick sedimentary beds was rapid, resulting in today's low, rounded mountains reaching at most 500 m elevation. The easily eroded rock also permitted the development of the extensive wave-cut terraces on which the present sand dunes have developed.

The Klamath Mountains are old and geologically complex. Their history begins in the Paleozoic, 500 mya, with the deposition of volcanic and sedimentary rocks. Metamorphosis and folding were followed by additional deposition in the Triassic, 200 mya. Extensive metamorphism followed. During the Jurassic, 150 mya, more sediments were deposited, and these were subsequently intruded by ultramafic (rich in iron with little feldspar) and granitic volcanic rock. In the early Cretaceous, 130 mya, additional deposition of sediments, followed by folding and deformation in the middle Cretaceous, occurred. Extensive peneplanation occurred in the Miocene and Pliocene, 26 to 2 mya, resulting in the present day topography. Because of the erosion-resistant rock, the development of terraces suitable for the development of sand dunes has been somewhat limited, and extensive terraces are found only in a few places.

Sea-level changes, the result of both land (tectonic) and water (eustatic) rise and fall, have played a significant role in the history of this area. During the late Pliocene and early Pleistocene, 1 mya, there occurred a period of extreme submergence, indicated by wave-cut terraces found as high as 450 m above present sea level. Subsequent uplift lowered the shore line to about 90 m below present sea level, and it was during this period that the rivers and streams cut their trenches across the continental shelf. Resubmergence then took place again. Attempts to correlate eustatic activity with the many terraces found at many elevations along the coast are complicated by the instability of the Coast Ranges (Russell 1970).

Eustatic activity since late Pleistocene is associated with the cycles of glaciation of that period; and the last major lowering of the shore line, to about 140 m below present sea level, coincides with the maximum of the last, or Wisconsin, glaciation (about 18,000 yrs ago). Each cyclic resubmergence resulted in sand dune activity in places where the shore topography permitted. Earlier dune areas were usually obliterated by later activity. In some places the earlier dunes extended farther inland and still remain. They are usually called "Pleistocene dunes" and can be distinguished by their reddish color and iron concretions (Figure 3). As the glaciers melted after the last (Wisconsin) maximum, sea level rose, bringing about the latest episode of dune activity. This rise has been termed the "Flandrian transgression" and the dunes resulting the "Flandrian dunes" (Cooper 1967, p. 7).

Figure 3. Exposure of Pleistocene sand along the beach at Sand Lake, Locality 9. This compacted, weathered, darker sand serves as substratum for the post-Pleistocene (Flandrian) dunes. 1965.

CLIMATE

The climate of this coastal region is marine, and although it appears to be remarkably uniform throughout, there are shifts that are reflected in the dune systems and in the vegetation. Breckon and Barbour (1974), using the unmodified Koeppen system, show a shift in climate at 46°N latitude. To the north it is Cfb--mesothermal with no dry season, while southward it is Csb--Mediterranean with a summer dry period[2]. Temperature and precipitation data for three stations in the coastal region are summarized in Table 1. Although the differences seem slight, the decreased precipitation southward is effective in causing changes in the dune flora. Overall, however, even with 80% of the precipitation occurring in the winter months, the temperature and moisture regimes are very conducive to plant growth.

The seasonal pattern of temperature is the result of proximity to the ocean, which has a modifying effect in preventing seasonal extremes. The precipitation pattern reflects the seasonal shifts in offshore atmospheric pressure systems. In winter, the Aleutian Low, a series of low-pressure centers that passes over the North Pacific, dominates the weather pattern. These low-pressure centers are responsible for the frontal storms that move over the coast in winter, bringing heavy rains and strong south to southwesterly winds. In summer the North Pacific High dominates, bringing fair weather and north-northwesterly winds. Also, in summer the land-sea breeze effect contributes winds that reach high velocities in the afternoons.

While this general pattern holds for the entire coastal region, there is a definite shift southward in the all-year importance of the northerly components. In Washington and Oregon, both the northerly winds of summer and the southerly winds of winter are important in the dune-forming process. In southern Oregon and northern California only the northerly winds, acting through most of the year, are important. This is the result both of the decreased frequency of winter cyclonic storms and of the change in coastal trend. The differences in wind regimes are illustrated in Figure 4 using data from two stations: Newport on the central Oregon coast, and Pt. Arena,

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[2]After Trewartha (1954): C - humid mesothermal, coldest month between 18°C and 0°C; f - no dry season; driest month over 6 cm ppt; s - dry period in summer; b - warmest month below 22°C.

Table 1. Average annual, July, and January precipitation and temperature for three stations on the Pacific Northwest coast. Note the decrease in annual precipitation between North Bend and Eureka. (From Cooper 1958, 1967.)

	PRECIPITATION					
	Annual		July		January	
Station	cm	in	cm	in	cm	in
North Head 46°18'N	147.8	59.10	2.4	0.96	22.0	8.78
North Bend 43°25'N	160.3	64.13	1.2	0.49	27.3	10.90
Eureka 40°47'N	91.0	36.35	0.2	0.09	15.5	6.20

	TEMPERATURE							
	Annual		July		January		Range	
Station	°C	°F	°C	°F	°C	°F	°C	°F
North Head 46°18'N	10.0	50.0	13.9	57.2	5.6	42.1	8.4	15.1
North Bend 43°25'N	10.9	51.9	15.1	59.4	6.7	44.2	8.4	15.2
Eureka 40°47'N	11.2	52.3	13.4	56.4	8.4	47.2	5.1	9.2

in northern California, 2° south of Cape Mendocino, but representing the general situation in northern California.

Another factor in the wind regime pattern is the presence of sheltering headlands and capes. On the north and central Oregon coast this sheltering effect is seen in the northeasterly trend of almost all of the dune systems north of Florence. In these situations the northerly summer winds have minimum influence, and the southwest winds of winter are considered unidirectional effective winds. In other places the summer winds are the effective winds.

In some situations the sheltering effect does not readily explain the unidirectional effective wind (such as the situation just south of Heceta Head (Locality 19) where, contrary to what one might expect, the effective winds are the summer northwesterlies).

Clouds and fog are present throughout the year, with cloudy skies occurring on half the days of the year. Fog becomes increasingly common southward, especially during summer, occurring on nearly half the days of June through September. This phenomenon is limited to the immediate coastal strip. Subsidence inversions (caused by the compression warming of sinking air) trap cooler surface air. The strong summer northerlies cause upwelling of cold water near the coast. This cold water cools the marine air just above it, causing fogs (Figure 5).

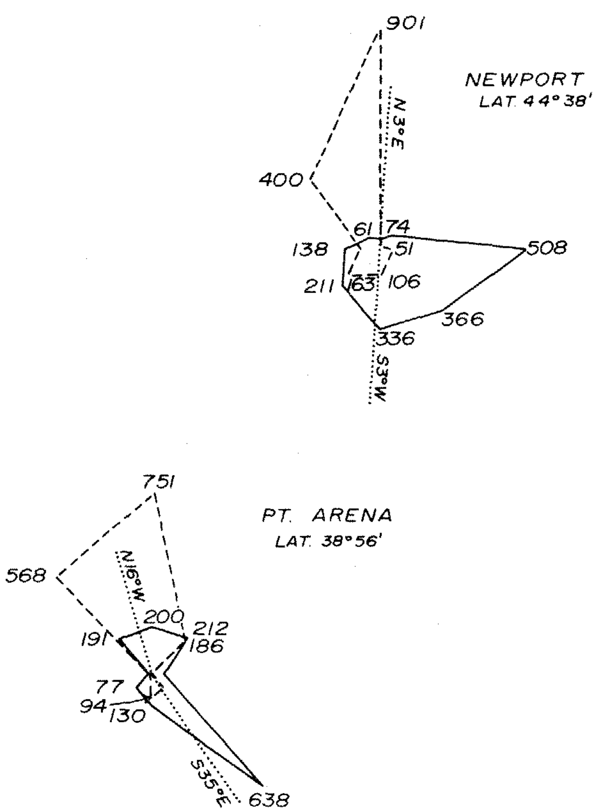

Figure 4. Wind regimes for two locations along the Pacific Northwest coast, central Oregon (Newport) and northern California (Pt. Arena). Numbers refer to total velocity (sum of all measured velocities) for a given compass direction. The dotted line (.....) shows the trend of the coast. The solid line (——) and the dashed line (-----) refer to January and July winds, respectively. (Redrawn from Cooper 1967.)

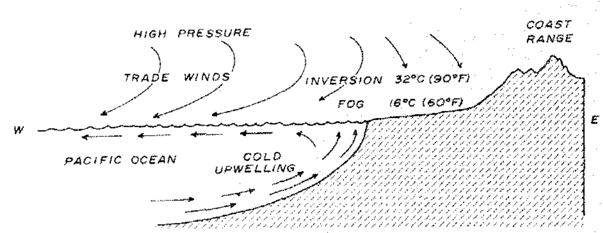

Figure 5. The development of coastal fogs. Subsiding air over the coast produces a persistent upper-air temperature inversion, trapping cool air and fog in a surface layer near the shore. (Based on Strahler and Strahler 1978.)

These fogs usually dissipate later in the day, but may last for days at a time.

HYDROLOGY

Rivers, ocean currents and waves, and precipitation are all part of the complex hydrological system operating in the dune landscape. Numerous rivers and streams discharge sediment-loaded flows into the ocean (Table 2). The gauged drainage area of 26 coastal rivers in the region totals 745,823 km^2 of which the Columbia River accounts for 661,838 km^2 or 89% of the total. The measured mean annual rate of discharge of these rivers is 9754 m^3/sec of which the Columbia River's discharge is 7222 m^3/sec or about 74%. Little information is available on the amount of sediment actually carried by the rivers and of their importance in creating and maintaining the present-day dune landscape. There can be no doubt that the sediment loads of the Columbia River are responsible for the dune systems of Localities 1 to 4. The situation is more complex, however, along most of the rest of the coast where the rivers are small and presumably carry a much smaller total sediment load.

Once discharged into the ocean, sediments that do not immediately settle to the bottom are transported north and south along the coast. The principle ocean current pattern is provided by the Subarctic Current which moves east across the Pacific Ocean driven by the prevailing westerlies (Figure 6). As it approaches the northwest coast of North America it divides to flow north and south. The southern branch becomes the California Current, about 150 km wide. Its flow in summer, boosted by the northwest winds, is about 10 cm/sec. In winter the southward flow is interrupted by the northward-flowing Davidson Current, moving at 25-45 cm/sec. This current, 90 km in width, flows between the shore and the California Current. It is thought to be the surface expression, perhaps in response to the southerly winds of winter, of the northward, year-round, deep-flowing California Undercurrent.

While these currents are very influential in the general movement of sediments along the coast, longshore currents are probably more important at the local level and in short-term shoreline processes. Longshore currents operate in the surf zone and are generated by waves striking the shore at an angle (Bascom 1964, p. 218-219). When this happens, part of the wave's energy is dissipated as an impulse to the water in a direction parallel to the shore. With the breaking of many waves, a chain of impulses is set in motion which moves sand steadily along the shore (Figure 7). In summer the longshore current moves southward; in winter it moves northward. Because of the strong winter wave activity, the net movement of sediments by longshore currents is northward along the Oregon and Washington coasts (U.S. Army Corps of Engineers 1971). In northern California, however, because of the trend of the coastline and the slightly different wind regime, net longshore movement seems to be toward the south (Cooper 1967, p. 17).

In some places, where there are shallow offshore sand bars, or where the waves approach the beach parallel to the shoreline trend, rip currents are created (Figure 8). A circulation pattern develops in which the longshore currents will flow in two directions toward troughs or low points in the beach profile which carry the water off-

Table 2. Mean annual river discharge into the Pacific Ocean from northern California, Oregon and Washington ocean drainage basins. Only gauged river basins having a mean annual discharge of at least 10 m^3/sec are considered. (From Proctor et al. 1980.)

		Gauged Drainage Area		Measured Mean Annual Discharge	
Sub-region	River Basin	km^2	mi^2	m^3/sec	10^6 acre ft/yr
Washington coast, north	Queets River basin	1150	443.8	117	2.99
	Quinault River basin	684	264.0	79	2.02
	Hoh River basin	655	252.8	71	1.82
	Quillayute River basin	990	382.0	62	1.59
	Dickey River basin	223	86.1	14	0.36
Washington coast, south	Chehalis River basin	4700	1813.8	220	5.63
	Humptulips River basin	337	130.0	37	0.95
	North River basin	567	218.8	27	0.69
	Willapa River basin	409	157.8	24	0.61
	Naselle River basin	231	89.1	15	0.38
	Columbia River basin	661838	255406.2	7222	184.69
Oregon coast, north	Nehalem River basin	1730	667.6	77	1.97
	Wilson River basin	417	160.9	34	0.87
	Nestucca River basin	236	91.1	28	0.72
	Trask River basin	376	145.1	27	0.69
Oregon coast, central	Alsea River basin	924	356.6	51	1.30
	Siletz River basin	524	202.2	45	1.15
	Siuslaw River basin	882	340.4	25	0.64
Oregon coast, south	Rogue River basin	12800	4939.6	302	7.72
	Umpqua River basin	10100	3897.6	228	5.83
	Coquille River basin	1960	756.4	70	1.79
California coast, north	Smith River basin	1670	644.5	106	2.71
	Klamath River basin	31400	12117.4	564	14.37
	Eel River basin	8950	3453.8	234	5.98
	Mad River basin	1260	486.2	44	1.13
	Redwood Creek basin	720	277.9	31	0.79

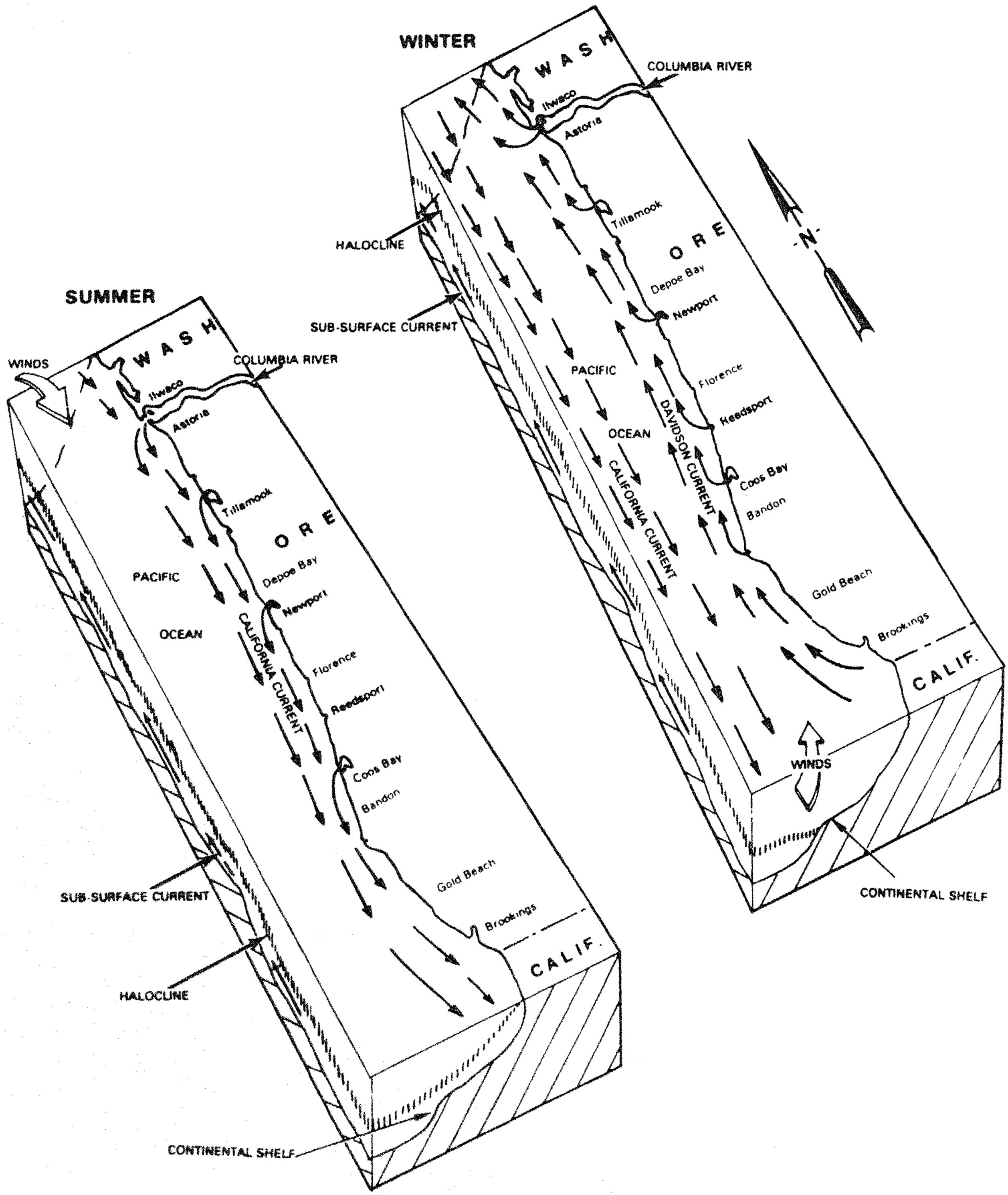

Figure 6. Ocean currents along the Pacific Northwest coast. The halocline is a vertical zone in which the salinity changes rapidly, in this case increasing with depth. (U.S. Army Corps of Engineers diagram reproduced from USDA-SCS 1975.)

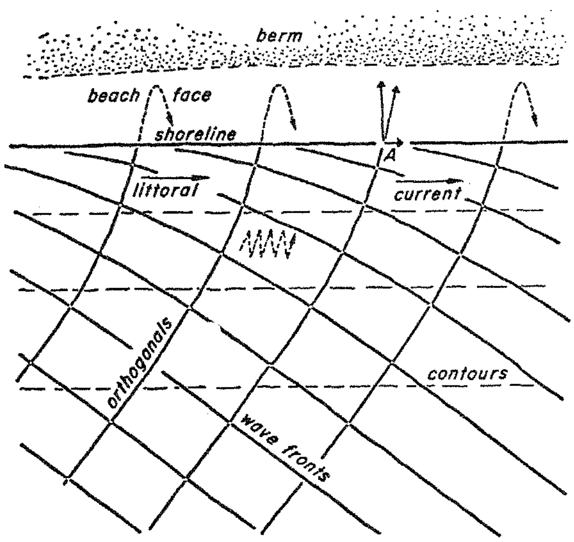

Figure 7. Longshore or littoral currents. The dotted lines at the top show the path of sand grains in their movement (to the right) with every wave. (Reproduced from Bascom 1964.)

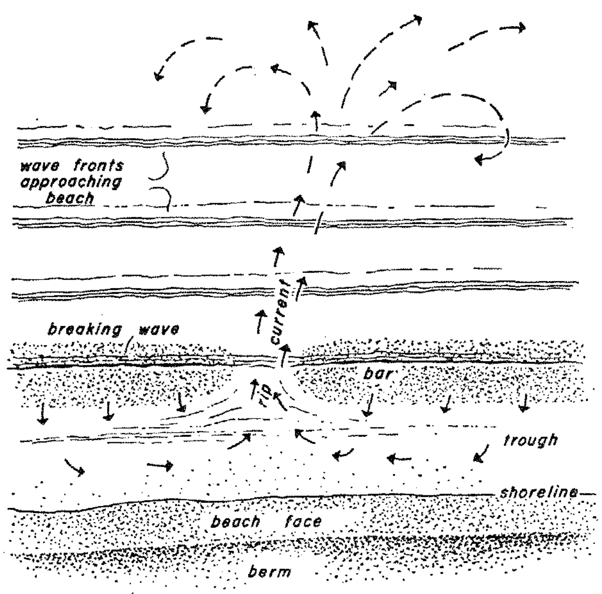

Figure 8. Rip currents are created when waves break parallel to the shore or on a shallow bar. (Reproduced from Bascom 1964.)

shore as a fast, narrow current. Once established, the current deepens the trough, and it can develop eventually into a deep embayment in the beach. In severe storms, large waves break ashore over the deeper rip-current embayment with less loss of energy. The resulting force with which the waves hit foredunes or seacliffs can cause massive erosion.

Longshore currents and rip currents in any one place are a function of wave energy, shore configuration, and shoreline orientation (trend). Their occurrence and effect is difficult to predict, or, where known, cannot be considered stable.

While the rivers and ocean currents supply the sands that are the foundation of the dune landscape, water in the form of precipitation is an important agent in shaping that landscape. The high rainfall, 150 cm or more a year along much of the region's coast, maintains a high water table that creates lakes and ponds and stable sand surfaces, and provides conditions favorable for plant growth.

In addition, the dune sands act as reservoirs of fresh water. Considerable work has been carried out investigating their potential as a water resource. Work by Frank (1968), Schlicker and Deacon (1974), the University of Washington (1974), Robison (1973), Christenson and Rosenthal (1982), and others have shown that the dune aquifers range from 35 m to 70 m in thickness. The water table is the top of the groundwater zone, which is bounded to the east by the basal bedrock of the coastal mountains. It extends west under the ocean, forming an interface with salt water above it in a curving lens (Figure 9). Because of the uniform nature of these aquifers

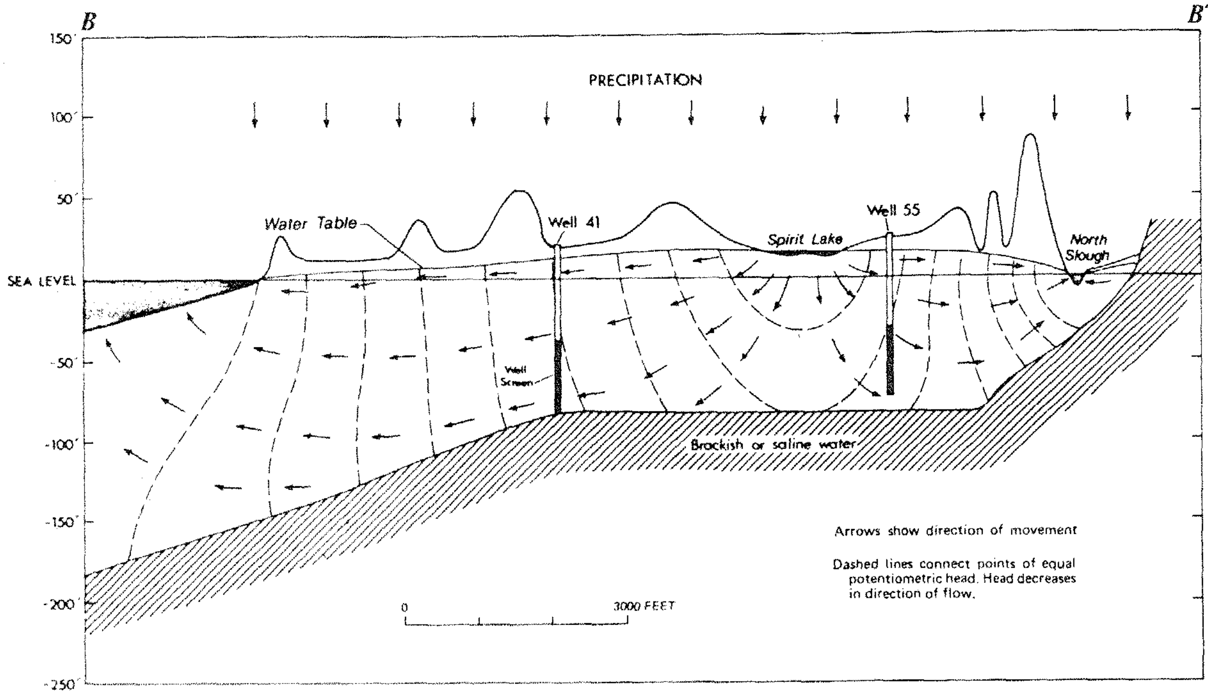

Figure 9. Cross section through a dune aquifer showing inferred movement of ground water. Note that Spirit Lake is formed by the intersection of the dune surface with the water table. (Reproduced from Robison 1973).

(clean sand), most precipitation soaks rapidly into the ground with minimal loss to evaporation and run-off (no streams originate in the dune areas). The ground water drains either to adjacent lakes and streams or into the ocean. It is estimated that with a recharge rate[3] of 138 cm/yr , some 15,000 m^3/ha/yr (200,000 ft^3/ac/yr) or 15,200,000 l/ha/yr (1,600,000 gal/ac/yr) would be available for use (Christenson and Rosenthal 1982).

The water is of generally good chemical quality (Schlicker and Deacon 1974). It tends to be somewhat acidic (pH 5.7-6.2), and in some cases, dissolved iron exceeds the desired maximum limit. It comes out of the ground at a temperature of about 13°C, and is mostly colorless and clear. In a few cases it has a light brown color from peat material buried in the sand. This seems to be a local condition. A number of places along the coast (such as the Clatsop and Florence areas) rely heavily on the dune aquifer for domestic water supplies.

SUBSTRATE

The immediate sources of sediments that ultimately form the dune landscape are the outflow from rivers and the erosion of shore formations exposed to wave attack. The sedimentary formations of the Oregon coast are particularly

[3]Net infiltration from 150 to 162 cm/yr precipitation, the remainder lost to evaporation and surface run-off.

susceptible to erosion, as are the exposed parts of the dune systems already in existence.

An analysis of sands from the Oregon coastal dunes (Twenhofel 1946) shows that in most samples 99% of the particles are in the 0.5 to 0.12 mm size range (medium to fine sands), with 80% of the grains at or near 0.25 mm (Schlicker and Deacon 1974). This is characteristic of wind-blown dune sands in other parts of the world (Ranwell 1972, p. 154). The composition of these sands is primarily (70% to 90%) quartz and feldspar, while heavier, darker minerals occur in minute amounts. The color of the sand varies slightly from place to place, ranging from light yellowish brown to a darker brownish gray. The darker, heavier sediments, products of the erosion of basaltic and metamorphic rocks, tend to be concentrated toward the beaches. In southern Oregon and northern California the high concentrations of coarse, dark sediments result in black beaches and dunes in some areas. The lighter colored sands of the north and the darker sands of the south are shown in the frontispiece.

Dune sands are very poor soils. There is no accumulation of organic matter, nutrient status is so low it cannot be effectively measured, and reaction is about neutral (Tables 3 and 4). Because of the high rainfall and rapid drainage, salinity is not an important factor in dune soils even on areas just above the beach.

Under long-established coniferous vegetation, a true soil begins to develop. The soil profile is characterized by a thin, very dark grayish-brown surface horizon (or layer), grading into a lighter grayish-brown horizon and finally into the yellowish-brown color of the original dune sands[4]. The first two layers can vary in depth from 12 to 50 cm. These soils are acid in reaction (pH 5.1 to 6.0), have excessive drainage, and are low in nutrients and humus.

On the lower areas, imperfectly drained soils develop which have a thin surface layer of dark gray to almost black organic matter under which is grayish sand. There may be stains of yellowish-brown and iron-cemented nodules deeper in the gray sand. These soils are very acid (pH 4.5 to 5.0) and poor in nutrients and humus. With long-continued standing water and plant growth, extremely acid peat soils will develop, with partially decomposed organic material reaching a depth of 1.5 m. Table 5 summarizes profile characteristics for typical dune soils.

PLANTS

Plants are important agents in the shaping of the coastal dune landscape. They act in two ways. First, they can initiate the development of a particular dune form, either by "actively" interacting with the wind-blown sand, or simply by their presence, a sort of "passive" effect. Secondly, plants act as stabilizers of sand surfaces by protecting them from the erosive force of the wind.

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[4]Colors in profile descriptions are based on specific samples, sometimes on dry, sometimes on wet samples. The descriptions given here and in Table 3 were developed from several sources and are presented for illustrative purposes only.

Table 3. Chemical analysis of beach, moving dune, stabilized ridge, deflation plain, and dune forest soils near Arcata, California. Samples were taken from a 30-cm depth. Data are in parts per million except for pH and humus. (From Johnson 1963).

	Substance												
Site	pH	Humus %	NH_3	NO_3	P_2O_5	K_2O	Ca	Mg	Na	SO_4	HCO_3	Cl	Total N
Beach	8.2	0.27	1.7	11	4.6	16	37	12	67	8	146	63	112
Foredune	7.1	0.74	1.4	9	7.8	12	24	12	35	8	98	28	350
Moving dune	6.8	0.35	0.9	3	0.3	12	24	11	20	8	85	21	126
Stable ridge	6.5	2.27	1.9	25	7.7	18	41	9	26	12	122	28	1134
Deflation plain	5.9	2.08	5.9	4	1.7	62	45	28	89	136	171	105	684
Dune forest	5.6	7.48	3.0	15	7.3	31	53	22	57	8	134	48	1988
Requirements of a good soil	6.0-7.0	1+	-	25	10	40	100	20	100	100-1000	-	200	700

Table 4. Chemical analysis (pH, organic matter, and total salts) of foredune and deflation plain soils along a transect near Carter Lake on the central Oregon coast. (From Wiedemann 1966.)

Sample Site	Distance from high tide line (m)	pH	Organic matter (%)	Total salts (mmhos/cm)
Windward slope of the foredune	27	7.4	0	1.63
Crest of the foredune	78	7.0	0.12	0.13
Lee slope of the foredune	136	5.8	0.36	0.10
Deflation plain	296	5.5	0.18	0.11
Deflation plain hummock	482	5.9	0.36	0.10
Inner edge of the deflation plain	528	5.6	0.60	0.11

Table 5. Characteristics of typical dune soils of the Northwest Pacific Coastal Region. (Sources: Bowlsby and Swanson 1964; University of Washington 1974; USDA-SCS 1975; U.S. Department of Agriculture, Soil Conservation Service, Portland, Oregon, Official series descriptions; A.M. Wiedemann, The Evergreen State College, Olympia, Washington, unpublished field notes.)

General soil type	Profile description		Dune forms where the type is typically found
1. Active sand dunes	Surface -	Bare or thin layer of undecomposed leaves, needles, and twigs.	Foredune, sand hummock, sand plain, parabola dune, blowout, transverse dune, oblique dune retention ridge, deflation plain (in part).
	0-150+ cm -	Yellowish-brown to gray fine sand.	
2. Recently stabilized dunes	Surface -	2 to 8 cm undecomposed and partially decomposed leaves, needles, and twigs.	Dune ridge, sand plain, remnant forest mound.
	0-12 cm -	Very dark gray fine sand.	
	12-50 cm -	Yellowish-brown fine sand with a few reddish-brown and yellow stains along root channels.	
	50-150+ cm -	Yellowish-brown fine sand.	
3. Old stabilized	Surface -	2 to 8 cm undecomposed and partially decomposed leaves, needles, twigs.	Dune forms obliterated by long-term erosion. These soils represent Pleistocene dune activity and are commonly seen in highway cuts.
	0-12 cm -	Grayish-brown sandy loam.	
	12-50 cm -	Reddish-brown sandy loam with iron-cemented nodules and hard-pan fragments.	
	50-100 cm -	Brown to pale brown loam with cemented sandy material.	
	100-150+ cm-	Yellowish-brown fine sandy loam, weakly cemented.	
4. Stabilized low dune areas	Surface -	2 to 5cm black decomposed plant remains matted by roots.	Deflation plain, swale
	0-50 cm -	Yellowish-brown to brownish-gray fine sand with brown mottles.	
	50-150+ cm -	Yellowish-brown fine sand.	

Plants that initiate the development of dune forms must be especially well adapted to rather extensive sand burial. Along the Pacific Northwest coast only a few species have the ability to survive massive sand burial through continual growth above accumulating sands. None of these species, however, are sand stabilizers in the sense that the sand is more or less permanently protected from the wind. Stabilization requires the development of a complete cover, effectively stopping sand movement at the surface of the ground and permitting nonadapted plants to become established. The "sand-loving" species tend to build mounds and ridges that eventually erode away, allowing continued sand activity. Other species, tolerant of a limited amount of sand burial, but spreading rapidly by means of rhizomes and above ground runners, are more efficient in the stabilization process.

This "active" accumulation of sand is in contrast to plants acting as barriers to the flow of wind. Rising in front of a vegetation mass, the wind loses its power to transport sand. The sand it is carrying and pushing along piles up windward of the vegetation. This accumulation results in the development of several kinds of dune forms.

Plants also act in the shaping of the dune landscape through stabilization. Some dune forms are preserved through the stabilization process. Others are destroyed because stabilization of sand surfaces prevent further sand from moving. Degradation of a dune form because of a reduction in sand supply is known as "sand starvation."

Not all dune forms require the action of plants for their initiation. Destruction of plant cover, erosion of the sand surface, and sand drift, (the interaction of wind and sand alone) are also important agents of landscape development.

CHAPTER THREE

COASTAL SAND DUNE MORPHOLOGY

The coastal sand dune landscape is a complex mosaic of many dune forms. The forms are the basic morphological units making up the coastal dune systems which characterize the various dune localities along the coast of this region.

The dune forms are the result of the interaction of the environmental factors sand, wind, water, and plants. Each combination of factors produces unique, identifiable forms that recur over the landscape. Wind and sand alone produce the spectacular forms for which these dune areas are known--extensive, moving dunes occurring in regular patterns. Wind, sand, and plants produce both small and large dunes of a different form, which move slowly, if at all, and which may occur in rather irregular and complex patterns. Water and vegetation are the stabilizers, slowing sand movement and ultimately stopping it.

In the 25 years since Cooper's (1958) work was published, the morphology of the coastal dunes has been described in a variety of ways. Crook (1979a) basically retained Cooper's terminology, but developed a classification system based on varying states of stability. Battelle (1974) used the notion of "habitat" (the physical or structural environment comprising a biotic community) in their description of 15 sites along the Washington and Oregon coast. The U.S. Forest Service (Pinto et al. 1972) and the Soil Conservation Service (USDA-SCS 1975) both developed systems of "mapping units" based on geomorphic features, degree of stability, and vegetation for their descriptive studies based on management considerations. Each of these was developed for a specific purpose, and they range in effectiveness from somewhat ambiguous to very complex.

McKee (1979) describes a system of classification based on two descriptive attributes--the shape or form of the sand body, and the position and number of slipfaces (steep lee-side surfaces). Dune forms will be described from this perspective, emphasizing formative process and morphology. Because McKee's classification is based on inland dune areas where precipitation is low and plants are generally not abundant, not all coastal dune forms can be fitted to his system. The coastal dune forms described here, their characteristic features, and the corresponding units of the McKee classification are listed in Table 6.

DUNE FORMS

Beach

The beach extends along the coast everywhere except where steep cliffs form the shore and technically is not a dune form. The beach is, however, important because it is the

Table 6. Formative elements, characteristic features, and classification of the dune forms of the Pacific Northwest Coastal Region.

Dune form	Formative elements	Characteristic features	Name in McKee's (1979) classification of basic dune forms
Transverse ridge	Wind, sand	Long, sinuous, asymmetric unvegetated ridges (100⁺m long; 1 to 6 m high); trend at right angles to NW winds of summer. Advance to SE.	Transverse ridge
Oblique dune	Wind, sand	Unvegetated. Long, sinuous, symmetric ridges, 1000 m long, 25 m high; trend oblique to SW winter winds and NW summer winds. Advance to NE.	Linear
Retention ridge	Wind, sand, plants	Asymmetric ridge with slipface invading forest or shrub vegetation. Forms in front of vegetation barrier.	None
Foredune	Wind, sand, plants	Slightly asymmetric ridge above beach high tide line. Forms from sand accumulating in vegetation. Presently to 100 m wide and 10 m high.	None
Parabola dune	Wind, sand, plants	Asymmetric U or V shaped ridge, highest at the apex. Range in size from 100 m to several km in length. Formed by unidirectional effective winds.	Parabolic
Sand hummock	Wind, sand, plants	Mounds of sand piled in and around vegetation, one to several meters in height. Generally unstable, eventually eroding away.	None
Blowout	Wind, sand, plants	Saucer or trough shaped erosional depressions in established vegetation. Vary widely in size. Adjacent blowouts may merge to produce sand plains.	Blowout
Sand plain	Wind, sand	Flat to undulating sand surface. If extensive may have transverse ridge pattern present. May be partially or completely vegetated. Not wet.	Sheet
Deflation plain	Wind, sand, water	Flat sand surface formed by erosion of sand to the water table. Standing water during the rainy season. Quickly vegetated.	None
Dune ridge	Other dune forms and plants	Ridge remnants of other dune forms that have been completely stabilized by vegetation (parabolas, foredunes, retention ridges).	None
Swale	Wind, sand, water, plants	Long, narrow depressions between dune ridges (successive foredunes, parabola marginal ridges, trough blowouts). Very wet, frequently with standing water	None
Remnant forest	Wind, sand, plants	Erosional remnants in an area of active sand movement. Usually large (200 to 500 m in diameter, 30 m high) with old growth forest on top.	None
Ponds and lakes	Wind, sand	Ephemeral ponds formed where water table is seasonally high. Lakes form in front of dunes damming streams, and in swales.	None

transition zone between land and sea, and because it is the direct source of the sand that creates the dune landscape. The beach is defined (Bascomb 1964, p.13-23) as the area in which the sand is moved by ordinary wave action. Seaward, the limit is about 10 m below low-tide level, while landward the limit extends to the edge of a permanent shore feature. Very high tides and storm waves can extend farther inland and "move sand," but these are not ordinary.

In winter, because of the erosive action of storm waves, the beach is steep and narrow. Much of the accumulated sand is washed out to deeper water to form offshore sand bars. As much as 1.5 to 4.5 m of sand can be lost in a winter season. In summer, the sediments are carried back onto the beach, which becomes broad and gently sloping. The amount of sand transported inland off the beach in dune areas is not known, but it is thought that most sand deposited on the beaches is washed back to sea again, part of a continuous cycle of deposition and erosion. In very severe storms, sand may be deposited farther out, in water too deep to permit its return to the beach.

Some beaches associated with sand dunes are on the inner sides of spits or peninsulas and protected from wave action. Deposition by tidal current results in very gently sloping tidal flats composed of varying mixtures of sand and mud. Because of the wind regimes and the lack of ocean-transported sand, very little sand is supplied to the dune system from these beaches.

Transverse Dunes (Figures 10 and 11)

The northwest winds of summer are responsible for the development of dunes whose trend (the direction of a line parallel to the crest) is transverse to the resultant[5] wind direction, N10°W, or blowing toward an azimuth of 170° (Figure 12). Movement is in the general direction of the resultant wind. These dunes occur in a regular pattern on extensive areas where there is an abundant sand supply and a unidirectional effective wind (Figure 13). The crests are sinuous and vary greatly in length; some can be traced for more than 1000 m.

Intercrest distance is also variable, but averages about 34 m (Cooper 1958, Figure 4). In profile, the windward slopes are long and gentle, ranging from 3° to 12°, while the lee slope is a slipface at about 33°. Height from the base ranges from 1 to 6 m.

An interesting feature of these dunes, described by Cooper (1958, p. 31-33) is a tongue of sand extending downwind from the slipface, directly below a high point on the ridge crest. He thought these "lee projections" to be erosion remnants of a transverse dune that has progressed downwind. He also points out that while the long axis of the lee projections is consistently parallel to the resultant direction of the summer winds, the trend of the dunes seem to rotate 11° to 23° landward from the line that is normal (at right angles) to the resultant wind direction. He could offer no explanation for this phenomenon.

During the winter the strong south-southwesterly winds erode the transverse dunes severely. The degree of degradation depends upon the size of the dune and exposure to

[5]Resultant wind direction: an "average" value that takes into account both wind speed and direction over a period of time.

Figure 10. Transverse ridge zone. The dunes are moving toward the camera. Tenmile Creek, Locality 22. June, 1983.

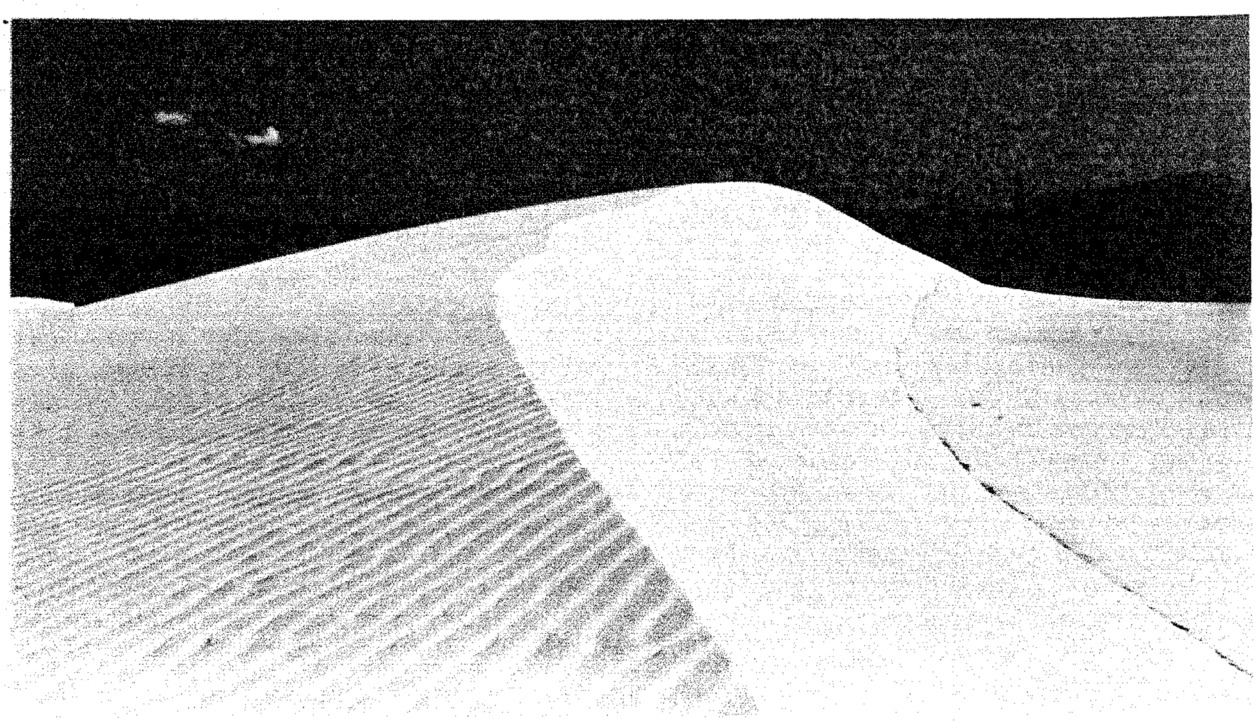

Figure 11. Transverse ridge, side view. Well-developed crest about 2 m high. North of Florence, Locality 29. August, 1964.

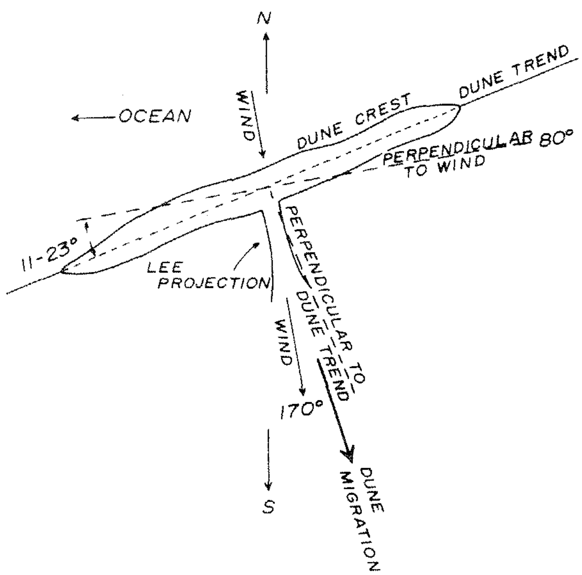

Figure 12. Transverse ridges move in the general direction of the resultant summer winds. The trend of the ridge rotates 11° to 23° landward from the line that is at right angles to the resultant wind. The lee projection is parallel to the resultant wind.

the winds, ranging from a mere rounding of the crests to near obliteration with only a gently rolling surface remaining. Rejuvenation of the ridges seems to occur on the foundation remaining from the previous year.

Transverse dunes developed over very extensive areas in the past. With the foredune cutting off sand supply and the deflation plain extending farther and farther inland, sand supply and areas suitable for the development of transverse dunes become more and more restricted. Because of their continual mass movement, vegetation does not develop to stabilize them. The sand will continue to move in the form of transverse dunes, eventually to be incorporated into the larger masses of sand lying inland.

Oblique Dunes (Cover; Figure 14)

On very extensive sandy areas, open to the full force of the summer and winter wind regimes, and with an abundant sand supply, massive sand dunes develop that have crests oriented at right angles to the south-southwesterly winds of winter. They occur as a series of parallel dunes spaced 150 to 560 m apart, with an average spacing of 300 m. The average height above the inter-dune base is 25 m, with extremes to 60 m. The crest length is usually less than 1000 m, but can go as long as 2000 m. Cooper (1958, p. 49-58) called these dunes oblique ridges because their trend is oblique to both the summer and winter winds, parallel to his calculation of the resultant wind forces. He felt that they did not advance, but rather extended inland in the direction of the dune trend, this extension being caused by both the winter and summer winds. He gave the rate of extension of one such dune as 1.63 m/yr. Cooper hypothesized that their origin was due to the differential advance of a "precipitation ridge" (see retention ridge) that originated close to shore. Lagging extra large masses of sand served as the beginnings of the large dunes.

In their detailed study of the oblique dunes, Hunter *et al.* (1983) have clarified some aspects of origin and movement. Working with aerial photographs dating to 1939, in conjunction with extensive field work and analysis of wind data from Newport, Oregon, they have concluded that these dunes are essentially transverse to the south south-southwesterly winter storm winds, and that they advance an average of 3.8 m/yr towards an azimuth of 26°. This is the calculated resultant direction of sand

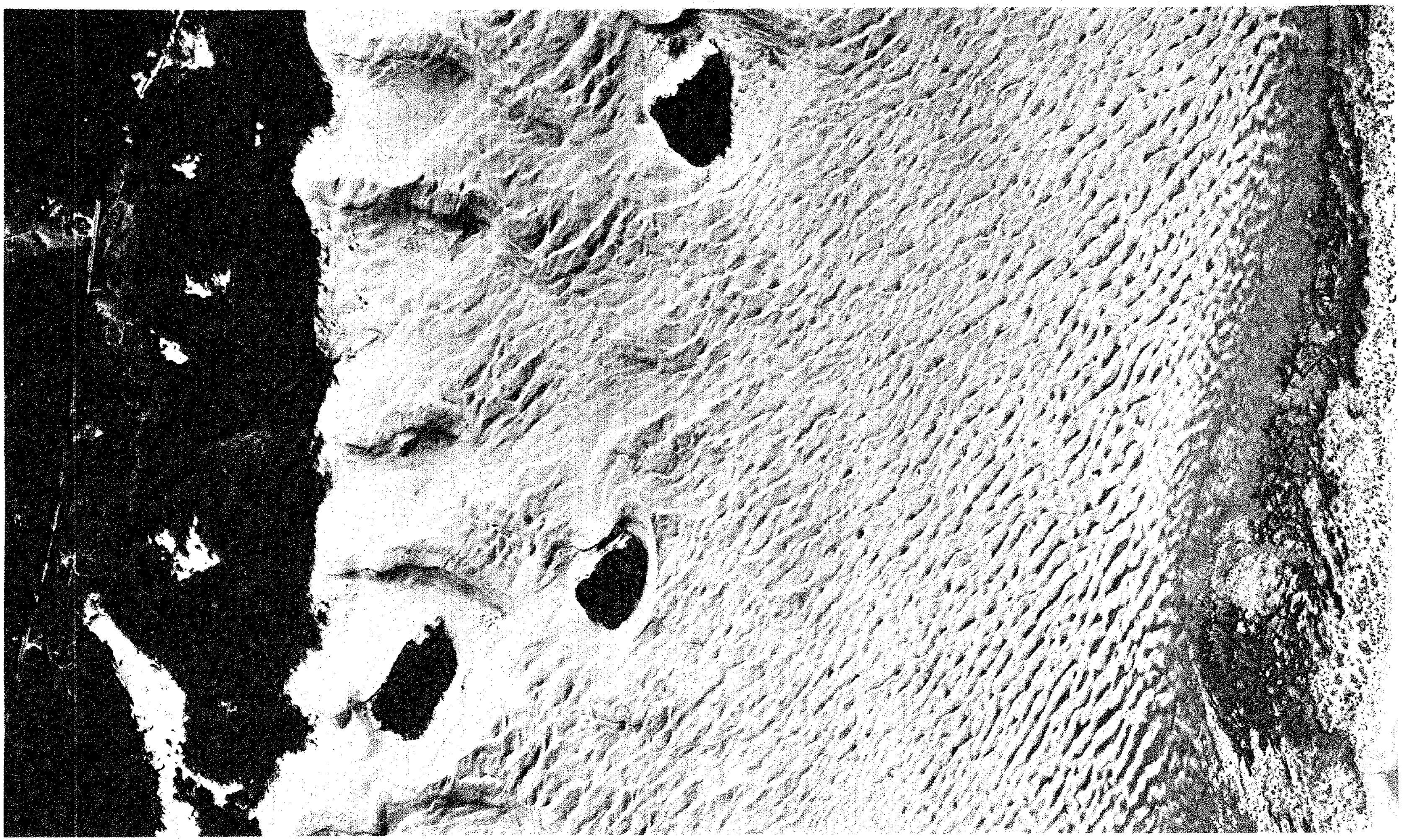

Figure 13. Transverse dune system, vertical aerial photograph. South is at the top. Ground features from left to right: Woahink Lake, US Highway 101, forested inner dune margin (dune ridge) with blowouts, retention ridge, oblique dune zone, forested remnants, transverse ridge zone, deflation plain, foredune, and beach. Note the transverse ridges extending onto the oblique dunes. The path of the northwest summer winds lies diagonally across the photograph from lower right to upper left. Locality 20 just south of Cleawox Lake. Scale approximately 1:15000. (U.S. Geodetic Survey aerial photograph, Index 54A, No. 55-W-1061, 16 October 1955, Washington, D.C.)

transport by all winds blowing from the south. However, when sand transport by the northerly winds of summer and the inhibition of sand transport by winter rains were taken into account, a resultant transport direction of 45° was determined. This direction is at an angle of 71° to the dune trend, and in this sense the dunes can be considered oblique rather than transverse[6] (Figure 14). The south-southwesterly winds of winter are responsible for the overall orientation and movement of the dunes while the northerly winds of summer reverse the upper parts of the dunes and probably help keep their crests relatively straight. The origin of oblique dunes poses no problems beyond those posed by any eolian dunes; special initial conditions are not required for their origin or growth.

Because of their exposure to wind and the activity of sand over their surfaces, the oblique dunes are not likely to become stabilized by vegetation in their present form. Cooper (1958, p. 58-60) states that they cannot be maintained indefinitely. He theorizes that failure of sand supply at the shore, suppression by transverse ridges, and encroachment by vegetation will all work toward the obliteration of the oblique dune pattern. In the light of the previously cited work by Hunter et al., the most likely sequence of events is that the present oblique dunes will continue their advance, which is basically inland, to merge with the retention ridge (or in some cases to become massive parabola dunes). This would happen even if no vegetation developed to seaward. The current development of such vegetation, and the resulting "sand starvation", could prevent the formation of new oblique dunes, but this assumes that the sand supply from the beaches is sufficient to build such massive dune forms.

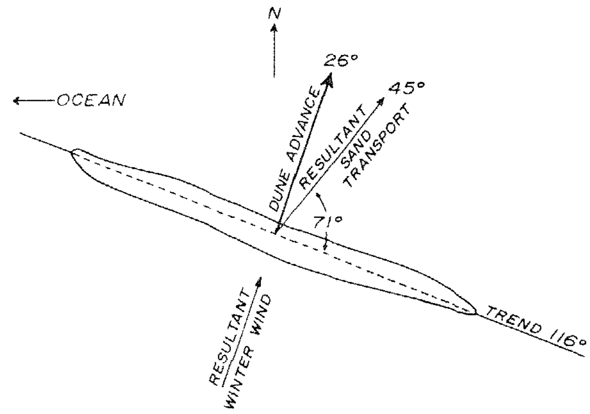

Figure 14. The oblique dune is basically a large transverse ridge moving in the direction of the resultant winds of winter. Because of rain and summer winds, the resultant sand transport is deflected landward.

Foredune (Figure 15)

The foredune is a ridge of sand parallel to the beach just above the limit of ordinary wave action. It is formed by the interaction of wind, sand, and vegetation. Plants tolerant of sand burial become more or less permanently established above the high-tide line. Sand transported up from the beach by the wind collects in and around the vegetation, both by entrapment and deposition (the plants deflecting winds upward, causing transport to

[6]According to the morphodynamic classification scheme proposed by Hunter et al. (1983) a dune is transverse if the resultant transport of sand is at an angle of 75° to 90° to the dune trend, oblique if the angle is 15° to 75°, and longitudinal if it is 0° to 15°.

Figure 15. Foredune. European beachgrass and maritime pea. Note the smaller dunes building up at the seaward base of the main dune. These rarely last through a winter season because of storm waves. Yaquina Bay, Locality 15. July, 1964.

cease). The plants are able to maintain growth even though buried completely. As the plants continue to grow, a ridge of accumulated sand develops and increases in height. Along the Pacific Northwest coast this ridge has attained heights of 10 m and a base width of over 100 m. Its seaward side is steep, while the lee side slopes gently from the crest.

Along most of the coast, this type of foredune has developed relatively recently, probably since about 1910 when European beach grass (Ammophila arenaria) was introduced in the Coos Bay region. European beach grass (used for centuries in Europe to build foredunes and to stabilize areas of moving sand) was widely planted in the 1930's and again in the 1950's. It also spread rapidly by natural means. Prior to the introduction of this species, the foredune was made up of a series of generally closely spaced mounds (see sand hummock) produced by native plant species especially well-adapted to massive sand burial (Figure 16). Remnants of this kind of foredune can still be found on the dune areas of northern California.

The ultimate size of the present foredune along the northwest coast is not known, but it is possible to speculate on the basis of observation and information from other places. As the foredune becomes higher, the windward side becomes steeper, and less sand is carried to the top. It is not uncommon to see smaller mounds form at the windward base as the result of European beach grass plants becoming established there. These can form in one summer season and continue to develop over a number of seasons if there are no winter high tides or storms to wash them out. If these smaller dunes would continue to build up they would effectively reduce the windward slope of the foredune and allow more sand to reach the crest. However severe winter wave action is frequent enough that these smaller dunes are invariably cut back and washed out. The established foredune itself can be cut back as much as 2 m in one winter by storm waves.

Studies in Japan by Tanaka and Uzui (1973) show that as dune height and windward slope increase, erosion of dune crest increases. This erosion results in sand moving inland, widening the foredune. With time a great mass of sand will gradually move inland, probably to become stabilized by vegetation as a new foredune builds. This occurs on the west coast of Europe (Ranwell 1972) where conditions of wind, sand supply, and vegetation are very similar to those on the northwest coast. Ranwell (1958) calculated that it took about 50 years to build a foredune to maximum height (15 m),

Figure 16. Foredune zone of sand hummocks formed by native plant species. American dunegrass in the foregound. South spit, Humboldt Bay, Locality 23. June, 1983.

the point at which landward movement would begin. It would then take another 30 yrs for a new foredune to develop. Whether such a cycle takes place along our coast remains to be seen, but the similarity of conditions to those of western Europe make it a strong possibility.

Retention Ridge (Figure 17)

When winds that are moving sand encounter an obstacle in the form of dense shrub or tree vegetation, they are deflected upwards. The sand ceases movement and begins to pile up, forming a retention ridge[7] with a long, gentle windward slope and a steep lee slope. As the ridge increases in height, sand slides down the steep lee slope (slipface), resulting in a slow forward creep of the ridge. If the ridge becomes

[7]Cooper (1958, p. 55) called this a "precipitation ridge" because the wind "precipitates" its sand load as it is deflected over the forest barrier. The term "retention ridge" (McKee 1979, p. 96) seems more appropriate for this form.

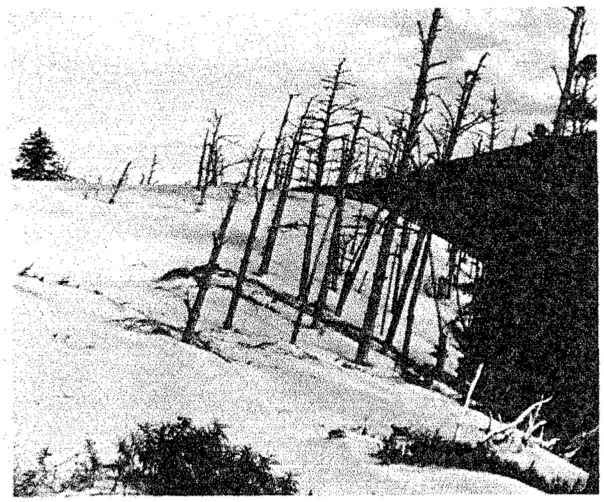

Figure 17. Retention ridge at the inner margin of the transverse ridge system. The slipface is the moving front of the ridge. Most trees are intolerant of sand burial and soon die as sand covers the ground at the base of the trunks. South of the Siuslaw River, Locality 20. July 1964.

massive enough, it will advance over and destroy the vegetation barrier. Generally it is a long continuous ridge moving on a broad front under the influence of both summer and winter wind regimes. Cooper (1958, p. 115) estimated that the ridge moves forward (eastward) at a rate of 1.6 m/year. Plants can colonize the steep lee slopes of still-active massive ridges if the rate of deposition is relatively slow. If accumulation slows even further because of vegetation development windward of the ridge, the windward slope will eventually be covered with vegetation. The effectiveness of the process can be seen in the well-developed forests on the steep lee slopes of some of the older, stabilized ridges.

Parabola Dune (Figures 18 and 19)

A parabola dune is basically a U-shaped or "parabolic" retention ridge. It is highest and most massive at the apex. The marginal ridges taper gradually because of continuous erosion of the extreme windward ends. An erosion trough lies between the marginal ridges. The profile of the apex shows a gradual slope to windward and a steep slipface on the lee side. Parabola dunes may range in size from as much as 4 km in length with 1.5 km between the marginal ridges to much smaller dunes less than 100 m long.

Their origin is dependent upon an abundant sand supply, well-developed vegetation, and a strong unidirectional effective wind. Where the extent of shoreline favorable to the development of dunes is limited, as is frequently the case adjacent to river mouths, sand will accumulate in massive amounts against the vegetation barrier. At some point where the vegetation is not quite as dense or resistant, the sand will "break through" and advance more rapidly than the rest of the retention ridge. This break-through point becomes the apex, where accumulation and advance is concentrated. A trough is scoured out behind (to windward) the apex and the marginal ridges form. These ridges also advance into vegetation, but much more slowly, and so the parabolic form emerges. These dunes can be quite large, with the crest of the apex as much as 35 m above the base and advancing as much as 6 m/yr (A. Wiedemann, The Evergreen State College, Olympia, Washington; unpublished data).

This same process can take place in areas where a well-developed retention ridge is already advancing into vegetation. At a point where the vegetation is less resistant the sand mass will move forward more rapidly. Sometimes called "trough blowouts" these masses of sand usually move under the influence of either the summer or winter winds and can become parabola dunes. Adjacent parabola dunes can join as their marginal ridges intersect. When this happens the parabolic configuration is lost and a typical retention ridge reforms.

Vegetation eventually develops on the marginal ridges and the entire dune becomes stabilized. Under certain conditions the apex can be blown out, leaving the marginal ridges as two more or less parallel sand ridges (depending upon the original shape of the parabola and its size). New parabola dunes may form later. If they are large, they will override and destroy the earlier stabilized dune, or, if smaller, will advance between the marginal ridges of the earlier dune. Examples of both situations can be found.

Sand Hummock (Figure 20)

Plant species that can tolerate burial by sand are responsible for the building of hummocks--mounds of sand that can reach 5 m in height.

Figure 18. Parabola dune system. The dunes are moving southeast. The inner edge of the lowermost dunes is about 750 m from the beach. Note the development of the transverse ridge pattern. The Lanphere-Christensen Dunes Preserve lies in the middle part of the photograph; Samoa mills at the top right. North spit, Humboldt Bay, Locality 33. June, 1983.

They begin with sand accumulating in the stems and leaves of the plant and eventually covering it. The following season the plant grows out of the covering sand, increasing in size and causing more sand to be deposited. Species such as yellow sandverbena (Abronia latifolia),

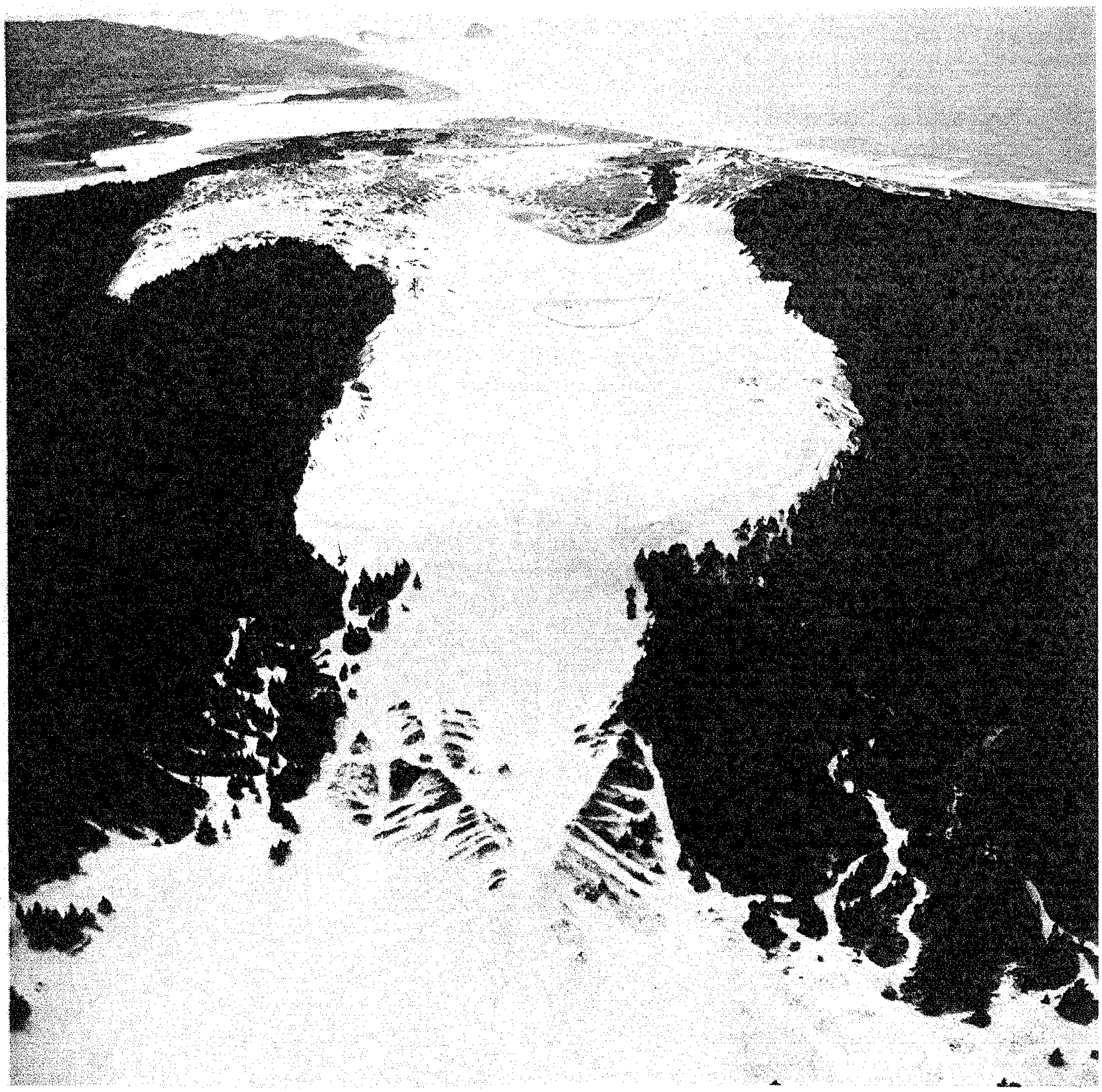

Figure 19. Parabola dunes at Sand Lake, Locality 9. The view is southwestward with Haystack Rock in the distance. The first and second parabola dunes (see Appendix II) are visible. Note the deflation plain at the windward base of the first dune and the ephemeral pond at the base of the lee slipface. The second dune has built up very high because of the constricting vegetation. As it advances, the sand channel will be widened. August, 1983. (Photograph by Art Hare.)

Figure 20a. Sand hummocks formed by European beachgrass. Because of the very strong northwest winds at this location, the hummocks are oriented in straight lines parallel to the wind. The hummocks are 2 to 3 m high. Near Sutton Creek, Locality 19. July, 1964.

Figure 20b. Sand hummock formed by a native plant species, silver bur-sage. These hummocks can reach 3 m in height. Sand Lake, Locality 9. July, 1964.

dune tansy (Tanacetum douglasii), Hooker willow (Salix hookeriana) and salt rush (Juncus lesuerii) are all effective hummock builders. European beach grass, however, builds the largest and most numerous hummocks. They are found wherever this species can become established (almost everywhere except very wet sites) and where sand is being transported by wind.

Hummocks can frequently result from extensive plantings of European beachgrass which were not followed with shrub and tree plantings, as was the case in the 1930's in some areas. Differential survival of plants resulted in bare patches of sand in the planting. Sand from these patches was blown into the patches of living plants. Growth in European beach grass is stimulated by sand burial, so these patches quickly evolved into hummocks.

Sand hummocks generally are not stable features. They are cyclic dune forms either being formed, or having reached some maximum size, are being eroded away, usually from the bottom up (sand erosion around the base). In some areas with very strong unidirectional effective winds and well established European beach grass, the foredune is replaced by a system of large hummocks, usually arranged in a row that runs parallel to the wind direction. In some cases, hummocks can become stabilized. This happens when they are sheltered from strong erosive winds (because of the development of dune forms to windward), or if stabilizing vegetation develops quickly enough to prevent erosion.

Blowout (Figure 13)

Where vegetation cover is disturbed sufficiently to expose the sand to wind, erosion will take place with sand being blown out of the disturbed site. Such a "blowout" can take two forms: either a long, narrow trough with a moving pile of sand at its head (a possible incipient parabola dune), or a saucer-shaped bowl with sand piled along the lee side. The size of a blowout varies considerably, from a few square meters in area to several hectares. As troughs or bowls enlarge they may join with other blowouts, resulting eventually in a sand plain, or the blowouts may simply become revegetated. Where there has been a history of blowout formation and stabilization, the ground surface is very irregular.

Sand Plain (Figure 21)

Sand plains are large, relatively level or gently sloping areas of sand. The surface may be irregular, but changes in relief are not great unless other dune forms occur on the plain. Generally the sand plain occurs between the beach and the beginning of the retention ridge. It is a broad expanse of sand on which other dune forms (transverse ridges, sand hummocks, etc.) develop if conditions of wind and sand supply necessary to the formation a particular dune form are present.

In general the sand plain is dry with the water table some distance below the surface. The establishment of vegetation is a slow process. Only if sand movement is reduced will species tolerant of some degree of sand covering become established, leading eventually to full vegetation cover. Reduction in sand movement on a sand plain might be due to the sheltering effect of nearby developing vegetation or to the trapping of sand farther downwind by developing vegetation.

Deflation Plain (Figures 13 and 22)

In certain areas, the wind erodes the sand surface close to the water table, resulting in a wet sand surface very resistant to further

Figure 21. Sand plain formed to windward of one of the large parabola dunes at Sand Lake, Locality 9. The red fescue--dune goldenrod community is stabilizing the area. Note scattered lodgepole pine becoming established in the open area. September, 1964.

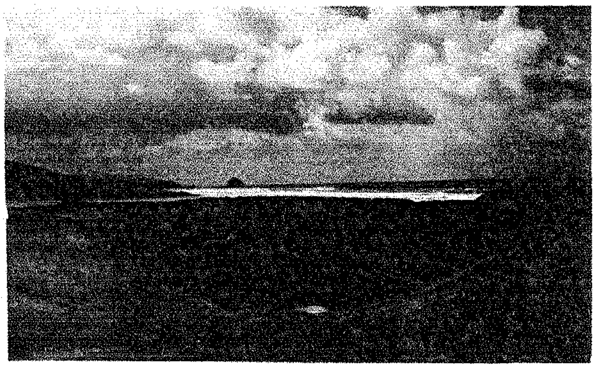

Figure 22. Deflation plain formed at the windward base of a large parabola dune at Sand Lake, Locality 9. The lowest part of the deflation plain is on the right, where part of a marginal ridge is visible. A forested remnant of an earlier marginal ridge is seen on the left. On the horizon is Haystack Rock at Cape Kiwanda. April, 1964.

erosion. Such places are called deflation plains. Their formation usually occurs when sand supply to the eroding surface is reduced or cut off entirely. Reduction in sand supply frequently occurs in the troughs between the marginal ridges of large parabola dunes because the sand is being used for the development of a new parabola dune downwind or because of extensive vegetation development in the area that was originally the source of the sand. A total interruption of the sand supply has occurred on the lee side of the extensive foredunes that have developed along the coast. A deflation plain has come into existence that has increased continuously in width over the past 40 yrs and in some places is now up to 2 km wide. The deflation plain will continue to increase in width as sand is eroded to the water table along its eastern edge.

Long term fluctuations in ground-water levels can cause deflation plains to develop or disappear (Cooper 1958, p. 109). Drainage waters from dune lakes may appear at some distance from the water source, effectively raising the water table. Lowering of the ground-water table because of altered drainage patterns or ground-water depletion could change the character of an existing deflation plain. The patches of wet sand, however, which commonly appear on extensive sand plains during winter and early spring are caused by temporary rises in the water table as a result of heavy winter precipitation and are not considered deflation surfaces.

Because of the stability of the deflation-plain surface and the abundance of moisture, vegetation develops rapidly. In as little as 30 yrs, a tall, dense thicket of shrubs and trees will develop that is virtually impenetrable to a person trying to walk through the area.

Dune Ridge (Figure 23)

Sand ridges result from the stabilization by vegetation of a dune in essentially unaltered form. Successive foredunes on a prograding shoreline, the marginal ridges of large parabola dunes, and retention ridges all stabilize as dune ridges. (These three dune forms are defined in terms of their origin. Once created and stabilized, they merge into a generally single, recognizable form.) Dune ridges will remain stable as long as the vegetation is undisturbed. Destruction of plant cover would result in sand movement different from the formative processes, and the dune ridge form would be obliterated. Dune ridges should not be confused with transverse ridges, which do not stabilize.

Remnant Forest Mounds (Cover; Figure 13)

These are dune forms having their origin in the degradation of earlier dune forms that had become stabilized. They are related to the stabilized dune forms located farther inland currently being destroyed by sand activity. They occur as large, spectacular, isolated, forested mounds. They vary in size but most are 200 to 500 m in diameter and about 50 m high. Old-growth forest covers the top, while younger vegetation occurs on the constantly eroding sides. The forest on the top of one of these remnant forest mounds was calculated to be at least 500 years old (Cooper 1958, p. 100). Their existence may be due to differential erosion during the current cycle of activity. Another possibility is that the existing forest

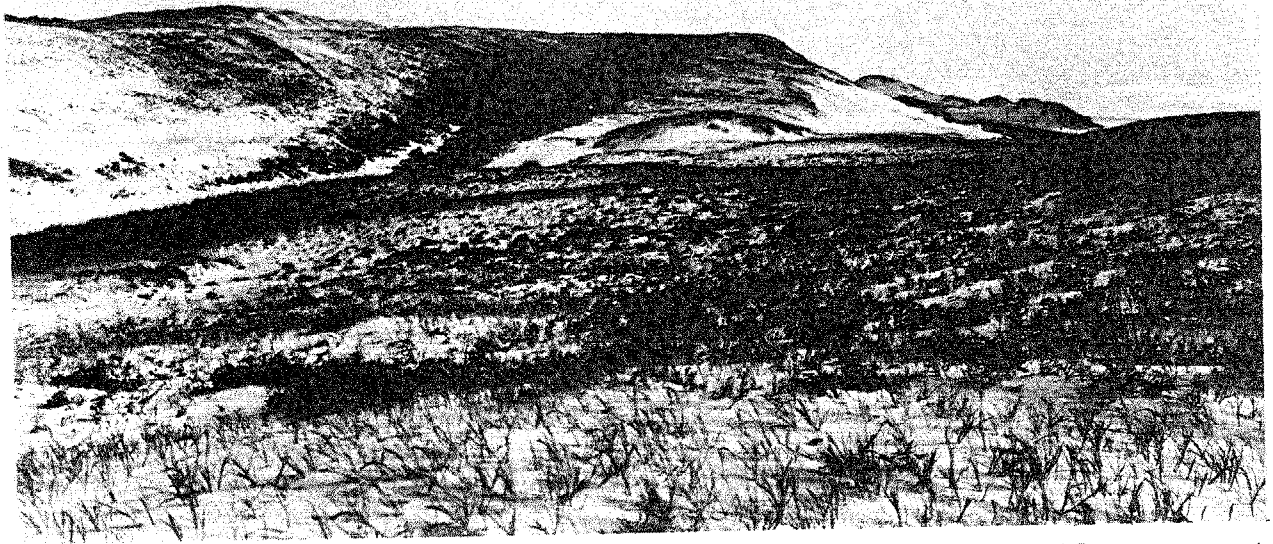

Figure 23. A dune ridge at Sand Lake, Locality 9. It is probably a remnant marginal ridge of a parabola dune. It is being stabilized by the seashore bluegrass--beach pea community. The dark band on the side of the ridge is bracken, an unusual occurrence in this kind of habitat. The plant cover in this area has been totally destroyed by ORV activity since this photograph was taken. May, 1964.

vegetation was burned and these areas escaped destruction.

Ponds and Lakes (Figure 24 and 25)

Bodies of water are found both on the dunes and along the inner margin of the dunes at the base of the retention-ridge slipface. These latter are called marginal lakes, and they originate either through the damming of small streams by the dune sands moving inland or by dune ground water flowing out of the dunes into the depression between the sand mass and the mountain front. Most of these lakes are less than 50 ha in size, but a few are much larger. Dune ponds and lakes form on deflation surfaces and in swales, and usually are the result of the dune surface intersecting the ground-water table. The largest reach 75 ha^2 and are relatively permanent. Many smaller ponds are ephemeral, drying up toward the beginning of summer and appearing again the following winter. The lakes of one dune area (the Oregon Dunes National Recreation Area) and the range in their size and depth are listed in Table 7.

Swales (Figure 26)

Low-lying areas between sand ridges are swales. Usually they are quite wet, with standing water usually in winter, but frequently all year long. Swales are common to localities where a prograding shore-line has resulted in a series of relatively closely spaced sand ridges. Successive ridges produced by the marginal ridges of adjacent parabola dunes may also have swales between them. Blowouts can create mounds and ridges which may have swales between them. A swale is not created through wind deflation of

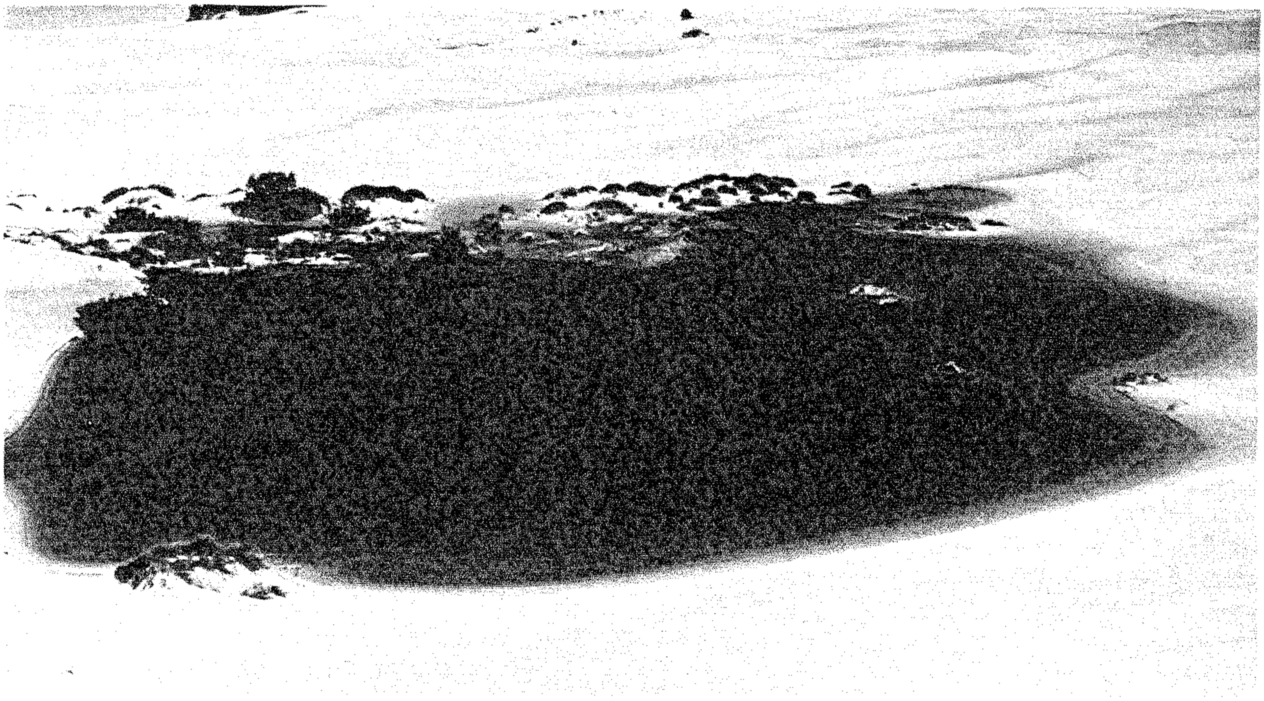

Figure 24. Ephemeral dune pond. These ponds usually dry up by early summer, but in years of high precipitation they may persist into the fall. Tenmile Creek, Locality 22. June, 1983.

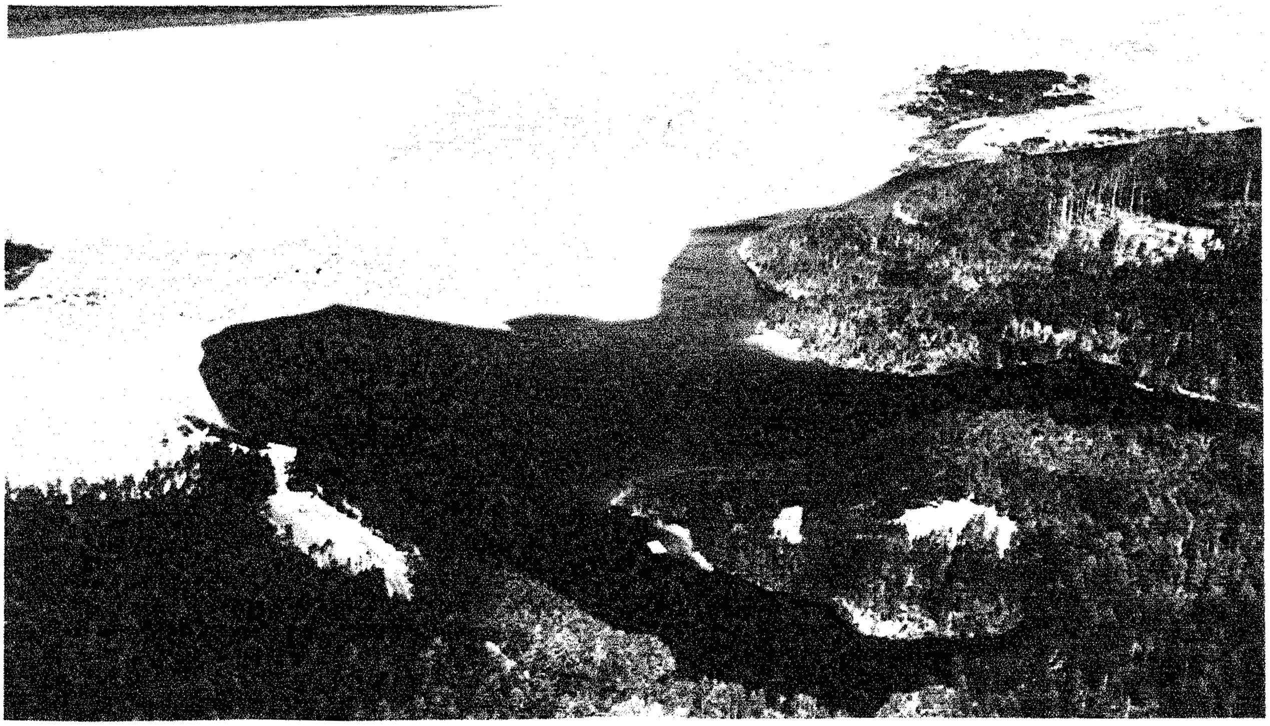

Figure 25. Dune lake formed by the damming of a small creek by sand. An overflow channel is marked at the upper right by vegetation extending into the open sand. Cleawox Lake, Locality 20. June, 1964.

Table 7. Approximate surface area and depth of lakes on the Oregon Dunes National Recreation Area in years of average precipitation. (From Pinto *et al.* 1972.)

Lake	Surface Area ha (acres)		Depth m (ft)	
Bear	4.9	(12.0)	5.5	(18.0)
Cleawox	33.2	(82.0)	14.6	(48.0)
Siltcoos Lagoon	2.0	(5.0)	1.8	(6.0)
Siltcoos	1167.2	(2882.0)	5.5	(18.0)
North Erhart	0.7	(1.7)	6.1	(20.0)
Erhart	0.4	(1.0)	6.1	(20.0)
Loon	1.2	(3.0)	6.1	(20.0)
Taylor	1.2	(3.0	5.8	(19.0)
Carter	11.3	(28.0)	11.6	(38.0)
Lost	2.4	(5.8)	9.2	(30.0)
Perkins	1.9	(4.7)	9.2	(30.0)
Tahkenitch	607.5	(1500.0)	6.4	(21.0)
Elbow	4.9	(12.0)	7.6	(25.0)
Threemile	27.1	(67.0)	9.8	(32.0)
Schuttpeltz	2.0	(5.0)	4.6	(15.0)
Hall	6.1	(15.0)	12.8	(42.0)
Clear	9.7	(24.0)	7.6	(25.0)
Saunders	23.1	(57.0)	9.2	(30.0)
Butterfield	15.4	(38.0)	10.7	(35.0)
Beale	4.1	(10.0)	7.6	(25.0)
Snag	12.2	(30.0)	3.1	(10.0)
Sandpoint	32.4	(80.0)	3.7	(12.0)
Spirit	0.8	(4.0)	3.1	(10.0)
Horsfall	101.3	(250.0)	4.6	(15.0)
Bluebill	14.2	(35.0)	4.6	(15.0)

the sand surface to the water table. It is characteristically long and narrow. Natural stabilization proceeds, and vegetation quickly becomes established in the swales unless enough water is present to form a pond or small dune lake.

DUNE SYSTEMS

A dune system is characterized by a set of dune forms recurring in a pattern over the dune landscape and by the nature of the coastal landform they occupy. It is the product of the various environmental factors interacting in certain ways in the different localities. Certain dune forms tend to characterize a given system, but they are not restricted to that system.

Along the Pacific Northwest coast four types of dune systems can be distinguished. In general, the *parallel ridge system* is found in the north, and south of the region, the *parabola dune system* in the north-central part of the region; and the transverse ridge system in the south-central. The bay dune system is scattered along the entire region. Many localities represent more than one system.

Parallel ridge system (Localities 1 through 4, 6, 15, 19, 24 through 29 (Figure 26))

This system is best developed on the prograding shoreline north and south of the Columbia River. Its characteristic dune form is the dune ridge (stabilized foredune). These ridges are arranged in a parallel series that extends over 2 km inland in some places. Development of the system began when the sea reached its maximum elevation after the last glaciation, about 6000 yrs ago.

The enormous sediment loads of the Columbia River were carried north and south by offshore longshore currents to be deposited on

Figure 26. Parallel ridge system. Clatsop Plains, Locality 4. View to north. Sunset Beach Road runs across the center of the photograph. Two of the nine ridges are easily visible just to the right of Sunset Lake, which is a swale lake. US 101 top right. August, 1983. (Photograph by Art Hare.)

beaches and blown inland. Vegetation developing at the high-tide line created a foredune. Deposition exceeded beach erosion and eventually a new line of vegetation developed farther out, initiating a new foredune. The height and number of the dune ridges that resulted was a function of rate of sand deposition on the beaches. There are fewer, lower ridges to the north, but with more extensive progradation over a longer shoreline (60 km). To the south there are more numerous, higher ridges over a shorter shoreline distance (30 km).

Swales occur between closely spaced ridges. Some of these swales are filled with lakes or ponds. Sand plains developed between the more widely spaced ridges. Blowouts and hummocks develop in areas where sand is active. Most of these ridge systems were stabilized prior to Caucasion settlement. Subsequent disturbance because of agricultural activity resulted in massive erosion in some localities that became the subject of intensive stabilization efforts.

Parallel ridge systems are also found where a series of retention ridges have become stabilized. They usually represent the culmination (through stabilization) of a long period of sand activity in which the sand of a number of dune forms eventually becomes incorporated into a single ridge. Localities 15, 19, 24, and 25 are examples of such areas. Generally a currently active retention ridge is also present.

Parabola dune system (Localities 9 through 13, 16 through 18, 30, 31, 33) (Figure 27))

These systems are characterized by massive parabola dunes (or complexes of such dunes) located primarily along the north-central

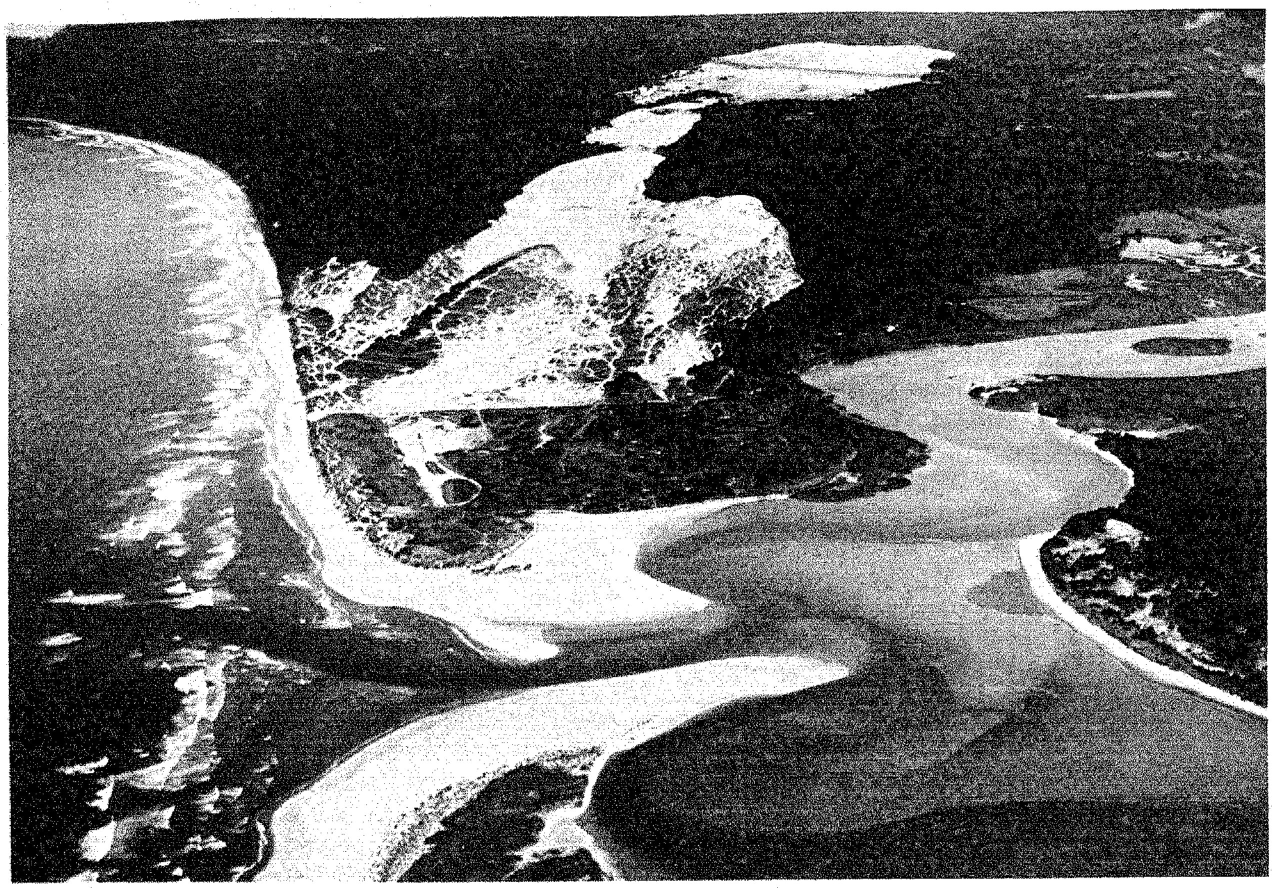

Figure 27. Parabola dune system at Sand Lake, Locality 9. The currently active dunes move northeastward along the axis of the system. Vehicles are not permitted in the darker, vegetated area just north of the entrance to Sand Lake. The light area just behind the foredune is a drag strip. Cape Lookout upper left. August, 1983. (Photograph by Art Hare.)

Oregon coast. They are the result of unidirectional effective winds, mostly south-southwesterly, but a few northwesterly. Many are associated with river or bay mouths. All are separated from one another by capes, rocky headlands, or sea cliffs. For the most part their development began during the period of rising sea level after the last glaciation. Maximum development of the form occurred during the period of submergence, with resultant erosion of the seaward ends as the sea level continued to rise.

The extent to which the system survives today at any locality depends on how far inland it progressed during the formative period. At Locality 9 (Sand Lake) most of the system still remains, while at many other localities only barely recognizable remnants can be distinguished. Extensive sand plains and deflation plains are frequently found windward of the parabola dunes, often with transverse ridges and hummocks present. Where successive parabola dunes have formed, stabilized remnants of the earlier dunes are present. A foredune may be present at the beach end of the system, and blowouts are a common feature of areas in early stages of stabilization. Where many small parabolas constitute the system (as on the north coast of California) the marginal ridges of these dunes may coalesce and erode away. A retention ridge will result.

Transverse ridge system (Localities 20-23) (Cover and Figure 13)

Along the south-central Oregon coast, shore conditions were favorable to the accumulation of large amounts of sand for great distances, both longshore and inland. These systems account for the greatest area of dunes in the region under consideration. A relatively level, low-lying coastal plain allowed the sand to move inland up to 4 km from the present shoreline as the sea level rose. With maximum submergence and relative shoreline stability, the systems have remained active.

Extensive sand plains are characteristic of these systems, and where the plain is not stabilized, the transverse ridge pattern develops. The oblique dunes, unique to this system, are a result of massive sand supplies and interacting winds. Parabola dunes occur frequently, but these tend to be small compared to those farther north. A retention ridge defines the inner or landward extent of the system, and a foredune or in some places, sand hummocks, define the seaward side next to the beach.

Deflation plains occur on the lee side of the foredune and at the windward base of some parabola dunes. Blowouts occur frequently in either old or newly established vegetation. Marginal lakes are characteristic of this system because of the wide front over which the sand has moved inland. Ephemeral ponds occur at the edges of deflation plains, in the troughs between oblique dunes, and in low places in forested areas (stabilized trough blowouts). Large, shallow dune lakes are a characteristic feature of some localities in this system.

Bay dune system (Localities 5, 7, 8, 14, 32) (Figure 28)

These dune systems are defined by their location on sand spits, barrier dunes, or peninsulas formed

Figure 28. Bay dune system. The end of the spit (top) is typical Snowy Plover nesting habitat. Note the erosion of the foredune. Netarts Bay, Locality 8. (Oregon Department of Transportation, 10 March, 1978.)

across the mouths of bays. They can range in width from several hundred meters to several kilometers, and in length from 3 km to over 10 km. They are not characterized by any special set of dune forms. The foredune, sand plain, deflation plain, blowout, sand ridge, sand hummock, and swale are the most common forms seen. On the larger peninsulas, parabola dunes, transverse ridges, and ponds and lakes can occur.

CHAPTER FOUR
DUNE PROCESS

The coastal sand dune landscape as we see it today is the product of thousands of years of coastal marine and wind processes. Enough is known of recent geological history to trace the sequence of probable events, which, along with natural phenomena such as stabilization by plants, soil formation, and fire, have produced the present dune systems.

At the peak of the last Pleistocene glaciation (variously estimated at 20,000 to 30,000 yrs ago), sea levels were depressed by about 140 m below the present level. At that time the shoreline extended much farther out, at least 3 km, according to Cooper (1958, p. 130). The coastal plain, or terrace, on which many of the present dunes lie is about 50 m below present sea level. At the maximum depression of sea level, this terrace would have been as much as 100 m above sea level.

As world climate warmed and the glaciers melted, sea level began to rise. The rise was gradual and was probably accompanied by many temporary fluctuations--rapid rise, none, or even reversal. As the waters rose, sediments deposited on the beaches were blown inland on receptive shores by the prevailing wind regimes. Dune systems formed which were continually eroded at their seaward ends. These sediments were then reincorporated into new dune systems. The amount of sediment deposited onto beaches must have been much higher at that time than at present. Melting glaciers released enormous sediment loads which eventually found their way to the sea.

About 6,000 yrs ago, the rate of submergence slowed considerably and about 3,650 yrs ago a condition of "still stand" was reached. Coleman and Smith (1964) estimate the rate of submergence at 20 cm per century for the period 8,000 to 3,650 yrs ago. Since then, there have been minor fluctuations, including those of the last 50 yrs when sea levels rose by 12 to 15 cm. However, because of tectonic activity (the rising of land masses along the Pacific coast), the net rise of sea level on coastal dune shores has been about 5 cm (Hunt 1974, p. 602).

Data reported by Christensen and Rosenthal (1982) from deep-well drilling at Florence, Oregon, are of interest in reconstructing dune history. Drilling shows that the dune sands rest on a marine terrace 49 m below present sea level. Woody materials from this terrace were carbon-14 dated at 27,000 yrs old. A sample taken at 27 m below present sea level dated 8,830 yrs, and one taken at present sea level (13 m below present land surface) at 2,340 yrs. Up to the 27-m level, the sediments were a mixture of sand, silt, clay, and organic materials indicating that up to about 9,000 yrs ago river-transported sediments (from the Siuslaw River) were deposited on the dunes. More rapid deposition of beach sand since that time probably prevented the further accumulation of river-transported materials.

While one must be careful about drawing conclusions from limited data, it is interesting to note that there was little accumulation of sand between "still stand" (essentially present sea level), 3650 yrs ago, and 2340 yrs ago, the age of the sample collected at the same level. Since that time there has been considerable depostion, and this is of interest for the discussion later in the chapter.

As sea-level rise slowed around 6,000 yrs ago, Cooper (1958) states that the dunes reached their farthest inland advance and their greatest volume.[8] Most areas had become completely stabilized, either as parabola dune complexes or as massive retention ridges and associated deflation plains. The continued slow rise of sea level eroded away the stabilized dune masses, leaving only remnants in some cases. Some of these remnants are "perched" on higher ground with no present contact with receptive shore. In other places recent sand erosion has uncovered the remains of large trees adjoining the present-day beach. If there is any validity to the data mentioned above, this period of overall stability probably lasted for some time.

[8]The area of the coast north and south of the Columbia River had no dunes at this time because of the bluffs and cliffs that made up the bay shorelines in this area. Dune building occurred in the succeeding 6,000 yrs as explained in the section on parallel ridge systems.

STABILIZATION AND REJUVENATION

One of the most remarkable features of these coastal dune systems is their instability--the cycles of stabilization and rejuvenation that are apparent everywhere. Because of the mild climate, vegetation becomes established easily and quickly and development is rapid. Progression from herbaceous to shrub to permanent forest can take place within the lifetime of one person. This is demonstrated by a forested area directly west of Cleawox Lake (Locality 20) (Figure 29). Described in 1915 as a low meadow with grass and strawberry plants, it had developed into a forest with trees 30 cm in diameter and 12 m tall by 1965 (Wiedemann 1966, p. 188-203).

Some of this vegetation will remain a long time, growing into old-growth climax forest. More commonly, however, dunes become active again and much of the vegetation is partially or completely buried by moving dunes. As the sand moves on, decaying remnants of forest of all sizes become exposed again. Occasionally the cycle is so rapid that one sees new forest developing among the remains of the previous one.

With the establishment of vegetation is initiated the development of soil. These soils demonstrate the instability of the sand dune environment. Eroding sands frequently expose "buried profiles," layers of soil that had developed to some extent under forest and were then buried as new sand moved over the area. One of the most striking examples of this can be seen at Cape Kiwanda on the Oregon coast (Locality 10). The south face of the

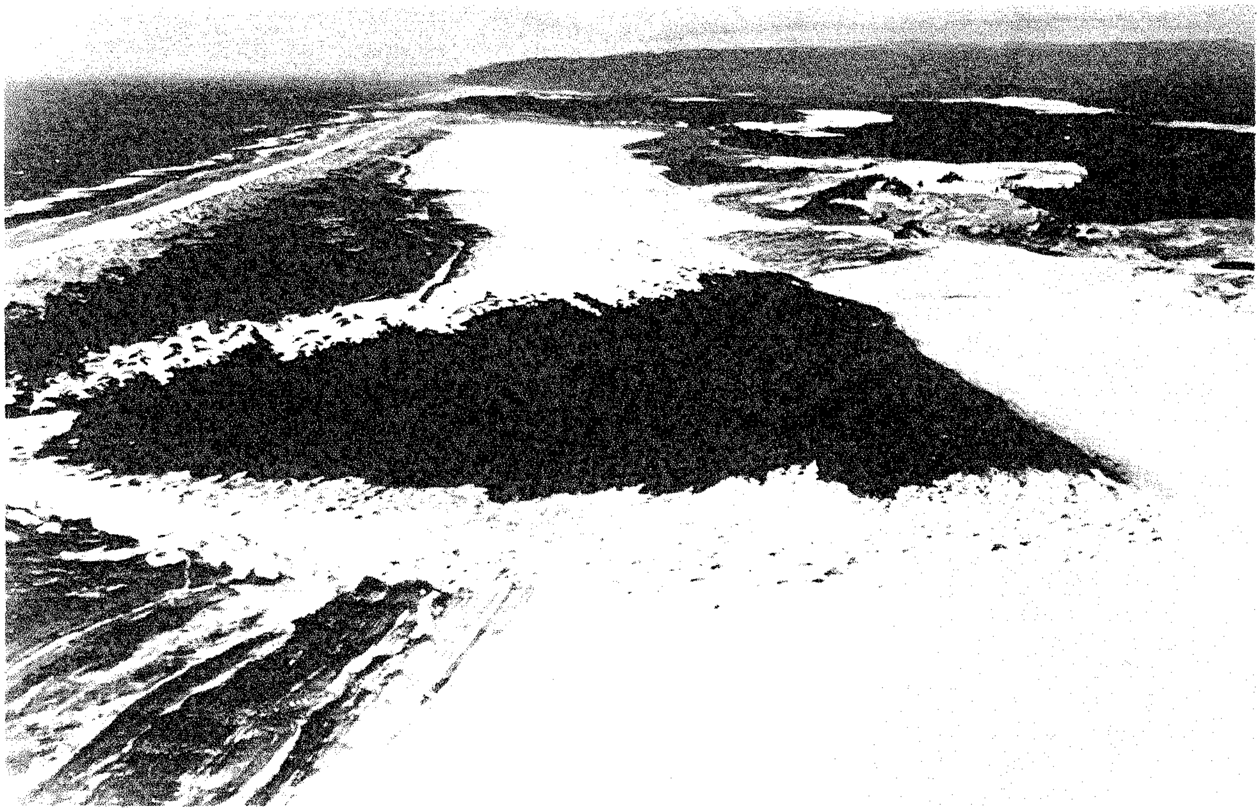

Figure 29. Deflation plain and vegetation development caused by drainage from a dune lake. View is toward the north. The oldest vegetation is at the left. The "striped" nature of the vegetation at the lower left results from the planting of legumes and grasses to improve wildlife habitat. Most of the sand hummocks at the north and south ends are formed by Hooker willow. At the time the photograph was taken the area was about 1400 m long (N - S) and 600 m wide at the widest point. West of Cleawox Lake, Locality 20. June, 1964.

thick sand mantle atop Cape Kiwanda shows six buried soil layers, all within a vertical distance of 25 m (Figure 30). Clearly "stability" is a variable state, subject to the action of many factors.

The factors responsible for sand activity in any particular area are difficult to determine (unless there is a historical record). Cooper (1958, p. 131) states that all of the dunes were stabilized by the time of maximum submergence. For the massive retention ridges along the inner margins of the dune areas and for the largest parabola dunes (such as at Sand Lake, Locality 9), stabilization was probably a one-time phenomenon. Road cuts through these dune forms reveal no buried profiles, but a very well-developed surface profile. Given Birkeland's (1974) estimate of at least 1,000 yrs for a soil surface horizon to develop under ideal conditions, it is entirely likely that at least some of the dune forms in some places have escaped the stabilization-rejuvenation cycle. These places are usually the extreme inner margins of the present dune fields.

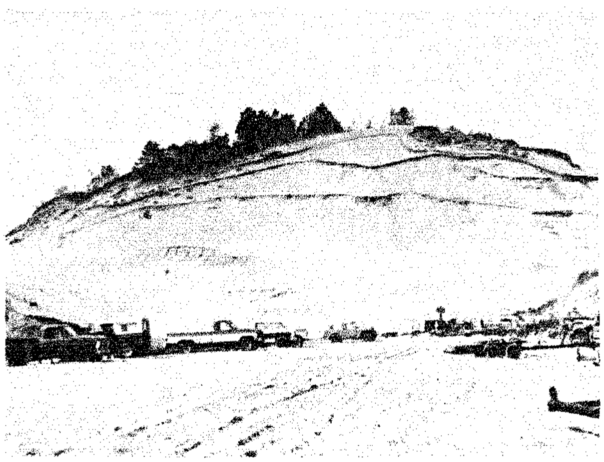

Figure 30. Buried soil profiles on the remnant dune mass on top of Cape Kiwanda. At least six profiles are distinguishable. Locality 10. August, 1983.

On areas closer to the shore, exposed profiles range from a few centimeters of incipient soil development to nearly fully developed surface horizons 30 cm thick. In many places the surfaces of these profiles bear bits of charred wood, evidence that fire may have destroyed the protecting cover, permitting rejuvenation. While not common, extensive fires did occur prior to Caucasian settlement (Cooper 1958, p. 74). Fires in the early part of the 19th century destroyed much forest along the Oregon coast, as noted in pioneer journals and coast surveys (Wiedemann 1966, p. 90). These fires would probably have been natural in origin since the beach- and river-dwelling aboriginals would not have made a practice of burning to maintain grasslands as was the case in many inland areas.

Although fires could account for rejuvenation on a local scale, the current activity, which seems uniform in extent from Tillamook Head all the way into northern California, is more difficult to explain. Climatic changes could cause changes in vegetation or wind regimes that would bring about renewed activity. However, Hanson (1947), as a result of his study of pollen in peat profiles from sand dune depressions, sees no evidence of coastal climatic change in the post-glacial period. He postulates that periods of accelerated sand movement may be related to climatic fluctuations farther inland, changes which could have increased wind velocities sufficiently to bring about extensive rejuvenation. Studies in Europe (Ranwell 1972, p. 18) show that dune activity historically has been related to periods of exceptionally stormy weather. It is suggested that these periods of storminess are related to recurrrent astronomical events affecting tidal maxima. The major tidal maxima occur in 1,700-yr cycles, the last occurring in Europe in 1433 A.D.

Changes in coastal configuration as a result of differential rates of erosion of headlands and intervening stretches may affect patterns and volume of beach accumulation, and hence sand supply to the dunes. Tectonic changes in the coast line could create the effects of submergence or emergence, increasing or decreasing sand activity (Russell 1970). Increased sediment loads, perhaps reflecting climatic change far from the dune areas themselves, could provide massive new supplies of sand for rejuvenation.

THE PRESENT SITUATION

The generalized picture seems to suggest an ultimate stabilization of the coastal dunes several thousand years ago. Cessation of submergence or perhaps even slight reversal may have combined in concert with other factors to reduce sand supply from the beaches. This permitted the development of an extensive deflation plain leeward of the retention ridges at the inner margin of the dune field. In some places, a second retention ridge seaward from the first, but parallel to it (Locality 19), or a smaller parabola dune enclosed within a larger one (Locality 9) suggest interruption of this process. General stabilization occurred but with frequent local instability.

Large-scale rejuvenation then occurred. Using dune movement studies and the present distance of the retention ridge from the beach, Cooper (1958, p. 14) estimates a minimum time of 2,750 yrs since the present activity began. This is sufficient time for restabilization to occur on a local basis on deflation plains and other places where sand movement temporarily slows. This vegetation is, in turn, again destroyed by local rejuvenation.

This is the pattern we see today; it is especially well developed north of Florence, Oregon (Locality 19), and north of Coos Bay, Oregon (Locality 23). At Sand Lake (Locality 9), a parabola dune of the current cycle of activity has traversed the entire 6,000 m to the mountain front between the marginal ridges of the older stabilized dunes. Three more parabola dunes are following in its path. Based on the current rate of movement of the newest parabola dune (6 m/yr), the current activity would have begun at least 1,000 yrs ago. The three later dunes, however, have very little forest vegetation in their path and presumably would move more rapidly than the first one did. A time of 2,000 to 3,000 yrs to account for the activity in this area would not seem unreasonable.

Comparison of dune movement data with the drilled-well data discussed earlier strongly suggest a resurgence of dune-building activity 2000 to 3000 yrs ago. It cannot be determined if the bulk of the sand involved in the current activity represents materials already in place, or if it resulted from a temporary buildup in supply to the beaches. The bulk of this sand has already moved inland almost to the inner margin of the dune field (and farther in a few places). Except on a very local basis, there is no evidence of very large amounts of new sand accumulating near the beaches. The volume of sand collected in the newly formed foredune seems quite insignificant when compared to the massive oblique dunes and extensive transverse dune areas already in existence.

The most likely sequence of events for the future is that the sand of the transverse ridges and oblique dunes, because of their direction of movement, will eventually be incorporated into the inner retention ridge. Using the rate of oblique dune movement calculated by Hunter et al. (1983), this could take at least 1,000 yrs. No new oblique dunes or transverse ridge systems will form. This may be the result of sand accumulation in the foredune. However, it is also very likely that even in the absence of the present foredune system, not enough sand would be available from the beaches to maintain the present system of active dunes. As the active dunes work into the retention ridge, the leeward deflation plain will increase in width. Sand movement will slow, and eventually the entire system will be covered by vegetation, stabilizing even the retention ridge -- a full turn of the cycle once again.

CHAPTER FIVE

BIOTA

FLORA

The vascular plant flora of the coastal dunes appears to be remarkably uniform from Cape Flattery to Cape Mendocino. However, the flora changes toward the southern part. The change is due to the climatic shift at 46°N latitude noted earlier, from a mesothermal to a Mediterranean type climate (Breckon and Barbour 1974). This shift is not reflected in the flora until 43° 30'N, near Coos Bay, Oregon. While not an abrupt change, it does mark the southern limit of the significant influence of the Subarctic Beach Flora and northern limit of the Dry Mediterranean Beach Flora (Figure 31). This boundary also corresponds closely to the northern boundary of the California Floristic Province (Howell 1957) and the boundary at 44°N given by Hitchcock and Cronquist (1973) for the northward extension of the Klamath Flora.

The significance of this can be seen in the presence or absence of species on either side of this general boundary. A number of dune species do not occur north of Coos Bay: silvery phacelia (Phacelia argentea) and beach sagewort (Artemisia pycnocephala), for example. Likewise, large-headed sedge (Carex macrocephala) and sweet gale (Myrica gale) do not occur south of Coos Bay. A few more southerly species just barely make it into the region at the southern end: Hottentot-fig (Mesembryanthemum edule) and sea-fig (M. chilense). Some species occur throughout the region, but become more important in one part or another: chaparral broom (Baccharis pilularis), for example, is far more common in northern California, while western red cedar (Thuja plicata) is more frequently seen in the dune forests of the north part of the region. Ten species occurring within the region are endemic to the Pacific coast of North America, and

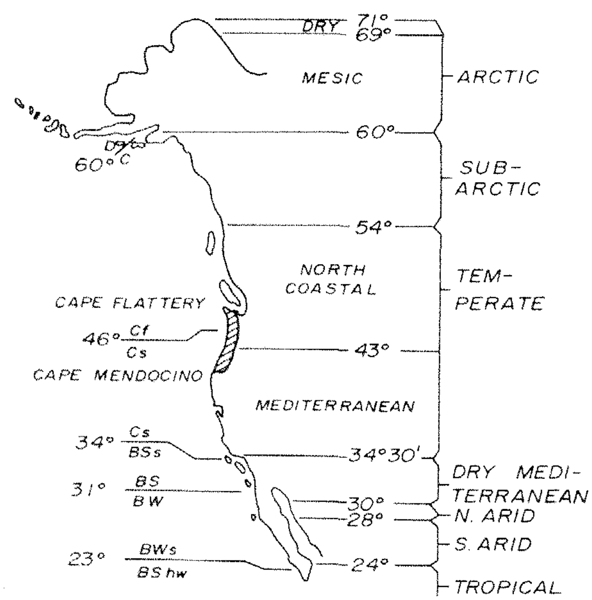

Figure 31. Pacific Coast ecofloristic zones and subzones and major climatic boundaries (Koeppen system). The Pacific Northwest Coastal Region is shaded. (Redrawn from Barbour et al. 1975.)

are restricted to maritime habitats. One of these, dune tansy (*Tanacetum douglasii*), occurs entirely within the region between 49°N and 40°N, and another, wedge-leaved silver bursage (*Ambrosia chamissonis* ssp. cuneifolia), is found only within one degree of latitude, from 47° 30'N to 46° 30'N (Breckon and Barbour 1974; Barbour *et al.* 1975, 1976).

No comprehensive vascular plant flora of the coastal dune systems is available. The work of Wiedemann (1966), Wiedemann *et al.* (1969), Johnson (1963), Parker (1974), and Barbour and Major (1977) includes lists of plant species that provide information about the dune flora. Only a small number of species are characteristic of the sand dunes; the remaining are generally distributed widely on nondune areas as well. Appendix III lists the principle vascular plant species encountered on the coastal dunes. Very little work has been done on the nonvascular cryptogams and fungi. Wiedemann (1966) lists the most common bryophytes he encountered on the deflation plains. Leuthner (1969) studied lichen habitats and associations on the deflation plains.

PLANT COMMUNITIES

Most of the reports written on the coastal dunes in recent years describe the vegetation in terms of habitat (USDA-SCS 1975, Pinto *et al.* 1972, Crook 1979a, Battelle 1974). Early studies of dune vegetation tend to be of a descriptive nature (House 1914 a, b; Byrd 1950, Egler 1934; Cooper 1919, 1920, 1922, 1936). More recently, detailed synecological studies, most based on floristics, have become available. Wiedemann (1966) and Kumler (1963) studied the deflation plains and active dunes, respectively, of the Oregon coast. Johnson (1963) and Parker (1974) looked at the coastal dune vegetation of northern California. Barbour *et al.* (1976) describe the beach and dune vegetation of the Pacific coast of the United States.

The entire coastal region is included in the *Picea sitchensis* Zone of Franklin and Dyrness (1973) in which Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) are the dominant climax species. In southwestern Oregon and northern California, coast redwood (*Sequoia sempervirens* (D.Don) Endl.) becomes increasingly important. However, coast redwood has not been known to occur on the dunes. Sitka spruce continues south to Cape Mendocino.

The occurrence of a climax community[9] on sand dunes is a rather unusual situation. One of the most striking characteristics of the sand dune environment is its instability. What is usually present is a mosaic of plant communities representing all of the stages of development toward what might be considered a climax community. However, the communities making up this mosaic are not necessarily discrete, temporary "successional stages" in the classic sense of "relay floristics" where one set of plant species is replaced by another until the climax is reached.

In the first place, many species of later "stages" tend to be present almost from the beginning, and for the most part are independent of other species in their establishment and subsequent history in the

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[9] Climax community: a community permanently occupying a habitat and which perpetuates itself indefinitely unless disturbed by outside forces (Daubenmire 1968, p. 25).

community. This corresponds to Egler's (1977, p. 164) notion of "initial floristic composition", which is well demonstrated in the coastal dune communities. Secondly, local conditions may prevent progress beyond a certain point. Continually disturbed environments such as the hummocks will always be occupied by the same plant community. Salt spray and wind or permanent high water may prevent the establishment of species not tolerant of these conditions. These situations could be viewed in the "polyclimax" perspective of Daubenmire (1968)[10]. Whatever interpretation is put on the observable situation, distinctive groupings of plant species can be recognized, and these groupings can be related to specific environmental conditions.

Plant communities are usually named according to the most characteristic (or dominant) species of that community. If several life form stages ("layers") are present--herbs, shrubs, trees--a characteristic species of each is included in the name. The characteristic species are usually, but not necessarily, present in all the stands[11] of a community. This is especially true of herbaceous communities, and this is the reason why more than one species may be listed. It is also necessary to realize that very few species are restricted to a single community--they cross "boundaries" readily. However, almost all will be more common in one community than any other. The following discussion utilizes information from Wiedemann (1966), Kumler (1963), Parker (1974), Barbour et al. (1976), Barbour and Major (1977), and Becking (Humbolt State University, Arcata, California; pers. comm. 1983). This discussion does not include the plant communities resulting from stabilization plantings (Chapter 6).

The standard (Latinized) name of the community is given first. Species of the same life form (herbs, shrubs, trees) are separated by a dash (--); those of different life forms by a slash (/). The English (common) name follows in parentheses. The number in brackets preceding the community name refers to the list of communities in Table 8.

The native pioneer foredune vegetation is composed of the [1] ELYMUS MOLLIS--ABRONIA LATIFOLIA COMMUNITY (American dunegrass--yellow sandverbena) (Figures 16 and 32). These species, along with others such as silver bursage (Ambrosia chamissonis), beach morning glory (Convolvulus soldanella), and dune tansy (Tanacetum douglasii) form the low hummock complexes (foredunes) that used to be widespread along the coastal dunes just above the high tide line. This community occurs in its pure form only in a few places today, and nowhere is it extensive.

The upper beach and active sand habitat has been largely taken over by the [2] AMMOPHILA ARENARIA COMMUNITY (European beachgrass) (Figure 15). There are very few associated species in the places where sand is most active. In the north, maritime pea (Lathyrus japonicus) is most common; and in southern Oregon and northern California, tree lupine (Lupinus arboreus) is distinctive in the community. Occasion-

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[10]Many possible climax types controlled by local microclimate.

[11]Stand: the community as represented on the ground. Each community has one or more stands occurring throughout the dune landscape wherever environmental conditions permit.

Table 8. Sand dune plant communities of the Pacific Northwest Coastal Region.

No.	Plant community[a]	General habitat	Comments
1.	Elymus mollis--Abronia latifolia American dunegrass--yellow sandverbena	Open dunes with blowing sand.	Native hummock forming species; threatened with loss of habitat; uncommon.
2.	Ammophila arenaria European beachgrass	Open dunes with blowing sand.	Forms large hummocks; requires sand covering; most widespread herbaceous community.
3.	Poa macrantha--Lathyrus littoralis seashore bluegrass--beach pea	Open dunes with blowing sand.	Native dune stabilizers; loss of habitat to European beachgrass, not common.
4.	Festuca rubra--Solidago spathulata red fescue--dune goldenrod	Sand plains with moderate sand movement.	Pioneer stabilizing herbaceous community; not widespread.
5.	Artemisia pycnocephala--Solidago spathulata beach sagewort--dune goldenrod	Sand plains with moderate sand movement.	Pioneer stabilizing herbaceous community; common south of Bandon, Oregon.
6.	Festuca rubra--Lupinus littoralis red fescue--seashore lupine	Sand plains with slight sand movement.	Pioneer stabilizing herbaceous community; common "dune meadow."
7.	Juncus falcatus--Trifolium wormskjoldii sickle-leaved rush--springbank clover	Wet deflation plains.	Pioneer herbaceous community; common.
8.	Carex obnupta--Potentilla pacifica slough sedge--Pacific silverweed	Very wet deflation plains.	Pioneer herbaceous community; common.
9.	Eleocharis palustris--Distichlis spicata creeping spike-rush--seashore saltgrass	Saline areas on deflation plains.	Herbaceous community; unusual, found mostly northern California.
10.	Spiraea douglasii/Typha latifolia Douglas's spirea/common cat-tail	Edges of ponds, lakes.	Aquatic community; relatively common.
11.	Gaultheria shallon--Vaccinium ovatum salal--evergreen huckleberry	Dry to moist sand plains.	Common shrub stage.
12.	Baccharis pilularis/Scrophularia californica chaparral broom/California figwort	Dry sand plains and ridges.	Shrub community of northern California dunes.
13.	Arctostaphylos uva-ursi/Rhacomitrium canescens kinnikinnick/silver moss	Dry sand plains and blowouts.	Pioneer community; uncommon and easily destroyed in ORV areas.
14.	Salix hookeriana--Myrica californica Hooker willow--Pacific wax-myrtle	Wet deflation plains.	Common shrub community.
15.	Pinus contorta/Rhododendron macrophyllum lodgepole pine/western rhododendron	Dune ridge tops.	Most widespread dune forest community.
16.	Pinus contorta/Arctostaphylos columbiana lodgepole pine/bristly manzanita	Sand plains and ridges.	Relatively uncommon open forest community.
17.	Picea sitchensis--Pinus contorta/Salix hookeriana/Eurynchium oreganum Sitka spruce--lodgepole pine/Hooker willow/ Oregon beaked moss	Wet deflation plains.	Commonly found, but rarely of great age.
18.	Pinus contorta/Carex obnupta lodgepole pine/slough sedge	Wet dune hollows and swales.	Open forest with very sparse shrub understory.
19.	Thuja plicata/Ledum glandulosum western red cedar/smooth Labrador-tea	Wet dune hollows and swales.	Unusual on the dunes.
20.	Pseudotsuga menziesii/Rhododendron macrophyllum Douglas fir/western rhododendron	Dune ridges.	Climax dune forest; uncommon because of logging; trees of great age.
21.	Tsuga heterophylla--Picea sitchensis/Gaultheria shallon/Blechnum spicant western hemlock--Sitka spruce/salal/deer fern	Sand plains, deflation plains.	Found in a few places in the beginning stages; also on forest remnants.

[a]Species of the same life form are separated by a dash (--); those of different life forms by a slash (/).

ally the native hummock species will occur in this community.

On areas back from the foredune zone and on sand plains where sand is a little less active, a group of species pioneer that rapidly cover the ground surface rather than form hummocks. This [3] POA MACRANTHA--LATHYRUS LITTORALIS COMMUNITY (seashore bluegrass--beach pea) (Figure 33) has distinctive associates: large-headed sedge (Carex macrocephala) (Figure 34), American glehnia (Glehnia leiocarpa) (Figure 35), coastline bluegrass (Poa con-

Figure 32. Yellow sandverbena. Leaves round in outline, 2 to 4 cm long; flowers yellow, 8 to 10 mm long. Sand Lake, Locality 9. May, 1964.

finis), seaside daisy (Erigeron glaucus), coast eriogonum (Eriogonum latifolium), and others. Plant cover may range from very open to completely closed. European beachgrass can become established in this community in its early stages when sand is more active, or the community can become established in stands of European beachgrass that have begun to deteriorate because of a lack of blowing sand. Both because of the spread of European beachgrass, and because of increased off-road vehicle activity (Chapter 6), this community does not occur extensively anywhere.

Where sand is shifted by the wind only slightly, such as on sheltered sand plains, old blowouts, or other disturbed areas, the [4] FESTUCA RUBRA--SOLIDAGO SPATHULATA COMMUNITY (red fescue--dune goldenrod) (Figure 36) develops. This community is found primarily in the north of the region, while in the south, the [5] ARTEMISIA PYCNOCEPHALA --SOLIDAGO SPATHULATA COMMUNITY (beach sagewort--dune goldenrod) is more common. Other species found in this community include seashore lupine (Lupinus littoralis), black knotweed (Polygonum paronychia), and coast strawberry (Fragaria chiloensis). The species of these communities will also be found in deteriorating European beachgrass stands.

Figure 33. Seashore bluegrass--beach pea community. Mostly a mixture of seashore bluegrass and beach pea. Beach morning glory in the foreground; silver bursage on the mound to the left. South spit, Humboldt Bay, Locality 33. June, 1983.

Figure 34. Large-headed sedge. Plants 15 to 20 cm high with large flowering heads. An important sand pioneer species in the north of the region. Sand Lake, Locality 9. May, 1964.

Figure 35. American glehnia. Very low-growing plant, frequently partly buried. Small, white flowers in several tight clusters (umbels). Sand pioneer in the seashore bluegrass--beach pea community. Sand Lake, Locality 9. May, 1964.

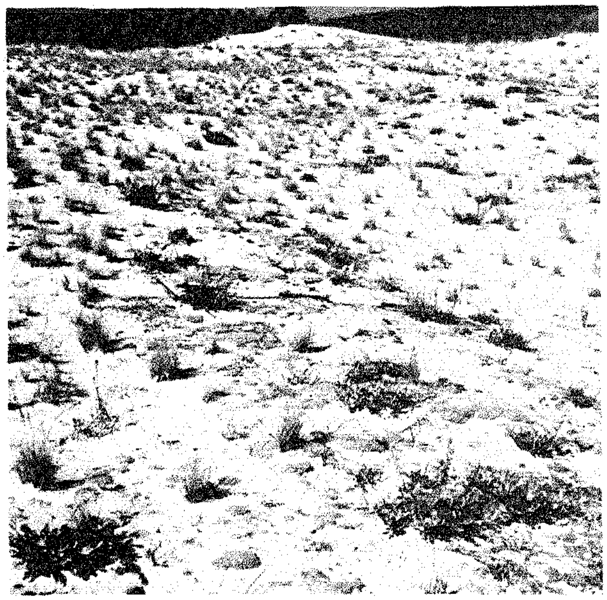

Figure 36. Red fescue--dune goldenrod community. There is considerable bare ground but the sand is not active. Note patches of silver moss. This species is intolerant of sand burial. Sand Lake, Locality 9. September, 1964.

The damp, stable sand surfaces of the deflation plains provide ideal habitat for the rapid development of plant communities. In places where there is ample moisture, but no standing water during any part of the year, the [6] FESTUCA RUBRA--LUPINUS LITTORALIS COMMUNITY (red fescue--seashore lupine) develops. This is the typical "meadow" of the sand dunes, and is the community that is probably richest in numbers of species. This community does not seem to occur in northern California.

Where water stands on the surface for one to three months during the winter, the [7] JUNCUS FALCATUS--TRIFOLIUM WORMSKJOLDII COMMUNITY (sickle-leaved rush--springbank clover) is found. This community is also high in number of species. Where water stands four to six months of the year, the [8] CAREX OBNUPTA--POTENTILLA PACIFICA COMMUNITY (slough sedge--Pacific silverweed) occurs.

In northern California, on the Humboldt Bay spits, ocean waves occasionally wash across the foredunes. In the low places where this water settles, [9] ELEOCHARIS PALUSTRIS--DISTICHLIS SPICATA COMMUNITY (creeping spikerush--seashore saltgrass) appears, essentially a sand dune salt marsh. Sand-dune sedge (Carex pansa), curly dock (Rumex crispus), brass buttons (Cotula coronopifolia), and other plants characteristic of slightly saline habitats are also found.

Where there is permanent standing water, such as the shallow margins of dune ponds and lakes, aquatic plant communities are found. These vary widely, depending upon such factors as water depth, water chemistry, and flucuation in water level. These are not treated in detail here, but typically a [10] SPIRAEA DOUGLASII/TYPHA LATIFOLIA COMMUNITY (Douglas's spirea/common cat-tail) would be found along the shallow edges of lakes and ponds.

These herbaceous plant communities tend to be present in a complex mosaic over the dune landscape. At any point along the environmental gradient from dry, unstable sand to very wet, stable sand there will be intergradation of the communities if the gradient is gradual. Very different communities, however, can appear side by side just as easily if there are sharp changes in the local environment. This is especially true where moisture is a controlling factor. It should be pointed out, too, that the only species that are unique to sand dune areas are those that are adapted to conditions of blowing sand (essentially communities 1 to 5) All the others can he found on nondune areas. areas.

In many of these communities, individual shrub and tree seedlings will be present quite early. Several types of shrub community can develop. The [11] GAULTHERIA SHALLON--VACCINIUM OVATUM COMMUNITY (salal--evergreen huckleberry) will occur on drier sites (sand plains, slopes, and ridges) mainly in the north of the region; while in northern California the [12] BACCHARIS PILULARIS/SCROPHULARIA CALIFORNICA COMMUNITY (chaparral broom/California figwort)is found on the drier sites, with tree lupine (Lupinus arboreus) as a frequent associate. On quiet sand plains and inactive blowouts, the unusual [13] ARCTOSTAPHYLOS UVA-URSI/RHACOMITRIUM CANESCENS[12] COMMUNITY (kinnikinnik/silver moss) (Figure 37) can be found. Because such areas are favored by off-road vehicles, the occurrence of this community is becoming limited. In the wetter areas, where water stands to some extent during the year (deflation plains, swales), the [14] SALIX HOOKERIANA--MYRICA CALIFORNICA COMMUNITY (Hooker willow--Pacific wax-myrtle) is most common. In all four of these communities seedlings of lodgepole pine (Pinus contorta) are almost always found, while many of the wetter sites will also have Sitka spruce seedlings.

The most common forest community is the [15] PINUS CONTORTA/RHODODENDRON MACROPHYLLUM COMMUNITY (lodgepole pine/western rhododendron) (Figure 38), developing mostly on the higher, well-drained sites. When mature, at about 100 yrs, these forests have open canopies, and it is not unusual to find Douglas fir

Figure 37. Kinnikinnick--silver moss community. The ground is completely covered by the two species. Eventually the kinnikinnick shades out the moss and lodgepole pine becomes established. Sand Lake, Locality 9. September, 1964.

(Pseudotsuga menziesii) both as young and canopy tress. In northern California, rhododendron is absent in these forests, but wavy-leaf silk-tassel (Garrya elliptica), infrequent in the north, is common. The [16] PINUS CONTORTA/ARCTOSTAPHYLOS COLUMBIANA COMMUNITY (lodgepole pine/bristly manzanita) is frequently encountered on sand ridge tops and other dry sites where the forest canopy is open. Reindeer moss (Cladonia rangiferina (L.) Web. in Wigg.) is commonly present.

On the deflation plains, a [17] PICEA SITCHENSIS--PINUS CONTORTA/-SALIX HOOKERIANA/EURYNCHIUM OREGANUM[13] COMMUNITY (Sitka spruce--lodgepole pine/Hooker willow/Oregon beaked moss) develops. The relative amounts of Sitka spruce and lodge-

[12] Rhacomitrimm canescens. (Hedw.) Brid.

[13] Eurhynchium oreganum (Sull.) Jaeg.

Figure 38. Lodgepole pine/western rhododendron community. Approximately 100 yr old pine forest north of Florence, Locality 19. Trees are dying and falling over, opening the canopy. Note the western hemlock in the center of the photograph. September, 1964.

pole pine present in any stand will vary considerably, depending upon such factors as seed supply and exposure to wind and salt spray. Usually the lodgepole pine is initially dense and provides shelter to the Sitka spruce seedlings, which are not tolerant of salt spray. In these situations, the Sitka spruce become evident when they reach about 4 m in height, and begin to grow more rapidly than the lodgepole pine.

Where water stands a good part of the year, a [18] PINUS CONTORTA/-CAREX OBNUPTA COMMUNITY (lodgepole pine/slough sedge) is commonly found. Sphagnum moss (Sphagnum spp.) can occasionally be found in these places. Also in wet habitats, but where acid bog conditions have developed through long accumulation of organic matter, a [19] THUJA PLICATA/LEDUM GLANDULOSUM COMMUNITY (western red cedar/mountain Labrador-tea) can occur. Sphagnum moss is frequently present, and, in a very few places, the California pitcher plant (Darlingtonia californica) has become established.

Given enough time, climax type forests can develop. Only small areas exist on the present day dunes. On the higher, dry sites, the [20] PSEUDOTSUGA MENZIESII/RHODODENDRON MACROPHYLLUM COMMUNITY (Douglas fir/western rhododendron) eventually develops from the initial lodgepole pine forest. Western hemlock is a frequent associate. In northern California, grand fir (Abis grandis) occurs with the Douglas fir on the dunes. On the more moist areas the "zonal" or "climatic climax" can develop: [21] TSUGA HETEROPHYLLA--PICEA SITCHENSIS/GAULTHERIA SHALLON/BLECHNUM SPICANT COMMUNITY (western hemlock--Sitka spruce/salal/deer fern). Very little of this type of forest is found on the dunes.

The successional relationships that can be traced among these communities are illustrated in Figure 39. Some of these relationships may be easy to see in the field, while others are a bit tenuous simply because the "dividing line" between communities may be vague. The AMMOPHILA ARENARIA and the ELYMUS MOLLIS--ABRONIA LATIFOLIA COMMUNITIES are a sort of "pioneer climax" because of the instability of the habitat. Vegetation becomes established; hummocks form and then erode away to reform elsewhere. Occasionally stabilization of these hummocks takes place because of reduced erosion.

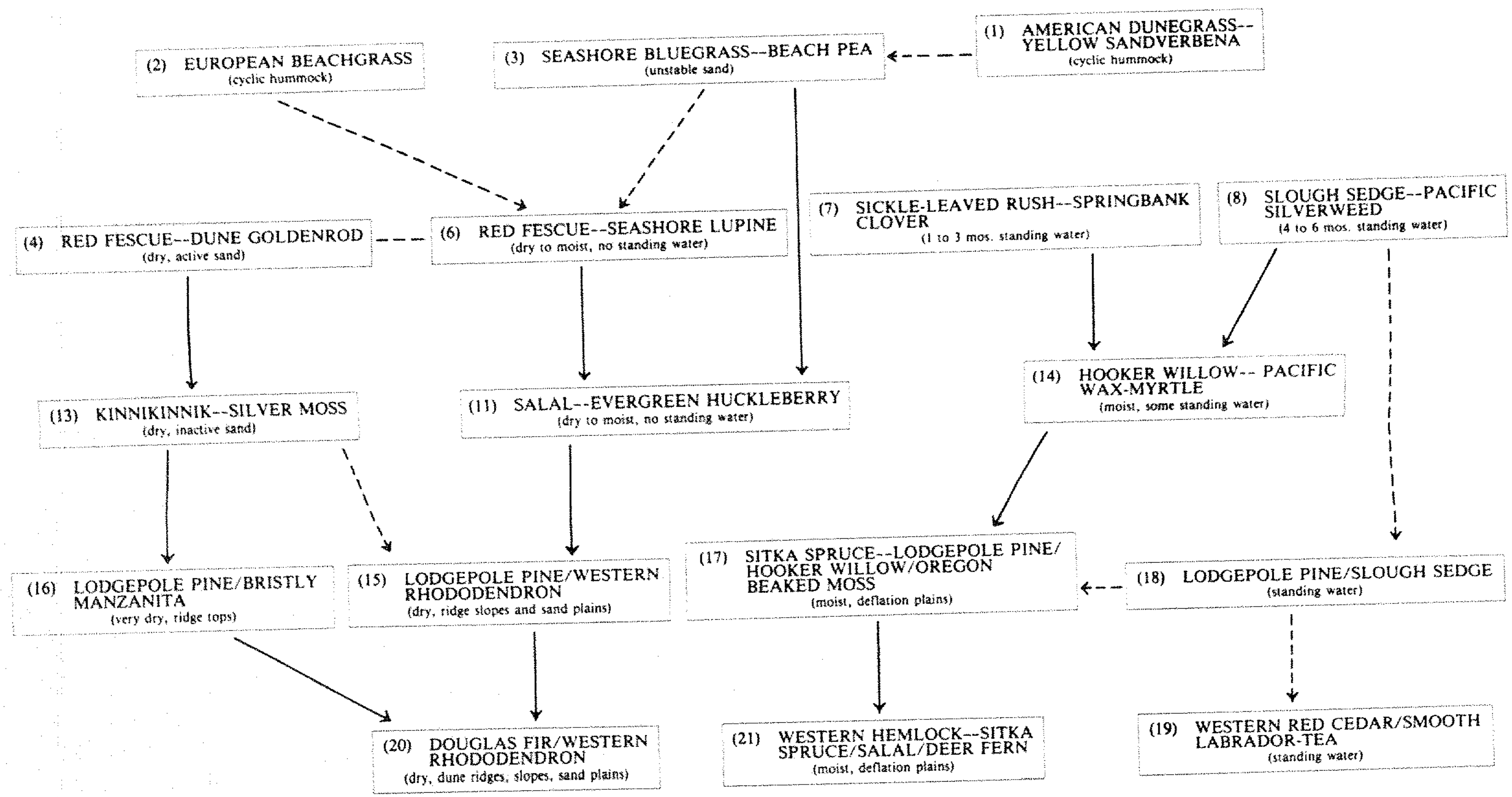

Figure 39. General successional relationships of sand dune plant communities of the Pacific Northwest coastal dunes. Plant communities resulting from stabilization plantings are not included, nor are plant communities found only on the sand dunes south of Bandon, Oregon. The number in parenthesis before each plant community refers to the number of that community in Table 8. The solid line (———) shows the most common and obvious successional pathways. The dashed line (-------) shows the less common or possible pathways.

In general there are no successional relationships among the five herbaceous communities that develop on sites with varying degrees of sand activity and levels of soil moisture. However, both the FESTUCA RUBRA--SOLIDAGO SPATHULATA COMMUNITY and the POA MACRANTHA--LATHYRUS LITTORALIS COMMUNITY could be succeeded by the FESTUCA RUBRA--LUPINUS LITTORALIS COMMUNITY if moisture conditions are favorable.

The shrub communities invariably follow on from one of the herbaceous communities. Close to the shore, shrub vegetation may persist indefinitely because wind and salt spray inhibit the growth of trees. Trees may be present, but they never grow taller than the predominant shrubs. The forest communities usually succeed the shrub communities, but it is not unusual for the tree species to become established in the herbaceous vegetation. When this happens, thickets of either lodgepole pine or Sitka spruce can develop that grow into older forests having a minimum of understory vegetation.

PLANTS AND THE ENVIRONMENT

Plants growing on coastal dune areas encounter a number of adverse environmental conditions: substrate instability, soils poor in nutrients, strong winds, salt spray, and soil water situations ranging from deficient to permanent standing water. Some of these factors are restrictive in that only plants with special adaptive features can tolerate them. Only plants that can grow through covering layers of sand will grow in unstable areas. Extensive tillering by European beachgrass, the rhizomes of large-headed sedge, the vines of beach morning glory, and the thick rootstocks of sandverbena are all examples of such adaptation. Large seeds with a food-storage capacity that permits germinating seedlings to grow through a deep sand covering is another example of adaptation found in American glehnia and beach pea.

Strong winds and wind-borne salt spray have a significant effect on plant life, especially near the shore. The main effects are deformation of growth form and injury to the growing tips. Many shrubs and trees respond by developing a low, much-branched, bushy growth form--lodgepole pine is a good example. Others, such as Sitka spruce, are intolerant of such exposure, and can become established only in the shelter of other plants. In some areas, development of vegetation is restricted to a low, compact growth form. Many trees may be present in the apparently dense shrub cover, but the growth of both trees and shrubs is restricted to a uniform "wind-pruned" height. As distance from the shore increases, the height of the vegetation increases until some distance inland the trees actually dominate and forest prevails.

Because of the high annual rainfall and cool temperatures, soil water is rarely lacking, even on exposed dune ridges. Water deficiency may occur at the end of long, dry summers or in years of abnormally low rainfall. High rates of evapotranspiration caused by strong, constant winds can be a problem, especially near the shore. Plants of these areas have adaptations to prevent water loss: leaves that roll up longitudinally on European beachgrass and American dunegrass; thick, waxy cuticles on the leaves of coast strawberry; and thick, hairy leaves on silver bursage. Adaptations to high water table are necessary to plants on deflation plains and interdune hollows. Rush, willow, and sedge species are commonly found in wet habitats.

The lack of essential plant nutrients poses an interesting problem on dune soils. Plants become established and seem to flourish on a substrate that appears to be devoid of such nutrients. The foredune supports a large amount of vegetation, especially European beachgrass. Ranwell (1972, p. 166) discusses the role of bacteria and fungi as suppliers of nitrogen. Data from studies in Great Britain show high concentrations of these organisms in dune sands supporting a cover of European beachgrass. Van der Valk (1974), working on the Atlantic coastal dunes of the United States, determined that the annual input of potassium, sodium, calcium, and magnesium from salt spray and precipitation exceeded the loss of these nutrients to leaching and plant use. The retention capacity of these dune soils is very low, but input of nutrients is continuous.

By contrast, the development of plant cover on high sand plains away from the shore and with little sand movement is very slow. When European beachgrass is planted on these areas, applications of fertilizer always produce dramatic increases in growth. In one case, aerial spraying of fertilzer overlapped onto the adjoining sparse FESTUCA RUBRA--SOLIDAGO SPATHULATA COMMUNITY, resulting in the rapid growth of the red fescue into a dense, continuous cover. In these situations the lack of nutrients clearly limits plant growth. On older dune soils, excessive drainage, acidity, and poor nutrient status are limiting factors. Plants found on these soils are characteristic of these conditions wherever they are found: lodgepole pine, western rhododendron, and bristly manzanita. Studies of sand dune plant--soil relationships have been limited.

FAUNA

The northwest Pacific coast region is included in its entirety in Shelford's (1963) "hemlock--red cedar--wapiti assocation" of the "rainy western hemlock forest biome."[14] The characteristic large mammals of this association include the wapiti, or Roosevelt elk, black-tailed deer, bobcat, and black bear. Of the many small mammals, the deer mouse, snowshoe hare, and Douglas squirrel are very common. The Red Crossbill, Chestnut-backed Chickadee, and Steller's Jay are abundant and characteristic birds.

The coastal sand dunes are a "faciation" (a subdivision of an association) of the hemlock--red cedar--wapiti association, and in general reflect its fauna. Pinto _et al_ (1972) list 426 species of wildlife (birds, fish, shellfish, mammals, amphibians, and reptiles) that inhabit or use the Oregon Dunes National Recreation Area and offshore waters. This number includes animals of nondune (but adjacent) habitats, and animals that have not been actually observed, but are expected to use the various habitats. Records for other dune areas are meager.

Very little information is available on the ecology and behavior of sand dune animals. Reardon (1959) studied the mammals of the dunes on the Oregon coast, especially the

[14]This biome includes the _Picea sitchensis_ zone and the _Tsuga heterophylla_ zone (Sitka spruce and western hemlock) of Franklin and Dyrness (1973) as well as the _Sequoia sempervirens_ (coast redwood) forests of southern Oregon and northern California.

adaptive behavior of the common deer mouse (*Peromyscus maniculatus*) on the forested dune remnants. Wilson (1980) studied the nesting ecology of the Snowy Plover (*Charadrius alexandrinus*). Maser *et al.* (1981) provide detailed descriptions of the natural history of 96 coastal mammals, but there is no specific discussion of the sand dunes and their animals.

The invertebrate fauna of the dunes is very poorly known. Extensive research in Europe (Ranwell 1972) indicates that sand dunes support many kinds of invertebrates with complex interactions. Shelford (1963, p. 228) describes the characteristic invertebrates for a number of dune habitats on the Oregon coast (Table 9). The bee fauna of the coastal dunes at Humboldt Bay (Locality 33) has been studied by Gordon (1983). His work covers floral visitation, species distributions, nesting locations, flight seasons, and abundance estimates. There is also much interest in the rare and endangered Oregon silverspot butterfly which occurs on some dune areas (Stine 1982).

WILDLIFE HABITATS

Many different systems of classifying landscapes on the basis of habitat have been developed. The simplest is based on vegetation life form (physiognomy), and some condition of the substrate (usually the amount of water present). For the coastal dune systems seven habitats can be easily identified: open dunes, grassland and meadow, shrub thicket, forest, marsh, riparian, and lakes and ponds. The waters of rivers and streams flowing through the dunes are not considered dune habitat here because of their origin and termination in such widely different ecosystems. The borders of these streams are, however, a special dune habitat (riparian).

Each of these habitats has a characteristic fauna, but many animals will be found in more than one habitat. Also, based on current knowledge, none of the habitats, as they occur on sand dunes, are critical to the existence of any animal species. (Both the Snowy Plover and Oregon silverspot butterfly, discussed in Chapter 6, utilize nondune habitats.) However, knowledge of the dune fauna, especially the invertebrates, is incomplete, and it cannot be assumed that there are no animals that are entirely dependent on dune habitat for their existence.

From other perspectives, all of the dune habitats can be considered critical. Wetlands generally are considered critical habitats. The dune marsh, riparian, and lakes and ponds habitats are included in the palustrine, lacustrine, and riverine systems of the U.S. Fish and Wildlife Service's classification of wetlands and deep-water habitats of the United States (Cowardin *et al.* 1979). The marsh, riparian, and older forest (especially snags) are considered critical habitats as discussed by Pinto *et al.* (1972, p. 49) and Proctor *et al.* (1980, Vol. 2).

As noted in the following discussions, a number of these dune habitats can be considered critical, either because they are unique to the dunes (open dunes), or because that habitat on the dunes constitutes a major proportion of the total habitat area of that type along the coast (meadow, marsh, lakes and ponds). All of the animals listed can be found in similar nondune habitats, but if the dune habitat is all there is, then it becomes critically important.

Table 9. Invertebrate animals of the Pacific Northwest coast dunes. (Adapted from Shelford 1963.)

Habitat	Invertebrates
Meadow/Grassland	On sand:
	Ant (*Formica neogagates lasioides*) (These 3 species
	Ant (*Formica fusca subaenescens*) counted at
	Spider, immature, sand colored 60 per m^2)
	Coast tiger beetle (*Cicindela bellissima*) - Small numbers
	Scarabaeid beetle (*Polyphylla decimlineata*) - Dug from sand
	On grasses:
	Green leafhopper (*Laevicephalis siskiyou*)
	Snout beetle (*Trigonoscuta pilosa*)
	Bee (*Psithyrus variabilis*)
	Tenebrionid beetle (*Coelus ciliatus*)
	Melyids
	Beetles
Shrub Thicket	In and under vegetation:
	Tenebrionid beetle (*Coelus ciliatus*)
	Tenebrionid beetle (*Eleodes*)
	Ant (*Formica neogagates lasioides*)
	Ant (*Formica fusca subaenescens*)
	Click beetle larvae
	Spiders, three types
Young forest	In and on fallen tree trunks:
	Ant (*Formica fusca neorufibarbis*)
	Ant (*Formica fusca subaenescens*)
	Ant (*Camponotus sansabeanus vicinus*)
	Termite (*Zootermopsis angusticolles*)
	Yellow-margined millipede (*Harpaphe*)
	In undergrowth:
	Click beetle (*Ctenicera bombycinus*)
	Click beetle (*Athous pallidipennis*)
	Robber fly
	Neuropteron (*Aqulla*)

Table 10 lists the dune habitats and shows their relationship to dune forms, plant communities, and other classification systems. In the following discussions, a few characteristic animals are listed for each habitat. Appendix IV lists the vertebrate animals that are known to occur (based on observation) in each of these habitats.

Open Dunes

Unvegetated sand plains, blowouts, transverse ridges, and oblique dunes are all areas that provide little or no cover for wildlife. Many animals, from large mammals to insects, cross these areas. It is not uncommon, for example, to see a rough-skinned newt slowly making its way across a wide stretch of sand. Otherwise little apparent use is made of them. One exception is the use of the sand at the windward base of the foredune, especially at the ends of sand spits, by the Snowy Plover for nesting habitat. Another kind of use, easily observed in summer, is the feeding by swallows above the open dunes.

It is also becoming apparent that there may be invertebrate animals that make extensive use of open sand areas (Figure 40). Gordon (1983) lists 43 species of bees inhabiting undisturbed dune ecosystems, many utilizing open dune areas (Figure 41; Table 11). Some of these may be restricted to this habitat. No known work of a similar nature has been carried out on the Oregon and Washington dunes.

The open dune habitat is potentially a critical and endangered one. European beachgrass, by its rapid spread, is reducing the area of open dunes; while the disturbance of off-road vehicle activity can make habitation or use of these areas by animals difficult or impossible.

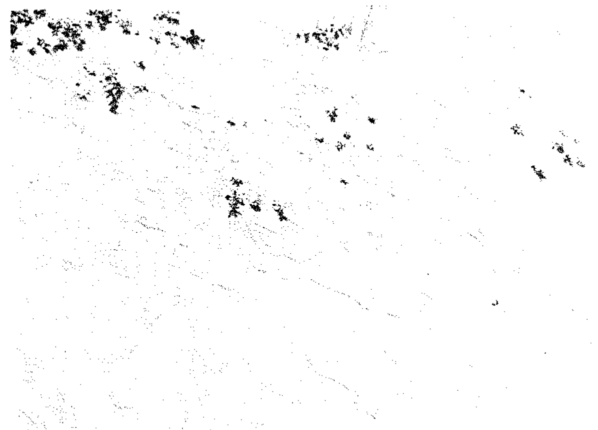

Figure 40. Insect tracks and burrows on open sand. Patterns such as this tend to be concentrated around plants such as the beach evening primrose in this photograph. North spit, Humboldt Bay, Locality 33. June, 1983.

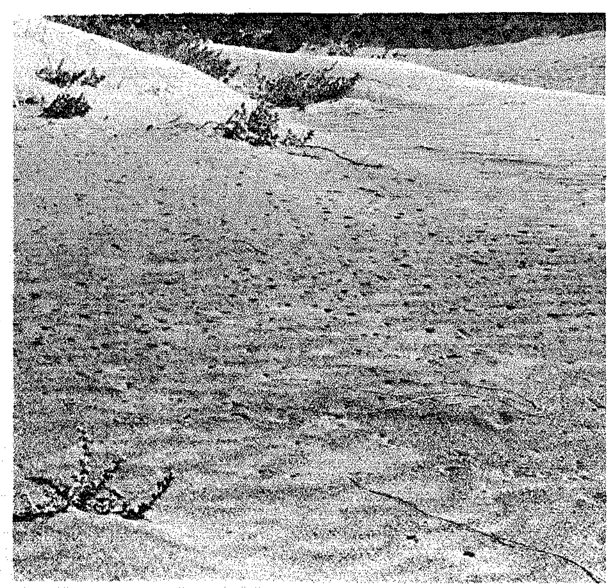

Figure 41. Area of bee burrows on open sand. Lanphere-Christensen Dunes Preserve, Humboldt Bay, Locality 33. June, 1983.

Table 10. Characteristics and classification of sand dune wildlife habitats of the Pacific Northwest Coastal Region.

Habitat	Characteristic dune forms	Characteristic plant communities	U.S. Fish and Wildlife Service wetland classification[a]	U.S. Forest Service habitat classification[b]
Open dunes	Sand plain, oblique dune, transverse ridge, parabola dune, blowout.	None	None	None
Grassland and meadow	Foredune, sand hummock, deflation plain, sand plain.	European beachgrass; red fescue--seashore lupine; seashore bluegrass--beach pea	Palustrine, emergent (PEM).	Foredune (FD), hummocks (HWS, HW, HA), deflation plain (DG)
Shrub thicket	Sand plain, deflation plain, dune ridge, swale	chaparral broom/California figwort; salal--evergreen huckleberry; Hooker willow--Pacific wax-myrtle	Palustrine, scrub/shrub (PSS).	Deflation plain (DGL, DT), plantations (P)
Forest	Sand plain, deflation plain, dune ridge, remnant forest mound.	lodgepole pine/western rhododendron; Sitka spruce--lodgepole pine/Hooker willow/Oregon beaked moss; Douglas fir/western rhododendron	Palustrine, forested (PFO).	Deflation plain (DST), forest ridge (SFR), transition forest (TF, TFO)
Marsh	Deflation plain, swale.	slough sedge--Pacific silverweed; Hooker willow--Pacific wax-myrtle	Palustrine, emergent, scrub/shrub (PSS (PEM).	Marsh (M)
Riparian	Any of the preceding.	Any of the preceding.	None.	Riparian, lakeside (R-L)
Lakes and ponds	Ephemeral ponds, dune lakes.	Douglas's spirea/common cat-tail	Lacustrine, littoral and limnetic (R1,R2).	Lakes - ponds (L-P)

[a] Based on Topical Wetland Overlays Coos Bay 1 (Reedsport) and Coos Bay 2 (Coos Bay), in conjunction with "Information and legend for large scale draft topical overlays", National Wetlands Inventory, U.S. Fish and Wildlife Service. These overlays show 23 Palustrine mapping units, 6 Lacustrine units, and 4 Riverine units for the dune areas. Associated Marine and Estuarine units were not considered.

[b] From Pinto et al. 1972, p. 47.

Table 11. Bee species found by Gordon (1983) on the coastal sand dunes of Humboldt Bay, California.

Andrenidae	**Colletidae**
Andrena (Andrena saccata Viereck)	Colletes hyalinus oregonensis Timberlake
Andrena (Melandrena) sp. 1	Hylaeus (Prosopis) citrinifrons (Ckll)
Andrena (Tylandrena) sp. 1	Hylaeus (Hylaeus) maritimus Bridwell
Andrena (Tylandrena) sp. 2	
	Halictidae
	Dialictus cabrillii (Ckll)
Anthophoridae	Dialictus longicornus (Crawford)
Anthophora urbana urbana Cresson	Evylaeus kincaidii (Ckll)
Ceratina (Zadontomerus) acantha Provancher	Halictus (Halictus) rubicundus (Christ)
Clisodon furcatus pernigris (Cresson)	Lasioglossum olympiae (Ckll)
Emphoropsis miserabilis (Cresson)	Lasioglossum pavonotum (Ckll)
Epeolus minimus (Robertson)	Sphecodes fortior Ckll
	Sphecodes sp.1
	Sphecodes sp.2
	Sphecodes sp.3
Apidae	**Megachilidae**
Apis millifera Linn	Anthidium palliventre Cresson
Bombus (Fervidobombus) californicus Smith	Coelioxys (Boreocoelioxys) rufitarsus Smith
Bombus (Pyrobombus) caliginosus (Frison)	Megachile (Xanthosaurus) perihirta Ckll
Bombus (Pyrobombus) edwardsii Cresson	Megachile (Xeromegachile) wheeleri Mitchell
Bombus (Pyrobombus) mixtus Cresson	Osmia (Monilosmia) albolateralis Ckll
Bombus (Bombias) nevadensis Cresson	Osmia (Chenosmia) dolerosa Sandhouse
Bombus (Bombus) occidentalis Greene	Osmia (Acanthosmoides) integra Cresson
Bombus (Pyrobombus) sitkensis Nylander	Osmia (Osmia) lignaria Say
Bombus (Pyrobombus) vosnesenskii Radoszkowski	Osmia (Acanthosmoides) physariae Ckll
Psithyrus (Fernaldaepsithyrus) fernaldae Franklin	Stelis (Chelynia) leucotricha (Ckll)
Psithyrus (Laboriopsithyrus) insularis (F. Smith)	

Grassland and Meadow

This habitat includes the drier European beachgrass-dominated foredunes and hummocks, the grasslands of the stabilizing sand ridges and plains, and the more moist meadows of the deflation plains. Areas with widely spaced low shrubs are also included. The most common birds seen in these areas include the Savannah Sparrow, White-crowned Sparrow, Golden-crowned Sparrow (in winter), Song Sparrow, Meadowlark, American Goldfinch, Northern Harrier, and American Kestrel. Both striped skunk and the Beechey ground squirrel are frequently seen, the latter utilizing the hummocks for burrows and feeding on the seeds of European beachgrass. The deer mouse is common, but not easily seen. Common garter snakes and the Pacific tree frog are the most commonly seen reptiles and amphibians. The rare Oregon silverspot butterfly occurs on a few dune meadows close to the shore (see discussion under "endangered species", Chapter 6). The tracks of insects and other invertebrates are frequently seen in the more open areas of this habitat. The large debris nests (up to a meter tall) of mound-building ants are encountered in somewhat more shrubby areas.

Meadows are not extensive along the coast, occurring mainly on dunes and rocky headlands. Loss of meadow by natural succession to forest is probably balanced over the long term by the creation of new meadow by renewed sand activity and other destruction of forest. Meadows very close to the shore (including headlands) are probably maintained for a long time because of the effects of salt spray and wind. Extensive use of natural dune meadows, both for agriculture and urban development, results in a loss of habitat that may approach the critical stage for some species (the Oregon silverspot butterfly is a good example).

Shrub Thickets

Shrub thickets can range from low-growing (1 to 2 m) vegetation that is dense but not completely closed, to tall (2 to 4 m), dense, impenetrable stands of shrubs and young trees. These thickets are found on sand ridges and sand plains in the process of stabilization and on deflation plains. Brush rabbits and black-tailed deer are common in this habitat, along with deer mice and Townsend's voles. A greater variety of birds use this habitat. In addition to those found in the meadow habitat, the most commonly seen include Bushtit, American Robin, Rufous Hummingbird (summer) and Yellow-rumped Warbler (winter). The reptiles and amphibians are similar to those of the meadow habitat.

Shrub thickets are common along the coast. Human activity, such as logging, creates more such habitat. It is probably least critical of all dune habitats in terms of loss of area.

Forest

The dune forest habitat tends to have enough of an open canopy to permit the development of a dense shrub layer. Younger forests may tend toward the shrub thicket type of habitat, while older forests will approach the climax forest situation with very large trees, closed canopy, and sparse shrub and herbaceous understory. This latter type is not commonly encountered on the dunes. The forest habitat has a great diversity of wildlife. Dead trees or snags are common and utilized by many animals. Cavity nesters such as Tree Swallows, woodpeckers, and owls use snags as nesting sites. Birds of prey--Red-tailed Hawk, Osprey, and Bald Eagle--use them for perching sites. Pileated Woodpeckers are seen on snags in the older forests. These forests are also utilized by Great Blue Herons for the establishment of heronries. A large number of resident passerine birds utilize these forests: Steller's Jay, Black-capped Chickadee, Bushtit, Wrentit, Bewick's Wren, Golden-crowned Kinglet, Ruby-crowned Kinglet, Cedar Waxwing, Purple Finch, Dark-eyed Junco, Song Sparrow, and others. Among mammals, the Pacific mole, racoon, Townsend's chipmunk, chickaree, bushy-tailed woodrat, and black-tailed deer are characteristic. Rough-skinned newts, Pacific tree frogs, garter snakes, and northern alligator lizards are common reptiles and amphibians.

Young forests (100 yrs or less) are extensive on dune lands in some areas. They develop rapidly in most cases, once stabilization begins, especially on deflation plains. Older forests are rare, not only on the dunes, but all along the coast. The critical elements of these forests are the large trees and dead and dying trees so important to certain species. Any reduction of such habitat that still exists is critical.

Marsh

Areas with standing water most of the year and with a variable amount of vegetative cover define the marsh habitat. Low deflation plains; swales; very shallow, sometimes ephemeral, dune ponds; and the edges of larger ponds and lakes are examples of such areas. The vegetation can range from grasses and sedges to shrubs to open forest. Grebes, several species of duck, and

Tundra Swans use this habitat extensively during the winter. Resident birds include Great Blue Heron, Mallard, Wood Duck, American Coot and Common Snipe. Mink, beaver, and muskrat are characteristic mammals, while rough-skinned newts and several species of frogs are commonly seen.

As a wetland, marsh is considered critical habitat almost everywhere it occurs. Along the immediate coast, almost all marshes are associated with the dune areas. The total area is limited, and losses can be critical to the large numbers of animals dependent on marsh habitat at some stage in their life cycles.

Riparian

The vegetation bordering dune ponds and lakes, and the streams flowing through the dunes is a special habitat. In terms of species and growth form, this vegetation is generally of the same kind as that found on adjoining deflation plains and other dune areas. It is the relationship to open or flowing water that is significant. While the animals utilizing this habitat include many found in other habitats, some are more likely to be found here: shrews of several species, river otter, the white-footed vole, Pacific jumping mouse, and several species of salamander. Of the birds, the Belted Kingfisher is common here all year, while in summer the Osprey and several species of swallow are conspicuous residents and users of this habitat.

The greatest threats to this habitat are logging (especially along rivers), and commercial development (around lakes). The amount of river riparian habitat on the dunes is small, but there are many lakes and ponds. Because most coastal lakes and ponds are associated with the dunes, any loss of this dune habitat affects the total habitat available.

Lakes and Ponds

Dune lakes and ponds vary considerably in size, but almost all, even the smallest, are host to various kinds of animals. As many as 20 species of fish are found, mostly in the larger marginal lakes such as Tahkenitch and Siltcoos. Rough-skinned newts, river otter, beaver, and muskrat are common in this habitat. Most of the birds utilizing the marsh habitat are also found around the lakes and ponds, especially the overwintering species. In addition, loons, Great Egret, and several additional species of duck are winter users. Characteristic residents include the Common Loon, Double-Crested Cormorant, Great Blue Heron, and American Coot.

As wetlands, lakes and ponds are critical habitats. Although relatively numerous through this coastal region, they do not constitute an extensive total area. High levels of human activity and pollution are both factors which can affect animal use, especially on smaller bodies of water.

CHAPTER SIX
HUMAN IMPACT

Coastal dune lands attract the attention of people wherever they occur. In areas with a long history of increasing human population, sand dunes become an important land resource. Along the coasts of Europe, particularly, many of the extensive sand dune areas have been so altered by human activity over the past five centuries that their original nature cannot be determined (Ranwell 1972, Chap. 13).

Heavy grazing, deforestation, water extraction, and introduced species have all had an impact on these European dune systems. One striking example was the control of vegetation by the grazing of enormous numbers of rabbits. The sand dunes, especially in Britain, were used extensively in medieval times as rabbit warrens. Wild populations became established and spread without control. The grazing of these many rabbits maintained the vegetation as a low-growing meadow over large areas. Only after these populations were drastically reduced in the 1950's because of disease, and the resulting dramatic change to a dense shrub and tree vegetation was observed, was the effect of the rabbits noted. In more recent times, pollution, recreation (golf courses and heavy visitation use), and afforestation have also made a significant impact.

Many of these factors are also important in North America. The dune systems of the Atlantic coast have been subjected to many changes as a result of nearly four centuries of settlement and development by European man (Godfrey and Godfrey 1974). Caucasian settlement of the Pacific coast has been very recent, but even this period of about 150 yrs has resulted in dramatic impacts. One need only consider the massive dune system (a minimum of 36 km^2 according to Cooper (1967, p. 42) now completely covered by the city of San Francisco.

Farther north, along the Pacific Northwest coast, populations are less dense, and impact has been less severe. However, the impact is no less significant. Since this region has some of the most spectacular coastal dunes in the world, an understanding of the effect of human influence and a knowledge of present and potential problems seems crucial.

GENERAL IMPACT

Settlement and Primary Industry

The first towns along the coast were established at river mouths, on bays, or on sand plains. Long Beach Peninsula and the Clatsop Plains (Locality 3 and 4), with their parallel ridge dune systems, were the focus of early settlement around the mouth of the Columbia River. Part of Newport (Locality 15) and most of Florence (Locality 19) are built on sand dunes. Small settlements are found on parts of other dune areas as well. Such settlement destroys dune forms and obliterates dune landscape, but the original towns were small and their overall impact relatively minimal.

One of the early attractions of some of the dune areas were the extensive grass meadows, such as on Long Beach Peninsula, the Clatsop Plains, and the area around Bandon (Locality 24, 25). These grass meadows were probably successional stages in the development of dune vegetation to forest communities, but some may have been long lasting. In their journals, Lewis and Clark in 1806 describe the Clatsop Plains as "prairie" (Cooper 1958, p. 174). Small-farm owners made use of these areas for grazing. Overgrazing quickly destroyed the plant cover and rejuvenation of sand activity occurred. As a result of this grazing damage and of human settlement, apparently no trace remains of these once extensive grasslands, either around the Columbia River or in the Bandon area. Similar rejuvenation occurred in other places where agriculture was attempted on sand dunes, but the extent was not nearly so great.

There was some development of cranberry bogs where acid peat soils formed in dune swales. This use, mostly north and south of the Columbia River, and to some extent, just north of Coos Bay (Locality 23), has been relatively insignificant. Logging also has not been important as an agent of change, mostly because the dune areas do not support extensive stands of merchantable timber. Old-growth forests of western hemlock and Sitka spruce were limited in extent. Most of these have been logged, but some remain.

Fire as a human agent of change in the past 130 yrs has not been important. Although fires increased in frequency in the adjoining mountain forest, the dune vegetation was hardly affected. Rapid control of fires and the isolation of the dune areas are probably the principle reasons for this. Natural fires in the past swept over great areas and could have spread to dune forests much more readily.

Urban and Industrial Exploitation

Since the end of World War II, the amount of dune lands utilized for urban expansion has increased greatly. Expanding populations and increasing incomes have resulted in the development of subdivisions with large lot sizes and space-consuming shopping malls. While this expansion radiates from established centers, resorts and vacation home projects develop into new areas affording proximity to the ocean (Figure 42). Such use can be particularly devastating, both physically and aesthetically. The north spit of Grays Harbor (Locality 1) is one example where extensive leveling and building has obliterated the parallel ridge system. Farther south the fine parabola dune system just north of Waldport (Locality 16) has been similarly destroyed by large-scale leveling of the land.

Dune lands have been used for industrial development. A large pulp mill was built in 1960 on the dunes north of Coos Bay (Locality 23). An army base and coastal defense batteries were located on the Clatsop Plains (Locality 4), and a Coast Guard station on the north spit of Humboldt Bay (Locality 33). An airport has been built on the dunes at Crescent City (Locality 31). Roads are made to build and maintain jetties. All of these activities have their effect in

Figure 42. Residential development on the foredune, deflation plain, and inner dune ridge of a parallel ridge system. The drainage channel is artificial. Long Beach peninsula, Locality 3. August, 1983. (Photograph by Art Hare.)

destroying dune landscape and reducing the amount of natural dune area remaining.

Removal of sand from beaches and dunes for industrial and construction purposes in both northern California and Oregon has occurred frequently (Lindberg 1979). Mineral- (chromite, platinum, gold, etc.) bearing sands were mined from 1852 to 1945 in Coos and Curry County, Oregon. Sand for ceramics, container glass, foundry molding, construction fill, and concrete continues to be removed. No estimate is available of the amount removed each year, but it is considered to be an amount sufficiently large enough to create potential environmental problems.

The use of ground-water resources has increased with urban and industrial expansion. Water was first pumped from a dune field on an extensive scale in the area just north of Coos Bay (Locality 23). By 1973, 15,200,000 l/day (4,000,000 gal/day) were being extracted from 18 wells (Robison 1973), and plans are being made to increase this. The dunes of the Clatsop Plains supply water to that area (Frank 1968), while the town of Florence, Oregon, relies almost entirely upon the dunal aquifer for its water (Christensen and Rosenthal 1982). Dune fields are also used for liquid and solid waste disposal. The long-term effects of both pumping and waste disposal are poorly known and the subject of increasing numbers of studies.

Stabilization

Whenever moving sand interferes with the activities of human beings, programs of stabilization are initiated. Most commonly this involves the establishment of a plant cover that prevents wind from reaching the sand surface. Such programs have been carried out for several centuries in Europe, many of them because incorrect land use resulted in extensive areas of reactivated dunes.

In North America, similar programs were begun, either to prevent sand from covering property and obstructing traffic, or to repair the effects of destructive land use practices (Godfrey and Godfrey 1974). The earliest program on the west coast was the stabilization of dune masses at Golden Gate State Park in San Francisco, begun in 1869 (Cooper 1967, p. 19). Plantings of sand-stabilizing vegetation along the Oregon coast began in 1910 (McLaughlin and Brown 1942), mostly to prevent sand encroachment onto private property, military installations, roads, and railroads and into rivers.

In 1935 work began on the 1,200 ha of active sand on the Clatsop Plains of the northern Oregon coast (Locality 4). Caused both by extensive overgrazing and rapid accretion related to jetty construction, these dunes "...were menacing forts, military reservations, roads and private property...(and)...threatening to impede the flow of ocean-going commerce..." (McLaughlin and Brown 1942, Foreword). In 6 yrs the entire area was stabilized by vegetation.

The next major focal point of stabilization efforts was the dune area between the Siuslaw and Siltcoos Rivers (Locality 20). The objective of these plantings was to stop deposition of sand into the Siuslaw and Siltcoos Rivers and to protect recreational areas. About 280 ha were planted between 1948 and 1963. In addition, another 600 ha of deflation plain were planted to annual and perennial grasses and legumes to provide wildlife habitat (Green 1965). Very little stabilization planting has taken place on public lands since the 1960's. However, commercial developments on dune lands have required extensive plantings. The Ocean Shores (Locality 1) and Bayshore (Locality 16) resort projects, and residential subdivisions in Florence (Locality 19) are examples of such areas.

Although it is difficult to estimate with any degree of accuracy, probably no more than 3,000 ha of open sand dunes on publicly owned lands have been stabilized by planting programs. (This includes the publicly financed program on the Clatsop Plains, where much of the land is privately owned.) Except on the Clatsop Plains where there has been residential development, these stabilized areas remain as vegetated dune lands. No estimate has been made of the dunes lost to stabilization by development: agriculture, towns, industry, airports, subdivisions, and military installations.

The stabilization process has been described in detail by McLaughlin and Brown (1942), Brown and Hafenrichter (1962), and Ternyik (1979). The first step is always the planting of European beachgrass. Other species such as American beachgrass (_Ammophila breviligulata_) and American dunegrass are used, but only in special situations. Application of fertilizer is considered a necessary part of the initial planting project. The normal application is 227 kg/ha of ammonium sulphate (21% nitrogen).

Secondary plantings are necessary since the "sand stilling" dune grasses lose vigor and do not grow well when sand deposition ceases. Although native and introduced grasses and legumes were used for secondary plantings on the Clatsop Plains to provide a permanent meadow-type vegetation, the planting of woody species is more common. Scot's broom (_Cytisus scoparius_) and lodgepole pine are planted 2 to 3 yrs after the grass plantings (Figure 43). In southern Oregon and northern California, tree lupine is also planted as a sand stabilizer.

Green (1965) noted that European beachgrass attained maximum size 3 yrs after planting. The Scot's broom grows rapidly, providing cover. It shades out the European beachgrass and is eventually shaded out itself by the lodgepole pine. In a 28 yr old plantation of European beachgrass and Scot's broom, she found lodgepole pine (which had seeded naturally) 3 to 8 m tall. The Scot's broom was tall (up to 4.2 m) and spindly. The beachgrass was present only as scattered stems. There was a well-developed shrub and herbaceous understory of native and naturalized dune forest species.

Figure 43. Oregon coastal dune stabilization planting. European beachgrass is 6 yrs old, Scot's broom and lodgepole 5 yrs after planting. Scot's broom is about 1.5 m tall. Note the sparse cover of European beachgrass, a condition that develops after sand burial ceases. South of the Siuslaw River, Locality 20. 1964.

Other methods of stabilization include brush matting, oil penetration, wire net, rock and gravel, and sand fencing. While these methods have been used both in Europe and North America, they are considered strictly temporary, used to provide control until vegetation develops or, more commonly, until asphalt, concrete, and buildings are put into place.

Recreation

Until relatively recent times, recreational use of the coastal dune areas has had only a small impact. Most significant has been the development of campgrounds in state parks and on national forest lands. Some of these are large and attract great numbers of visitors, especially in summer. Examples include Ocean City State Park (Locality 1) in Washington; and Ft. Stevens (Locality 4), Cape Lookout (Locality 8), Honeyman (Locality 20), and Bullards Beach (Locality 24) State Parks in Oregon. All are on sand dunes, but the actual impact of visitor foot traffic on the dune vegetation and dune forms away from the campgrounds themselves is insignificant. No data exist, but one need only walk a thousand meters out into the sand at Honeyman State Park even during the height of the tourist season to realize that "observing the dunes" is not a common recreational activity!

It is different, however, where roads provide easy access to the beaches. Sometimes roads run just behind the foredune, in other cases farther back, but there are always numerous trails running to the beach and these can cause severe damage to vegetation. Vogt (1979) and Ranwell (1972, Chap. 13) review field studies of "trampling effects" on dune vegetation in Great Britain. Because of high population pressures in Europe, these can be quite severe. Similar studies in North America have not been found.

What has received considerable attention in North America is the increasing use of off-road vehicles (ORV's) on sand dunes. Vogt (1979) briefly reviews the field studies of the impact of ORV traffic over sand dunes. Fowler (1978) outlines the growth of the ORV recreation phenomenon along the Oregon coast, and discusses planning and management options. A review of the literature dealing with off-road vehicle recreation is included in Fowler (1979).

Almost every dune area along the coast has felt the effects of this activity. Probably most pronounced is the destruction of vegetation (Figure 44). Grasses on fore-

Figure 44. Results of off-road vehicle activity on the Sand Lake dunes, Locality 9. This area is the lower deflation plain of the first parabola dune, just north of the beach access road (Appendix II). August, 1983. (Photograph by Art Hare.)

dunes, meadows on sand plains and deflation plains, and even shrubs and trees have been destroyed. This invariably results in rejuvenation of sand activity. On open sand, there may be some degradation of dune forms (the crests of oblique and parabola dunes). The most pronounced effects are aesthetic: noise, crowding, and litter.

One of the most dramatic examples of this recreational phenomenon can be seen at Sand Lake (Locality 9). In 1964, during a summer weekend, a dozen vehicles could be seen wandering about the 4 km^2 of open sand. Fifteen years later, on a major 3-day weekend during the summer, an estimated 5,000 vehicles would turn these dunes into a maelstrom of noise and moving machines. Some of the finest examples of native sand-plain and sand-ridge meadow vegetation along the coast have been destroyed. The partially stabilized marginal ridge of one of the parabola dunes has been dissected into a series of rapidly eroding hummocks. The main deflation plain as well as adjoining forests serve as camping areas and vegetation has been trampled and broken.

The situation became so severe that an elaborate management plan had to be developed which included designation of use areas, safety rules regarding equipment and operation, law enforcement, protection of private property, and access control. Today there is a large campground (100 units) with its own sewage disposal system and a drag strip with guard rails and control tower. The number of vehicles using the area during heavy use periods is controlled by requiring the purchase of a permit for each "street-legal vehicle." On one recent weekend (Memorial Day, 28-30 May, 1983), 1700 permits were available and almost all were issued. Since each street-legal vehicle can tow or carry other vehicles, the total number of vehicles on the area can still be quite large.

The use of off-road vehicles continues to grow, and the pressure from interest groups (off-road vehicle clubs) for access to dune areas is powerful. Driving on the beaches is regulated by complicated rules, especially in Oregon. Vehicles are banned on some State- and Federally-owned dune areas, but enforcement is frequently difficult. Even private property is not exempt from this pressure. In one case a landowner constructed a strong fence to exclude vehicles and campers. In another, the owner resorted to carrying firearms to help ward off aggressive and often belligerent ORV drivers. Overall, the long term physical impact of such activity is probably minimal, especially if vegetation damage is minimized.

MANAGEMENT PROBLEMS

Introduced Plant Species

Many of the plant species found on the coastal dunes have been introduced since the time of European settlement. These plants have helped change the appearance of the dune landscape, and have altered the plant communities. Some introductions were accidental, coming with animals, animal feed, and garden plants and seeds. Most were intentional, to be used as ornamentals, agricultural crops, or in stabilization programs.

In the foredune area, almost all of the now-characteristic plants have been introduced: European beachgrass, the sea rockets, sea-figs, maritime pea, and Australian fireweed (Erechtites arguta, E. prenanthoides). Most of the common meadow species are European in origin: sweet vernalgrass (Anthoxanthum odoratum), velvet-grass (Holcus lanatus), bentgrasses (Agrostis spp.), little hairgrass (Aira praecox), annual brome-grasses (Bromus spp.), hairy cats-ear (Hypochaeris radicata), red sorrel (Rumex acetosella), and curly dock (Rumex crispus).

Several exotic shrubs have also become well established. Scot's broom is widely planted but does not spread extensively on sand dunes on its own (as it does in other areas). Tree lupine (Figure 45), introduced from South America, has spread widely

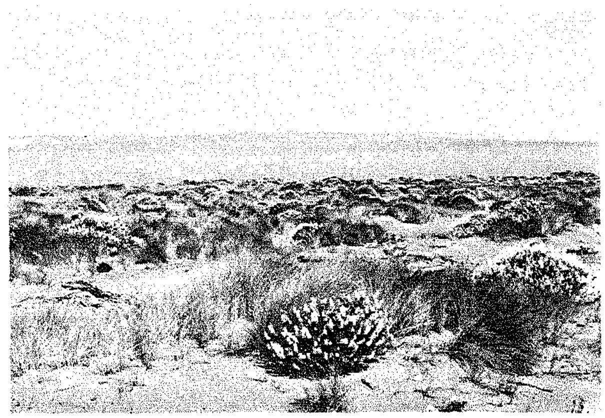

Figure 45. European beachgrass community with tree lupine. North spit, Humboldt Bay near Samoa, Locality 33. June, 1983.

on the northern California dunes.[15] It has been planted along the Oregon coast, but does not seem to spread naturally to any great extent. Probably the most notorious introduced shrub is gorse (Ulex europaeus). It was reputedly brought to the Bandon area from Ireland in 1873 as a hedgerow plant (Hanneson 1962). By 1949 it covered 10,000 ha, mostly around Bandon, including the dunes there (Locality 24), but it ranged north along the coast to Grays Harbor and inland to the Puget Trough and Willamette Valley. Control and eradication is a difficult, expensive task.

It is of interest that some 80 species of trees were tested for dune-stabilization use on the northwest coast (Brown and Hafenrichter 1962). None of the introduced species were useful or became established. Plantings of maritime pine (Pinus pinaster) survived, but did not thrive. This is the same species

[15]Some botanical authorities feel this species is native to California.

that has been planted on 80,000 ha of sand dunes on the Bay of Biscay in France at the same latitude.

Introduced species that become established and spread aggressively usually do so at the expense of native species. Uncommon native species with very restricted habitats are the most likely to be affected. Very little concern has been expressed in the past about the possible impacts of exotic plant introductions. There is no evidence in many of the current multitudinous planning documents relating to coastal zone management of such concerns, though the threat is ongoing. A number of exotic species, for example, have recently become established in saltmarsh and mud-flat habitats in the Pacific northwest, and the potential for drastic changes in the native ecosystem is quite strong (L. Kunze, Washington Natural Heritage Program, Olympia, Washington; pers. comm. 1983). Given the other pressures of resource development it is probably a minor concern, but it is nonetheless a real one.

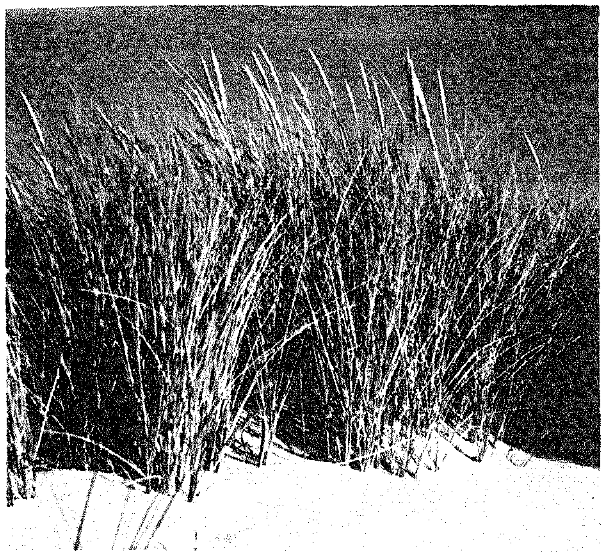

Figure 46. European beachgrass. Stems to 1 m high, connected by tough rhizomes; leaves folded and smooth, 2 to 4 mm wide; flower clusters 15 to 30 cm long and 10 to 15 mm wide. Plants grow and flower most vigorously when at least partially buried by sand. Tenmile Creek, Locality 22. June, 1964.

The Special Case of European Beachgrass

Of all the impacts of human activity discussed thus far, probably the most extensive and far reaching in its effect was the introduction of European beachgrass (Figure 46). Its effect has been both geomorphological (effect on dune forms) and biological (creation of new habitats and competition with other species).

Huiskes (1979) reviews what is known of the species. It is native to coastal Europe where it evolved under conditions of massive sand movement. Its latitudinal range is roughly 30°N to 60°N (and similarly 30°S to 60°S in the southern hemisphere where it has been introduced). It grows well in nutrient-poor sands, tolerating burial up to 1 m deep, but it is intolerant to sea salt in the substrate. Sand burial appears to be necessary to stimulate growth and flowering. Seeds are produced in great numbers on vigorous plants (those exposed to sand burial), and germinate readily. Reproduction by seeds is limited to moist areas such as deflation plains. Vegetative reproduction through the dispersal of plant parts such as rhizomes and tillers account for most of the natural distribution of the species. There are no known serious animal feeders or plant parasites.

A closely related and very similar species, American beachgrass, is native to the North

American east coast and Great Lakes region. It seems to have similar ecological requirements to those of European beachgrass. Data from North Carolina (Woodhouse et al. 1977) show that this species is short lived (2 to 5 yrs) and highly susceptible to at least one disease and one insect. These problems may be related to growth near the southern limit of its range (34°N).

European beachgrass has spread along the west coast of North America from 34° to 55°N latitude. In only a very few locations has it not taken over entirely in the foredune zone just above the beach. These areas, most notably parts of the north and south spits of Humboldt Bay (Locality 33), give a clue to the appearance of the vegetation of the foredune zone prior to the takeover by European beachgrass. Even here, however, the high beachgrass ridge is gradually replacing the loosely aggregated collection of relatively low hummocks formed by the native species.

The biological effect of the grass is to crowd out, through rapid growth and dense cover, the native hummock builders. In many places where they once occurred commonly, such species as American dunegrass, sandverbena, silver bursage, beach morning glory, and dune tansy occur sparingly or are not seen at all.

Since virtually all of the sand blown off the beach is trapped by European beachgrass foredunes or hummock fields, there is concern that "sand starvation" (discussed earlier) could change the character of the large moving dunes. Although this is open to much speculation, informal consideration has been given to trying to find a way to get sand moving inland again. There is no precedent since getting European beachgrass established has historically been of greater importance than destroying it. Recent experiments in northern California (S. VanHook, Lanphere-Christensen Dunes Preserve, Arcata, California; pers. comm. 1983) have involved salt, black polyvinyl sheeting, digging and pulling, burning, and herbicides to try to control the species. The best method thus far has been burning (the grass burns readily, but is not killed) followed by an application of the herbicide "Roundup."[16] Pulling young plants is also effective, but requires constant patrolling.

European beachgrass is permanently established on the Pacific Northwest coastal dunes. Its ultimate impact on native species and dune morphology is not known. Although considerable research on its ecology and physiology has taken place in Europe, very little has been done in North America, or in the numerous other places in the world where it has been introduced. Any possibilities at all of "managing" this species along the northwest coast will depend upon a program of research that examines both anatomical and physiological response to local conditions.

Endangered Species

A number of plant and animal species that occur on the sand dunes are on one or more state lists of rare, sensitive, threatened, or endangered species. Only one is protected by Federal law as a threatened or endangered species. These lists are usually maintained by state natural heritage programs, but may originate with groups such as

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[16] Glyphosate - a broad spectrum, nonselective herbicide, readily broken down in the soil to carbon dioxide by microbial degradation (Watson 1981).

state game departments, native plant societies, or the Nature Conservancy. The following discussion and Table 12 include species which are on one or more lists as of June, 1983.

Oregon silverspot butterfly (*Speyeria zerene hippolyta*). This butterfly (Figure 47) is listed as a threatened species by the U.S. Fish and Wildlife Service, giving it the protection of the Endangered Species Act.[17] Critical habitat was also designated for the species.[18]

Its primary habitat is coastal meadow that supports the growth of the western blue violet (*Viola adunca*)[19] which is its primary food source. According to Hammond and McCorkle (1982) most of these meadows are established, stable communities on rocky headlands. This is prime habitat for the growth of western blue violet. This violet occurs on dune meadows, but only on those which have been established for a long period of time. Only 6 out of 24 reported sites are on "old dunes." The three largest and most vigorous populations are on rocky headlands, while two of the three small, weak populations are on old dune sites. Other dune areas are listed as prime sites for rehabilitation of habitat and eventual butterfly introduction, with the best considered to be the Camp Rilea area on the Clatsop Plains (Locality 4). The dune sites presently considered important to the Oregon silverspot butterfly recovery plan are listed in Table 13. Stine (1982) reviews the biology and ecology of the species and outlines the recovery plan.

Snowy Plover (*Charadrius alexandrinus*). This bird is listed in the Federal Register as a candidate for protection as a threatened or endangered species (Figure 48). It is considered "threatened" by the Oregon State Department of Fish and Wildlife and the California Department of Fish and Game and "endangered" by the Washington State Department of Game. It breeds in early summer in two widely separated locations: the alkaline basins and sand dunes of southeastern Oregon and along the coast of Washington, Oregon, and California. Its nesting habitat along the coast is the loose sand above the high-tide line in sparse foredune vegetation or driftwood, especially at the ends of sand spits. Past and present nesting sites are reported from the northern limits of the dunes at Copalis Beach, Washington (Locality 1), south to Humboldt Bay (Locality 33) (Proctor *et al.* 1980; Burley 1979; The Natural Diversity Data Base, California Department of Fish and

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[17]The Endangered Species Act requires that all Federal agencies, in consultation with the Secretary, Department of Interior, ensure that actions funded, authorized, or carried out by them are not likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of its Critical Habitat. Other provisions of the Act make the taking or killing of endangered or threatened species by anyone illegal and provide support to state agencies involved in the protection of these species.

[18]Oregon. Lane County. T.16S., R.12W. Those portions of Section 15 and of the south half of section 10 which are west of a line parallel to, and 1500 ft (455 m) west of, the eastern section boundaries of Section 10 and 15.

[19]Also known as western long-spurred violet, early blue violet, hook violet, blue violet, and western dog violet.

Table 12. Rare, threatened, or endangered animal and plant species of the Pacific Northwest coastal dunes.

Species	Status	Information source	Range	Habitat
Oregon silverspot butterfly (Speyeria zerene hippolyta)	Threatened (Federal protection).	Office of Endangered Species, U.S. Fish and Wildlife Service[a] Stine 1982 Hammond and McCorkle 1982	Along the coast, from Westport area of Washington to Lily Lake, just north of Florence, Oregon.	Old established meadows close to shore, with Viola adunca. Very few dune locations, although there is potential for introduction in Festuca rubra-Lupinus littoralis meadow communities.
Snowy plover (Charadrius alexandrinus)	Candidate for Federal protection. Threatened or endangered by the State Game Departments of California, Oregon, and Washington.	Office of Endangered Species, U.S. Fish and Wildlife Service Wilson 1980 The Oregon Natural Heritage Data Base[b]	Southern coast of Washington to Baja California.	Seaward base of foredunes, especially on sand spits. Occasionally found in deflation plains and on vegetated foredune.
Menzies' wallflower (Erisymum menziesii)	A candidate for state protection in California.	The Natural Diversity Data Base, California[c]	Endemic to sand dunes between Crescent City and Monterey, California.	Semi-stabilized dunes, in association with the Poa macrantha-Lathyrus littoralis community.
Silvery phacelia (Phacelia argentea)	Threatened in Oregon (no state protection). Rare or endangered in California by CNPS.[e]	The Natural Diversity Data Base, California The Oregon Natural Heritage Data Base	Coastal sand dunes from Coos Bay, Oregon, south into California.	Active sand areas associated with Elymus mollis-Abronia latifolia and Poa macrantha-Lathyrus littoralis communities.
Pink sandverbena (Abronia umbellata var. acutalata	Extirpated in Washington. On the review list in Oregon.	Washington Natural Heritage Program[d] The Oregon Natural Heritage Data Base	Coastal sand dunes along the coasts of Washington, Oregon, and California.	Active sand areas associated with Elymus mollis-Abronia latifolia and Poa macrantha-Lathyrus littoralis communities.

[a] Office of Endangered Species, U. S. Fish and Wildlife Service, 2625 Parkmont Lane, Bldg B2, Olympia, WA 98502. Telephone: 206/753-9444.
[b] The Oregon Natural Heritage Data Base, 1234 Northwest 25th Avenue, Portland, OR 97210. Telephone: 503/228-9561.
[c] The Natural Diversity Data Base, California Department of Fish and Game, 1416 - 9th Street, Room 1225, Sacramento, CA 95814. Telephone: 916/322-2493.
[d] Washington Natural Heritage Program, Department of Natural Resources, 3113 Seminar Building, The Evergreen State College, Olympia, WA 98505. Telephone: 206/753-2449.
[e] California Native Plant Society. Botanist Telephone: 916/324-3816.

Table 13. Habitat or potential habitat for the Oregon silverspot butterfly on the Pacific Northwest coastal dunes. (From Hammond and McCorkle 1982.)

Site name and general location	Dune locality	Comments
Lily Lake, 11 km N of Florence, Oregon	19	US Forest Service land. No violets or butterflies present, but area good for introduction of both.
Tenmile Creek, about 21 km N of Florence, Oregon	17	Private land. Few violets still present, but no butterflies. Due for development.
Old sand dunes 1.5 to 3 km N of Gearhart, Oregon	4	Private land. Small number of violets and butterflies present. Probable future development.
Camp Rilea Military Reservation near Cullaby Lake	4	State land. Few violets and butterflies. Prime area for habitat rehabilitation.
Loomis Lake area, Long Beach Peninsula, Washington	3	Private land. Small number of violets and butterflies. Probable future development.
Nahcotta, Long Beach Peninsula, Washington	3	Private land. Grassland, but no violets or butterflies present.
Westport area, Washington	2	Private land. No butterflies, few violets found. Very little suitable habitat.

Game, Sacramento, California; pers. comm. 1983). Beach and dune ORV traffic pose the greatest threat to the nesting stability of these birds (Wilson 1980).

Menzies' wallflower (*Erisymum menziesii*). This plant is a candidate for State listing (which provides legal protection) as a rare or endangered species in California. It is a herbaceous biennial of the mustard family (Figure 49), endemic to the coastal sand dunes between Monterey and Crescent City, California (Localities 31 to 33). It is usually found growing in semistabilized dune areas associated with the POA MACRANTHA-LATHYRUS LITTORALIS COMMUNITY. It occurs sparingly and any reduction in habitat area could effect its survival as a species.

Silvery phacelia (*Phacelia ar-*

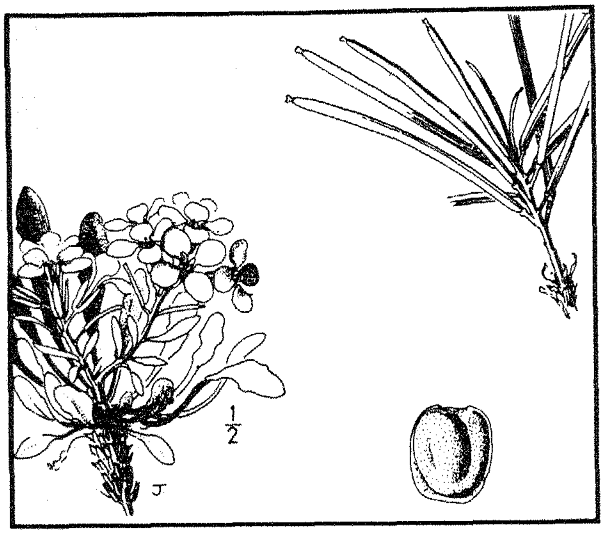

Figure 49. Menzies' wallflower. Flowering stems 5 to 15 cm long; flower petals bright yellow, 15 to 20 mm long; fruits 4 to 8 cm long. (From Abrams 1940, reprinted by permission of Stanford University Press.)

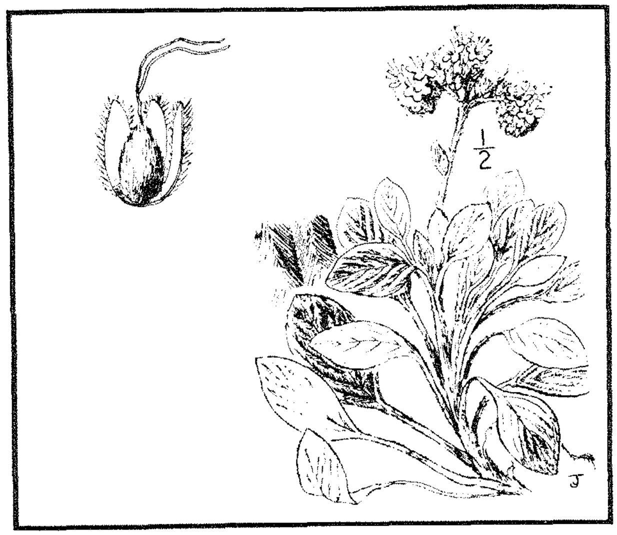

Figure 50a. Silvery phacelia. Prostrate stems, 10 to 30 cm long; leaves silvery, 2 to 5 cm long; petals yellowish white, 5 to 6 mm long. (From Abrams 1940, reprinted by permission of Stanford University Press.)

Figure 50b. Silvery phacelia. Kellogg Beach, north of Crescent City, Locality 31. August, 1983.

gentea). In Oregon, this perennial plant of the waterleaf family (Figure 50) is listed as "threatened throughout its range," while in California it is listed by the California Native Plant Society as a "rare or endangered species." It is found along upper beaches and in unstabilized dune areas associated with the ELYMUS MOLLIS-ABRONIA LATIFOLIA COMMUNITY. It occurs from Bandon, Oregon, south into California (Localities 24 to 33). The greatest threats to the species are loss of habitat to European beachgrass and ORV traffic.

Pink sandverbena (Abronia umbellata var. acutalata). A herbaceous perennial (Figure 51) that is listed as "extirpated" in Washington, and in Oregon is on the review list for inclusion as a rare or endangered species. It grows on active dune areas along the entire coast in association with the ELYMUS MOLLIS-ABRONIA LATIFOLIA COMMUNITY. It occurs very sparingly and the primary threats to its survival are loss of habitat to European beachgrass and ORV activity.

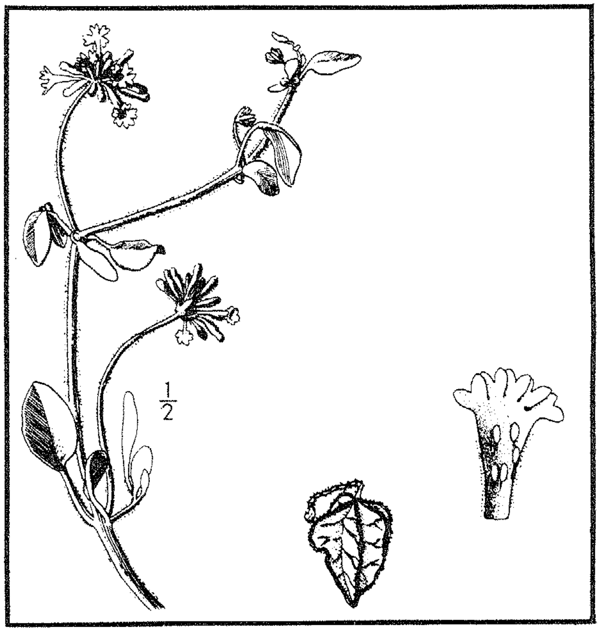

Figure 51. Pink sandverbena. Slender, prostrate stems, 20 to 100 cm long; leaves oblong, 2 to 6 cm long; flowers pink to purple, flower tube 6 to 8 mm long. (From Abrams 1940, reprinted by permission of Stanford University Press.)

Landforms, Habitats and Plant Communities

Many of the sand dune areas that have good examples of dune forms and dune systems are publicly owned. The U.S. Forest Service has extensive holdings at Sand Lake (Locality 9) and between Heceta Head and Coos Bay in Oregon (Localities 19 to 23). The Washington State Parks and Recreation Commission and the State Parks Division of the Oregon State Transportation Commission also own sand dune lands. Leadbetter Point (Locality 3) and Umpqua Lighthouse State Park (Locality 22) are examples.

Much of the sand dune area between the Siuslaw River and Coos River in Oregon (Localities 19 to 23) was proposed for National Seashore status in the early 1960's. This proposal failed, but the many years of investigation and public hearings produced a wealth of information on these dunes (U.S. Congress 1959, 1963, 1966). Eventually, in 1972, U.S. Forest Service holdings were designated the Oregon Dunes National Recreation Area (U.S. Congress 1972) with an area of 13,022 ha. Although managed for recreation, parts of the NRA are closed off to ORV use, an important factor in being able to observe and study natural dune process.

A considerable portion of the magnificent parabola system at Sand Lake (Locality 9) is owned by the U.S. Forest Service. Heavy ORV use, however, changes dune forms and obscures natural processes. It is also destructive to natural vegetation. Private holdings, especially on the outermost marginal ridges, could lead to development which would destroy the integrity of the system.

Leadbetter Point (Locality 3) and Netarts Spit (Locality 8) are excellent examples of relatively undisturbed bay dune systems that are publicly owned. The only threat to their integrity might be development for recreational purposes. The extensive dune areas around Bandon, Oregon (Locality 24, 25, 26), and Humboldt Bay (Locality 33) are almost entirely privately owned. There seems to be little prospect of preventing private development on these areas in the future.

On the other hand, almost all of the dunes of the Point St. George area (Locality 31) have passed into public ownership within the last couple of years. The State of California purchased about 3600 ha of private land, most of which will be administered as a State park by the

Department of Parks and Recreation (D. Scott, California Department of Parks and Recreation, Crescent City, California; pers. comm. 1983). The remainder, which includes Lake Earl and Lake Talawa, and the land surrounding these lakes, is administered by the Department of Fish and Game. Although most of this area has a long history of disturbance by human activity, the basic forms remain, and are a good representation of the northern California dune systems.

Although each of the three states in which the coastal dunes are located has provisions for the establishment of "natural areas" (the actual designations vary), none has been created on sand dune areas. The U.S. Forest Service, a leader in the setting aside of "Research Natural Areas" on its lands, has not yet given such status to any part of its sand dune holdings. The only private effort has been the establishment by The Nature Conservancy of the Lanphere-Christiansen Dunes Preserve at Humboldt Bay, California (Locality 33).

Certain plant communities are threatened along the entire coast by European beachgrass encroachment, ORV activity, and development. These include the ELYMUS MOLLIS--ABRONIA LATIFOLIA COMMUNITY, the POA MACRANTHA--LATHYRUS LITTORALIS COMMUNITY, the FESTUCA RUBRA--SOLIDAGO SPATHULATA COMMUNITY, and the ARCTOSTAPHYLOS UVA-URSI/RHACOMITRIUM CANESCENS COMMUNITY. These are communities of active and semistabilized sand and meadows. Old-growth forest communities are rare. On publicly owned lands, they are more or less secure, but examples should be identified of the PSEUDOTSUGA MENZIESII/RHODODENDRON COMMUNITY and the TSUGA HETEROPHYLLA--PICEA SITCHENSIS/GAULTHERIA SHALLON/BLECHNUM SPICANT COMMUNITY.

There is an urgent need to identify communities, habitats, and landforms that should be protected. A start at this is being made by natural heritage programs in all three states (references in Table 12) and other groups such as state game departments, The Nature Conservancy, and native plant societies (Burley 1979).

Dune Groundwater

The extensive use of dune ground water for industrial and domestic use could lead to problems associated with lowering of the watertable. In the Netherlands, where there is a long history of sand-dune ground-water exploitation (Ranwell 1972, p. 216), dune plant communities in some areas began to change drastically as formerly moist habitats dried out. Salt-water intrusion into the ground water also took place. The situation was dealt with by recycling purified waste water from large cities back into the dune aquifers.

Studies on the Oregon coastal dunes near Coos Bay (Locality 23) by Robison (1973) show a direct connection between the many shallow lakes and ponds of the area and the water table. Lake levels have been lowered because of pumping. Management techniques explored to minimize the adverse effects of pumping include location of wells, well design, varying the seasonal rate of pumping, and recharge by direct pumping into the lakes. As far as is known, no one is studying the effect of pumping on deflation-plain plant communities in the area.

Monitoring of water in observation wells along the shoreline shows no trace of salt. The fresh water apparently extends offshore for some distance. The distance and the nature of the fresh water-salt water interface is not known, nor is there any information yet about the amount of water that can be extracted before salt-water intrusion begins.

Extensive housing developments on many dune areas rely on septic tanks for sewage disposal. This could result in contamination of the ground water, a critical matter since such developments usually draw their water from wells in the same vicinity (Christenson and Rosenthal 1982). Nitrates and phosphates could also find their way to adjoining lakes and streams, resulting in the pollution of these bodies of water.

The extensive use of the sand-dune ground-water resource clearly requires study and careful planning. Crook (1979b) discusses ground-water planning and management considerations for the Oregon coast, and Fowler (1979) reviews the relevant literature.

Property Hazards

Because of their proximity to the ocean, coastal dune areas are popular residential development sites. However, the very features that make the coastal landscape so attractive--the beach, wind, sand, and the everchanging mood of the sea--also create hazards. Much has been said and written of these hazards by way of warning but generally without effect.

Probably the most tenuous places to build are the peninsulas and spits formed across bay mouths. Products of complex patterns of sediment transport by ocean currents, they can appear substantial and permanent. Bayocean Peninsula, on Tillamook Bay in Oregon (Locality 7), was the site of an ambitious and elaborate resort development begun in 1907 (Hanneson 1962; U.S. Army Corps of Engineers 1971). Serious erosion of the peninsula began in the early 1930's. The last house fell into the sea in 1960. It is thought that the erosion was associated with the construction of the north jetty on Tillamook Bay in 1917.

A more recent situation involved the spit across the mouth of Siletz Bay (Locality 14). Houses built in the center of this spit in the early 1970's were virtually on the beach 10 yrs later (Figure 52). This erosion was caused by the development of rip-current embayments which permitted the rapid erosion (up to 35 m in a few week's time) of the foredune on which the houses are built. Protection of the houses, but not the vacants lots, by riprap resulted in individual houses, or groups of houses, situated on promontories extending out onto the beach. Erosion continues during each winter storm period, but not always in the same place. Rip currents may migrate north-south within one storm season, or they may appear in new locations in subsequent seasons. These rip currents can occur anywhere along the shore, but their effect is most drastic and noticeable on sand spits, especially if houses have been built there. Work by Komar (1979) indicates that sand-spit erosion is part of a natural cycle of erosion and accretion.

On the east coast of North America and on the coastal dune areas of Europe, the creation of a foredune is considered one of the principle defenses against ocean storm damage of both natural and man-made features. The maintenance of foredunes is a critical part of coastal-dune management plans and building houses on them is virtually unthinkable (Ranwell 1972; McHarg 1969; Godfrey and Godfrey 1974).

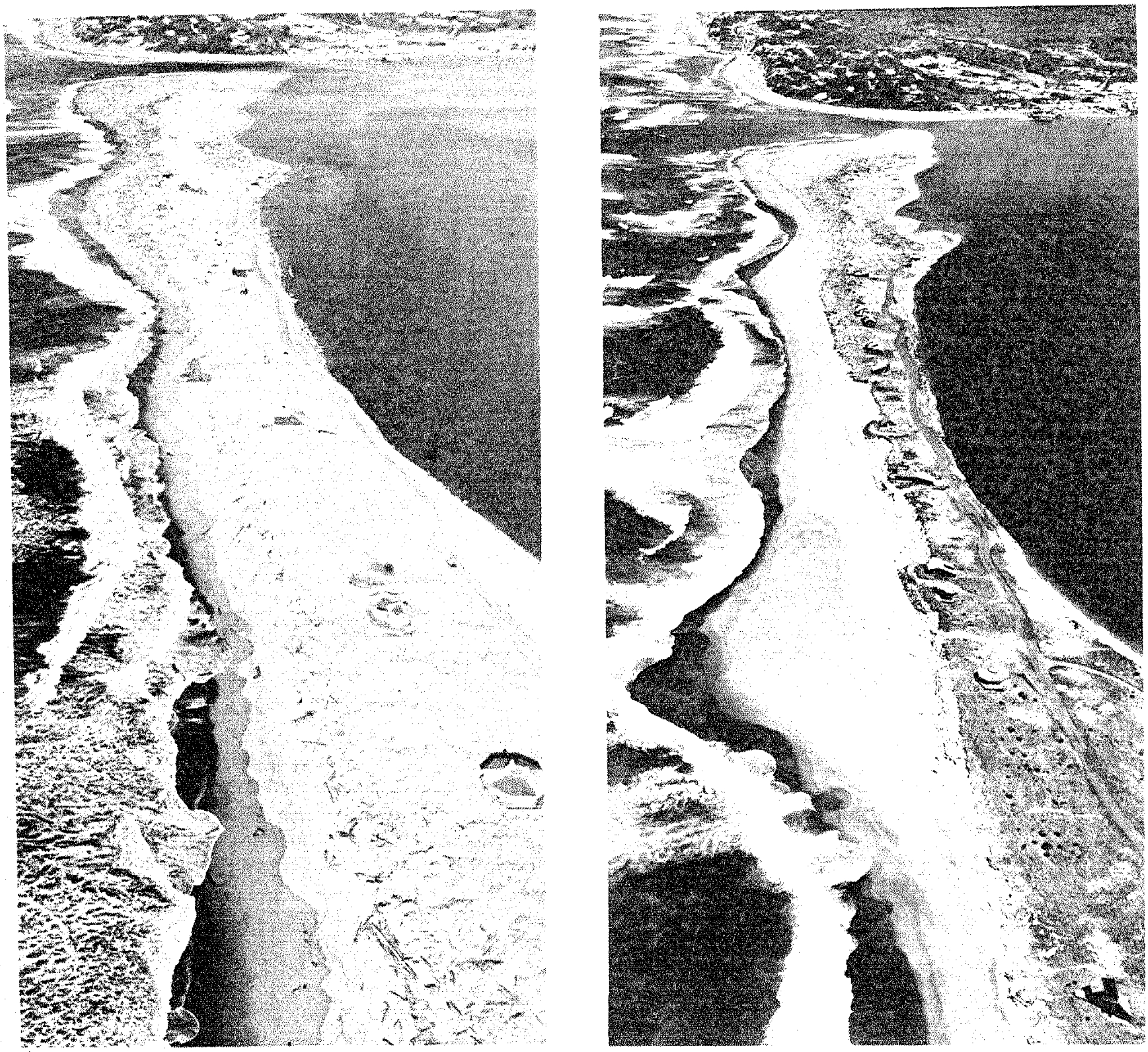

Figure 52. Residential development on a sand spit. The left photograph, taken 6 February 1973, shows the houses in the center of the spit. The right photograph, taken 19 May 1978, shows the effect of severe winter storm erosion. Siletz spit, Locality 14. (Oregon Department of Transportation.)

Along the Pacific Northwest coast, well-developed foredunes formed by European beachgrass are prime building sites. This can be readily seen on almost any dune area that is in private ownership. The potential danger from high winds and waves, extreme tides, and seismic sea waves (tsunami) is well documented (Proctor et al. 1980, Vol. 2). Erosion of nonspit beaches and dunes can also occur. Cape Shoalwater on Willapa Bay (Locality 2) is eroding away at the rate of about 50 m/yr--about 3,500 m have been eroded since 1887 (U.S. Army Corps of Engineers 1971).

In other places, accretion is a problem, if not an immediate hazard. Long Beach Peninsula (Locality 3) has grown seaward by about 600 m since 1950 (Reuf 1975), while the southern end of the Clatsop Plan (Locality 4) has gained over 60 m between 1939 and 1968 (U.S. Army Corps of Engineers 1971). The current problems in these areas are mainly social and legal--who owns the new land and what to do about lost ocean vistas. Future problems will involve erosional cycles that are poorly understood and unpredictable. An extensive literature exists (Fowler 1979) to help people deal with the hazards of building on the unstable zone next to the ocean.

At best these measures can only be temporary restraints, interfering with a system in long-term dynamic stability. As Godfrey and Godfrey (1974) point out in their plea for an ecological approach to dune management, "we speak of man's 'battle with the sea' and 'his struggles with erosion', but this is really a battle to save works of man himself; the beaches, if left alone, are in no danger of obliteration by the sea".

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APPENDIX I

COASTAL SAND DUNE LOCALITIES

Locality number and name, location, predominant dune form(s), and general features of sand dunes of the Pacific Northwest Coastal Region are shown below. The U.S. Geodetic Survey map quadrangle(s) for each locality is given in parenthesis following each location description. The notes are given at the end of the table. Locality numbers and names follow Cooper (1958) except for Localities 31-33 which correspond to Cooper's (1967) California 1-3.

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
1. Grays Harbor North	Grays Harbor County, Washington North side of entrance to Grays Harbor (Point Brown) north 25 km to Copalis Head. (Point Brown, Copalis Beach, Moclips; 7.5' Series)	Parallel ridge. Bay dune on the southern third.	Extensive prograding shore. Commercial development.
2. Grays Harbor South	Pacific and Grays Harbor County, Washington North side of the entrance to Willapa Bay (Cape Shoalwater) north 20 km to the south side of the entrance to Grays Harbor. (North Cove, Grayland, Westport, Point Brown; 7.5' Series)	Parallel ridge.	Mostly coastal strip. Ridges poorly defined. Extensive wave erosion at Cape Shoalwater.
3. Willapa Bay	Pacific County, Washington Columbia River (North Head) north 30 km to the end of Long Beach Peninsula (Leadbetter Point). (Cape Disappointment, Ocean Park, Oysterville, North Cover; 7.5' Series)	Parallel ridge. Bay dune on the north end.	Low, widely spaced, extensive swale lakes and bogs. North end is undisturbed - State park and wildlife refuge.

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
4. Clatsop Plains	Clatsop County, Oregon Mouth of the Columbia River south 26 km to Seaside, past the outlet of the Necanicum River. (Warrenton, Gearhart, 7.5' Series; Cannon Beach, 15' Series)	Parallel ridge.	Prograding shore with well-defined ridges, at least 9 in some places (Note 1).
5. Nehalem River	Tillamook County, Oregon The mouth of Nehalem Bay north 8 km to Neahkahnie Mountain, and east to Neahkahnie Lake. Nehalem, 15' Series)	Parabola dune. Bay dune south half.	Formed by southwest winds (Note 2). Mostly obliterated by human activity.
6. Rockaway	Tillamook County, Oregon Rockaway north 4 km to Nedonna Bach, and south 2.5 km to Spring Lakes. (Nehalem, 15' Series)	Parallel ridge.	Single dune ridge on a barrier beach.
7. Tillamook Bay	Tillamook County, Oregon Watseco south 2.2 km to the Tillamook Bay jetty, east to Smith Lake; Kincheloe Point south 6.5 km to Cape Meares. (Nehalem, 15' Series)	Parabola dune. Bay dune on the spit.	Much-eroded parabola dune north of Tillamook Bay entrance. Large spit with trough blowouts. Site of Bayocean Resort destroyed by erosion.
8. Netarts Bay	Tillamook County, Oregon From 1 km south of Oceanside south 2.1 km to the south end of Netarts; entire Netarts spit south 8 km to Cape Lookout. (Tillamook, 15' Series)	Parabola dune. Bay dune on adjacent spit.	Remnants of 3 large parabola dunes north of the spit. Spit largely undisturbed (Note 3).
9. Sand Lake	Tillammok County, Oregon South side of Cape Lookout south 8 km to Tierra Del Mar. (Tillamook, 15' Series)	Parabola dune.	Massive, active parabola dunes extending 6 km inland (Appendix II).

Locality number and name	Location (*USGS map quadrangle*)	Dune form(s)	General features
10. Nestucca Bay	Tillamook County, Oregon From 2 km north of Cape Kiwanda (Miles Lake) south 8.5 km to the end of the north spit of Nestacca Bay. (Hebo, 15' Series)	Parabola dune. Bay Dune on spit to the south.	Three massive parabola dunes, being stabilized by recent plantings. Soil profiles on Cape Kiwanda.
11. Neskowin Creek	Tillamook County, Oregon From Daley Lake, 1.5 km southwest of Oretown, south 5.2 km to the outlet of Neskowin Creek. (Hebo, 15' Series)	Remnant parabola dune. Parallel ridge.	Narrow beach-dune barrier, considerable erosion at present.
12. Salmon River	Lincoln County, Oregon South side of the outlet of the Salmon River, 4 km north of Roads End. (Hebo, 15' Series)	Remnant parabola dune.	Small area at river mouth with no predominant dune form.
13. Devils Lake	Lincoln County, Oregon From the outlet of Devil's Lake north 4.5 km to Roads End. (Cape Foulweather, 15' Series)	Remnant parabola dune.	Three narrow remnants perched on a terrace cliff. No connection with the beach. Dense residential development.
14. Siletz Bay	Lincoln County, Oregon North of Gleneden Beach; entire south spit of Siletz Bay, 4 km long. (Cape Foulweather, 15' Series)	Bay dune.	Extensive residential development. Site of recent severe erosion (Chapter 6). Pestricted access.
15. Yaquina Bay	Lincoln County, Oregon About 0.8 km north of the mouth of Yaquina Bay (the short, stubby "spit"); Yaquina Bay 3 km south to Henderson Creek. (Yaquina, 15' Series)	Remnant parabola dune. Parallel ridge.	Parabola pattern north of river obliterated. Prograding shore south of river with well-defined ridges.

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
16. Alsea Bay	Lincoln County, Oregon From the end of the north spit of Alsea Bay north 5 km to the outlet of Fox Creek. (Waldport, 15' Series)	Parabola dune.	Narrow parabola dunes, now mostly obliterated by residential development.
17. Tenmile Creek	Lane County, Oregon Outlet of Tenmile Creek, 10 km south of Yachats. (Heceta Head, 15' Series)	Remnant parabola dune.	Small erosional remnant area perched on terrace cliff.
18. China Creek	Lane County, Oregon South side of China Creek from the outlet of China Creek south 4 km to the north side of Heceta Head. (Heceta Head, 15' Series)	Parabola dune.	Narrow parabola dunes formed by northwest winds. Completely vegetated.
19. Siuslaw River North	Lane County, Oregon From the south base of Heceta Head south 14 km to the Siuslaw River (Florence), and east 4 km to Mercer Lake and Clear Lake. (Heceta Head, 15' Series)	Stabilized parallel ridge. Parabola dune.	Low dunes extending 4.5 km inland. Extensive forest vegetation. Considerable residential development (Note 4).
20. Siuslaw River South	Lane County, Oregon North end of the south spit of the Siuslaw River south 15 km to the Siltcoos River; west of US 101. (Siltcoos Lake, 15' Series)	Transverse ridge	Extensive active dunes. Well-developed transverse ridge and oblique dune patterns. Very little forest vegetation.

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
21. Umpqua River North	Lane and Douglas County, Oregon Siltcoos River south 23 km to the end of the north spit of the Umpqua River, west of US 101 (Siltcoos Lake, Reedsport; 15'Series).21.	Transverse ridge. Bay dune at south end. Parabola dune.	Relatively narrow strip, few oblique dunes. Massive parabola dunes at Tahkenitch Creek formed by both northwest and southwest winds.
22. Umpqua River South	Douglas and Coos County, Oregon Umpqua River south 10.5 km to Tenmile Creek; west of US 101. (Reedsport, 15' Series)	Transverse Ridge. at south end.	Broad area of extensive transverse ridges, oblique dunes, and forest remnants. Five giant parabola dunes at the north end (Note 5 and Apendix II).
23. Coos Bay	Coos County, Oregon Tenmile Creek south 17 km to the end of the north spit of Coos Bay; west of US 101. (Reedsport, 15' Series; Empire, (Charleston, 7.5' Series)	Transverse ridge. Parallel ridge. Bay dune at south end.	A broad, low area with many lakes. Complex mosaic of vegetation and active sand.
24. Coquille River North	Coos County, Oregon South end of the north spit of the Coquille River north 10 km to the outlet of Whisky Run Creek. (Bandon, 15' Series)	Parallel ridge.	Widely spaced ridges with broad deflation plains. Old-growth forest cut.
25. Coquille River South	Coos County, Oregon South side of Coquille Point (Bandon) south 11 km to the outlet of Fourmile Creek. (Bandon, 15' Series)	Parallel ridge.	Similar to Locality 24. Extensive meadows. Long history of agricultural use on the broad deflation plains.
26. Fourmile Creek	Coos and Curry County, Oregon Outlet of Fourmile Creek south 14 km to Floras Lake. (Bandon, Langlois, Cape Blanco; 15' Series)	Parallel ridge. Parabola dune.	Broad, low area. Ridges and old parabolas north end; active, small, tongue-like parabolas over remainder of the area (formed by NW wind).

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
27. Sixes River	Curry County, Oregon South side of the outlet of the Sixes River, 2 km north of Cape Blanco.	Parallel ridge. Parabola dune.	Very small area with 1 ridge and 1 small parabola dune.
28. Elk River	Curry County, Oregon South side of the outlet of the Elk River, 5.5 km south of Cape Blanco. (Cape Blanco, 15' Series)	Parallel ridge.	Remnant ridges. Extensive agriculture and logging.
29. Euchre Creek	Curry County, Oregon Outlet of Euchre Creek, 2.5 km south of Port Orford. (Port Orford, 15' Series	Parallel ridge.	Small area with one ridge. Gray sand.
30. Pistol River	Curry County, Oregon Outlet of the Pistol River, 17 km south of Gold Beach, south 3 km to Crook Point. (Gold Beach, 15' Series)	Parabola dune.	Stabilized and active dune, formed by northwest winds. Largest dune area in Oregon south of Locality 26.
31. Point St. George	Del Norte County, California. End of the south spit of the Mad River, 18 km south to Point St. George and Crescent City. (Crescent City, 15' Series)	Parabola dune	Formed by northwest winds. Mostly tongue and trough parabolas, but 3 large parabolas to south. History of agricultural use (Note 6).
32. Big Lagoon	Humboldt County, California. Redwood Creek (Orick) south 46 km to Patrick's Point (Dry Lagoon State Park.) (Rodgers Peak, Orick, Trinidad; 7.5' Series	Bay dune.	Long, narrow bay barriers. Black, coarse sand.

Locality number and name	Location (USGS map quadrangle)	Dune form(s)	General features
33. Humbolt Bay	Humboldt County, California. North and south of Eureka and Humboldt Bay, from the Mad River, 38 km south to the Eel River. (Eureka, Ferndale, 15' Series)	Parallel ridge. Parabola dune. Bay dune.	Stabilized ridges. Active, small parabolas formed by northwest winds. Spits north and south of bay entrance (Note 7.)

Note 1. An excellent cross section of the parallel ridge system here can be seen along the Sunset Beach Road which heads west off US 101 about 8.5 km (5.3 mi) south of Warrenton. At this point US 101 runs along the crest of the ridge that is second from the inner margin. Sunset Beach Road cuts through or over 9 ridges, and crosses an interdune lake (Sunset Lake).

Note 2. All of the parabola dunes down to Locality 17 are formed by the southwest winds of winter. From Locality 18 south, most are formed by the northwest winds of winter. The main exceptions are on Locality 22.

Note 3. Netarts spit (Locality 8) is owned by the State of Oregon. It is essentially undisturbed, and an excellent example of a bay dune system. It can be reached through Cape Lookout State Park.

Note 4. Locality 19 has several interesting features. Lily Lake at the extreme north end is a pristine dune lake. There is no easy access, but it can be viewed from above on the highway. The lake is at present in some danger of disturbance due to adjacent private development. A side road 8.0 km (5.0 mi) north of Florence (junction of US 101 and Oregon 126) leads to the Darlingtonia Wayside. Here, associated with the western red cedar/smooth Labrador-tea community is a fine stand of California pitcher-plant (*Darlingtonia californica*). Just a few meters south of this road, the Sutton Creek Road (a U.S. Forest Service road) heads west to the beach. Along this road are good views of the low, undulating, ridge-and-swale topography of this locality. The predominant vegetation is approximately 100-yr-old lodgepole pine/western rhododendron forest. At the end of the road is a picnic area, and access to Sutton Creek and the beach. There is also a stand of the winter flowering shrub, wavy-leaf silk-tassel (*Garrya elliptica*), around the parking lot.

Note 5. The very large parabola dunes next to Clear Lake on Locality 22 have well-developed climax forest (Douglas fir/western rhododendron) on their stabilized lee slopes. There is no easy access. However, forest of this type can be seen along the trail that leads from the Tahkenitch Creek Campground to the open dunes (Locality 21).

Note 6. The easiest access to the dunes of Locality 31 is along the Kellogg Beach road which can be reached by turning off US 101 onto County D3 on the south side of the Smith River. Turn north on Lake Earl Road, then west on Mosely Road, then south on Lower Lake Road to Kellogg Road. There are other access points just north of Crescent City. The entire dune area west of Lake Earl is owned by the State and open to the public (though vehicles are prohibited in most places).

Note 7. The least disturbed dunes of this locality lie just south of the mouth of Mad River. Take the first exit off US 101 south of the river, and follow the river mouth access road. It is also possible to visit the Lanphere-Christensen Dunes Preserve, but permission is necessary. For information, call the Preserve (707/822-6378) or write: Dr. Ken Lang, Department of Biological Sciences, HSU, Arcata, CA 95521. Of particular interest on the Preserve are areas of hummock foredune formed by native species; European beachgrass, so prevalent elsewhere, has not yet taken over here. It is also possible to see some of this "native foredune" along the south spit, reached by traveling through Eureka, around South Bay, and over Table Bluff. The dunes on the north spit, around Manila, Samoa, and the Coast Guard Station have been severely disturbed.

APPENDIX II
DESCRIPTIONS OF SPECIFIC DUNE AREAS

Detailed descriptions of two sand dune systems. Includes geographic location, dune forms, plant communities, and suggested field trip route.

SAND LAKE (LOCALITY 9).
Map, Appendix Figure II-1; and Figures 19, 22, 27, 44.

This is an extensive parabola-dune system reflecting three episodes or periods of dune activity. The parabola dunes of the first two episodes remain as two sets of stabilized dune ridges, one set enclosed within the other. Three parabola dunes of the third episode are presently active. This system has been formed in its entirety by the south-southwest winds of winter which drive the dune sands onto the south flank of Cape Lookout. The long axis of the system (trending roughly northeast to southwest) extends over 6 km. Most of the area is U.S. Forest Service land, the rest is owned by Tillamook County, the Boy Scouts of America, and private individuals. Sand Lake itself is a salt water lagoon bordered by salt marsh. A few small streams enter it.

The dune forms that can be seen on this system are: active parabola dune, stabilized dune ridge, retention ridge, foredune, sand hummocks, deflation plain, sand plain, blowout, ephemeral pond, and dune lake. It is also a good place to see ORV activity (particularly on 3-day summer weekends), and the effects of ORV activity. There are exposures of Pleistocene sand along the beach. This substratum slants upward toward Cape Lookout, appearing first just north of the beach access road. The plant communities found on this dune system include:

- American dunegrass--yellow sandverbena
- European beachgrass
- seashore bluegrass--beach pea
- red fescue--dune goldenrod
- red fescue--seashore lupine
- sickle-leaved rush--springbank clover
- slough sedge--Pacific silverweed
- salal--evergreen huckleberry
- kinnikinnick/silver moss
- Hooker willow--Pacific wax-myrtle
- lodgepole pine/western rhododendron
- lodgepole pine/bristly manzanita
- Sitka spruce--lodgepole pine/-pine/Hooker willow/Oregon beaked moss
- Douglas fir/western rhododendron

This dune system can be reached from both the north and south. From the north, turn west off US 101 in downtown Tillamook on the road to Cape Lookout State Park over Cape

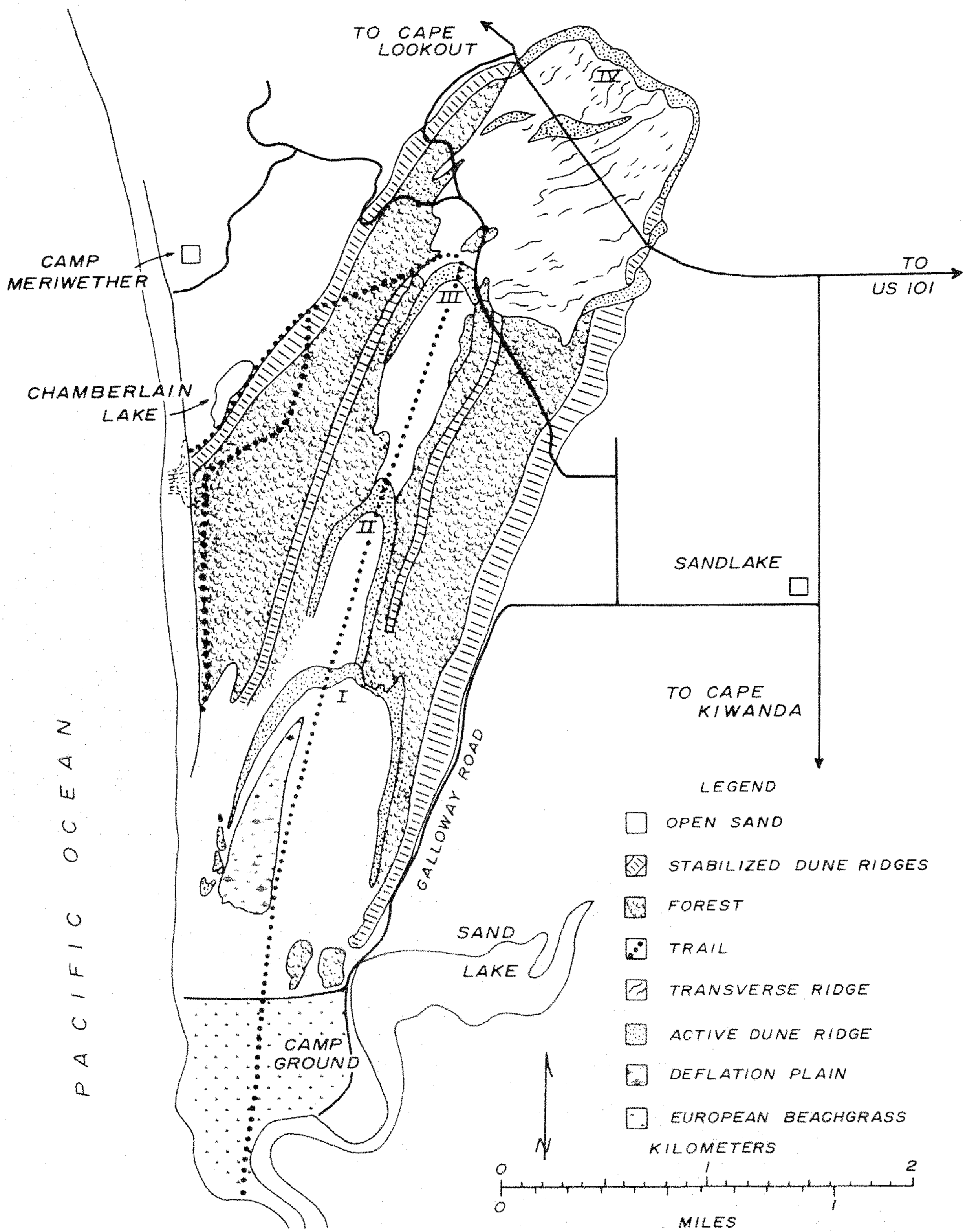

Figure II-1. Sand Lake sand dunes (Locality 9). The suggested exploratory walk is shown as a dotted line ("trail"). Vegetation is not shown for the area surrounding the dune system.

Lookout. Shortly after the descent from the Cape begins there are two "scenic overlooks" that provide panoramic views of the dune system and Cape Kiwanda to the south (these overlooks are within 1.0 km (0.6 mi) from the Cape Lookout trailhead). At the base of the Cape, the road crosses the northern end of the dune system, cutting through the two stabilized ridges of the oldest parabola dune (Episode I). The ridges formed by the dune of the second episode have been destroyed in this area by the erosional activity of the current episode. Shortly past the second (eastern) ridge, there is a "T" road junction. Turn right (south) to the Sandlake junction (1.5 km; 1.0 mi). A small store and service station is located on the corner.

To get to this point from the south, leave US 101 at the Pacific City turnoff, 22 km (14 mi) north of the junction of US 101 and Oregon 18 at Lincoln City.[20] Proceed through Pacific City, past Cape Kiwanda, and through Tierra del Mar to the Sandlake junction (17.5 km; 14.4 mi).

At the Sandlake store, turn west on the Galloway Road. There is another "T" junction 1.0 km (0.6 mi) from the store. Turning north on this road leads to the northern part of the dune system. Continuing west, the Galloway Road turns southward at the base of the massive outer dune ridge and parallels it for some distance. At the end of the ridge it heads west again to the beach. The campground lies to the south of this beach access road.

The best way to view the area would be to walk from the sand spit at the south end of the system (the entrance to Sand Lake) northeast up the axis of the dunes to the gravel road that crosses the dunes at the north end, 5.5 km (3.4 mi). Return to the south end by the roads around the east side, or by walking down the beach.

The end of the sand spit is Snowy Plover nesting habitat, but birds have not been seen in this area for some time. The area between the spit and the beach access road has well developed fordune and sand hummocks. ORV's are prohibited in this area. The predominant plant community is EUROPEAN BEACHGRASS with maritime pea. Remnants of the YELLOW SANDVERBENA--AMERICAN DUNEGRASS community are scattered about. In the central part, away from the blowing sand, European beachgrass is declining in vigor, and the RED FESCUE--DUNE GOLDENROD, and RED FESCUE--SEASHORE LUPINE communities are developing. The campground is established on the site of a European beachgrass nursery planted around 1940. The high sand ridge to the west and south of the campground is actually a foredune-like ridge produced as sand from the then-bare spit was blown onto the grass around the edges of the plantation. The vegetation of the campground area is a complex collection of native and disturbed-area exotic species.

The area from the beach access road north to the Cape Lookout Road (paved) is open to ORV activity. The two forested hills to the east, and just north of the beach road, are remnants of the ridges formed by the first- and second-episode par-

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[20]This route passes through the dune system of Locality 10. A stop should be made at Cape Kiwanda to note the series of buried soil profiles in the sand piled on top of the Cape which lies to the north of the beach opposite Haystack Rock.

abola dunes. These ridges extended to the present day shoreline, and farther, in the past since they were formed as sea level was rising. Since relative stability of sea level was attained there has been erosion of the seaward ends of the ridges both by wave and wind action. A few hundred meters north of the beach road, the Pleistocene sand substratum is exposed along a small seasonal creek draining onto the beach. Just beyond this point the extensive deflation plain of Dune I (the most recent) begins.[21]

On this deflation plain, the most widespread community is the RED FESCUE--SEASHORE LUPINE. There are patches of the SICKLE-LEAVED RUSH--SPRINGBANK CLOVER and SLOUGH SEDGE--PACIFIC SILVERWEED communities also scattered about. Because the deflation plain is heavily used by ORV enthusiasts as a campground, only remnants of the SALAL--EVERGREEN HUCKLEBERRY and HOOKER WILLOW--PACIFIC WAX MYRTLE shrub communities remain. Scattered lodgepole pine is also present. Without disturbance, the lowest part of the deflation plain (the western edge) would be a lodgepole pine thicket today. Along the eastern edge, where the surface slopes gradually upward, the SEASHORE BLUEGRASS--BEACH PEA and the RED FESCUE-DUNE GOLDENROD communities are found, along with many European beachgrass hummocks.

The sand ridge to the east of the deflation plain and the line of dissected knolls to the west are both part of the marginal ridges of Dune I. Prior to the advent of the ORV, the west ridge was more continuous, with stabilizing herbaceous vegetation covering much of it. Native sand hummock species were also common. Today only fragments of the AMERICAN DUNEGRASS--YELLOW SANDVERBENA community can be found. The earlier dune ridges of the first and second episodes have been destroyed by erosion in this area, and their sands incorporated into the present active dunes. Seaward of the western ridge is a complex of knolls and blowouts, all associated with the development of Dune I (and its predecessors). One of the highest knolls has buried soil profiles exposed on its eroding sides. One of the profiles is thick and well developed, indicating long established forest on the site. It probably belongs to the parabola dune ridge of the first episode.

The many dead trees on both sides of the windward slope of the parabola dune indicate the presence of well-developed forest prior to the current episode. From the crest of this dune (Dune I), the windward slope of the next dune (Dune II) can be seen straight ahead. At the base of the slipface of Dune I there is usually an ephemeral pond in spring and summer up to a meter deep. The forest on both sides is primarily LODGEPOLE PINE/WESTERN RHODODENDRON community. From the crest of Dune II, the highest of the currently active dunes, a view can be had to the far end of the complex. The active "sand channel" is very constricted here, accounting for the height of the sand mass. At the base of the dune is a large blowout-like bowl formed as a result of the planting of European beachgrass across the path of the dune in 1967. The planting was to protect a road that was to be built into a projected campground on the west dune ridges. The present appearance of the site is the result of sand de-

[21]The active parabola dunes are numbered sequentially from south to north.

position in the grass and ORV activity.

The "sand channel" widens to a broad sand plain leading to the windward slope of Dune III. The form of this dune is complicated by another European beachgrass planting made in the 1950's to protect a telephone line and trail into the Boy Scout Camp. The dune has now passed over the planting, raising it a considerable distance (the foredune effect), but the crest is more spread out because of the grass. It is the smallest of the three active dunes. What would be Dune IV, the first to pass along the axis (though actually there could have been more than one) is now against the mountain front in the form of a broad, slowly advancing retention ridge. The very broad area of sand plain here is the result of a long period of blowout activity. It is slowly being stabilized by the RED FESCUE--DUNE GOLDENROD and KINNIKINNICK/-SILVER MOSS communities with scattered lodgepole pine. There has been much destruction of this vegetation by ORV activity. As recently as 15 yrs ago the area between Dune II, the forest, and the gravel road was almost entirely covered by a carpet of silver moss and kinnikinnick. Just across the gravel road, opposite Dune III, is a fence constructed by a private property owner to exclude ORV traffic. The difference in vegetation development on the two sides of the fence is obvious.

The gravel road that runs past the front of Dune III is the same one mentioned above that heads north off Galloway Road. It crosses the two east dune ridges before reaching the open sand plain. Just past the little patch of old forest at the base of Dune III (developed after Dune IV passed through) the road forks. The left fork is a former access road to the Boy Scout Camp. The right fork crosses over the massive west dune ridge, descending the outside of the ridge to intersect the Cape Lookout highway. A small but excellent example of the dune climax DOUGLAS FIR/WESTERN RHODODENDRON forest is found on this dune slope.

Off to the west side of Dune III, in the open forest at its base, is the beginning of a trail that heads southwest over the dune ridges toward the beach. Since it is heavily used by ORVs now it should be easy to find. It was built originally during World War II as a jeep trail to carry supplies into coast lookouts on the beach cliff. This trail was also used for many years as access to the Boy Scout Camp during the time that the scouts were required to walk into the camp from an unloading point east of the dune complex. The trail crosses the two west dune ridges. There is a mixture of forest communities along this trail. On the higher ridge slopes and tops, the LODGEPOLE PINE/WESTERN RHODODENDRON community predominates. There are large, old Douglas fir present, indicating an approach to the dune climax forest community. In the deep swales between the ridges, the SITKA SPRUCE-LODGEPOLE PINE/HOOKER WILLOW/OREGON BEAKED MOSS community is found.

At the top of the outer ridge the ORV trail turns more southward along what used to be the Coast Guard communication-line maintenance trail. It had all but grown over when the first ORVs arrived. It passes through LODGEPOLE PINE/BRISTLY MANZANITA forest, and then thickets of young lodgepole pine and Sitka spruce before coming out on the seaward side of the west marginal ridge of Dune I. The original trail, now obscure and blocked by fallen trees, continues down the seaward side of the dune ridge. At the base of this ridge is Chamberlain Lake, formed when this first parabola dune dammed a small stream. It is easily seen from the old trail. The lake and surrounding area is on land owned by the Boy Scouts of America. Anyone wishing to explore this area should obtain persmission from the resident camp ranger.

It is possible to get to the beach through the Boy Scout camp or from a number of points along the ORV trail. Once on the beach, there is access to the base of Cape Lookout to the north, and to the beach road at the south end of the system. Of special interest is the drainage of Chamberlain Lake from the base of the sea cliff over black cobble beach; and the sea cliff itself, composed of very old, compacted sands, discolored by long-term chemical weathering processes.

The entire trip will take 4 to 6 hrs, though more should be allowed. In bad weather, or for a shorter trip, start from the gravel road at the north end, and walk south to Dune III. This can be accomplished in 1 to 2 hrs. It is also possible to walk from either the gravel road or the paved Cape Lookout Road north over the sand plain (ORVs not permitted in the area north of the paved road) to the retention ridge which is the edge of the dune system lying against Cape Lookout.

TENMILE CREEK (LOCALITY 22).

Map, Appendix Figure II-2: Cover; and Figure 14

The dunes between the Siuslaw River and Coos Bay (Localities 20 to 23) are all part of an extensive transverse ridge system in which the predominate dune forms are the result of the interaction of sand and wind. Almost any access point to the dunes in these four localities will provide good examples of many of the dune forms and plant communities discussed in this report. The specific area described here is accessible through the Eel Creek Campground of the U.S. Forest Service, located near Lakeside, Oregon, on US 101. The campground entrance is 17.5 km (11.0 mi) south of the junction of US 101 and Oregon 38 in Reedsport, Oregon.

The dune forms that can be seen here are: oblique dune, transverse ridge, blowout, dune ridge, retention ridge, swale, ephemeral pond, deflation plain, foredune, sand hummock, and sand plain. The plant communities that can be see include:

European beachgrass
seashore bluegrass--beach pea
red fescue--dune goldenrod
red fescue--seashore lupine
sickle-leaved rush--springbank clover
slough sedge--Pacific silverweed
salal--evergreen huckleberry
kinnikinnick/silver moss
Hooker willow--Pacific wax-myrtle
lodgepole pine/bristly manzanita
Sitka spruce--lodgepole pine/-Hooker willow/Oregon beaked moss
lodgepole pine/slough sedge
Douglas fir/western rhododendron
western hemlock--Sitka spruce/salal/deer fern

The trail from the parking lot passes for a short distance over a dune ridge that is the eastern

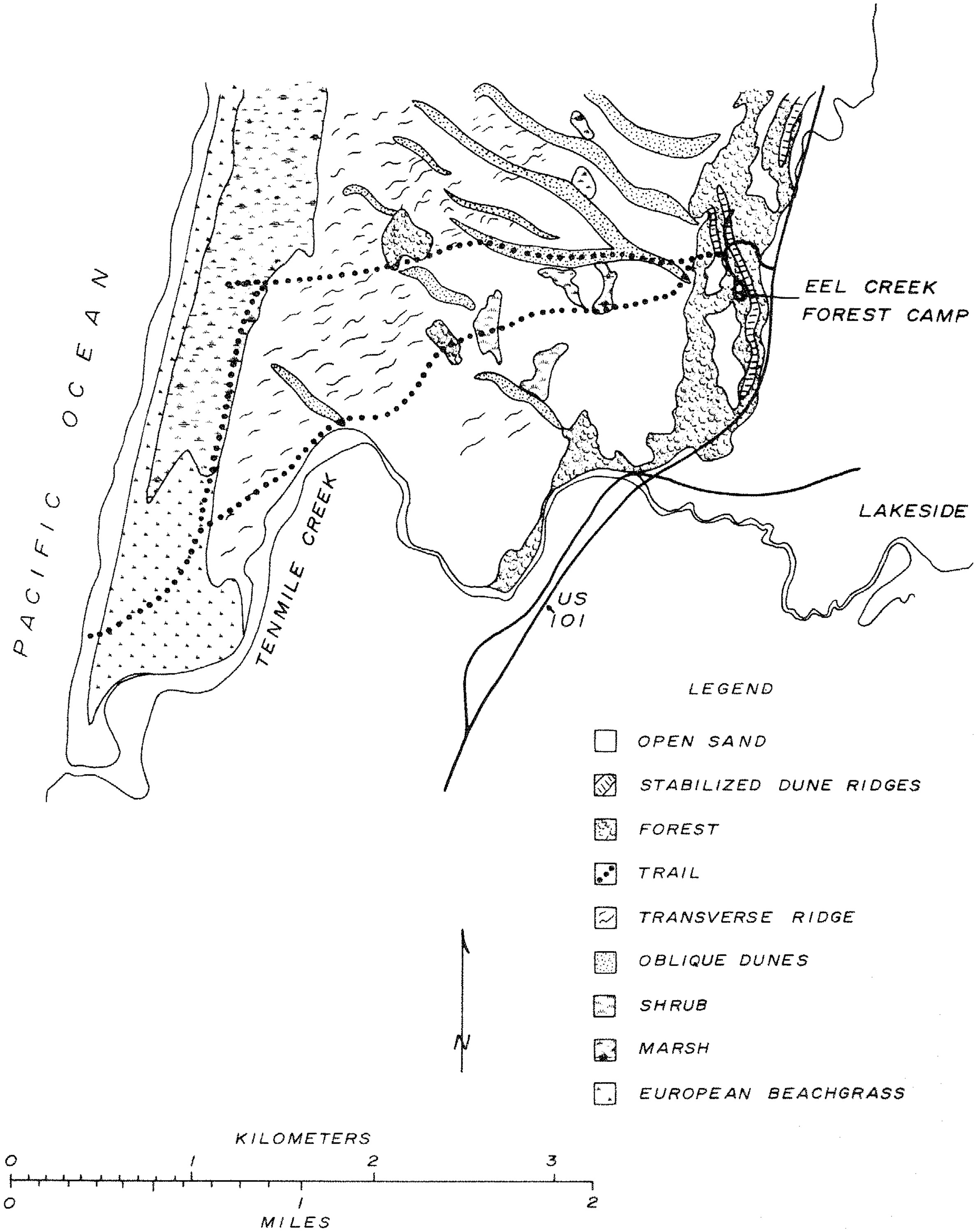

Figure II-2. Tenmile Creek sand dune area (Locality 22). The dotted line is a suggested exploratory route. The forest on the south side of Tenmile Creek is not shown.

margin of the dune system. There is DOUGLAS FIR/WESTERN RHODODENDRON forest on the side of the ridge, and on the top, an excellent example of LODGEPOLE PINE/BRISTLY MANZANITA forest. A short, branched staircase trail leads south to a large saucer blowout that is being stabilized by the RED FESCUE--DUNE GOLDENROD and KINNIKINNICK/SILVER MOSS communities. Beyond the staircase, the trail branches to the right; continue straight ahead to emerge onto the active sand area. Both north and south from this point, a retention ridge is slowly invading the established forest.

Straight ahead is the inner end of an oblique dune. From the top of this dune there is a good view of the entire area to be discussed. To the north and south are similar oblique dunes, including a very high one farther north that is apparently passing over a forested remnant, since there are both live and dead trees emerging from the crest. Transverse ridges can be seen moving up the flanks of the oblique dunes, especially out toward their seaward ends (the transverse-ridge pattern will be obscured by erosion in late winter).

The deep hollows or swales between the oblique dunes are usually wet and frequently contain ephemeral ponds. A sparse herbaceous and shrub vegetation frequently develops on these areas. Directly seaward from the crest of the dune is a forested remnant with a WESTERN HEMLOCK--SITKA SPRUCE forest community on the top (indicating that it was probably a low area in the dune landscape at one time!). Although the remnant is being continually eroded, the erosion is slow, and occurs in different places at different times--the development of vegetation (especially lodgepole pine) on the slopes is evidence of this. On the south side of the remnant mound, near the base, is an exposure of the Pleistocene substratum. It is about 20 m long and 1.2 m thick. The surface 0.6 m is dark brown with a silty texture. The boundary with the underlying yellowish-brown sand is quite distinct.

South of the forest remnant and its associated oblique dune to the east are a series of three low, vegetated areas characteristic of the deep interdune swales. The easternmost is mostly herbaceous and shrub with a few small trees. A pond is frequently seen here. The middle area has young forest (10- to 15-yr-old lodgepole pine), while the westernmost has fairly old forest (25 to 35 yrs, a LODGEPOLE PINE/-SLOUGH SEDGE community). All of these areas are being invaded from the north by sands blown in by the summer winds. Sand hummocks formed by Hooker willow and trough blowouts are seen in this area. Both the SEASHORE BLUEGRASS--BEACH PEA and RED FESCUE--DUNE GOLDENROD are developing as stabilizing vegetation in this area.

The area between the forest remnants and windward ends of the oblique dunes and the shore deflation plain is an extensive sand plain on which the transverse-ridge pattern develops to a striking degree in the summer months. These ridges are most fully developed in late summer and early autumn (August to October) before the winter storm winds begin eroding the profiles.

Just west of the sand plain the shore deflation plain begins. A number of vegetation zones are evident. At the active sand margin are EUROPEAN BEACHGRASS hummocks. As the contact with the water table moves inland, the hummocks are deprived of blowing sand. The hummocks gradually erode away and the beachgrass slowly dies off. This is the second zone. In the third zone, various deflation plain herbaceous communities begin to become established, mostly the SICKLE-LEAVED RUSH--SPRINGBANK CLOVER * and SLOUGH SEDGE--PACIFIC SILVERWEED communities, but also patches of RED FESCUE--SEASHORE LUPINE. Seaward of this third zone, the shrub communities become obvious, again mostly HOOKER WILLOW--PACIFIC WAX-MYRTLE, but with some SALAL--EVERGREEN HUCKLEBERRY. Beyond this fourth zone, forest dominates in a fifth zone with lodgepole pine thickets. Sitka spruce becomes strikingly visible as the trees reach 3 to 5 m in height. This is the beginning of the SITKA SPRUCE--LODGEPOLE PINE/-HOOKER WILLOW/OREGON BEAKED MOSS community. It should be noted that zones 3 to 5 intergrade as a successional sequence without distinct boundaries. Even in the herbaceous zone it is possible to find shrub and tree seedlings.

The well-developed foredune can be reached by crossing the deflation plain, though passing through the shrub and tree thickets may be difficult. There is also considerable standing water through winter and spring. Access to the beach is also possible by walking south along Tenmile Creek. At about the point where the creek turns to the south, there is an area where wood and soil profiles from a previous forest vegetation are being exposed by erosion.

The Sitka spruce forest south of Tenmile Creek has developed on a deflation plain resulting from the protecting influence of the creek. Sand blowing southward in summer is carried away by the creek. This forest, as well as the herbaceous and shrub vegetation in the bend of the creek right next to the water, is a good example of the riparian habitat.

It is about 3.0 km from the parking lot to the beach. At least 4 hrs should be allowed for a walk out and back. A full day of 6 to 8 hrs would be better to permit time for a detailed look at this magnificent dune system. ORV activity is prohibited in this area.

APPENDIX III

LIST OF VASCULAR PLANTS OF THE DUNES

Partial list of the vascular plant species of the sand dunes of the Pacific Northwest Coastal Region. Standard and English names taken from Hitchcock and Cronquist (1973) in most cases. Species found only below Latitude 43°N are from Munz and Keck (1959). In a few cases species are known by more than one standard name; these are indented and placed in parenthesis following the main entry. Many species have more than one English name, but only the most commonly used name is listed. The numbers in parenthesis in the third column indicate the plant community in which the species is most likely to be found (refer to Table 8 for community name). The terms in the third column are defined at the end of the list.

Standard name	English name	Plant community and occurrence
Abies grandis (Dougl.) Forbes	Grand fir	(15,20) Common on dunes of northern California
Abronia latifolia Eschsch.	Yellow sandverbena	(1) Dune-maritime endemic, common
Abronia umbellata Lam.	Pink sandverbena	(1) Dune-rare
Achillea borealis Bong. (Achillea millefolium L.)	Yarrow	(6) Widespread
Agoseris apargioides (Less.) Green	Seaside agoseris	(3) Dune
Agrostis alba L. (Agrostis ampla Hitchc.)	Redtop	(6) Widespread
Agrostis exarata Trin.	Spike bentgrass	(6) Widespread
Agrostis pallens Trin.	Dune bentgrass	(3) Dune-maritime endemic, common
Agrostis palustris (Huds.) Pers.	Creeping bentgrass	(6) Common
Aira caryophyllea L.	Silver hairgrass	(3,6) Common
Aira praecox L.	Little hairgrass	(3,6) Common
Alnus rubra Bong. (Alnus oregona Nutt.)	Red alder	(14,17) Widespread
Ambrosia chamissonis (Less.) Greene (Franseria chamissonis Less.)	Silver bursage	(1,3) Dune-maritime endemic

Standard name	English name	Plant community and occurrence
Ammophila arenaria (L.) Link	European beachgrass	(2) Dune-Common
Ammophila breviligulata Fernald	American beachgrass	(2) Dune-uncommon
Anaphalis margaritacea (L.) B. & H.	Pearly everlasting	(3,6) Widespread
Angelica hendersonii Coult. & Rose	Henderson's angelica	(3,6) Common
Anthoxanthum odoratum L.	Sweet vernalgrass	(6) Widespread
Arbutus menziesii Pursh.	Pacific madrona	(16) Common
Arctostaphylos columbiana Piper	Bristly manzanita	(16) Common
Arctostaphylos uva-ursi (L.) Spreng	Kinnikinnick	(13) Common
Armeria maritima (Mill.) Willd.	Thrift	(6) Common
Artemisia pycnocephala (Less.) DC.	Beach sagewort	(5) Dune-common south of 43°N
Aster chilensis Nees.	Common California aster	(6,7) Common
Aster subspicatus Nees.	Douglas aster	(6,7) Common
Baccharis pilularis DC.	Chaparral broom	(12) Common south of 43° N
Blechnum spicant (L.) Roth	Deer-fern	(19,21) Occasional
Boschniakia hookeri Walpers.	Small ground-cone	(15) Saprophyte-uncommon
Botrychium multifidum (Gmel.) Trevis.	Leathery grape-fern	(8) Uncommon
Cakile edentula (Bigel.) Hook.	American searocket	(1) Dune and beach
Cakile maritima Scop.	European searocket	(1) Dune and beach
Cardamine oligosperma Nutt.	Little western bittercress	(6) Widespread
Cardionema ramosissima (Weinm.) Nels. & Macbr.	Sandmat	(4) Common
Carex lenticularis var. limnophila (Holm) Cronq. (Carex hindsii Clarke)	Hind's sedge	(7) *
Carex livida (Wahl.) Willd.	Pale sedge	(7) *
Carex macrocephala Willd.	Large-headed sedge	(3) Dune-common north of 43°N
Carex obnupta Bailey	Slough sedge	(8,18) Widespread
Carex pansa Bailey	Sand-dune sedge	(7,9) Common
Carex oederi Retz. (Carex viridula Michx.)	Green sedge	(7) *
Castilleja litoralis Pennell	Pacific paintbrush	(6) Common
Centaurium umbellatum Gilib.	Centaury	(6) Common
Cerastium arvense L.	Field chickweed	(6) Widespread

Standard name	English name	Plant community and occurrence
Cerastium viscosum L.	Sticky chickweed	(6) Widespread
Convolvulus soldanella L. (*Calystegia soldanella* (L.) R. Brown)	Beach morning glory	(1,3) Dune-common
Cotula coronopifolia L.	Brass buttons	(9) Salt marsh
Cytisus scoparius (L.) Link	Scot's broom	Ruderal
Darlingtonia californica Torr.	California pitcher-plant	(19) Insectivorous-uncommon
Daucus pusillus Michx.	Rattlesnake weed	(6) *
Distichlis spicata (L.) Greene	Seashore saltgrass	(9) Salt marsh
Drosera rotundifolia L.	Round-leaved sundew	(7) Insectivorous-uncommon
Eleocharis palustris (L.) R. & S. (*Heleocharis palustris* (L.) R.& S.)	Creeping spike-rush	(9) *
Elymus mollis Trin.	American dunegrass	(1) Dune-common
Epilobium watsonii Barbey	Watson's willowherb	(6) Common
Epipactis gigantea Dougl.	Giant helleborine	(14) Uncommon
Erechtites arguta DC.	Cut-leaved coast fireweed	(2) Occasional
Erechtites minima (Poir.) DC. (*Erechtites prenanthoides* misapplied)	Toothed coast fireweed	(2) Occasional
Erigeron glaucus Kerr.	Seaside daisy	(3) Common south of 43°N.
Eriogonum latifolium Sm.	Coast eriogonum	(3) Common south of 43°N.
Erysimum menziesii (Hook.) Wettst.	Menzies' wallflower	(5) Dune-endemic to northern California
Festuca arundinacea Schreb.	Tall fescue	(6) Widespread
Festuca myuros L.	Rat-tail fescue	(6) Widespread
Festuca rubra L.	Red fescue	(4,6) Widespread
Fragaria chiloensis (L.) Duchesne	Coast strawberry	(1,3,5) Common
Garrya elliptica Dougl.	Wavy-leaf silk-tassel	(15,17) Occasional
Gaultheria shallon Pursh	Salal	(11,15,17) Widespread
Gentiana sceptrum Griseb.	Staff gentian	(6) Occasional
Glehnia leiocarpa Mathias (*Glehnia littoralis* F. Schm.)	American glehnia	(1,3) Dune-maritime endemic, common
Gnaphalium chilense Spreng	Cotton-batting plant	(6) Common
Gnaphalium purpureum L.	Purple cudweed	(6) Common
Habenaria greenei Jeps. (*Habenaria elegans* var. *maritima* (Greene) Ames) (Genus *Piperia* of some authors)	Greene's bog-orchid	(7) Occasional

Standard name	English name	Plant community and occurrence
Holcus lanatus L.	Velvet-grass	(6) Widespread
Hypericum anagalloides C. & S.	Bog St. John's-wort	(8) Common
Hypericum perforatum L.	Common St. John's-wort	Ruderal
Hypochaeris radicata L.	Hairy cats-ear	(4,6) Widespread
Juncus bufonius L.	Toad rush	(7) Occasional
Juncus falcatus E. Meyer	Sickle-leaved rush	(7) Common
Juncus lesueurii Boland.	Salt rush	(4,5,7) Common
Juncus nevadensis Wats.	Sierra rush	(7) Common
Lathyrus japonicus Willd.	Maritime pea	(2) Common
Lathyrus littoralis (Nutt.) Endl.	Beach pea	(1,3) Dune-maritime endemic, common
Ledum glandulosum Nutt.	Mountain Labrador-tea	(19) Uncommon
Ledum groenlandicum Oeder	Bog Labrador-tea	(14) Uncommon
Leontodon nudicaulis (L.) Merat (Leontodon leysseri (Wallr.) G. Beck)	Hairy hawkbit	(4,16) *
Lilaeopsis occidentalis C.&.R.	Western lilaeopsis	(8) Occasional
Lolium perenne L.	Perennial ryegrass	(6) Widespread
Lonicera involucrata (Rich.) Banks	Black twin-berry	(14) Occasional
Lotus corniculatus L.	Birdsfoot-trefoil	(6) Occasional
Lotus formosissimus Greene	Seaside lotus	(6) Occasional
Lupinus arboreus Sims	Tree lupine	(2,12) Common south of 43°N
Lupinus littoralis Dougl.	Seashore lupine	(3,4,6) Dune-common
Lupinus variicolor Steud.	(None)	(3) Occasional south of 43°N
Lycopodium inundatum L.	Bog clubmoss	(8) Uncommon
Lycopus uniflorus Michx.	Northern bugleweed	(8) Occasional
Madia sativa Mol.	Coast tarweed	(12) *
Maianthemum dilatatum (Wood) Nels. & Macbr.	False lily-of-the valley	(17 Common
Mentha arvensis L.	Field mint	(6) *
Mesembryanthemum chilense Mol. (Genus Carpobrotus of some authors)	Sea-fig	(1) Dune-common in Locality 33
Mesembryanthemum edule L. (Genus Carpobrotus of some authors)	Hottentot-fig	(1) Dune-common in Locality 33
Mimulus dentatus Nutt.	Tooth-leaved monkey-flower	(7) Common

Standard name	English name	Plant community and occurrence
Mimulus guttatus DC.	Yellow monkey-flower	(7) Widespread
Montia perfoliata (Donn) Howell	Miner's lettuce	(11,14) Widespread
Montia spathulata (Dougl.) Howell	Common montia	(4) Common
Myrica californica Cham.	Pacific wax-myrtle	(14) Common
Myrica gale L.	Sweet gale	(14) Uncommon
Oenothera cheiranthifolia Hornem. (Camissonia cheiranthifolia (Hornem. ex. Spregn.) Raim.)	Beach evening primrose	(5) Dune-maritime endemic, common south of 43°N
Orthocarpus castillejoides Benth.	Paintbrush owl-clover	(3,5) Occasional
Orthocarpus purpurascens Benth.	Common owl-clover	(3) Occasional
Orthocarpus pusillus Benth.	Dwarf owl-clover	(6) Widespread
Parentucellia viscosa (L.) Car.	Yellow parentucellia	(6) Widespread
Phacelia argentea Nels. & Macbr.	Silvery phacelia	(1,3) Dune-uncommon to rare, south of 43°N
Phacelia bolanderi Gray	Bolander's phacelia	(1,3) Dune, occasional
Picea sitchensis (Bong.) Carr.	Sitka spruce	(17,21) Widespread
Pinus contorta Dougl.	Lodgepole pine	(15,16,17,18) Widespread
Plantago hookeriana F. & M.	Hooker's plantain	(5) Occasional
Plantago lanceolata L.	English plantain	Ruderal
Plantago maritima L.	Seaside plantain	(9) Occasional
Poa confinis Vasey	Coastline bluegrass	(3) Common
Poa macrantha Vasey (Poa douglasii Nees)	Seashore bluegrass	(3,4,5) Dune-maritime endemic, common
Polygonum hydropiperoides Michx.	Water pepper	(10) Occasional
Polygonum paronychia C. & S.	Black knotweed	(3,4,5) Dune-maritime endemic, common
Polypodium glycyrrhiza D.C. Eat.	Licorice-fern	(4,6) Occasional
Polypodium scouleri Hook. & Grev.	Scoulers polypody	(17) Uncommon
Polypogon monspeliensis (L.) Desf.	Annual Beard-grass	(7) Occasional
Potentilla pacifica Howell (Potentilla egedii var. grandis (Rydb.) J.T. Howell	Pacific silverweed	(8) Common
Potentilla palustris (L.) Scop.	Marsh cinquefoil	(8) Common
Prunella vulgaris L.	Self-heal	(6) Widespread
Pseudotsuga menziesii (Mirbel) Franco	Douglas fir	(20) Widespread

Standard name	English name	Plant community and occurrence
Pteridium aquilinum (L.) Kuhn	Bracken	(3,11) Widespread
Ranunculus flammula L.	Creeping buttercup	(7) Common
Rhododendron macrophyllum G. Don	Western rhododendron	(15,20) Widespread
Rubus ursinus C. & S.	Pacific blackberry	(3,12) Occasional
Rumex acetosella L.	Red sorrel	Ruderal
Rumex crispus L.	Curly dock	(9) Occasional
Rumex maritimus	Seaside dock	(1) Beach-occasional
Sagina crassicaulis Wats.	Stick-stemmed pearlwort	(7) *
Sagina procumbens L.	Procumbent pearlwort	(7) *
Salix hookeriana Barratt	Hooker willow	(14,17) Widespread
Salix piperi Bebb	Piper's willow	(14) *
Sanicula arctopoides H. & A.	Snake-root	(3) Dune-occasional
Sanicula crassicaulis Poepp.	Pacific sanicle	(15) Occasional
Satureja douglasii (Benth.) Brig.	Yerba buena	(15) Widespread
Scirpus americanus Pers.	Three-square bulrush	(10) Widespread
Scirpus validus Vahl.	Tule	(10) Widespread
Scrophularia californica Cham. & Schlecht.	California figwort	(12) Widespread
Senecio jacobaea L.	Tansy ragwort	Ruderal
Senecio vulgaris L.	Common groundsel	Ruderal
Sisyrinchium angustifolium Mill. (Sisyrnchium bellum Wats.)	Blue-eyed grass	(7) Occasional
Sisyrinchium californicum (Ker.-Gawl) Dryand.	Golden-eyed grass	(7) Common
Solidago spathulata DC.	Dune goldenrod	(4,5) Dune-common
Spiranthes romanzoffiana Cham.	Hooded ladies' tresses	(7) Occasional
Spiraea douglasii Hook.	Douglas's spirea	(10) Widespread
Stellaria media (L.) Cyrill.	Chickweed	(6) Widespread
Tanacetum douglasii DC. (Tanacetum camphoratum, misapplied)	Dune tansy	(1,3) Dune-maritime endemic, common
Thuja plicata Donn.	Western red cedar	(19) Widespread
Trifolium wormskjoldii Lehm.	Springbank clover	(7) Common
Tsuga heterophylla (Raf.) Sarg.	Western hemlock	(21) Widespread
Typha latifolia L.	Common cat-tail	(10) Widespread

Standard name	English name	Plant community and occurrence
Ulex europaeus L.	Gorse	Ruderal
Vaccinium ovatum Pursh	Evergreen huckleberry	(11,15,20) Widespread
Veronica scutellata L.	Marsh speedwell	(8) Common

Terms used in the third column:

Dune - Occurs primarily or exclusively on sand dunes.

Maritime endemic - Occurs only on the beaches and dunes of the Pacific coast of North America.

Salt marsh - Occurs primarily in salt marsh habitats.

Ruderal - Weedy and commonly introduced plant growing on disturbed areas; not characteristic of any particular community.

Widespread - Occurs widely on dune and non-dune habitats; ubiquitous; obvious in the landscape.

Common - Refers to occurrence in appropriate dune habitats. These species are also found in similar non-dune habitats, but are not highly visible components of the landscape.

Occasional - Refers to occurrence in appropriate dune habitats. Occur sporadically, not always present in the habitat.

Uncommon - Not often encountered on the dunes.
* - Information on occurrence lacking.

APPENDIX IV

LIST OF VERTEBRATE ANIMALS OF THE DUNES

A. Birds. Sources of information: Pinto et al. 1972; University of Washington 1974; Checklist of the birds of the Lanphere-Christensen Dunes Preserve, Arcata, California, December, 1982; S.G. Herman and A.M. Wiedemann, The Evergreen State College, Olympia, Washington, unpublished field notes. Only species actually observed on the dunes are included in this list. Standard and English names and the order of listing follows that shown in the Thirty-fourth supplement of the American Ornithologist's Union check-list of North American Birds (Supplement to the Auk, Volume 99, No. 3, July, 1982). See the end of the table for explanation of the abbreviations.

English name (Standard name)	Habitats BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
Red-throated Loon (*Gavia stellata*)			x						u/u	w/w
Arctic Loon (*Gavia arctica*)			x						u/u	w/w
Common Loon (*Gavia Immer*)			x						c/u	w/w
Pied-billed Grebe (*Podilymbus Podiceps*)			x	x	x				c/u	r/r
Horned Grebe (*Podiceps auritus*)			x	x					a/u	w/w
Red-necked Grebe (*Podiceps grisegena*)			x	x					u/u	w/w
Eared Grebe (*Podiceps nigricollis*)			x	x					u/u	w/w
Western Grebe (*Aechmophorus occidentalis*)			x						a/c	w/w

English name (Standard name)	Habitats BE	 OS	 LP	 MA	 RI	 GM	 ST	 FO	REL NUM	SEA STA
Double-crested Cormorant (*Phalacrocorax auritus*)			x						a/c	r/r
Pelagic Cormorant (*Phalacrocorax pelagicus*)			x						c/c	r/r
American Bittern (*Botaurus lentiginosus*)				x		x			u/u	r/r
Great Blue Heron (*Ardea herodias*)			x	x	x		x		c/c	r/r
Great Egret (*Casmerodius albus*)			x	x	x				u/c	w/r
Snowy Egret (*Egretta thula*)			x	x					/r	/r
Cattle Egret (*Bubulcus ibis*)			x	x					r/u	r/r
Green-backed Heron (*Butorides striatus*)			x	x	x				r/r	r/r
Black-crowned Night-Heron (*Nycticorax nycticorax*)			x	x					u/u	r/r
Tundra Swan (*Cygnus columbianus*)			x	x		x	x		c/u	w/w
Canada Goose (*Branta canadensis*)						x			c/c	m/w
Wood Duck (*Aix sponsa*)			x	x	x				u/u	r/r
Green-winged Teal (*Anas crecca*)			x	x					c/u	w/w
Mallard (*Anas platyrhyncos*)			x	x	x	x	x		c/c	r/r
Northern Pintail (*Anas acuta*)			x	x		x			a/c	w/w

English name (Standard name)	Habitats BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
Blue-winged Teal (*Anas discors*)			x	x					u/u	m/r
Cinnamon Teal (*Anas cyanoptera*)			x	x		x			u/c	s/s
Northern Shoveler (*Anas clypeata*)			x	x					u/c	w/w
Gadwall (*Anas strepera*)			x			x			u/u	w/w
American Wigeon (*Anas americana*)			x	x		x			a/u	w/w
Canvasback (*Aythya valisineria*)			x			x			u/u	w/w
Redhead (*Aythya americana*)			x						u/u	w/w
Ring-necked Duck (*Aythya collaris*)			x	x					u/u	w/w
Greater Scaup (*Aythya marila*)			x	x					c/u	w/w
Lesser Scaup (*Aythya affinis*)			x	x					u/u	w/w
Common Goldeneye (*Bucephala clangula*)			x	x					u/u	w/w
Bufflehead (*Bucephala albeola*)			x	x					c/u	w/w
Hooded Merganser (*Lophodytes cucullatus*)			x						u/r	r/w
Red-breasted Merganser (*Mergus serrator*)			x						u/u	w/w
Ruddy Duck (*Oxyura jamaicensis*)			x	x					u/u	w/w

English name (Standard name)	Habitats								REL NUM	SEA STA
	BE	OS	LP	MA	RI	GM	ST	FO		
Turkey Vulture (*Cathartes aura*)					x	x		x	c/c	s/s
Osprey (*Pandion haliaetus*)		x	x	x				x	u/c	s/s
Black-shouldered Kite (*Elanus caeruleus*)				x		x		x	r/u	r/r
Bald Eagle (*Haliaeetus leucocephalus*)					x	x		x	r/r	r/w
Northern Harrier (*Circus cyaneus*)		x		x		x	x		u/c	r/r
Sharp-shinned Hawk (*Accipiter striatus*)							x	x	u/u	r/r
Cooper's Hawk (*Accipiter cooperii*)					x		x	x	u/u	r/r
Red-tailed Hawk (*Buteo jamaicensis*)							x	x	u/c	r/r
Rough-legged Hawk (*Buteo lagopus*)						x			u/u	w/w
American Kestrel (*Falco sparverius*)				x		x	x		u/c	r/r
Merlin (*Falco columbarius*)			x		x			x	u/r	w/w
Peregrine Falcon (*Falco peregrinus*)			x		x			x	r/r	w/w
Ring-necked Pheasant (*Phasianus colchicus*)						x	x		u/r	r/w
California Quail (*Callipepla californica*)						x	x		u/c	r/r
Virginia Rail (*Rallus limicola*)				x				x	r/u	r/r

English name (Standard name)	Habitats BE	 OS	 LP	 MA	 RI	 GM	 ST	 FO	REL NUM	SEA STA
American Coot (*Fulica americana*)			x	x		x			a/u	r/w
Black-bellied Plover (*Pluvialis squatarola*)	x		x		x				c/c	w/w
Snowy Plover (*Charadrius alexandrinus*)	x	x							u/r	r/m
Semipalmated Plover (*Charadrius semipalmatus*)	x								u/u	m/m
Killdeer (*Charadrius vociferus*)				x		x			c/c	r/w
Greater Yellowlegs (*Tringa melanoleuca*)			x			x			u/c	w/w
Lesser Yellowlegs (*Tringa flavipes*)			x			x			u/c	m/m
Willet (*Catoptrophorus semipalmatus*)			x			x			u/c	m/w
Spotted Sandpiper (*Actitis macularia*)				x		x			u/u	s/s
Whimbrel (*Numenius phaeopus*)	x		x	x		x			u/c	m/m
Long-billed Curlew (*Numenius americanus*)	x		x	x		x			u/u	m/w
Marbled Godwit (*Limosa fedoa*)			x			x			u/c	m/r
Sanderling (*Calidris alba*)	x		x							
Western Sandpiper (*Calidris mauri*)			x			x			a/a	m/w
Least Sandpiper (*Calidris minutilla*)			x			x			a/c	w/w

English name (Standard name)	BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
	Habitats									
Baird's Sandpiper (*Calidris bairdii*)			x			x			r/r	m/m
Pectoral Sandpiper (*Calidris melanotos*)				x		x			r/r	m/m
Dunlin (*Calidris alpine*)			x						c/a	w/w
Short-billed Dowitcher (*Limnodromus griseus*)			x						c/u	m/m
Long-billed Dowitcher (*Limnodromus scolopaceus*)			x						u/u	m/m
Common Snipe (*Gallinago gallinago*)				x		x			c/c	w/w
Red-necked Phalarope (*Phalaropus lobatus*)			x			x			a/u	m/m
Red Phalarope (*Phalaropus fulicaria*)			x			x			u/u	m/m
Bonaparte's Gull (*Larus philadelphia*)	x		x						a/u	m/m
Heermann's Gull (*Larus heermanni*)	x		x						c/c	s/s
Mew Gull (*Larus canus*)	x		x						a/u	w/w
Ring-billed Gull (*Larus delawarensis*)	x		x						c/c	r/w
California Gull (*Larus californicus*)	x		x						a/c	w/w
Western Gull (*Larus occidentalis*)	x		x						a/c	r/r
Glaucous-winged Gull (*Larus glaucescens*)	x		x		x				a/c	r/w

English name (Standard name)	Habitats BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
Black-legged Kittiwake (*Rissa tridactyla*)	x		x						u/u	w/w
Caspian Tern (*Sterna caspia*)	x		x						r/c	s/s
Band-tailed Pigeon (*Columba fasciata*)								x	c/u	s/m
Mourning Dove (*Zenaida macroura*)						x		x	u/c	s/s
Common Barn-Owl (*Tyto alba*)						x		x	u/c	r/r
Western Screech-Owl (*Otus kennicottii*)								x	u/u	r/r
Great Horned Owl (*Bubo virginianus*)					x		x	x	u/c	r/r
Snowy Owl (*Nyctea scandiaca*)		x				x			r/	w/
Northern Pygmy-Owl (*Glaucidium gnoma*)								x	r/r	/r
Short-eared Owl (*Asio flammeus*)		x		x		x			u/u	w/w
Common Nighthawk (*Chordeiles minor*)						x	x	x	u/u	s/s
Vaux's Swift (*Chaetura vauxi*)								x	u/u	s/s
Anna's Hummingbird (*Calypte anna*)						x		x	/c	/r
Rufous Hummingbird (*Selasphorus rufus*)						x	x	x	a/c	s/s
Allen's Hummingbird (*Selasphorus sasin*)								x	r/c	s/s

English name (Standard name)	Habitats BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
Belted Kingfisher (*Ceryle alcyon*)			x	x	x	x			u/c	r/r
Red-breasted Sapsucker (*Sphyrapicus ruber*)								x	u/u	r/r
Downy Woodpecker (*Picoides pubescens*)					x			x	u/c	r/r
Hairy Woodpecker (*Picoides villosus*)								x	u/u	r/r
Northern Flicker (*Colaptes auratus*)					x	x	x	x	c/c	r/r
Pileated Woodpecker (*Dryocopus pileatus*)								x	u/u	r/r
Olive-sided Flycatcher (*Contopus borealis*)								x	a/c	s/s
Western Wood-Pewee (*Contopus sordidulus*)								x	u/u	s/s
Willow Flycatcher (*Empidonax traillii*)					x	x		x	u/u	s/s
Western Flycatcher (*Empidonax difficilis*)					x			x	c/c	s/s
Black Phoebe (*Sayornis nigricans*)					x	x			/c	/r
Tree Swallow (*Tachycineta bicolor*)		x			x	x		x	a/c	s/s
Violet-green Swallow (*Tachycineta thalassina*)		x			x	x		x	u/c	s/s
Northern Rough-winged Swallow (*Stelgidopteryx serripennis*)		x			x	x		x	u/u	s/s
Bank Swallow (*Riparia riparia*)		x			x				r/r	s/s

English name (Standard name)	Habitats								REL NUM	SEA STA
	BE	OS	LP	MA	RI	GM	ST	FO		
Cliff Swallow (*Hirundo pyrrhonota*)		x			x			x	a/c	s/s
Barn Swallow (*Hirundo rustica*)		x			x	x		x	a/a	s/s
Steller's Jay (*Cyanocitta stelleri*)								x	c/c	r/r
American Crow (*Corvus brachyrhynchos*)	x				x	x	x	x	a/c	r/r
Common Raven (*Corvus corax*)	x				x	x		x	u/c	r/r
Black-capped Chickadee (*Parus atricapillus*)					x		x	x	u/	r/
Chestnut-backed Chickadee (*Parus rufescens*)					x		x	x	a/a	r/r
Bushtit (*Psaltriparus minimus*)					x		x	x	a/u	r/r
Red-breasted Nuthatch (*Sitta candensis*)					x			x	u/u	s/s
Brown Creeper (*Certhia americana*)					x			x	u/u	r/r
Bewick's Wren (*Thryomanes bewickii*)					x		x	x	c/c	r/r
Winter Wren (*Troglodytes troglodytes*)								x	c/c	r/r
Marsh Wren (*Cistothorus palustris*)				x	x				c/c	r/r
Golden-crowned Kinglet (*Regulus satrapa*)					x			x	c/c	r/r
Ruby-crowned Kinglet (*Regulus calendula*)					x		x	x	c/a	r/w

English name (Standard name)	Habitats								REL NUM	SEA STA
	BE	OS	LP	MA	RI	GM	ST	FO		
Townsend's Solitaire (*Myadestes townsendi*)					x		x	x	u/u	m/m
Swainson's Thrush (*Catharus ustulatus*)					x			x	a/c	s/s
Hermit Thrush (*Catharus guttatus*)					x			x	a/a	r/r
American Robin (*Turdus migratorius*)						x	x	x	a/a	r/r
Varied Thrush (*Ixoreus naevius*)					x		x	x	a/c	w/r
Wrentit (*Chamaea fasciata*)							x	x	c/c	r/r
Water Pipit (*Anthus spinoletta*)		x				x			c/c	w/w
Cedar Waxwing (*Bombycilla cedrorum*)						x		x	c/c	r/m
Northern Shrike (*Lanius excubitor*)		x					x		u/u	w/w
European Starling (*Sturnus vulgaris*)		x				x		x	a/a	r/r
Hutton's Vireo (*Vireo huttoni*)								x	u/c	r/r
Warbling Vireo (*Vireo gilvus*)							x	x	u/u	s/m
Orange-crowned Warbler (*Vermivora celata*)					x		x	x	a/c	s/s
Yellow Warbler (*Dendroica petechia*)					x			x	u/	s/
Yellow-rumped Warbler (*Dendroica coronata*)						x	x	x	c/a	r/w

English name (Standard name)	Habitats BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
Hermit Warbler (*Dendroica occidentalis*)								x	u/u	s/r
MacGillivray's Warbler (*Oporornis tolmiei*)								x	u/u	s/s
Common Yellowthroat (*Geothlypis trichas*)				x	x				u/u	s/s
Wilson's Warbler (*Wilsonia pusilla*)					x		x	x	c/c	s/s
Yellow-breasted Chat (*Icteria virens*)							x		r/u	s/s
Black-headed Grosbeak (*Pheucticus melanocephalus*)					x			x	u/u	s/s
Rufous-sided Towhee (*Pipilo erythrophthalmus*)					x		x	x	c/c	r/w
Savannah Sparrow (*Passerculus sandwichensis*)						x	x		a/c	r/r
Fox Sparrow (*Passerella iliaca*)					x	x		x	u/c	r/r
Song Sparrow (*Melospiza melodia*)						x	x	x	c/c	r/r
Golden-crowned Sparrow (*Zonotrichia atricapilla*)						x	x	x	u/c	w/w
White-crowned Sparrow (*Zonotrichia leucophrys*)						x	x	x	a/c	r/r
Dark-eyed Junco (*Junco hyemalis*)						x	x	x	a/c	r/r
Red-winged Blackbird (*Agelaius phoeniceus*)				x		x	x		c/c	r/r
Western Meadowlark (*Sturnella neglecta*)						x	x		c/c	r/w

English name (Standard name)	BE	OS	LP	MA	RI	GM	ST	FO	REL NUM	SEA STA
	Habitats									
Brewer's Blackbird (*Euphagus cyanocephalus*)		x		x	x	x	x	x	c/c	r/r
Brown-headed Cowbird (*Molothrus ater*)					x	x	x	x	c/c	s/r
Northern Oriole (*Icterus galbula*)					x		x		/u	/s
Purple Finch (*Carpodacus purpureus*)					x			x	a/c	r/r
House Finch (*Carpodacus mexicanus*)					x	x		x	u/c	r/r
Red Crossbill (*Loxia curvirostra*)								x	c/c	r/r
Pine Siskin (*Carduelis pinus*)						x		x	c/c	r/r
Lesser Goldfinch (*Carduelis psaltria*)						x		x	u/c	s/s
American Goldfinch (*Carduelis tristis*)						x	x	x	a/c	r/s

B. Amphibians, Reptiles, and Mammals. Sources of information: Pinto *et al.* 1972; S.G. Herman and A.M. Wiedemann, The Evergreen State College, Olympia, Washington, unpublished field notes. Only species observed on the dunes are included in this list. See the end of the table for explanation of the abbreviations.

English name (Standard name)	BE	OS	LP	MA	RI	GM	ST	FO	REL NUM
	Habitats								
Amphibians									
Northwestern Salamander (*Ambystoma gracile*)					x			x	

English name (Standard name)	Habitats								REL NUM
	BE	OS	LP	MA	RI	GM	ST	FO	
Pacific Giant Salamander (*Dicamptodon ensatus*)								x	
Rouch-skinned Newt (*Taricha granulosa*)			x	x	x			x	a
Dunn's Salamander (*Plethodon dunni*)					x			x	
Western Red-backed Salamander (*Plethodon vehiculum*)					x			x	c
Oregon Salamander (*Ensatina eschscholtzi oregonensis*)					x			x	c
Western Toad (*Bufo boreas*)						x	x		
Pacific Treefrog (*Hyla regilla*)			x	x		x	x	x	a
Red-legged Frog (*Rana aurora*)			x	x	x	x	x	x	
Bullfrog (*Rana catesbeiana*)			x	x	x				c
Reptiles									
Northern Alligator Lizard (*Gerrhonotus coeruleus*)						x		x	c
Common Garter Snake (*Thamnophis sirtalis*)				x	x	x	x	x	c
Northwestern Garter Snake (*Thamnophis ordinoides*)								x	c
Mammals									
Trowbridge Shrew (*Sorex trowbridgei*)					x				c
Vagrant Shrew (*Sorex vagrans*)					x	x	x		c

English name (Standard name)	Habitats								REL NUM
	BE	OS	LP	MA	RI	GM	ST	FO	
Pacific Shrew (*Sorex pacificus*)					x				c
Shrew-mole (*Neurotrichus gibbsi*)								x	c
Pacific Mole (*Scapanus orarius*)						x	x	x	a
Yuma Myotis (*Myotis yumanensis*)								x	u
California Myotis (*Myotis californicus*)								x	c
Hoary Bat (*Lasiurus cinereus*)								x	
Black Bear (*Ursus americanus*)					x			x	
Racoon (*Procyon lotor*)	x			x	x	x	x	x	c
Longtail Weasel (*Mustela frenata*)					x				
Mink (*Mustela vison*)				x	x	x	x	x	c
River Otter (*Lutra canadensis*)			x		x				c
Spotted Skunk (*Spilogale putorius*)								x	c
Striped Skunk (*Mephitis mephitis*)				x	x	x	x		c
Coyote (*Canis latrans*)								x	u
Gray Fox (*Urocyon cinereoargenteus*)								x	

English name (Standard name)	Habitats								REL NUM
	BE	OS	LP	MA	RI	GM	ST	FO	
Beechey Ground Squirrel (*Citellus beecheyi*)	x					x	x		c
Townsend Chipmunk (*Eutamias townsendi*)								x	a
Chickaree (*Tamiasciurus douglasii*)								x	a
Northern Flying Squirrel (*Glaucomys sabrinus*)								x	u
Beaver (*Castor canadensis*)			x	x	x		x	x	c
Deer Mouse (*Peromyscus maniculatus*)	x			x		x	x	x	a
Bushytail Woodrat (*Neotoma cinerea*)								x	c
California Redback Vole (*Clethrionomys occidentalis*)								x	c
Townsend Vole (*Microtus townsendi*)				x	x	x	x		a
Oregon Vole (*Microtus oregoni*)					x	x		x	
Muskrat (*Ondatra zibethica*)			x	x	x				c
Pacific Jumping Mouse (*Zapus trinotatus*)					x				c
Brush Rabbit (*Sylvilagus bachmani*)						x	x	x	a
Mule Deer (*Odocoileus hemionus*)	x			x		x	x	x	a

Habitats

BE - Beach	MA - Marsh	ST - Shrub thicket
OS - Open sand	RI - Riparian	FO - Forest
LP - Lakes and ponds	GM - Meadow	

REL NUM - Relative Numbers

a - abundant
c - common
u - uncommon
r - rare

SEA STA - Seasonal Status

r - resident
s - summer visitor
w - winter visitor
m - migrant

The left side of the slash refers to Washington and north and central Oregon; the right side to southern Oregon and northern California. The absence of a letter indicates the species has not been observed in that part of the region or that data is not available.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Sand dunes occur in 33 localities along the 950 km of North American Pacific coast between the Straits of Juan de Fuca (49°N) and Cape Mendocino (40°). The dune landscape is a mosaic of dune forms: transverse ridge, oblique dune, retention ridge, foredune, parabola dune, sand hummock, blowout, sand plain, deflation plain, dune ridge, swale, remnant forest, and ponds and lakes. These forms are the basic morphological units making up the four dune systems: parallel ridge, parabola dune, transverse ridge, and bay dune. Vegetation is well-developed on stabilized dunes. Of the 21 plant communities identified, nine are herbaceous, five are shrub, and seven are forest. A wide variety of vertebrate animals occur in seven distinct habitats: open dunes, grassland and meadow, shrub thicket, forest, marsh, riparian, and lakes and ponds. Urban development, increased rate of stabilization due to the introduction of European beachgrass (Ammophila arenaria (L.) Link), and massive disturbance resulting from heavy off-road vehicle traffic are the greatest threats to the long-term survival and stability of a number of sand dune habitats. Two animals and three plants dependent on dune habitats are listed as rare, threatened, or endangered.

17. Document Analysis a. Descriptors
Dunes, Sand, Wildlife, Management, Vegetation

b. Identifiers/Open-Ended Terms
Aeolian Processes, Deflation Plains, Sand Plains, Pacific Northwest, Oregon, Washington

c. COSATI Field/Group

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