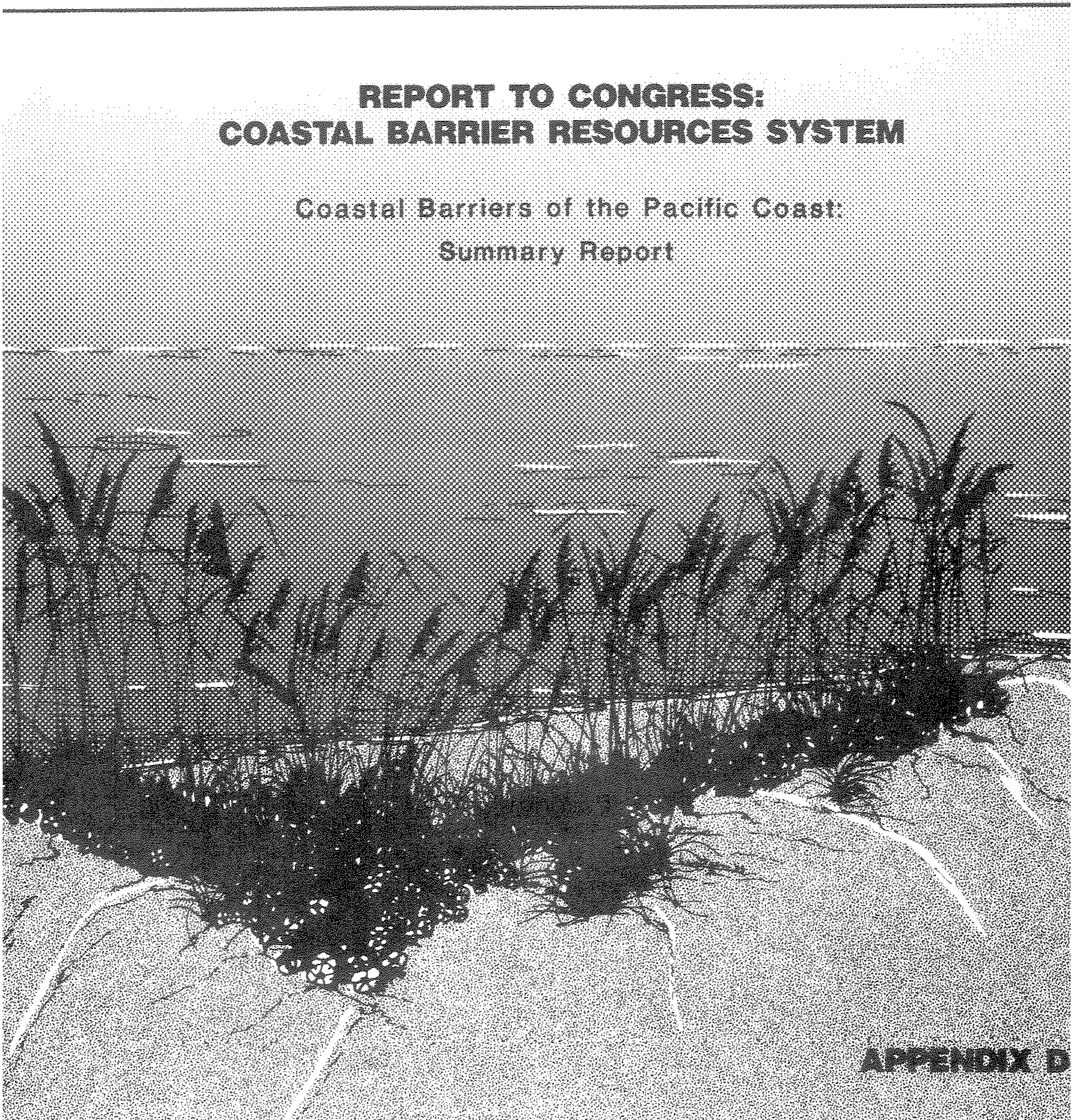
REPORT TO CONGRESS: COASTAL BARRIER RESOURCES SYSTEM

Coastal Barriers of the Pacific Coast: Summary Report



APPENDIX D

U.S. Department of the Interior

REPORT TO CONGRESS:
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COASTAL BARRIERS OF THE PACIFIC COAST: SUMMARY REPORT

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PREFACE

When the Coastal Barrier Resources Act was passed in 1982, Congress did not address the possibility of including barriers along coastlines other than those of the Atlantic Ocean and Gulf of Mexico. In 1983, the Coastal Barriers Study Group was directed by the Secretary of the Interior to identify and delineate the undeveloped coastal barriers on all U.S. coastlines. Other information concerning these barriers was also gathered. This appendix presents information about barriers along the Pacific coast (Washington, Oregon, and California).

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INTRODUCTION

The coastlines of the three contiguous States on the Pacific Ocean are remarkably different from the coastlines of the Atlantic and Gulf States. The pattern of numerous barrier islands fronting extensive bays and tidal marshes on the Atlantic and gulf coasts is replaced on the Pacific coast by small bay-mouth barriers and sand spits that block small permanent streams in the north and small intermittent streams in the south. The Pacific coast, furthermore, is primarily of tectonic origin, with extensive cliffs and rocky headlands that are several hundred feet high in some places and often drop with a sheer vertical surface to the sea or to very narrow beaches or reefs at their base. Other parts of the coast consist of well-developed terraces or benches of interglacial age. These are composed, in part, of soft sandstones or unconsolidated, water-borne sediments that overlie harder formations of older geological age.

The structure and variety of coastal features along the western shore of the three Pacific States is related to the complex geological processes at work along the western edge of the continent. The coast north of Cape Mendocino, California, is the site of convergence of three crustal plates: the Juan de Fuca Plate, the Gorda Plate, and the North American Plate (Figure 1). The Juan de Fuca and Gorda Plates are colliding with and being subducted underneath the advancing North American Plate. The uplift on the mainland is responsible for the Olympic Mountains of northern Washington, the Coastal Range of southern Washington and Oregon, and the Klamath Mountains of Northern California. The volcanic activity that formed the Cascade Range is also the result of the subduction zone under the North American Plate. South of Cape Mendocino, the Pacific Plate abuts the North American Plate and the shear zone between the two is the San Andreas Fault. Along the region west of Cape Mendocino, north of the 40th parallel, another shear zone, the Mendocino shear zone, extends westward. Regular earthquakes occur along these shear zones.

The markedly different morphology of the east and west sides of the North American continent is related to their relative positions on the moving North American Plate. On the eastern Atlantic, the trailing edge of the plate, the coast is characterized by a broad coastal plain and wide Continental Shelf; on the western, collision edge of the plate, the coast is mountainous and has a narrow shelf (Figure 2). Thus, much of the Pacific coast is abrupt and mountainous with only small interspersed reaches of sandy beaches while much of the east coast is low-lying coastal plain sheltered by offshore barriers.

The threat of hurricanes along the Atlantic and gulf coasts was one immediate concern that inspired the Coastal Barrier Resources Act. While hurricanes are less frequent along the Pacific coast, other storms, some of them generated as far away from southern California as the subantarctic region south of New

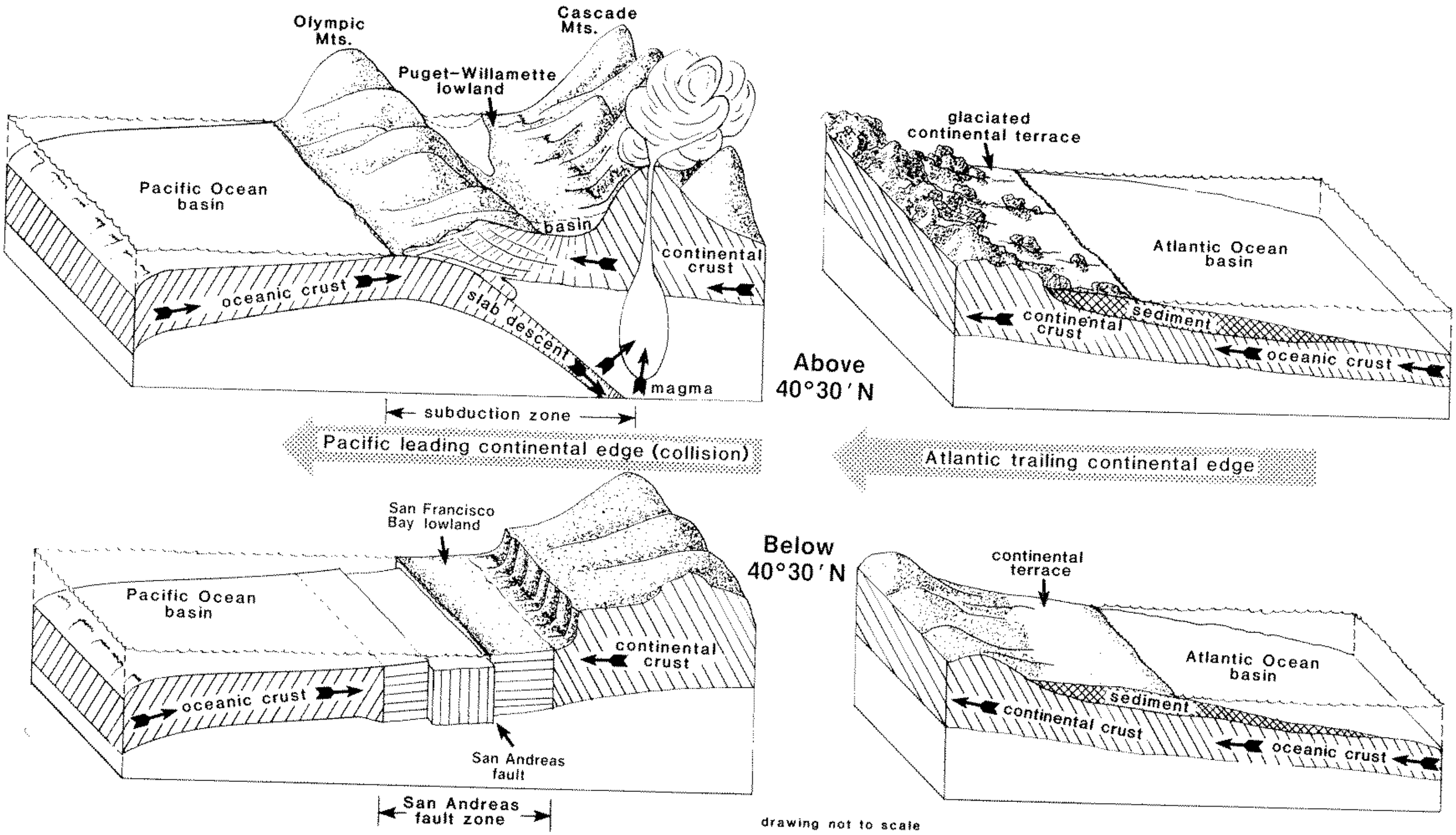

Figure 1. A schematic tectonic profile of North America.

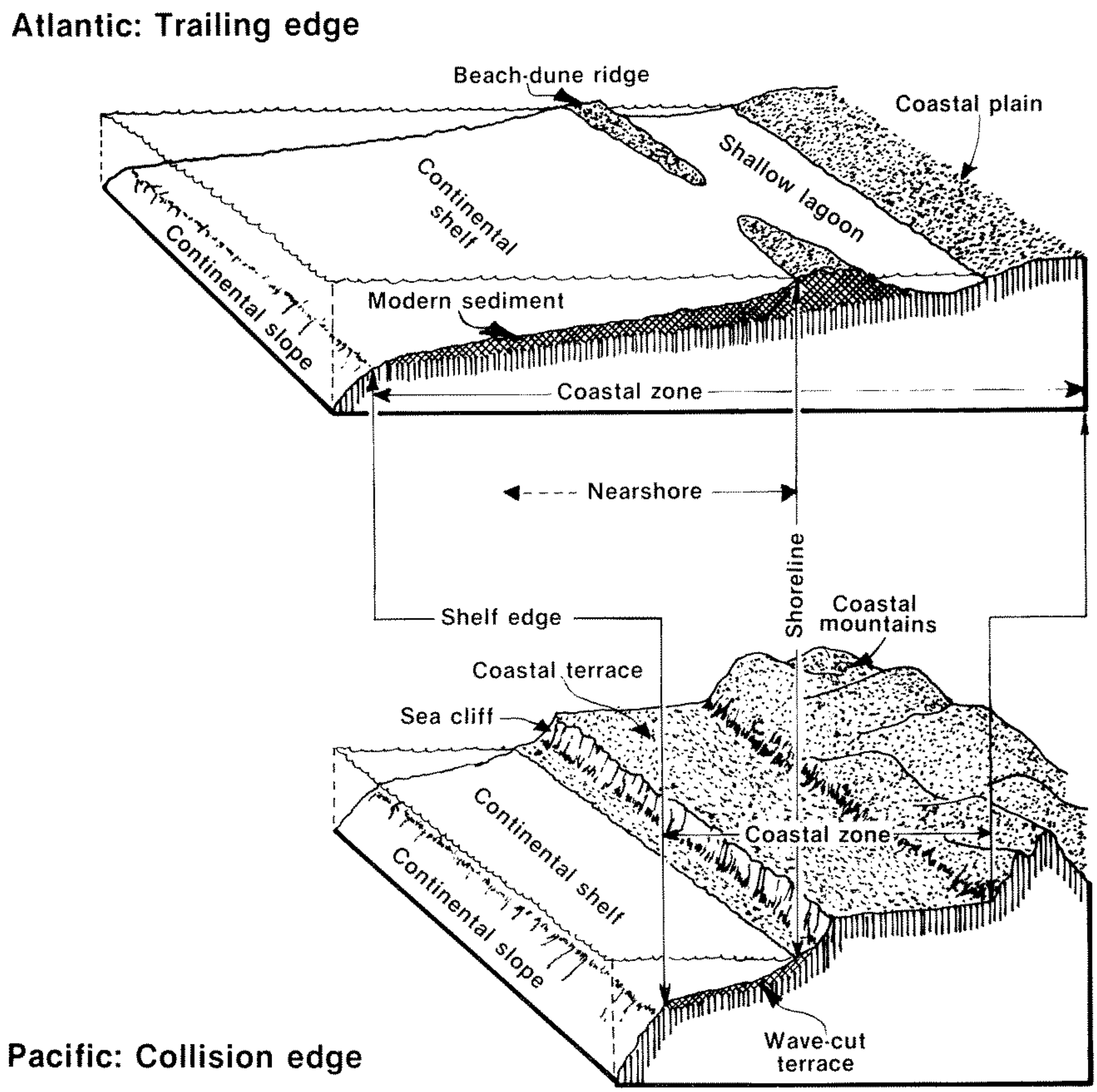

Figure 2. The general morphology of the Atlantic and Pacific coastal zones (Inman and Brush 1973).

Zealand, can be serious, especially when huge waves coincide with high tides. These storms can bite out huge chunks of land and are sometimes accompanied by heavy rainfall that causes landslides. Such storms may also destroy significant sections of coastal highways, demolish buildings, and wash people out to sea (Hedgpeth 1986).

"Coastal barriers" on the Pacific coast are most commonly sand spits built up against or in front of coastal streams, forming bays or lagoons behind them. A lagoon (or laguna) is a coastal embayment without perennial stream inflow. In low rainfall climates, the streams are intermittent and during dry seasons the salinity of the lagoon is equal to or higher than the adjoining sea. "Estero" is the usual name for such coastal lagoons in California; the northernmost use of the term is Drakes Estero at Pt. Reyes, though Humboldt Bay is actually a lagoon or estero. Usually an estero is not an estuary, but it is always a coastal environment, whereas laguna is a term also applied to inland lakes or ponds.

The sands that form the beaches and dunes of the Pacific coast are, for the most part, derived from erosion of cliffs, bluffs, and other formations by wave attack, and from the outflows of rivers (Cooper 1958). The sediment derived from the rivers is roughly proportional to their average discharge. The largest river of the three contiguous Pacific States is the Columbia. Sediment used to be discharged by this river faster than it could be moved along the coast by littoral currents; the resulting dunes are massive. Today, dams, dredging, and other human activities have substantially reduced the Columbia's contribution to the littoral system. The Umpqua and Siuslaw Rivers are also substantial contributors to beach and dune development. On the California coast, the largest river flowing directly into the sea is the Klamath. Beach development at the mouth of the Klamath, however, is restricted to a comparatively small sand spit because of the bordering high hills on either side. In contrast, the Columbia River exits across a region of low hills recessed from the shoreline and supports several barrier beaches.

The barrier beach and dune complex in Washington north of the Columbia, fronting Willapa Bay and Grays Harbor, is extensive. South of the Columbia, from Clatsop to Tillamook Head, the "Clatsop Plains" beach system extends to the upland, which was once a coastal bluff, with a series of narrow lakes parallel to the shore and one small river-mouth embayment. As one proceeds south, the coastal dune fields are more closely associated with bluffs and terraces.

The essential difference between the Atlantic and Pacific coastal dunes is that on the Pacific coast, the extensive dune fields were formed at higher stands of the sea on what are now coastal benchlands or terraces. Most of these dune fields were established at the last sea transgression, known as the Flandrian transgression, which began at the end of the last Ice Age about 17,000 years ago and has continued since then. Some dune fields, most notably the now obliterated El Segundo dunes in California, are the result of earlier transgressions.

The development and maintenance of these dune systems requires an abundant source of sand from an adjoining and accessible beach. The ultimate sources for beach sand are the rivers and the sandstone bluffs and terraces which are eroded by wave action. Storm waves may pile up sand from shallow offshore deposits, and littoral currents move sand from all sources along the beach. Submarine canyons, especially in southern California, act as traps or sumps for moving sand, which is then lost to the beach system. Rocky cliffs and headlands prevent littoral drift, trapping the sand in pocket beaches. It is characteristic of such beaches that sand nourishment is reduced and the system is maintained to a large degree by the back and forth movement of the sand. This situation can occur on a large scale: Oregon's largest beach, fronting the dunes between Heceta Head and Coos Bay, is classified as a pocket beach (Komar 1979). Approximately 40% of the Washington-Oregon coast is bordered by dunes, whereas in California only 23% is dune-bordered (Cooper 1967).

On the Pacific coast, coastal barrier sand spits and tombolos form embayments, several of them without permanent, year-round streams to provide estuarine conditions. A conspicuous and well-developed example of this condition is Morro Bay, where the tombolo that joins Morro Rock to the shore forms the northern boundary of the bay and a long sand spit forms the southwestern boundary of the bay. At the present time, the entrance to Morro Bay is kept open by jetties and channel dredging. In its original condition it was probably closed during dry weather. The embayment behind the Smith River Spit is maintained by a rocky outcrop at the northern side of the channel which turns the river seaward across the spit.

Crescent-shaped sand spits, another type of bay formation, are built up by the counterclockwise currents south of headlands. The best examples of this formation are Bodega Harbor and Bolinas Lagoon in California. The crescent beaches at the northern end of Half Moon and Monterey Bays, CA, are northern extensions of long beaches. Several beaches that occur along coastal lowlands function as barriers by impounding the streams and waters behind them. The best example of this kind of barrier formation is the beach system that forms Humboldt Bay, CA, and the delta lagoons of the Eel River. From all these examples it is clear that although there are no Pacific coastal barriers that are exactly homologous to those on the Atlantic and gulf coasts, there are analogous formations of several different origins.

THE PACIFIC COAST: A PHYSICAL OVERVIEW

The coast of the three Western States--Washington, Oregon, and California--is composed of sheer cliffs, arrays of offshore islands, sea stacks interspersed with sandy beaches at the bases of cliffs, and terraces left over from previous higher stands of the sea. Along the approximately 1,500 mi of shore from Cape Flattery, Washington, to the Mexican border just south of San Diego, there are only three major breaks in the coastline that provide sea-level access to the interior valleys. These are (1) the Strait of Juan de Fuca, which leads into Puget Sound, (2) the Columbia River with its tributary, the Willamette River, which is part of the larger Puget-Oregon lowland between the Coastal Range mountains and the Cascades, and (3) the Golden Gate (San Francisco), through which flow the rivers that drain the Sierra Nevada Range and the southern part of the Cascades. There are also several smaller bays at river mouths; San Diego, San Pedro, and Humboldt Bays in California, and Coos and Yaquina Bays in Oregon are examples of these.

Although there are two coastal bays on Washington's outer coast (Grays Harbor and Willapa), Washington's outer coast and bays are the least of its shoreline. By far the greater part of the Washington coast is in Puget Sound, including the southern side of the Strait of Juan de Fuca. Puget Sound was formed by glacial forces during the Pleistocene (which ended about 10,000 yrs ago). Puget Sound is the only glaciated area in the coastal region of the three Pacific States. Glaciers scoured the major basins of Puget Sound during several cycles of advance and retreat during the Pleistocene. When the last glacier melted, heavy sediment deposits were dropped from the ice and were transported by meltwater streams. The Puget lowland rebounded from the weight of the glacial ice by uplifting up to 460 ft and sea level rose from the additional water added to the oceans worldwide. Puget Sound includes 2,500 mi^2 of water, about 2,300 mi of shoreline, and some 200 or more islands in Washington State.

The beaches of Puget Sound were molded from sand, gravel, and scattered patches of cobbles and larger rock left by the glacier. Bedrock is exposed as outcrops in some places, and there are also deltaic and marshy shores. Many rivers and streams enter Puget Sound and contribute sediment for the formation of these deposits in the Sound. All the usual beach forms occur in Puget Sound (Figure 3): sandy barrier spits, tombolos, pocket beaches, deltas, mudflats, and narrow beaches at the base of bluffs. Most of these are on a smaller scale than on the open coast because the wave energy is lower; however, damage to coastal landforms and property may be severe in winter storms.

About 950 of the more than 1,500 mi of Pacific Ocean coast are rocky. In Washington, about 87 of 143 mi (about 61%) of the ocean coastline consist of cliffs, some of them the most spectacular in the world. Forty percent of Oregon's 310-mi coastline is rocky, although interspersed with pocket beaches. Seventy percent of the California coast is rocky--some of it, like the "Lost Coast" of Mendocino County, with sheer high cliffs and very narrow or even nonexistent beaches.

Nevertheless, there are extensive reaches of sandy shores. More than 50 mi of the southern coast of Washington are sand spits and dune fields. These are the beach lands that flank Grays Harbor and front Willapa Bay. The most spectacular beach on the Pacific coast is that fronting the Oregon Dunes between Heceta Head and Coos Bay 50 mi to the south. There are some fresh-water impoundments behind these dunes, suggestive of an eastern barrier system; however, this dune field is an old structure composed of sands derived from previous high stands of sea level. The other large beach in Oregon is the Clatsop Plains, stretching for 29 mi between the Columbia River and Tillamook Head. The sands of this beach are derived from the Columbia River. The rest of the Oregon coast is essentially a region of pocket beaches (beaches not maintained by littoral drift) between massive headlands. Estuaries have formed at the mouths of the smaller rivers between the Columbia and Rogue Rivers, but the total estuarine area in Oregon is only about 41,000 acres (Figure 4). Coos Bay and its arm South Slough (a National Estuarine Sanctuary) compose the largest estuary completely within Oregon.

Almost precisely at the Oregon-California border the terrain changes from rugged coastal mountains to a coastal plain with a shore of steep beaches and a series of lagoons at stream mouths. This terrain is interrupted between Crescent City and the Klamath River by a section of high coastal hills and at Trinidad Head by a group of tombolos, but otherwise extends as far south as the Eel River. Humboldt Bay, north of the Eel River, is actually a large lagoon, a shallow embayment without significant tributary streams. The barrier beach that forms Freshwater Lagoon has been stabilized as a causeway for the coastal highway and is the last of the steep northwest beaches characterized by heavy wave action. Currents from the south result in accumulations of logs and sawed off stumps with roots ("pond lilies") on this beach. During heavy storms these relics of logging can be lifted and moved along the beach with violence, smashing into whatever may be in the way.

A few miles below the mouth of the Eel River is Cape Mendocino, where the San Andreas Fault meets the submarine Mendocino Escarpment which trends westward. From Cape Mendocino to the San Francisco Bay region the geography of the coast depends upon the position of the San Andreas fault line. Where the fault zone is close to the shore there are bold cliffs, as along the "Lost Coast" and the high cliff region between Fort Ross and the mouth of the Russian River. Where the fault zone is more to the landward, the characteristic coastline is low bluffs fronting a marine terrace. The largest coastal town between Eureka and San Francisco, Fort Bragg, is built on such a terrace. Two of these terraces have become the site of home developments in recent years: Shelter Cove (Point Delgada) and the Sea Ranch south of the Gualala River in Sonoma County. It should be noted that these coastal terraces are at the foot of steep hills susceptible to slumping and landslides from heavy winter storms and seismic action.

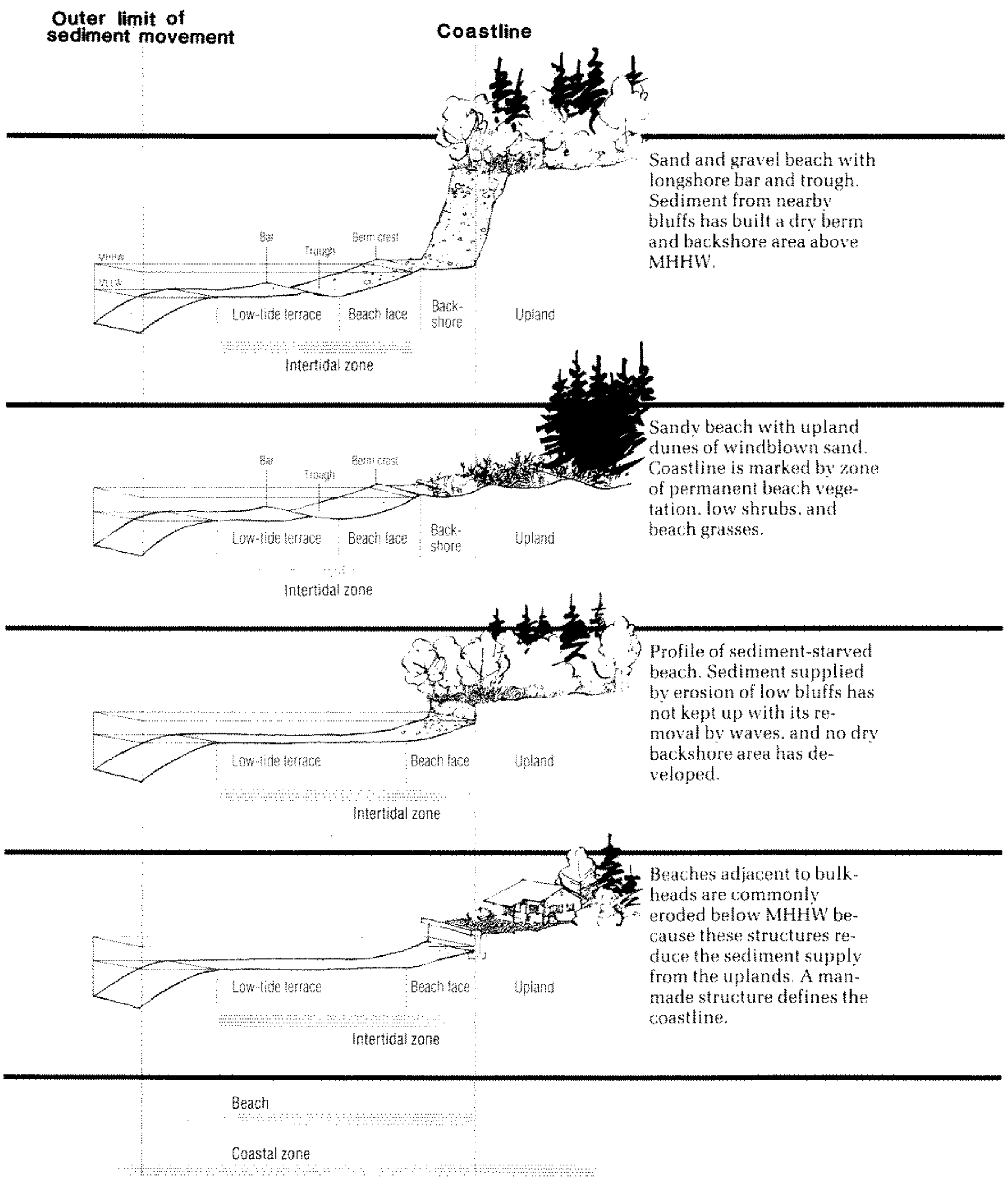

Figure 3A. Beach and shore features of Puget Sound (Downing 1983).

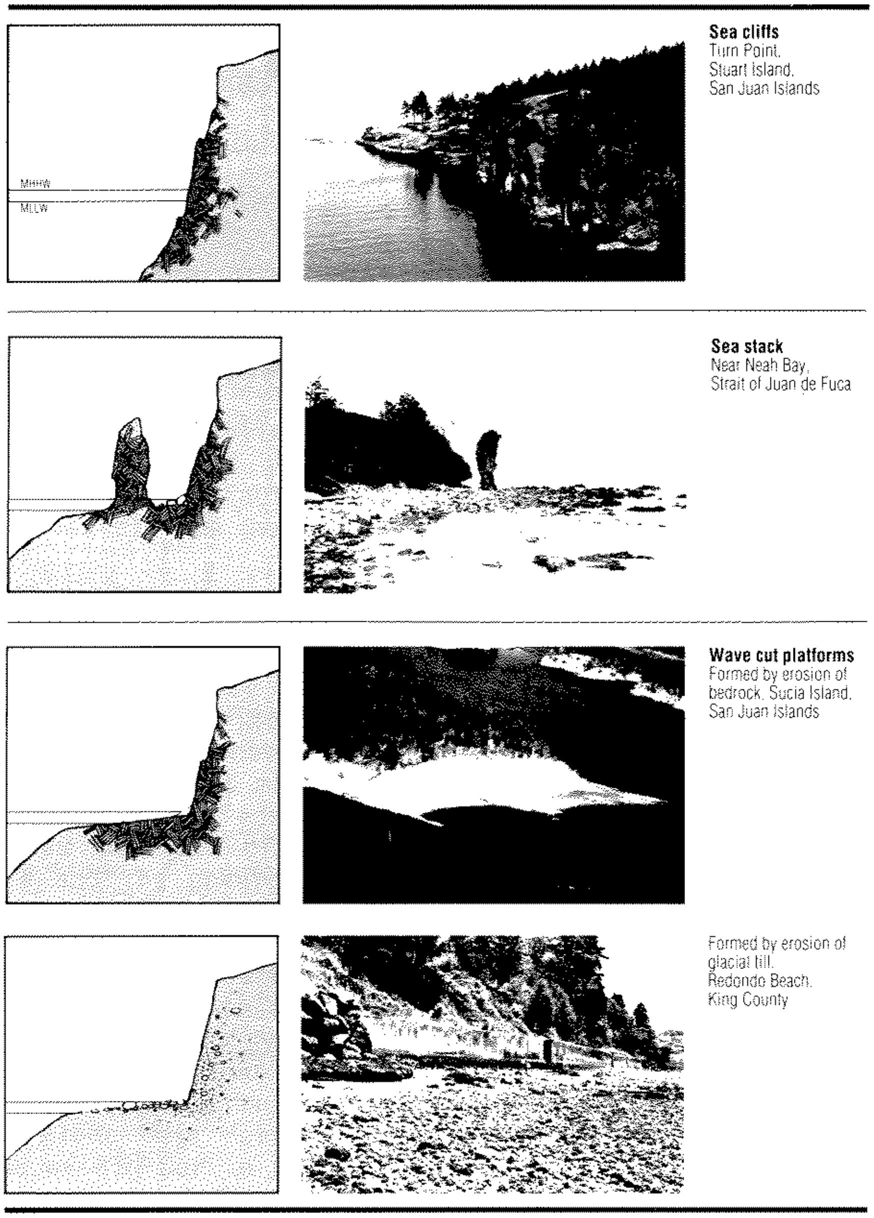

Figure 3B. Erosional features of Puget Sound (Downing 1983).

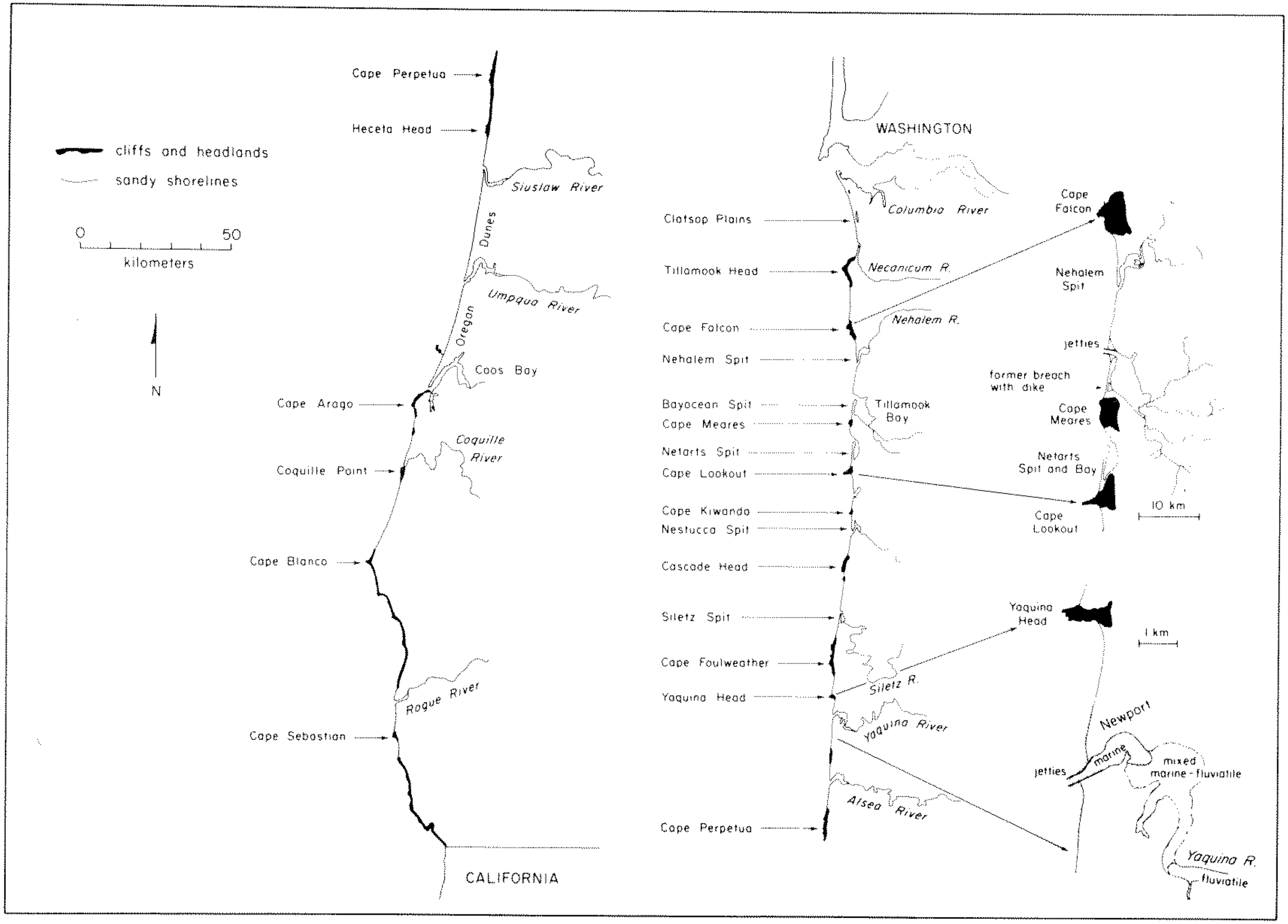

Figure 4. Coastal landforms along the Oregon coast (Komar 1979).

The terrace system is well developed south of the Russian River to Bodega Head and along the San Mateo-Santa Cruz shores. There are many pocket beaches along this part of the coast, and a conspicuous tombolo (now filled for a State Park parking lot) exists in the lee of Goat Rock south of the mouth of the Russian River. In addition to the frequent pocket beaches along this part of the coast, there are several larger beaches. The bar at the mouth of the Russian River builds up during low-water periods and before about 1910 often closed the river off completely. Some summer flow has since been maintained in the Russian River by diversion of water from the Eel River at Lake Pillsbury in Mendocino County.

South of Russian River, the most conspicuous beach features are the three recurved or crescent-shaped barriers east of Bodega Rock (Doran Beach), in Drakes Bay (Limanteur Spit), and east of Bolinas (Stinson Beach); Fourteen Mile Beach, north of Pt. Reyes, is another important beach feature. The three crescent-shaped barriers protect coastal lagoons or estuaries behind them. Fourteen Mile Beach has accumulated from sand carried south by littoral drift and caught behind the Pt. Reyes headland. It is a steep, windy beach, with a large freshwater pond, Abbots Lagoon, behind it.

Through Tomales Bay and Bolinas Lagoon the San Andreas Fault leaves the coast and extends into the land at San Francisco. Tomales Bay, often called in geology texts a "typical fault structure," is comparable only to the Gulf of California or possibly the Great Glen of Scotland.

The coast from Bodega Head to Half Moon Bay is notoriously unstable because the fault structure is so close to the shore. From Half Moon Bay southward to Monterey the fault zone lies inland and the coastal terrace is broader. The coastal bluffs are, however, more fragile and in some places are retreating rapidly. These were primarily agricultural lands that are now being encroached upon by urban developments. An attempt to open up the Half Moon Bay area to subdivision was made before World War I by the construction of the Ocean Shore Railroad, a feeder line from San Francisco. However, the tracks were laid across the face of the Devil's Slide area and as a result service was unreliable and the enterprise was abandoned (see Hedgpeth 1986 for photos of the railroad route).

In this region, the shore is characterized by extensive sandy shores and small pocket beaches as far south as Monterey, where granite characteristic of the western side of the fault system appears on the shore. Pure white sands of industrial quality make up the the beaches in this locality. South of Monterey the coast becomes rugged, with massive mountains and steep cliffs for about 45 mi. Along this formidable coast the only sandy beach is the tombolo tying the mass of Big Sur to the land.

South of Big Sur the coastal terrace reappears and becomes the principal feature of the coast, with occasional rocky interruptions around the headlands of Pt. Conception, Santa Barbara County, and southward toward Malibu. The principal features of the coast of San Luis Obispo County are the broad beaches from Cayucos Beach to Pismo Beach, the Pismo Dunes, and the conspicuous tombolo and sandspit formation at Morro Bay. Morro Rock, the anchor for the tombolo that forms the northern border to Morro Bay, is the most seaward of a row of volcanic plugs extending several miles inland. Morro Bay is the largest relatively unmodified bay in southern California. South of the Morro Bay sand spit the coastal hills approach the shore, and pocket beaches and coves appear. One of them, Diablo Cove, is the site of a nuclear power generating station.

Beyond the Pismo or Nipomo dune field and south of the Santa Maria River, which is the source of much of the beach sand, at Pt. Arguello and Pt. Conception the coast changes from a generally north to south direction and bends eastward to Santa Barbara. This is one of the most dangerous parts of the California coast, the scene of many shipwrecks on the rocky offshore reefs of the region. Seven destroyers went on the rocks in dense fog at Pt. Arguello in 1923. The coastal benchland broadens to the east, where the city of Santa Barbara is situated. Sandy beaches, some with scattered cobbles, are the dominant feature of this west to east trending coast. The coast bends southward again at Ventura and the coastal terrace narrows at Mugu Lagoon, restricted by the Santa Monica Mountains. Mugu Lagoon and the Ormand Beach wetlands immediately to the north are barrier and estuarine features. South of Mugu Lagoon, along the mountains, there is barely enough coastal terrace for the Pacific Coast Highway and the row of houses perched on the edge of the bluff. The steep hills above the highway have been made unstable by street work and excessive watering of lawns and shrubbery. Summer fires often destroy much of the anchoring vegetation, increasing the danger of landslides during heavy winter storms.

East of Malibu an extensive beach stretches southward to Redondo Beach, just north of the Palos Verdes Hills. The beaches around the base of Palos Verdes are narrow and rocky. On the southern side is Portuguese Bend, a notorious slide area where building is now prohibited. The southern tip of Palos Verdes is Pt. Fermin. To the east and northward are the massive developments of the Los Angeles and Long Beach Harbors.

For the most part, the shore of southern California from Los Angeles to San Diego consists of broad sandy beaches, occasionally interrupted by small lagoons and wetlands. These lagoons and wetlands include the Cerritos, Seal Beach, and Bolsa Chica wetlands, and Newport Bay. Many of these have been highly modified for marinas. Formidable coastal bluffs occur at Torrey Pines below Del Mar and at Pt. Loma.

The sandy beaches of southern California receive their sand from the intermittent streams of the region. Many of these have been dammed or turned into concrete troughs as protection against floods, but this practice interferes with the nourishment of the beaches, so they have tended to become narrower. On hot summer days, the southern California beaches are visited by millions of people. Cleaning up the sands after these invasions is also a major factor contributing to beach deterioration because it prevents growth of stabilizing vegetation and causes the sand to drift landward.

Pt. Loma is the last rocky headland on the California coast. At the base of this headland is a large flat reef well known for its invertebrate fauna. South of Pt. Loma is Coronado Spit, which extends for about 19 mi. This long coastal barrier forms the western shore of San Diego Bay in California. The northern part of this barrier has been greatly modified as North Island, part of San Diego Naval Base and site of the elegant Coronado Hotel. The southern part of the barrier and its surrounding wetlands at Imperial Beach near the mouth of the Tijuana River are very polluted as a result of the inadequate sewage treatment facilities of the city of Tijuana in Mexico.

CLIMATE AND STORMS

CLIMATE

The climate of the Pacific coast ranges from the cool, damp summers and heavy winter rainfall of Washington and Oregon to the "mediterranean" climate of central and southern California. Some snow falls on the coasts of Oregon and Washington, but no snow falls from the southernmost part of Oregon through California to Mexico. Figure 5 shows the average annual precipitation of the coastal regions of the three Pacific States. At the extreme southern part of California, especially in San Diego, the coastal region is classified as a cool coastal desert (Meigs 1973). Yet, even in this southernmost region, heavy rainfall from unseasonal storms may occur.

The wind pattern along the Pacific coast varies seasonally. In the winter, Aleutian lows dominate the weather and are responsible for heavy rains and strong south to southwesterly winds. North winds are responsible for the seasonal upwelling that provides nutrients for the high primary productivity of nearshore waters in spring and summer; this in turn supports the large populations of fishes and crustaceans that are one of the mainstays of the economy of the coastal region. Within 24 hours of the onset of the wind from the north, the southwestward movement of surface water (about 45° to the right of the wind direction) brings nutrient-rich water from depths of 500-1,000 ft to the surface. The most intensive known region of upwelling occurs along the coast of California between Pt. Arena and Pt. Reyes (Huyer 1984; Kosro and Huyer 1986).

STORMS

The storm wave regime of the Pacific coast is very different from the pattern of winter gales in the northern Atlantic and the tropical hurricanes of the southern and gulf coasts. Major storm waves are of at least three different origins on the Pacific coast: meteorological (winter storms), seismic (tsunamis caused by earthquakes or volcanic action at some distance from the region), and waves from distant, transpacific storms. All of these storm types can cause erosion of barriers and other shorelines, loss of structures, and other damage. Still another storm type, usually a conjunction of a northward drifting tropical storm with an early oceanic storm from the north or central Pacific, may produce heavy rainfall in southern California. When this occurs after late summer brush or forest fires in the coastal mountains, there may be severe flooding and landslides that erode coastal terraces and produce bluff retreat.

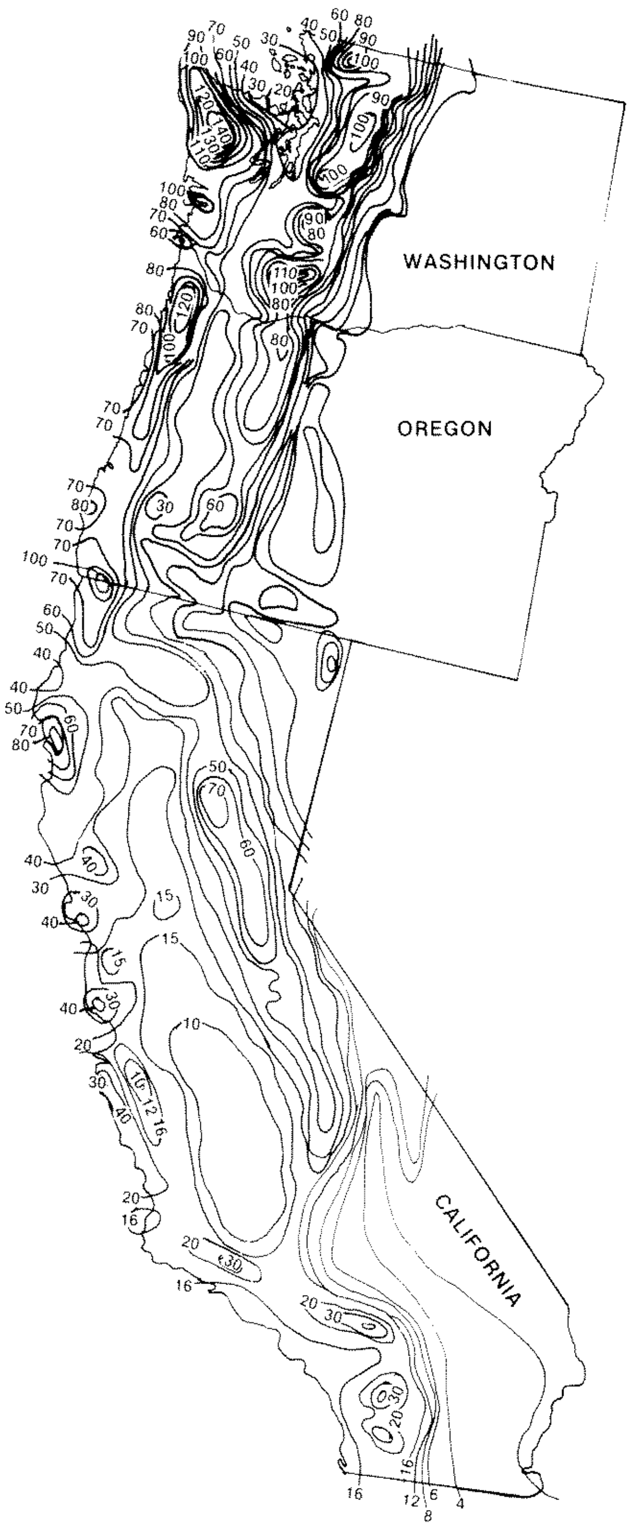

Figure 5. Mean annual precipitation (inches) in the coastal regions of Washington and Oregon, and throughout California.

Major storm and tsunami episodes may affect the coastline along fronts of several hundred miles, in contrast to the almost "point source" aspect of some hurricanes along the Atlantic coast. A complication peculiar to the eastern Pacific Ocean is the influence of El Niño events on the basic winter storm pattern. El Niño, it is now realized, is a climatic anomaly involving warming seas, sea-level rises, and wave trains from the west. This anomaly occurs 20-25 times per century. It also seems probable that volcanic eruptions may have some influence on the onset of El Niño episodes (now technically referred to as El Niño-Southern Oscillations [ENSO]). More than half of the eastern tropical storms making landfall in California occurred during the late summers of ENSO years. Since the development of satellite-imaging observations of storms on a large scale, we have gained much more understanding of these events.

The large storm system of March 1983 caused severe damage to bluffs and structures all along the Pacific coast. The beach was eroded and several houses were damaged at Stinson Beach, north of San Francisco; Fort Funston State Park, at the southern edge of San Francisco, was severely damaged by wave action and storm flooding. Because of the coincidence with high tides in the San Francisco Bay, there was dangerous erosion of some levees. Further south along the coast, several houses and seawalls at Santa Cruz were destroyed and houses and seawalls at Malibu were damaged. Some of the most severe damage occurred in San Diego County: seawalls broke, cliffs were badly eroded leaving houses and restaurants hanging in midair, and the coastal highway was undercut.

Since 1900 there have been 60 storms with wave heights more than 10 ft; 18 of these had wave heights exceeding 20 ft. The winter of 1982-83 was exceptionally severe: six separate storms with waves exceeding 20 ft hit the coast between December and March. Figure 6 shows the paths of North Pacific cyclones during March 1983.

Although the wind patterns associated with the storms of February 1986 were similar to those of 1983, there was no spectacular damage to coastal structures. Instead, the 1986 storms resulted in the heaviest rains of the century in northern California, causing severe flood damage to communities in floodplains. The most extensive damage was caused along the Russian, Napa, and Sacramento Rivers, and in smaller stream drainages in the San Francisco Bay counties.

Without extensive sand beaches protecting many bluffs and terraces, the damage from violent storms would be much greater than it is. Sand acts as a brake or drag on waves. Where there are barrier beaches fronting embayments, the sand absorbs the energy much as it does at the base of cliffs. The principal danger to beaches and barriers is not intense storms but a steady reduction in the sand supply caused by dams on tributary streams and the diversion or interruption of littoral transport along the seaward edge of beaches and barriers by bulkheads, groins, and jetties. In some situations, mining of beach sand has contributed to the problem.

Spits and low-lying barrier beaches survive severe storms with relatively slight effects as long as there is a supply of sand available to restore the

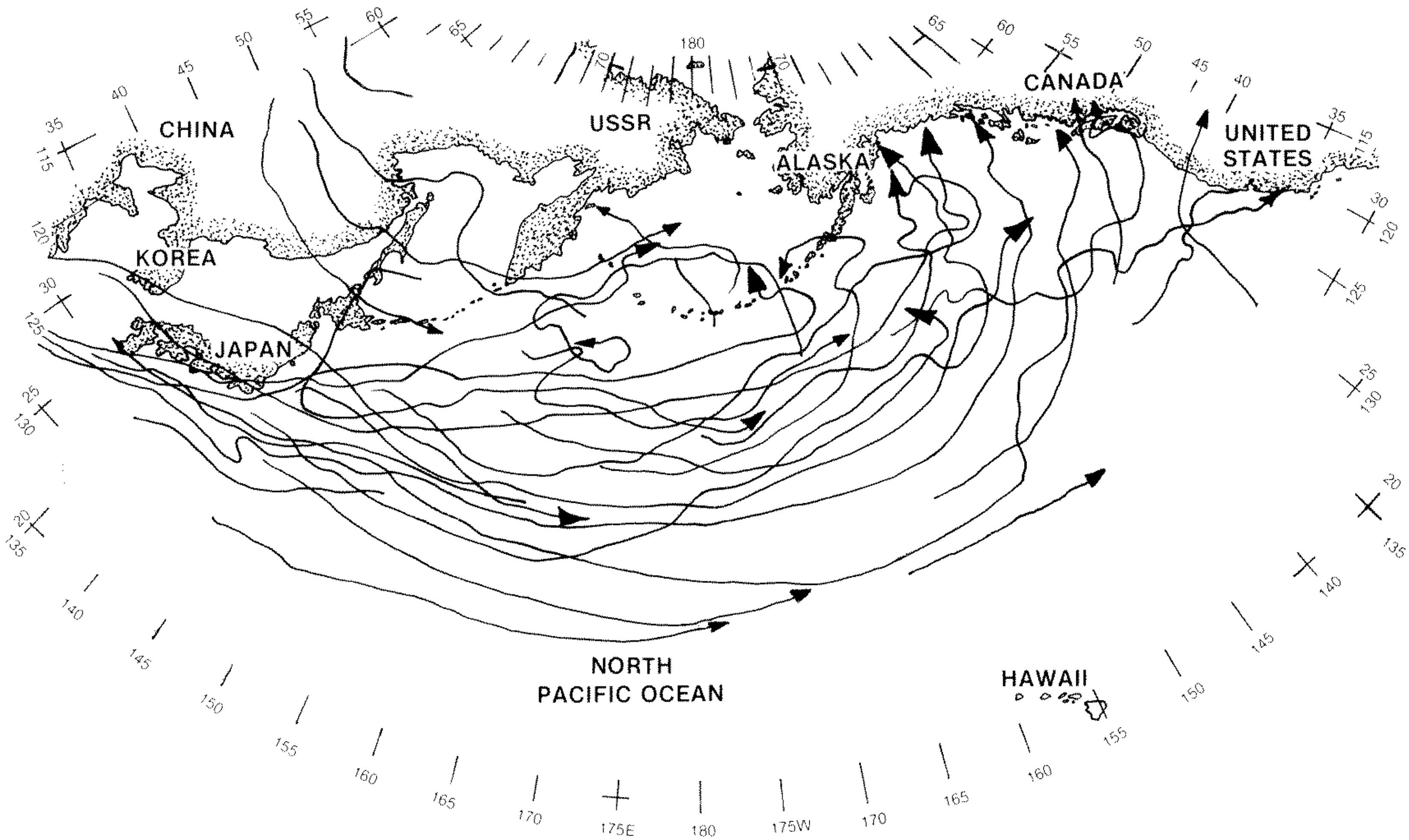

Figure 6. North Pacific cyclone (extratropical storm) tracks for March 1983 (NOAA Mariner's Weather Log 27:pl. 82).

beach. A severe storm is a short-term phenomenon, repeating the annual cycle of changing width and slope of the beach within a few hours. Sometimes a spit is eroded back or shortened and the dunes reduced or moved, but the sand begins to build up again towards its equilibrium condition almost as soon as the storm ends. The entrance to a bay may be relocated or shoaled, but this sometimes also happens without storms, as it did at the entrance to Willapa Bay. Shoaling of harbor entrances may be dangerous to navigation and require dredging to restore an entrance channel. Most of the storm damage on developed spits, as at Siletz Spit or Stinson Beach, has been caused by the break up of retaining walls or the transport of logs (especially in Oregon and Washington) along the beach. The Inn at Spanish Head at Lincoln City, Oregon, is an 11-story structure built against a cliff face with its lowest floor at 9 ft above high tide. Some years ago a heavy gale combined with high tide to move logs piled up above the berm toward the hotel. One of these logs, weighing several tons, smashed into the ground floor and imprisoned a guest in her room for several hours.

Heavy winter storms are usually accompanied by massive rainfall in coastal areas, which increases the sediment load in coastal streams and provides sand nourishment to the beaches. This aids in the recovery of the beach after the storm. Beaches cut back by the tsunami of 1964 recovered very slowly because there was no rainfall at the time.

"Tsunamis" (from Japanese, tsu = harbor and nami = wave) are generated by earthquakes or volcanic activity, often in faraway parts of the Pacific Ocean. Tsunamis generated by seismic activity in Chile or Peru produce wave anomalies that can be observed in southern California. Since tsunami waves move at speeds of 500 to 600 mph, their impact on shores and estuaries may be spectacular and devastating. The tsunami generated by the Anchorage, Alaska, earthquake of March 27, 1964 caused severe damage along Oregon and northern California the next day, destroying a large part of the downtown district of Crescent City. The dock at Dillon Beach was destroyed and wave anomalies were observed in San Francisco Bay. Figures 7 and 8 summarize the action of this Good Friday tsunami along the Oregon coast and as far south as Crescent City. The damage to both Anchorage and Crescent City was the determining factor for abandoning the plan to build a large nuclear power station at Bodega Head in California.

It is impossible to predict tsunamis before the seismic activity that initiates them, but once an earthquake has occurred it is possible to predict the direction and speed of the wave and the approximate time it can be expected to arrive at a given locality. However, the action of the tsunami at a particular location depends on the local bottom topography and the position of the headlands with respect to the wave direction. Sufficient information was not available to predict the local impact of the tsunami on Crescent City, and even if it had been, there would not have been time to do more than evacuate the area.

While there are formulas and equations for estimating wave force, estimating the total energy of a storm is difficult and perhaps impossible. Blocks of concrete weighing as much as 50 tons have been torn out of jetties, and entire houses have been carried away by massive waves which must involve many tons of

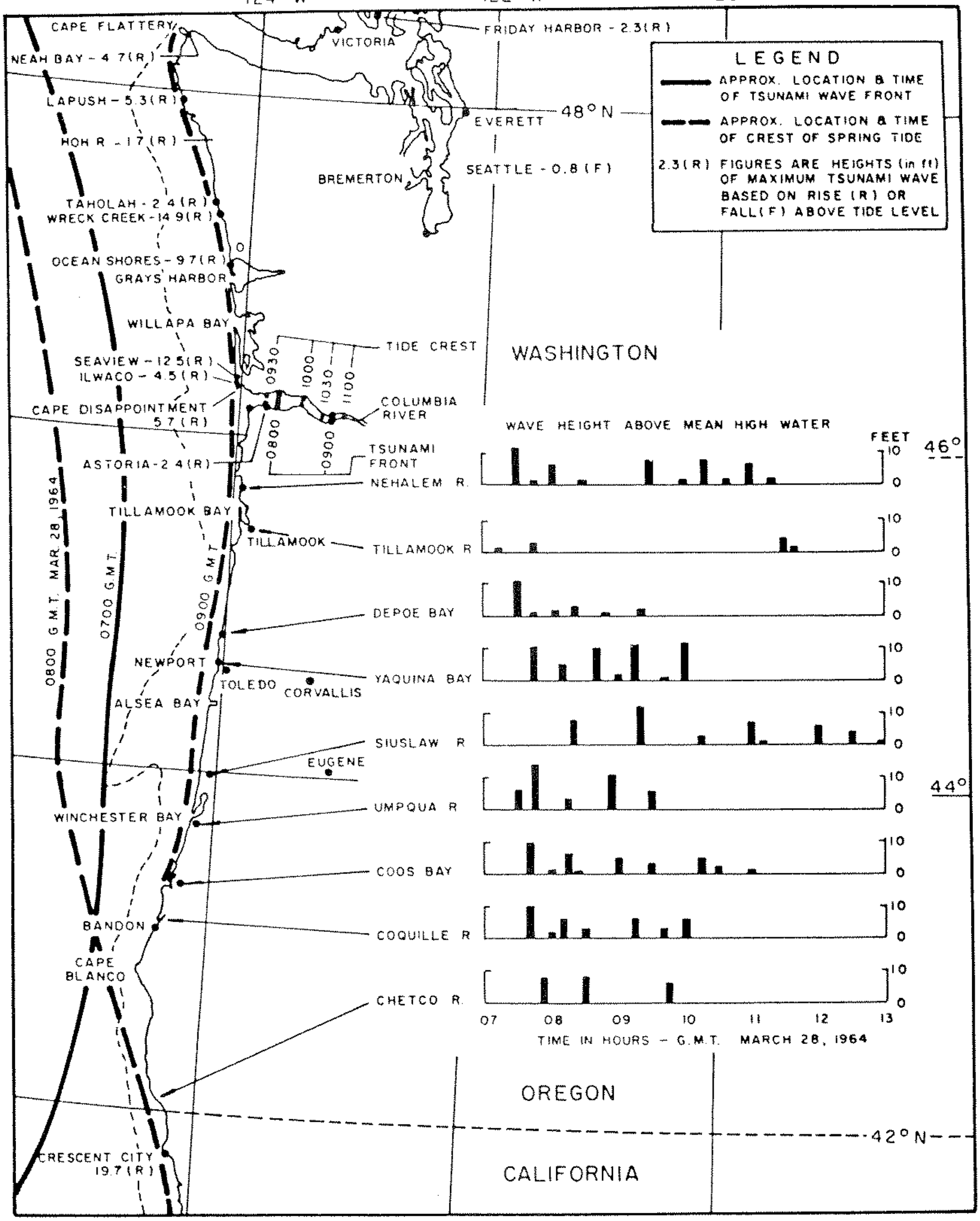

Figure 7. Maximum heights of tsunami waves recorded at tide stations or by observations along the Washington-Oregon coast, March 1964 (Komar 1979).

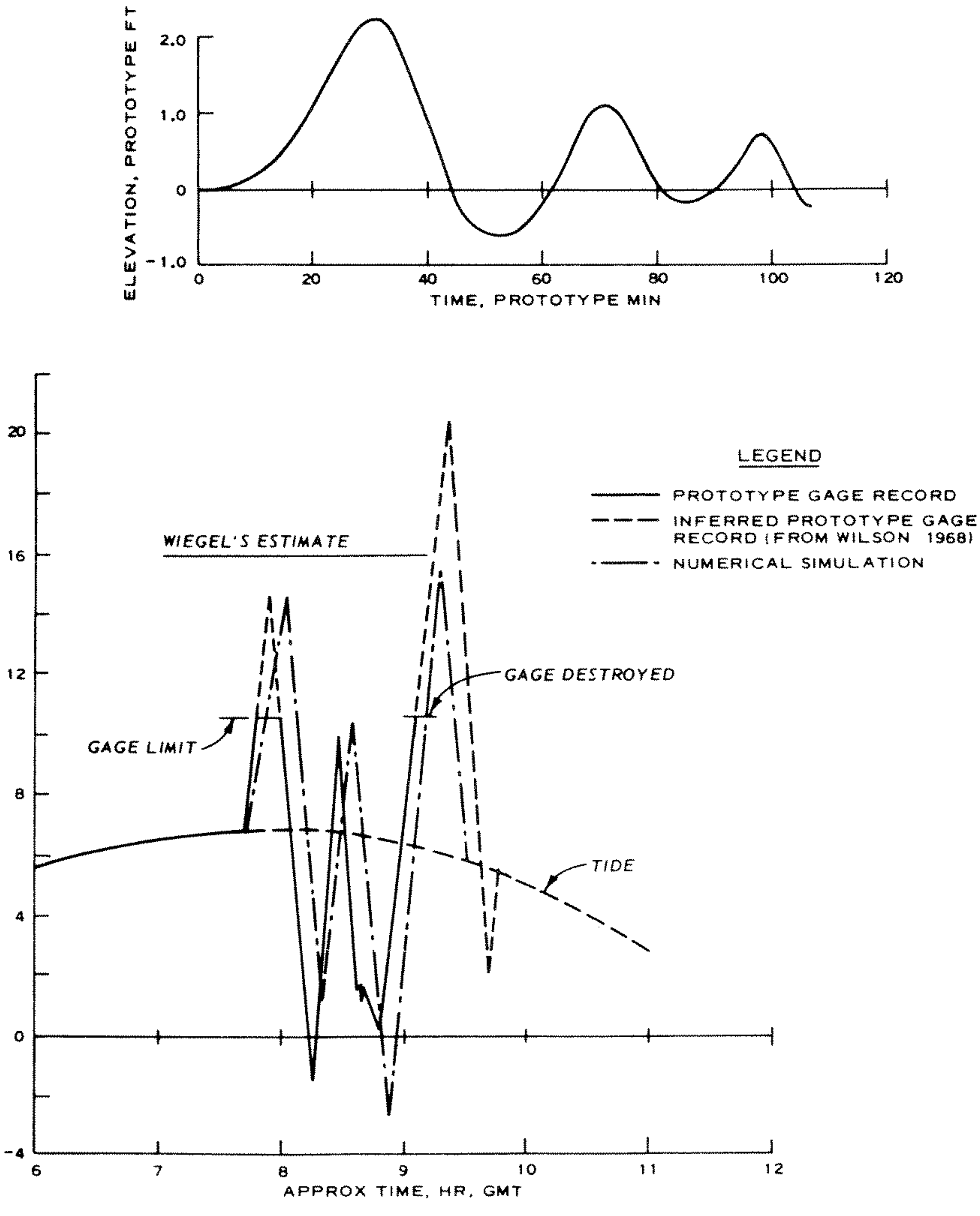

Figure 8. Recorded and inferred wave heights at Crescent City, California, during the March 1964 tsunami (Houston 1978).

water hurled against the land. In great Pacific storms, the waves generated across thousands of miles of open ocean surface can almost literally move mountains. When an already unstable land is loosened by improper grading or lubricated by irrigation so that it slips easily over underlying rock, the effects of storms become even more devastating. Unfortunately, the deadly combined effects of storm forces and human manipulations become disastrously obvious at places along the Pacific shore almost every year.

COASTAL ECOSYSTEMS

The coastal environments of the Pacific shore support a rich and varied biota. The algal flora alone comprises hundreds of species, including massive kelp that may grow almost 100 ft long. Along central California, in the Monterey region in particular, there are 440 species of seaweeds, and the invertebrate and vertebrate fauna are correspondingly rich. Some of the larger, more conspicuous species on rocky shores are found for several hundred miles along the coast, particularly the "big three" of the intertidal zone: the surf or California mussel (*Mytilus californiensis*), the seastar (*Pisaster ochraceus*), and the leaf barnacle (*Pollicipes polymerus*). These three are ecological markers from Canada to southern California.

On sandy shores there is an equally ubiquitous marker, the egg-shaped sand crab (*Emerita analoga*), which occurs sporadically on beaches from Vancouver Island to Baja California. Of greater significance to people are the gastronomically important razor clams (*Siliqua patula*) of the north and the Pismo clams (*Tivela stultorum*) of the south. The richness of the coastal waters and the nearby ocean is proverbial, although the great sardine fishery of the past is no more, and the commercial crabs have not done well in recent years. Nevertheless, fisheries are an important part of the economy of the three Pacific States.

Another important aspect of the flora and fauna of the shores is the value of this environment to education and research. There are 14 year-round, full-time marine stations and three seasonal ones located along the coast from Friday Harbor in the San Juan Islands (just north of Puget Sound) to San Diego. All but one of these (Batelle Northwest Laboratories) are associated with universities or colleges and are significant teaching as well as research facilities. The Federal Government and the three States also maintain fisheries laboratories along the coast. These laboratories emphasize the commercial and economic aspects of fisheries, but also cooperate with the universities. Several of the older, established university stations enjoy national or international reputations and attract students and visiting research scholars from many places, especially during the summer season.

THE SANDY BEACH ECOSYSTEM

The shape of the sandy beach reflects seasonal differences in wave and wind direction and littoral currents. Heavy surf in winter erodes or narrows a beach and steepens its profile; the summer beach is often broad and very gently sloped. The average size of the sand particles in sheltered sites is smaller than that of sands on the open beach. Since the slope of the beach and the size of the sand are indications of the intensity of physical forces, it is possible to gain a reasonable impression of the beach by looking at the profile and measuring the sand. As the waves reach the shore they form a series of bars. The presence of the outermost bar is indicated by the breaking waves. There may be several such bars, with longshore troughs in-between. These physical features provide regions of food concentration, and subtidal burrowing organisms, such as sand dollars and clams, may abound. As the waves move against the submerged bars, stranded objects are transported landwards and may eventually come to rest far up on the beach. Heavy winter storms may shift them back and forth along the shore or bury them deeper in the sand.

Because of the shifting nature of the beach there are few macroscopic intertidal plants in the environment except those attached to occasional stones or large objects. The dominant plants of intertidal beaches are microscopic diatoms, which give an olive-green tinge to the large, gently sloping beaches of Washington and Oregon. They flourish best in regions of cool summers and frequent fogs. Diatoms are less abundant in southern California beaches where their growth may be limited by intense sunlight. An important source of carbon for the sand beach ecosystem is detritus from seaweeds and the swarms of nearshore plankton that live on the edge of the shore. This food supply can support dense populations of such animals as surf clams, especially razor clams (Siliqua patula) on northern beaches and Pismo clams (Tivela stultorum) on California beaches. In the Pismo Beach area, Pismo clams were once found in immense quantities before they were fished out. Recently, the clams have been preyed upon by sea otters, which are more adept than people at finding them in the sand and even less concerned about size and bag limits.

The most conspicuous animal of the beaches is the sand crab (Emerita analoga), which is found sparsely and sporadically in Washington and Oregon, and is most abundant in southern California. This animal feeds by filtering plankton and detritus with its antennae as the water carries it down the beach with the tide and receding waves. The crab moves up and down the beach to take advantage of the maximum concentration of food. The sand crab is the most widely distributed animal of Pacific beaches; its four-month larval stage can be carried for long distances by nearshore currents. Smaller crustacea, especially copepods and mysids, are common members of the surf plankton. Several species of polychaetes live in the lower intertidal reaches of the beach. At higher beach levels there are often droves of beach hoppers (the amphipods Orchestia and Talorchestia) living among the flotsam of the beach. These animals live in burrows above high tide and come out at night to feed with the receding tide. Above the high-tide region of the beach, at the vegetation line, there are spiders, insects, and a maritime pill bug (Alloniscus perconvexus).

The top predators of this ecosystem are the various shorebirds. After feeding, these birds often fly off to the bays, lagoons, or uplands, thus removing energy from the beach ecosystem. The California least tern (Sterna albifrons browni) is an endangered species that nests on the beach and forages in adjacent coastal waters and wetlands. The general distribution and migratory periods of the species of shorebirds occurring on open beaches along the California coast are indicated in Figure 9. Only one shorebird species,

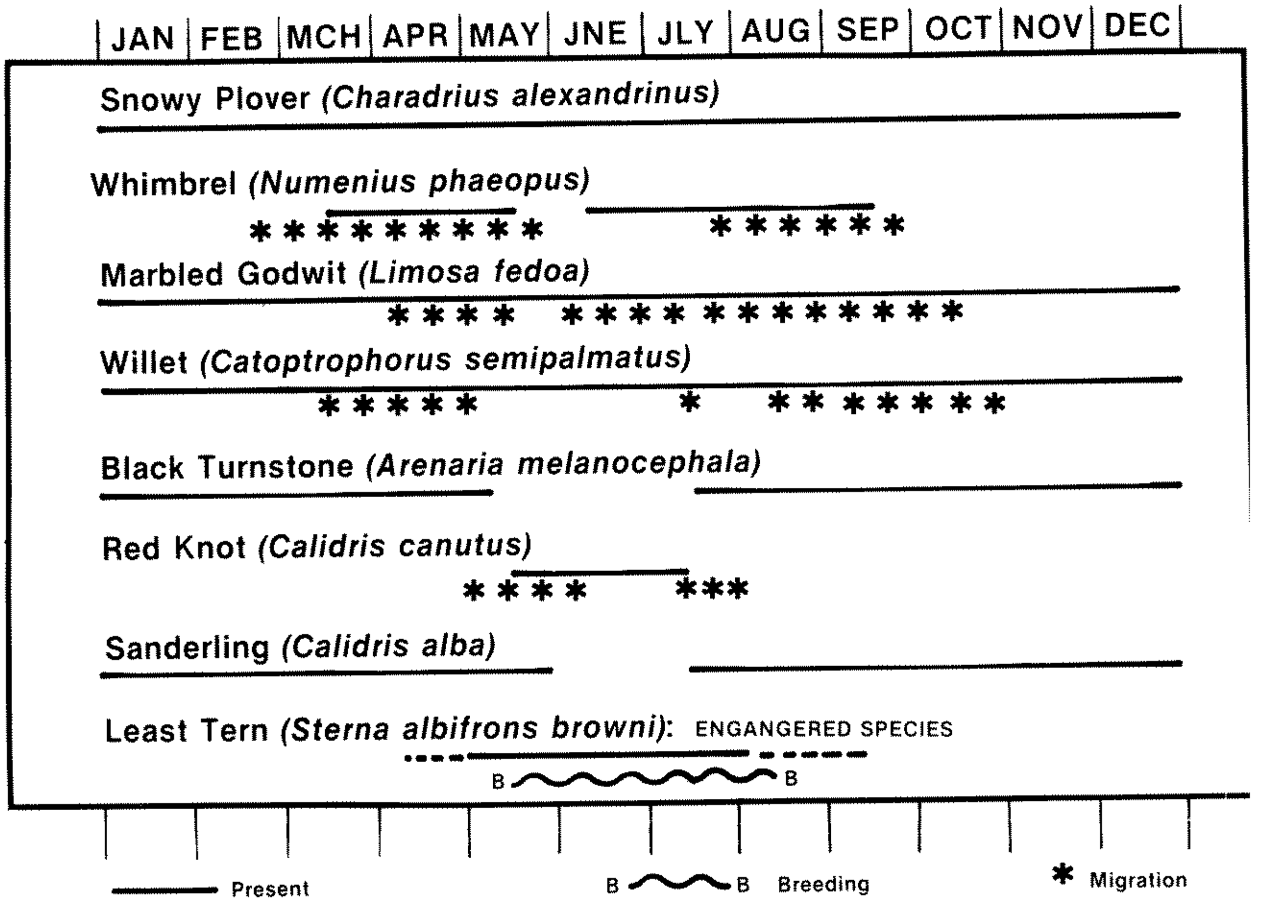

Figure 9. The temporal distribution and migration patterns of commo shorebirds on open beaches and tidal flats.

the western snowy plover (Charadrius alexandrinus), is a year-round resident (although summer distribution differs from winter distribution) that nests on the beach. Because of heavy human use of the open beaches, the snowy plover now avoids many summer nesting sites and the U.S. Fish and Wildlife Service (FWS) has classified it as a "sensitive species." The usual nesting site is high up on the beach or among the dunes; like their relatives the inland killdeer, they depend on their natural camouflage for protection from enemies. Since many of these sites are preempted by human activities, snowy plovers have taken to nesting on the dikes of salt ponds and similar marshland structures. A corresponding species of similar habits on the Atlantic coast, the piping plover, has lost so much of its nesting habitat to recreational and commercial development and dune stabilization programs that its population has been reduced to the extent that it is now an endangered species.

One fish, the grunion (Leuresthes tenuis) of southern California, has learned to use the beach for spawning. The grunion spawns during the spring at the next to highest tide of the fortnightly sequence so that its eggs hatch at the time the higher tide 2 weeks later washes them out of the sand. The grunion is the only fish in California that may be legally caught by hand (and no other way). From central California northwards, several species of smelt frequent the surf zone to spawn and are a popular prey of fishermen, who catch them with triangular nets. Fishes of the family Embiotocidae (viviparous perch) frequent the surf to feed or spawn, and are often caught by hook and line. Other species of perch occur in bays and lagoons.

The terrestrial maritime flora of the beach, from high tide into the foredunes, is sparse. Although 15 to 20 species are considered common members of the flora, only about five species occur at any given beach. Of these, the most frequent species are the sea rockets (Cakile maritima and C. edentula), which grow nearest the tide line and are the only annuals of the beach flora. Two grasses, the European beach grass (Ammophila arenaria) and the native American dunegrass (Elymus mollis) are common species north of Monterey. South of Monterey the sand-holding plants are perennial herbs with taproots. Native American dunegrass grows in loose clumps, but European beach grass grows in dense continuous stands that may exclude native species.

There are no permanent resident mammals of the Pacific coast beaches. Harbor seals, which prefer sand bars and spits for hauling out, are seasonal, as are the elephant seals that have recently taken over the mainland shore at Año Nuevo. Elephant seals may have used many other mainland locations before Spanish colonial times. Among the terrestrial mammals, raccoons often prowl beaches at night, primarily those of the bay shores. In some localities in southern California and Baja California ground squirrels have been observed digging grunion eggs. Sea otters make excursions from rocky shores to dig out Pismo clams, thus competing with people who feel that they have prior rights to these succulent marine invertebrates.

THE DUNE ECOSYSTEM

The sand dune landscape is the result of the interaction of sand, wind, water, and vegetation. Different combinations of these four elements are responsible for the many different dune forms found on the Pacific coast. Wind acting on sand without much water or any vegetation forms spectacular moving dunes in regular patterns. Water and vegetation change the shape of the dunes and stabilize them (Wiedemann 1984).

Where water is available, clumps or colonies of vegetation form hillocks or low mounds. The native dune grass (Elymus mollis) is important in Washington and to a lesser extent in Oregon. A sedge, Carex macrocephala, is abundant in Washington and Oregon, but is not very effective at stabilizing dunes. The salt rush (Juncus lesueurii) forms hillocks in moist stable surfaces behind the shore. Yellow sand verbena (Abronia latifolia) and burweed (Franseria spp.) form low scattered mounds in the north and larger dunes in the south, where ragweed (Ambrosia maritima) is also an effective builder of foredune ridges. Surface-binding plants, morning glory (Convolvulus soldanella), and the sand strawberry (Fragaria chiloensis) are widely distributed.

The most effective foredune stabilizer is the European beach grass (Ammophila arenaria), which was introduced from Europe in 1869 to stabilize the San Francisco dunes that are now part of Golden Gate Park. It has spread naturally along the coast and was introduced to the Coos Bay region about 1910. Cooper (1958) remarks that European beach grass "in the course of decades or centuries changes significantly the character of the whole dune complex." In recent years concern has arisen that this grass may change the Oregon dunes by halting the movement of sand into the back dune fields.

There are a dozen or more plants that have been introduced or found their way into the flora of the northwestern dunes of Washington, Oregon, and northern California in addition to the European beach grass. Some botanists believe that the yellow bush lupine (Lupinus arboreus) is an introduction from South America; others believe it is a native of California. The most notorious introduced plant, however, is gorse (Ulex europaeus), a densely growing spiny shrub with a high oil content. It is now a common coastal dune shrub from Bodega Bay to British Columbia. It is most abundant around Bandon, Oregon, where it caught fire and burned the town down to the sea in 1936. It is poisonous to livestock and tends to take over pasture land. Efforts to control it include using insects and chemicals.

In general, the subarctic flora of the northern dunes occurs as far south as about 43° 30', near Coos Bay. This flora tends toward a forest climax with such trees as Sitka spruce, Western hemlock, pines, red cedar, and Douglas fir. South of Coos Bay, red cedar no longer appears and chaparral broom (Baccharis pilularis) begins to appear. As one proceeds southward, trees become less significant and the climax cover is characterized by lodgepole pine, rhododendron, and manzanita. The southern California dune flora is more shrub-like, with willows in the swales and mock heather and dune lupine on the hillocks. In the moister, northern dune ecosystems there are grassland communities consisting of sedges, rushes, wild strawberries, and the like, while in southern California, filaree, plantains, toad-flax, and brome grass dominate the dune ecosystems.

There seem to be few animals exclusively characteristic of the dunes. An incomplete list of the fauna of the Oregon dunes, including all species that might occur on or near the dunes, includes over 400 species (excluding insects or arachnids). If species endemic to the dunes exist, it is most likely that they will be found among the arthropods.

The freshwater habitats in the dune ecosystem include vernal pools, perennial ponds, and lakes. On the northern coast, with heavy rainfall and numerous coastal streams, there is an abundant fauna of amphibians and reptiles. The bullfrog has been introduced from the midwest.

The native lowland fish of the streams, ponds, and lakes of the Pacific States originally included a variety of minnows, bullheads (Cottidae), and suckers. The sunfishes and bass of the mid-continent were represented by a single species in California, the Sacramento perch, and by a single freshwater member of the viviparous perches, the tule perch (Hysterocarpus traski). On the whole, the native fish fauna, aside from the various salmon, trout, and sturgeon, offered meager fare to the white settlers who followed the Gold Rush. In 1872, introductions of exotic species began with the importation of carp, considered at that time a delicacy. This introduction was followed by striped bass (Morone saxatilis) in 1879, which was remarkably successful, and a host of panfish and freshwater bass, catfish, shad, and so on. Some of these, most notably the carp and various sunfish, have been planted in the ponds and lakes of the dune ecosystem by anglers without official sanction. Mosquito fish (Gambusia affinis) have been planted in most lowland ponds larger then a bathtub, and the silverside, also introduced, has been spreading without further assistance. Both of these small fish feed on the same food as young striped bass and may be an important factor in the decline of that species.

The feeding habits and high fertility of carp have made it a menace. It grubs for its food in the bottom mud and among the aquatic vegetation much as a hog does on woodland, thus muddying up ponds and the shoal regions of lakes. It also eats the eggs and larval stages of other fish and has never lived up to the expectation that it would become a great table delicacy. Goldfish, discarded in ponds and lakes, are not much better as they increase in size. On the other hand, the native tule perch is being replanted in ponds and is doing well in Lake Merced in San Francisco, a relic of the dune ecosystem. Threespine sticklebacks (Gasterosteus aculeatus) are common inhabitants of coastal ponds; one subspecies, G. a. williamsoni of the Los Angeles Basin, is on the California endangered species list.

THE ESTUARINE ECOSYSTEM

In the estuarine ecosystem, freshwater from land drainages meets tidal water from the sea; in fact, the word estuary is derived from the Latin "aestus," meaning tide. This interaction of fresh and saltwaters results in a complex gradient of salinities over the length of the estuary, which shifts with tides and seasons. Water residence time in the estuary also changes seasonally. It is shortest when streams are flooding and longest during low flow periods and in drought years. It may require many days--as many as 45 in San Francisco Bay--for an estuarine system to be completely flushed out in dry seasons.

Estuaries act as nutrient traps and nursery grounds. River water, loaded with nutrients as well as sediments, provides favorable conditions for phytoplankton, which in turn support zooplankton communities. Young fish, suspension feeding organisms such as oysters and clams, and many species of worms and crustaceans thrive in estuaries.

There are three major estuarine systems on the Pacific coast: Puget Sound, the lower Columbia River, and San Francisco Bay. These three systems owe their origin to three different forces: glaciation, river flow, and tectonic processes. While none of these three major systems are primarily the result of barrier beach processes, most of the smaller estuarine systems on the Pacific coast were formed by wind and waves acting upon the lower reaches of streams, aided by changing sea level.

The lagoon system is the predominant coastal wetland type in Southern California. Many of these lagoons are opened to tidal flushing by winter storms and are closed shortly thereafter by the littoral drift of beach sand. As a result, the lagoon water often becomes more saline than seawater, and many marine species do not thrive because of the increased salinity, higher temperatures, and reduced productivity of such enclosed regions.

Estuarine sediments are typically coarse near their mouths and finer in the more sheltered regions. This difference is primarily a result of currents. Sandy and muddy bottoms are often stabilized by growths of eelgrass (Zostera marina), which provide shelter for small crustacea, mollusks, and juvenile fishes. In shallow areas, seagrasses are also an important source of oxygen for the water. On tidal flats there are a host of worms and clams living in permanent burrows and wandering through the sediments. In the northwest, several species of clams attain considerable size and are major sources of food. In many estuaries, rock cockles (Protothaca staminea) are abundant between stones and in the sand and gravel. Clams such as the horseneck (Tresus capax and T. nuttallii) and goeduck (Panope generosa) are abundant in the north, but do not occur in southern California estuaries; there they are replaced by cockles and sand clams. Before western people arrived, oysters (Ostrea lurida) were a characteristic inhabitant of rocks in estuaries. They appear to have been a mainstay of the aboriginal diet, judging from the extensive midden piles as far south as San Francisco Bay.

Birds are the principal predators of this system, as they are on the open beaches. One of the most conspicuous birds of coastal estuaries is the herbivorous black brant, which feeds on eelgrass during winter and spring. It has abandoned many bays in California from San Francisco southward, apparently because of development and industry.

One of the most significant aspects of Pacific coastal estuaries is their function as buffering and acclimation zones for anadromous fishes, notably various species of salmon. For juvenile salmon migrating to the oceans, estuaries provide food and a critical acclimation zone where they become adjusted to oceanic salinities. For adult salmon, estuaries are important staging areas where fish migrating from the sea to spawn become adjusted for the last strenuous journey to their spawning grounds far upstream.

Estuarine tidal flats and eelgrass meadows are also important habitat for the commercially important Dungeness crab (Cancer magister). In the early life stages (about fingernail size), these crabs feed on organisms in the surface layer of tidal flat sediments, especially the small clams Transenella tantilla (<9 mm) and Gemma gemma (<6 mm). These clams are also an important part of the diet of sanderlings. In the spring of 1985, there was a massive population of young crabs in Bodega Harbor and Tomales Bay that formed a living carpet on the flats. They exterminated the small clams and the sanderlings went elsewhere.

If one looks at the surface layer of a tidal flat with a microscope, a living layer of very small organisms, many of them <1 mm long, can be observed. These include protozoans, worms of many kinds, crustaceans (especially harpacticoid copepods), and other small invertebrates collectively referred to as the meiofauna. Although the significance of this component of the ecosystem is not completely understood, it is known to be an important part of the diet of young fish, including the Pacific halibut. Excessive continuous digging up or disturbance of the upper layers of tidal flats could have a serious effect on invertebrates and the juvenile fish they support.

Marshlands are an important part of the estuarine system, but the extensive saltgrass (Spartina) marshes of the east coast are not characteristic of the Pacific. In many estuarine areas on the Pacific coast, the usual environments occupied by Spartina in the east are occupied by the pickleweed, Salicornia. In California, Spartina distribution is spotty. Many of the bays have been converted to marinas, where vegetation of all sorts is limited. In Newport Bay there is a good stand of Spartina; in San Francisco Bay Spartina is sparse and restricted, and in Tomales Bay it is completely absent. In Oregon estuaries, the ecological niche of Spartina is occupied by a sedge, Carex lyngbya. The Spartina growing in Humboldt Bay has been identified as a species of Chilean origin, not the local S. foliolosa.

Introduced species of many diverse taxonomic groups now seem more characteristic of west coast estuaries than native species, and each new intensive systematic study reveals another immigrant. In San Francisco Bay, where there was no adequate 19th Century study, it is now impossible to be sure what is native and what is not. The most conspicuous introduced species, striped bass (Morone saxatilis), was extraordinarily successful until the last few years. It is now suffering reproductive failure; it has not yet been determined whether this problem is being caused by chemical pollution, parasitic infection, reduced stream flow, competition with more recently introduced species, or synergistic effects from some combination of these causes.

Most of the small, permanent streams that have estuarine reaches near their mouths and are important spawning streams for steelhead and silver (coho) salmon are in critical danger because of their location in the forested mountain country from northern California to Washington. Present-day forestry practices, including clear-cutting and overloading the cutover lands with pesticides and growth stimulants, can severely degrade estuarine water quality.

Logging not only degrades water quality, but also often results in downstream accumulations of logs and cuttings in estuarine reaches. These accumulations may interfere with the stability of baymouth spits, which provide important resting areas for salmon. There are very few major rivers left which are not "developed" with dams for power generation or diversion of irrigation water, and the small streams may become the mainstay for the perpetuation of salmon stocks.

ENDANGERED SPECIES ON THE PACIFIC COAST

The California gray whale, Eschrichtius robustus, after being hunted almost to extinction by whalers in the last century, has begun to recover under strict protection as an endangered species. Its increasingly obvious presence along Pacific shores is now sustaining a $35,000,000 industry of excursion boats and whale-watching voyages. The gray whale calves in the large lagoons of western Baja California, but is often observed swimming about in San Francisco and Tomales Bays. However, gray whales continue to be hunted by both Japanese and Russian whalers.

The northern elephant seal, Mirounga angustirostris, only a few years ago limited to a residual population on Guadalupe Island off the western coast of Baja California, has made an even more remarkable recovery than the gray whale. Elephant seals were first noted at Año Nuevo Island in 1955 and began to use the mainland beach at Año Nuevo about 10 years later. The first pup was born on the mainland in 1975, and by the winter of 1985-86 there were 640 elephant seals on the beach. The bulls arrive first, in November, and the pregnant females show up in mid-December. The population peaks in mid-January. In order to protect the bluff-top vegetation and to keep people from wandering on the beach too close to the animals, guard rails have been installed at the beach on the bluff's edge, and visits are by regularly conducted tours. These tours have become so popular that advance reservations are necessary, and regular bus service from inland communities to this comparatively isolated part of the coast for the tours has been arranged. An estimated 120,000 elephant seals have also established a rookery on the Farallon Islands. These animals are no longer hunted commercially for their oil, which undoubtedly explains their rapid increase.

The southern sea otter (Enhydra lutris nereis) once abounded from Alaska to southern California, and was hunted intensively for its valuable fur. It was reduced in the southern part of its range to a small population along the rugged coast south of Monterey. Since the discovery of this herd in the late 1930's after the opening of the coast highway, the sea otter has been protected as a threatened species. As its population has increased, it has expanded north of Monterey again as far as Santa Cruz. In an effort to improve its chances for recovery by establishing a new breeding colony, the U.S. Fish and Wildlife Service also translocated 60 sea otters from the central California coast to San Nicholas Island in 1987.

The sea otter has demonstrated an ability to harvest Pismo clams on open beaches, thus bringing it within the concern of this report. Because of its appetite for clams, abalone, and sea urchins (which have lately become a commercial fishery), sea otters have come more directly into competition with people.

The California Brown pelican (Pelecanus occidentalis californicus) ranges from British Columbia to Mexico; its original breeding range was from Monterey through Baja California in Mexico. In 1968 and 1969, the only significant breeding site was Anacapa Island; Santa Barbara Island was recolonized in 1980. Although at one time pelican productivity was greatly reduced by DDT and inadequate food supply, by 1988, reproducing populations had increased to where they are approaching recovery plan objectives. In the last few years, brown pelicans began to nest in an area near the Elkhorn Slough National Estuarine Sanctuary, on property that had once been a salt-evaporation works. About 2 years ago the California Conservancy obtained this property and turned it over to the California Fish and Game Department, the lead agency for managing Elkhorn Slough.

The California least tern (Sterna albifrons browni), the smallest of the terns, occurs in California from early April to September and probably winters in Mexico. It is distributed from San Francisco Bay to Baja California. It nests in bare areas of mixed sand, shells, and pebbles, mostly in southern California. There are perhaps a thousand pairs at this time. Breeding sanctuaries have been set aside in San Francisco, Bolsa Chica, and a number of military reservations.

The light-footed clapper rail (Rallus longirostris levipes) is on both the Federal and State endangered lists, and is a year-round resident in Salicornia marshes from Santa Barbara to San Quintin Bay, Baja California. It is protected in Newport Bay and Bolsa Chica and in several localities already set aside for the least tern. The recent expansion of refuge areas at Tijuana Slough also protects this bird. There are about 200 pairs remaining in California.

Belding's savannah sparrow (Passerculus sandwichensis beldingi) is a candidate for the Federal endangered list. This is a year-round resident of the Salicornia marshes of southern California and northern Baja California. It is now protected in Sal Beach, Upper Newport Bay, Bolsa Chica, and most recently in the Tijuana Estuary refuges. Only about 40% of its original range remains, and the breeding population was about 1,610 pairs in 1977.

The El Segundo blue (Euphilotes battoides allyni) butterfly is one of 13 insects on the Federal endangered species list (48 Federal Register 34182). The butterfly lives in what remains of the El Segundo Dunes, once a large coastal dune region now obliterated by the massive urban development of western Los Angeles. The butterfly survives in small colonies on two plots of land--one within the bounds of the Chevron Refinery at El Segundo and the other in a larger area on the property of the Los Angeles International Airport. It is not known how long the El Segundo blue will be able to find suitable habitat on the airport property. At the Chevron Refinery plot, the butterfly is protected from collectors by a chain-link fence adorned with a sign, ENDANGERED SPECIES SANCTUARY, and locked gates. The El Segundo Blue is completely dependent on wild buckwheat (Eriogonum parvifolium and E.

fasciculatum), and the Chevron preservation program includes elimination of competing vegetation and cultivation of buckwheat. Chevron has featured this effort in magazine advertisements and TV commercials. This rescue project at Chevron is being supervised by Dr. Chard A. Arnold of the Entomology Department at U.C. Berkeley. No estimates on population size are available, but it seems to be increasing slightly at the site. The adults live only a few days, which makes censusing difficult.

The Oregon silverspot butterfly (Speyeria zerene hippolyta) is a threatened species in northern Oregon and southern Washington. Its primary food is the western blue violet (Viola adunca) which grows in old dune meadows and on rocky headlands. A number of sites suitable for rehabilitation have been identified by the State of Oregon.

The peregrine falcon or duck hawk (Falco peregrinus) is widely distributed in North America and has been on the endangered list since 1984. Falcons have been observed along the Washington coast (possibly Peale's peregrine, Falco peregrinus pealei, of the Aleutians), but the only coastal record south of Washington for peregrines is Morro Rock (San Luis Obispo County), where breeding occurs. Morro Rock has been designated by California as an Ecological Reserve; rock climbing there is forbidden. At least one nesting pair has been observed on a high building in San Francisco; the pair preys upon the overabundant pigeons in the public parks.

PRESERVATION, CONSERVATION, AND COASTAL RESOURCE MANAGEMENT

FEDERAL PRESERVATION AND CONSERVATION

There are three national shoreline parks on the Pacific coast: Pt. Reyes National Seashore, Oregon Dunes National Seashore, and Olympic National Park. The Pt. Reyes National Seashore includes several miles of the shore of Tomales Bay, the rocky headlands of Tomales Bluff, Fourteen Mile Beach, and Drakes Estero, a large body of water protected from the open sea by Limantour Spit. The Pt. Reyes National Seashore extends southward to just north of Duxbury Reef, one of the few mudstone outcrops on the ocean coast. This National Seashore is contiguous with the Golden Gate National Recreation Area (except for the town of Bolinas) all the way to the Golden Gate. The Oregon Dunes National Seashore is, as the name implies, a long reach of beach with extensive dune fields. In Washington, the shoreline part of the Olympic National Park is for the most part a spectacular reach of cliffs, offshore stacks, and islets; almost no barrier shoreline is included.

Protected Federal lands also include the National Wildlife Refuges. On the coast these are primarily for the protection of marine birds. Most of the offshore rocks, stacks, and islands along the Washington and Oregon coasts and many along the California coast are part of the National Wildlife Refuge System.

In addition to these national parks and refuges there are several military reservations that control extensive beaches. Fort Ord covers the area between the Salinas River and Seaside in Monterey County, and Vandenberg Air Force Base controls part of the Nipomo Dunes area to Pt. Arguello. Mugu Lagoon is owned by the Navy and public access to the area is restricted. Camp Pendleton also excludes the public from the beach between about San Onofre and Oceanside in San Diego County.

STATE AND LOCAL PRESERVATION AND CONSERVATION

Five State parks in Washington lie on the coast. Oregon has an extensive park system, and California has a multitude of State, county, and municipal parks along the coast. In most of these, however, beach processes and ecological aspects are not specifically protected. However, any dedicated park or reserve does protect the area from uncontrolled residential development.

In addition to its park system, Oregon has several ecological reserves on the coast, primarily for the protection of intertidal flora and fauna. These have no legal status, but collection of specimens here is either forbidden or restricted. California has a plethora of various categories of reserves, special areas, and so on, but the only legal status is for areas designated by the Legislature as areas of "special biological significance." These are usually areas adjacent to marine research stations. The State recognizes the right to fish in most reserved areas.

California also has a State Coastal Conservancy, which is intended to be the action arm of the Coastal Commission "to protect and enhance California's coastal and San Francisco Bay resources." Its function is primarily to arrange for land purchases and provide funding for pathways, bridges, comfort facilities, and the like in coastal parks. It has no policy for land and beach preservation as such.

STATE COASTAL ZONE MANAGEMENT PROGRAMS

Washington

The Shoreline Management Act of 1971 (Revised Code of Washington, Chapter 90.58) is the official title (for reference purposes) of Washington's Coastal Zone Management Law. It occupies 13 printed pages. The Act is implemented in Chapter 173.14 to 173.22 of the Washington Administrative Code concerning definitions, guidelines for development of master programs, a listing of all the stream and lake shorelines of the State, and designations of wetlands. According to the opening statement of the Shoreline Management Act, "The Legislature finds that the shorelines of the State are among the most valuable of its natural resources and that there is great concern throughout the State relating to their utilization, protection, restoration, and preservation . . . There is, therefore, a clear and urgent demand for a planned, rational, and concerted effort, jointly performed by Federal, State, and local governments, to prevent the inherent harm in an uncoordinated and piecemeal development of the State's shorelines" (Revised Code of Washington, 90.58.020).

The Act is administered by the Department of Ecology and requires local agencies (cities and counties) to develop master programs for regulation of uses of shorelines. The programs are reviewed by the Department of Ecology and presented at public hearings where interested parties can submit statements and views. After 90 days the programs are adopted at public hearings by the Department of Ecology. If a local agency does not submit a program, the Department of Ecology is required to provide one. A special commission of the department (the Shoreline Hearings Board) is set up to hear appeals. Washington's Shoreline Management Act is the simplest shoreline management law of the three Pacific States. The Act has worked reasonably well and, most significantly, has resulted in better planning decisions.

Oregon

The Oregon coastal management legislation has no specific official name; it is often referred to as SB (Senate Bill) 100, and is to be found in Chapter 197 of the Oregon Revised Statutes (ORS) under the heading "Comprehensive Land Use Planning Coordination." This legislation sets up the Land Conservation and Development Commission. As the name implies, this commission has jurisdiction over both inland and coastal conservation and development. It consists of seven members, one from each congressional district, appointed by the governor and subject to Senate confirmation. At least one must be an elected city or county official at the time of appointment. In addition, there is a Joint Legislative Committee on Land Use whose duties are principally to make recommendations to the Legislature. The law requires local governmental bodies (cities and counties) to develop local plans according to statewide mandatory standards ("goals") and suggested approaches ("guidelines"), and subject to review and approval by the Commission. According to ORS 197.010, the purpose of the legislation is "to assure the highest possible level of livability in Oregon." The Commission is empowered (subject to approval by the Legislative Assembly) to designate "areas of critical concern" and establish boundaries and use provisions for such areas.

Filling and dredging are included under water laws ORS 541.605-541.665, which apply to inland waters as well as tidal and coastal waters. These statutes are administered by the Director of the Division of State Lands who may grant or deny permits in these matters and set conditions of use. The director may hear appeals, and an applicant who is denied may take the final order to the Court of Appeals. With respect to filling or dredging in an estuary, the director "shall require," as a condition of the permit, "mitigation," which is defined as "the creation, restoration, or enhancement of an estuarine area to maintain the functional characteristics and processes of the estuary, such as its natural biological productivity, habitats and species diversity, unique features, and water quality." The State is in the process of taking over the Federal Clean Water Act Section 404 program from the U.S. Army Corps of Engineers.

California

Article X, Section 4 of the California Constitution states that the people shall always have access to the navigable waters of California and ordains that the Legislature "will give the most liberal construction to this provision so that access to the navigable waters of this State shall always be attainable for the people thereof." During the 1960's, the development of the coast for residential and commercial purposes, beyond and above the necessary requirements for ports, increased at such a rate that it became obvious that within a few years there might be hardly any part of the coast, especially in southern California, accessible to the general public. Local government agencies were unable or unwilling to attempt to control the situation, and it was obvious the State Legislature would not act. The public reaction was to pass an initiative amendment, the "California Coastal Zone Conservation Act of 1972," to the State Constitution in November 1972. Popularly known as Proposition 20, this amendment set up a statewide California Coastal Zone Conservation Commission with two major responsibilities: to judge permit applications for use of land within 1,000 yd of the coastline, and to submit detailed recommendations to the Legislature for conservation and development of the coastal zone by 1976.

Proposition 20 also established six regional commissions. Permit applications originate with the regional commissions, and if appealed, are reviewed by the State commission. The regional commissions also assist local political bodies (including harbor commissions) in the preparation of local coastal plans. If a local agency does not meet the deadline for its local plan, the commission prepares a local plan. Each plan must be approved by the appropriate county board of supervisors before referral to the regional commission. At the outset of this program, the State Personnel Board set a preference for commission staff personnel with experience in urban planning, and it took some time before the commission was able to hire the necessary staff qualified to evaluate many of the technical considerations in the plans. The two-tiered committee structure has sometimes proved cumbersome and time-consuming.

In 1976, the Legislature adopted the California Coastal Act of 1976 and the State Coastal Conservancy Act of 1976. These are found in §§30,000 and 31,000 of the California Public Resources Code, Divisions 20 and 21, pages 181-288. The Coastal Conservancy Act sets up a seven-member committee (The Coastal Conservancy) with three ex officio and four public members. Its function is to carry out the policies of the Coastal Act concerning access and facilities for public use of the shore. The Conservancy can purchase land and grant funds to local agencies and citizens' groups for building structures and other facilities to improve and maintain shore accessways.

California's coastal legislation is the most complicated of the three Pacific coastal States. The Coastal Conservancy Act, however, is unique and its programs are some of the most successful aspects of California's coastal management program.

SUMMARY

Coastal barrier spits and bay-mouth barrier beaches are a characteristic feature of the Pacific coast shoreline and perform functions similar to the coastal barriers of the Atlantic coast in protecting the estuaries and lagoons behind them. There are also several extensive barrier-dune fields on the Pacific shore, of which the Oregon dunes are the best example. Vernal ponds, lakes, and ponded streams provide freshwater habitats in these regions.

Most barrier beaches and sand spits depend on sand transported by littoral drift for maintenance as ecologically viable habitats. Much of the sand transported by the process originates from the uplands, carried by stream flow or eroded from coastal bluffs.

Although beaches are equilibrium formations whose width, slope, and average sand grain size are determined by the forces of wind, waves, and currents, they can be quickly altered by intense storms, unusually high tides, or tsunamis. However, in reacting and adjusting to these disturbances, beaches are much more resilient features than rigid sea walls and jetties, which may break down or divert wave action so that it strikes with even greater force.

Structures built on beaches or cliff edges are at the mercy of storms. The Pacific coast had severe storms in 1983 and 1986. Some climatologists are suggesting that we are entering a period of wider variation in weather patterns; that is, we may expect a pattern of increased frequency of both heavy storms and quiet, possibly dry years. This may mean that building or water planning with the notion that the greatest anticipated storm may occur only once in a century may be erroneous, and that we can perhaps expect the "hundred year storm" much more often.

Sandy beaches are important habitats for fish, clams, and other organisms. Beach-inhabiting crustaceans, worms, and clams are an important food source for shorebirds. Migrating shorebirds use some lagoons and coastal estuaries as "staging areas," to prepare for or recuperate from their journeys. Estuaries are also critically important areas for migrating salmonid fishes.

The concept of "endangered species" is based on the conviction that such species are endangered by human activities, and that people can take measures to protect them and possibly enhance their survival. Several endangered species in the coastal environment have been placed under protection, such as the sea otter, elephant seal, and gray whale. These three species seem to be doing well, possibly because there is still enough aquatic and shoreline habitat left in which they can survive. Some terrestrial endangered species that have special environmental requirements may be in greater danger.

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