4 Temperate Zone Coastal Dunes

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4.1 Coastal Temperate Zone Climates

Almost half of the world's coastal areas are included in the temperate climatic zone, and of these areas, many support coastal dune systems. The objective of this chapter is to characterize the vegetation of these dune areas and to show how their plants can be sensitive indicators of small climatic shifts as well as the transitions to adjoining polar and Mediterranean/tropical climates. The use of the word "temperate" as in "temperate zone climate" implies a physical habitat that experiences neither wide extremes of temperature nor very low levels of precipitation. In its broadest sense, it refers to the areas of the Earth lying between 23.5° and 66.5° latitudes on both sides of the equator. These boundaries, however, are determined by astronomical factors that have very little to do with the physical and biological factors governing the growth and distribution of plants. For the purposes of this chapter, the classification of Bailey (1958), used by Van der Maarel (1993) in the *Dry Coastal Ecosystem* volumes, will be the basis for defining "temperate zones" based on physical data. Bailey uses a number of parameters in the classification: maximum mean temperature of the warmest month, minimum mean temperature of the coldest month, annual precipitation, and percent precipitation in summer. There are two types of temperate zones: "wet winter temperate" (WWT) and "wet summer temperate" (WST). Most temperate coastal zones fall into the wet summer group. Only a few, chiefly along the west coast of North America and in New Zealand, are of the wet winter type. All of the coastal zones of Europe, from the Baltic Sea to approximately the north shores of the Mediterranean Sea (about 60°N to 45°N) are of the wet summer type. In both Hemispheres temperate zones are bordered poleward by the subpolar (SPO) and toward the equator by the summer-dry subtropical (SDS) (Mediterranean) climatic zones.

The dune systems of these temperate coastal zones are characterized by a variety of distinct plant habitats: upper beach, foredune, backdune or sand plain, deflation plain, slack, and old stabilized dune, this last defining the inner margin of the Holocene dune field. Distinctive plant communities

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occupy these habitats. The upper beach and foredune are occupied by plants tolerant of salt spray, strong winds, and sand burial. These communities tend to be permanent because of the special adaptations required to grow and thrive. On the lee side of the foredune and the broad sand plain frequently found farther inland begins a succession with a set of plants that initially stabilize the sand. These sand-tolerant grasses and forbs gradually cover the sand surface with a dense mat-like layer of vegetation. Once this dune mat is fully developed, shrub species (and sometimes tree species concurrently) become established. The "shrub stage" may persist a long time or only briefly, depending on microclimatic conditions (such as the presence of ground water, the distance from shoreline, and salt spray effects, as well as a source of tree seeds). On the "most temperate" coastal areas, a forest eventually develops that contains many tree and shrub species found in adjoining habitats. Where there is a gradual shift to Mediterranean climates, scrub or chaparral develops and remains more or less permanently.

Table 4.1 is a floristic characterization of selected temperate zone coastal dune areas based on regions delineated by Van der Maarel (1993). Easily seen is the almost universal occurrence of similar species and genera on the upper beach and the active sands of the foredune. Behind the foredune, where stabilization is taking place, there is less similarity. At the shrub stage of vegetation development, communities are more heterogenous depending upon variation in the microclimates of the site. Finally, at the arborescent stage (if there is one) there is identity with the regional tree flora. This has been noted and discussed in many ways (see, e.g., Doing 1985).

The climatic zones, no matter what the basis for their delineation, do not have sharp boundaries, but change gradually. In general, plants signal the transition from one zone to another quite clearly, either as single species or as small groups of species. Because of the ameliorating effect of the sea on local climate, beach species tend to be almost azonal in their occurrence, having worldwide distributions at the species level (e.g., *Honkenya peploides, Cakile maritima*). On the foredunes identity is more at the generic level, especially in the Northern Hemisphere. In fact there seems to be a continuity in species and growth form around the Northern Hemisphere. Consider, e.g., *Carex macrocephala* and *Carex kobomugi* linking Asia and North America or *Leymus mollis* and *Leymus arenaria* linking northern Europe and North America. The connections in the Southern Hemisphere are not so clear; the small number of temperate climatic zones and the long isolation may be factors. However, the physiognomy and vegetation zonation are similar everywhere. There is, however, one universal link. The obligate psammophyte *Ammophila arenaria* (along with its subspecies and its congener, *Ammophila breviligulata*), has a distribution, both natural and human-induced, that lies roughly between 32° and 60° on both sides of the equator. Because of the effectiveness of these species in stabilizing active dunes, they (chiefly *Ammophila arenaria*) have been introduced into almost every part

Table 4.1. Floristic characterization of selected temperate zone (wet summer and wet winter) coastal dune areas. Areas were selected on the basis of their floristic and physiognomic representation of the major temperate zone dune systems. Location codes in parentheses refer to relevant chapters in Van der Maarel (1993), the letter A or B refers to volume, the number to the chapter in the volume. Species listed are typical of the locality, but not peculiar to it

Location	Beach and foredune	Dune mat[a]	Stabilized shrub	Old dune forest
S Norway	*Cakile maritima/Honkenya peploides*	*Cladonia* spp.	*Empetrum nigrum*	*Quercus robor*
58°N (A9)	*Ammophila arenaria/Elymus farctus*	*Sedum acre*	*Calluna vulgaris*	
Netherlands	*Cakile maritima/Elymus farctus*	*Festuca rubra*	*Hippophae rhamnoides*	*Quercus robor*
52°N (Al7)	*Ammophila arenaria*	*Oenothera ammophila*	*Salix arenaria*	*Betula pendula*
Japan	*Glehnia littoralis/Lathyrus japonicus*	*Calystegia soldanella*	*Rosa rugosa*	*Quercus dentata*
44°N (B13)	*Carex macrocephala/Leymus mollis*	*Carex kobomugi*	*Celastrus orbiculata*	
New Zealand	*Cakile edentula/Ammophila arenaria*	*Euphorbia glauca*	*Lupinus arboreus*	*Kunzea ericoides*
44°S (B15)	*Desmoschoenus spiralis*	*Calystegia soldanella*	*Sambucus nigra*	*Podocarpus totara*
New Hampshire	*Honkenya peploides*	*Hudsonia tomentosa*	*Myrica pensylvanica*	*Pinus rigida*
USA – 42°N (B22)	*Ammophila breviligulata*	*Lechea marítima*	*Prunus marítima*	*Acer rubrum*
S. Carolina	*Uniola paniculata*	*Iva imbricata*	*Ilex vomitoria*	*Quercus virginiana*
USA – 32°N (B22)	*Panicum amarum*	*Spartina patens*	*Myrica cerifera*	
Oregon	*Ambrosia chamissonis*	*Festuca rubra*	*Vaccinium ovatum*	*Pinus contorta*
USA – 47°N (B23)	*Ammophila arenaria/Leymus mollis*	*Solidago spathulata*	*Gaultheria shallon*	*Tsuga heterophylla*
Pt. Reyes	*Cakile marítima*	*Eriogonum latifolium*	*Ericameria ericoides*	Coastal scrub[b]
USA – 38°N (B24)	*Leymus mollis/Ambrosia chamissonis*	*Erigeron glaucus*	*Lupinus chamissonis*	
Argentina	*Cakile maritime*	*Panicum urvilleanum*	*Baccharis genistifolia*	*Acacia cavenia*
39°S (B33)	*Spartina coarctata*		*Celtis spinosa*	

[a]Dense ground cover of herbaceous species on back dunes and sand plains
[b]Coastal scrub and chaparral represent the transition to a Mediterranean climate

of the world. In Europe, with its long history of planting the species widely for "coastal defence" *Ammophila arenaria* is found on all coastal dune areas of the European temperate zone (Huiskes 1979). Its northern-most occurrence seems to be southern Finland, at 60°N (Hellemaa 1998). It was introduced into South Africa in the 1870s and widely planted. It did not naturalize, but maintained populations without spreading (noninvasive) (Hertling 1997). In Australia (Wiedemann, pers. observ.), it has been planted in the Perth and Sydney areas, but did not spread here either. It flowers poorly, if at all, and does not compete well with the native *Spinifex* species. Its poor growth at the latitudes of these three places (32°S) indicates the species is probably at the equatorial limit of its range. A little farther south, on the southwest coast of Western Australia (35°S), it grows well but still does not spread to any significant extent. At Wilson's Promontory in Victoria, southeast Australia (40°S), it grows and reproduces vigorously. It also grows well in Tasmania (41°–44°S) and is well established in New Zealand (40°–45°S). In 1927 it was introduced to the Falkland Islands (55°S) and today is a major component of the littoral vegetation (Moore 1968).

On the east coast of North America, the native *Ammophila breviligulata* has a natural distribution from eastern Canada (50°N) to South Carolina (32°S), where it is replaced by the ecologically equivalent *Uniola paniculata* (Stalter 1993). *A. breviligulata* is found also on the shores of the Great Lakes (Maun 1993). It occurs today in scattered small patches on the Pacific coast, but was introduced in stabilization plantings. From the moment in 1869, when *Ammophila arenaria* was first planted on the active dunes that today underlie the city of San Francisco, the species flourished. Within 75 years, both through natural spread and large-scale planting, *A. arenaria* spread along the entire west coast of N. America, from about 34°N at Los Angeles to Vancouver Island (49°N), then to 54°N on the Queen Charlotte Islands (Breckon and Barbour 1974). This distribution on the west coast of North America is of interest in two respects.

First, it is continuous between its latitudinal limits, from the subpolar in the north to full Mediterranean in the south; only a few upper beach species with global distributions share this characteristic. Secondly, it is on the west coast of North America that the first alarms were raised with respect to the effect of the grass on native plant communities and on the very morphology of the dunes themselves.

4.2 Coastal Dunes of Western North America

This very long, continuous temperate zone coastline, the very active "dune restoration" activities along its length, and the intimate knowledge the authors have of its history and characteristics, make this area suitable to present as a case study. Coastal dunes are a common feature along the 2091 km shoreline from Cape Flattery at the northwestern-most tip of Washington State to San Diego in California (48° to 32°N). Dunes occur on 610 km of this shoreline.

There are small dune systems on the west coast of Vancouver Island (49°N) and the northeast corner of Graham Island of the Queen Charlottes (54°N). The overall directional trend of the coast is west of south along the north half; at Cape Mendocino, about half way down, it rounds to east of south to the Mexican border. The annual wind regime is fairly consistent along the entire coast, with local deviations and a somewhat weakening of the general pattern southward (Cooper 1958, 1967). In summer (June to August) onshore winds from the sector N-NW greatly predominate. They result both from off-shore high pressure centers and sea-land winds. These winds have a high average velocity. In winter (December to March) onshore winds from the sector S-SW related to seasonal low pressure centers predominate. The centers produce frontal storms that bring heavy rains and strong south to southwesterly winds.

These wind regimes, along with abundant sand supply, an extensive receptive shore, and variations in coastal trend, produce a variety of dune forms (Wiedemann 1984). North and south of the Columbia River, accreting shorelines have resulted in a series of beach ridges parallel to the shore. South of the river at least nine ridges can be seen, all presently stabilized. Farther south on the Oregon coast very large parabola dunes (many over 1 km in length) have been produced, mostly by the winter winds. At one location "nested" parabolas, over 4 km in length have resulted from cycles of active sand movement and subsequent stabilization by plants. In California most of the dune systems are made up of parabola dunes (Fig. 4.1). On the central Oregon coast are extensive active dune fields (Fig. 4.2) extending several km inland with massive winter transverse dunes (crests 1000 m long and 50 m high) moving northward, formed and driven by the winter winds. Smaller transverse dunes are formed and driven southeasterly by the summer winds.

Neither of these two kinds of dunes is vegetated. The foredune has a significant history. Formerly present in southern California as a shoreline zone of large hummocks (or mounds) and as an upper beach ridge in northern California, early accounts and aerial photographs indicate it was absent along the Oregon coast (Cooper 1958), except for the prograding shoreline at the mouth of the Columbia River in the north. The present day foredune along the west coast is entirely the result of the introduction and spread of *Ammophila arenaria,* a high, broad foredune developed in less than 100 years. The native flora of the foredune has been almost entirely replaced by this aggressive species (Wiedemann 1998; Wiedemann and Pickart 1996).

Table 4.2 demonstrates the significant shift in climate along the Pacific coast as reflected in the distribution of selected dune species. It is distinctly wet winter from Neah Bay at the northern tip of the Washington coast to

Fig. 4.1. Parabola dunes at Humboldt Bay, northern California. View is to the south. The distance from shore to parabola tip exceeds 1000 m. (Photograph by A. Wiedemann, June l983)

Fig. 4.2. The winter transverse dunes of the central Oregon coast. View is to the south, the dunes moving toward the observer (note slip faces). Average crest length is about 1000 m and height above dune base can exceed 50 m (Cooper 1958) (Photograph by Oregon Dept. of Transportation, May 1972)

Table 4.2. There is a pronounced climatic shift at about 37°N, reflected in precipitation, temperature, and species distribution. Santa Cruz is about halfway down the coast between Neah Bay and San Diego. Only one species, *A. chamissonis*, continues into the true Mediterranean climate. The temperate zone species begin dropping out at Newport, the remainder are out by Santa Barbara

Locality Latitude	Neah Bay 48°N	Ilwaco 46°N	Newport 44°N	Coos Bay 43°N	Arcata 41°N	Santa Cruz 37°N	Santa Barbara 34°N	San Diego 32°N
Mean maximum temperature (°C), warmest month	15	19	17	19	16	24	23	25
Mean minimum temperature (°C), coldest month	3	2	3	3	5	3	4	8
Mean annual precipitation (mm)	1960	2060	1680	1610	1060	760	410	250
Precipitation in summer (%)*	23	22	27	18	14	8	6	9
Ambrosia chamissonis	—	—	—	—	—	—	—	—
Ammophila arenaria	—	—	—	—	—	—	—	
Fragaria chiloensis	—	—	—	—	—	—	—	
Abronia latifolia	—	—	—	—	—	—	—	
Leymus mollis	—	—	—	—	—			
Lathyrus japonicus	—	—	—	—	—			
Carex macrocephalus	—	—	—					
Phacelia argentea				—	—			
Eriogonum latifolium				—	—	—		
Abronia maritima						—	—	—

about Coos Bay on the southern Oregon coast. From there to Arcata, on the north coast of California, the gradual shift to a Mediterranean climate is reflected in the greatly decreased precipitation. New species appear in the transition zone. From Santa Cruz southward the climate is distinctly Mediterranean.

4.3 Conservation and Management

The introduction and spread of *Ammophila* has resulted in major changes in the dune landscape. A highly successful competitor, *A. arenaria* has "taken over" or created most of the existing foredunes throughout its current range. In most places it has virtually eliminated the native dune-forming species and the distinctive low, open, rounded and high diversity foredunes created by them (Fig. 4.3). The native dunegrass, *Leymus mollis,* was once prevalent on beaches and foredunes of the western U.S coast north of 38°N (Barbour and Johnson 1988). Significant stands of this grass are now restricted to dune systems at Point Reyes and Humboldt Bay, California. In addition, *A. arenaria* has invaded many back dune ridges and completely stabilized some formerly active dunes. At Bodega Bay, California, where *A. arenaria* was extensively planted (Cooper 1967), the entire parabola dune system has been virtually frozen under a dense blanket of *A. arenaria.* Along the central Oregon coast the massive high foredune created by *A. arenaria* (Fig. 4.4) has cut off all sand supply from the beaches to the back dunes. It is not known how dependent the high winter transverse dunes are on a continual supply of sand from the beach, but the lack of sand has resulted in the wind eroding an extensive back-dune sand plain to the water table – a "deflation plain". Vegetation develops quickly and follows the progressive development of the deflation plain toward the base of the high dunes (Fig. 4.5). The perceived "danger" (according to "dune managers") is that this scenic dune landscape will soon vanish under a dense mat of vegetation.

Despite the widespread invasion of *A. arenaria* worldwide, management (control and eradication) of this species has until recently been confined to the west coast of North America. In his seminal work on the coastal dunes of Oregon and Washington, Cooper (1958) noted the topographic and vegetation changes brought about by this species: higher, more sharply ridged, densely vegetated foredunes, and the colonization of open dune fields and dune mat leading to a hummocky topography dominated by *Ammophila* and overall to a repressive effect on the native dune flora. His observations were soon followed by alarm over the impact of the species on coastal dune biodiversity (Breckon and Barbour 1974; Barbour et al. 1976). By the early 1980s, experimental trials in controlling the species had begun at what is now the Humboldt Bay National Wildlife Refuge (Lanphere Dunes Unit) by The Nature

Fig. 4.3. Lower, more rounded profile of foredune at Humboldt Bay, California, after restoration (removal of *A. ammophila*). Vegetation is dune mat. (Photograph by A. Pickart)

Conservancy (Van Hook 1985). The first successful eradication program, using manual techniques, was completed there between 1992–1996 (Pickart and Sawyer 1998). Similarly, recent research on the impacts (primarily loss of native plant habitat) of the species in Australia and New Zealand (Duncan 2001; Heyligers l985; Humphries 1996) has led to the initiation of control efforts: attempts to stop its spread and, if possible to eradicate it.

There are currently numerous *A. arenaria* control programs being implemented along the US west coast that are intended to restore natural dune processes. Methods of control include one or a combination of techniques: manual removal, excavation/burial with heavy equipment, burning, and application of the herbicide glyphosate (Pickart and Sawyer 1998). Projects relying on manual removal enjoy the advantage of unaided native plant recovery through the dispersal of relict native plants and the ameliorating conditions (relative stability, fertility, and moisture) created by decaying rhizomes of *A. arenaria* left in place. However, this method is extremely labor-intensive and mostly suitable for areas in which *A . arenaria* has not become extensively established.

The original project at Humboldt Bay resulted in eradication of 10 acres (4 ha) of dense *A. arenaria* growing on the foredune and adjacent dune ridges.

Fig. 4.4. Typical steep profile foredune vegetated with *Ammophila arenaria* prior to restoration. Humboldt Bay, California. (Photograph by A. Pickart)

This project was carried out over a 4-year period (1992–1996) at a total cost of US$ 350,000. By the final year of treatment native cover was 36 % of that measured in comparable, uninvaded areas; by 2002 it had reached 100 % (unpubl. data). Removal of *A. arenaria* returns the dunes to an early stage of vegetation development, adding back in the important agent of instability. Species diversity is predictably lower (by approximately 10 %) than in comparable native areas. Restored conditions favor those species that rely on disturbance and openings in the vegetation, including the federally listed endangered annual species *Layia carnosa*, which occurred at increased densities in the year following restoration.

Although the first restoration efforts targeted only the earliest and most obvious plant invaders, advances in awareness and understanding of the dune ecosystem has led both to earlier detection of problems and to more systems-based approaches to restoration. Restoration efforts now focus on re-establishing dune processes, and involve management of multiple taxa in an integrated fashion. These include, in addition to *A. arenaria, Lupinus arboreus* (native south of 30°N, but introduced and invasive on dune systems to the north), *Carpobrotus edulis,* and a suite of annual grasses (including *Bromus diandrus, Vulpia bromoides, Briza maxima,* and *Aira* spp.). Vegetated dunes south of 38°N are also susceptible to invasion by *Ehrharta calycina,* which has led to the conversion of large areas of native dune scrub to non-native grass-

Fig. 4.5. Dune mat vegetation on the central Oregon coast with shrub (*Arctostaphylos)* and tree *(Pinus)* vegetation becoming established. (Photograph by A. Wiedemann)

land (Pickart 2000), and *Conocosia pugioniformis* which is in a relatively early stage of invasion, but has the potential to impact foredune and dune scrub communities (Albert and D'Antonio 2000).

The type and severity of these invasions vary. Some invoke complex ecosystem changes. For example, the intrusion of *Lupinus arboreus* into the native, herbaceous dune mat of northern California results in soil enrichment that triggers invasions of other plant species (Pickart et al. 1998). Together and individually, however, these invasions share the important consequence of greatly reducing or eliminating sand movement. Whereas plant succession in dunes moves the system naturally towards stability, non-native invasions greatly accelerate the process (Wiedemann and Pickart 1996). One result is rapid local extinction rates, with long-term consequences for the re-establishment of early successional species after the infrequent, large-scale tectonic events that periodically rejuvenate dunes in the Pacific Northwest (Clark and Carver 1992; Leroy 1999).

The full extent of the impacts of plant invasions on dune systems worldwide is unknown. There are only a few places in which any assessment has been attempted. At the Humboldt Bay dunes, a geographic information system (GIS) was employed to map and classify dune vegetation (Aria 1999). The results indicated that 52 % of total dune vegetation, or 82 % of non-forested vegetation, was dominated by introduced species. A rough estimate in 1997 of total area occupied by *A. arenaria* along the west coast of the US south of Florence, Oregon, exceeded 6000 ha (Pickart 1997). Clearly, "the *Ammophila* problem," and that of other invasive dune species, is of a magnitude far exceeding the resources available to address it. Careful prioritization of conservation efforts is essential, divided appropriately among preservation, restoration, and management, including steps taken to slow or prevent further invasions.

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