

1 A Perspective on Coastal Dunes

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1.1 Coastal Dunes and Their Occurrence

Coastal dunes are eolian landforms that develop in coastal situations where an ample supply of loose, sand-sized sediment is available to be transported inland by the ambient winds. They are part of unique ecosystems which are at the spatial transition between continental/terrestrial and marine/aqueous environments. Coastal dunes are part of the sand-sharing system composed of the highly mobile beach and the more stable dune. A large variety of coastal dune forms are found inland of and above the storm-water level of sandy beaches and occur on ocean, lake, and estuary shorelines. They are distributed worldwide in association with sandy beaches, producing a wide range of coastal dune forms and dimensions related to spatial and temporal variations in sediment input and wind regime (Gimingham et al. 1989; Nordstrom et al. 1990; Carter et al. 1992; Pye 1993; Hesp 2000). They tend to exist wherever barrier islands or wave-dominated depositional coastal landforms occur (Fig. 1.1).

1.2 Relevance of Coastal Dunes

Because they are found almost in all latitudes, the climate and biomes developing on coastal dunes are very diverse, covering ecological habitats which range from polar to tropical latitudes, and from deserts to tropical rain forests (Snead 1972; van der Maarel 1993a, b; Kelletat 1995). Thus, one of the most outstanding features in these ecosystems is their broad distribution and ecological diversity (in terms of geomorphological dimensions, environmental heterogeneity, and species variability). Yet, despite their seeming abundance on the global level, many coastal dune ecosystems have been severely degraded as a result of an excessive exploitation of natural resources, chaotic demographic expansion, and industrial growth. For a long time, coastal dunes

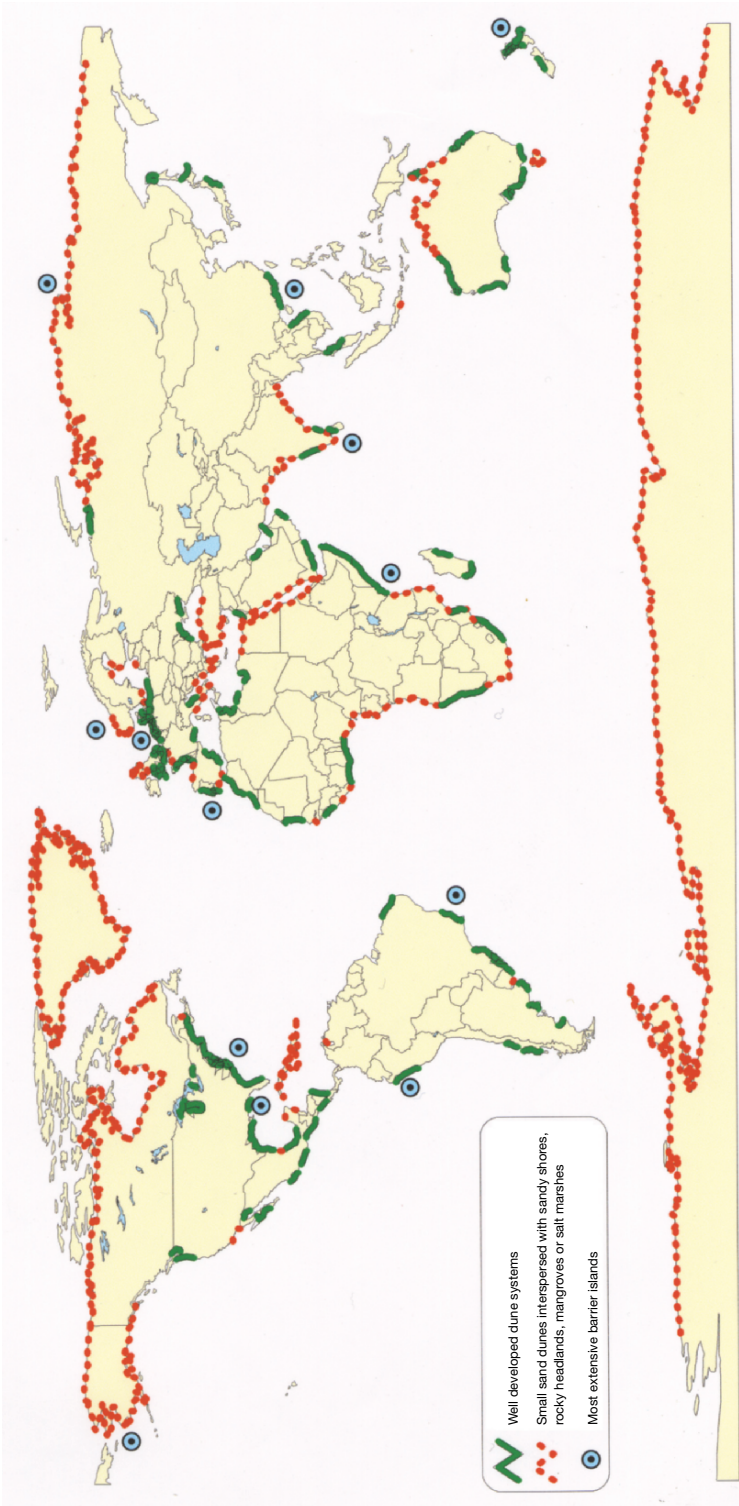


Fig. 1.1. Widespread distribution of coastal dunes is coincident with the worldwide occurrence of wave-dominated sandy beaches and with coastal barrier systems. Further, coastal dunes exist more extensively where areas of persistent coastal sand supply and dominant onshore winds favor episodes of inland transport to create broad dune fields. Active as well as stabilized coastal dunes of various scales and morphologies are recognized as products of coastal dynamics. (The map was generated from descriptions in van der Maarel 1993a, b)

have been used for many different purposes: coastal defense, water catchments, agriculture, mining, housing and tourism (Carter 1991). In addition, as part of the coastal landscape, dune areas serve as locations of groundwater recharge and assist in the retention of freshwater as a buffer against saltwater intrusion. Furthermore, specialized vegetable and fruit crops are grown in interdune depressions (van der Maarel 1993b). All these activities result in economic benefits to the human populations.

Besides their economic relevance, coastal dunes have intrinsic value related to their spatial and temporal dynamics at the sharp boundary between land and sea. For instance, they have been sites of important ecological research projects since the 19th century. Early studies conducted in these environments generated some of the first ecological theories that help to understand how ecological systems function. For example, during the early days of ecology as a science, Henry Chandler Cowles (1899) studied the spatial and temporal associations of the vegetation of Lake Michigan sand dunes. Cowles assumed that vegetational changes in space paralleled vegetation changes in time and, based on this assumption, his studies yielded the first evidence of succession. Furthermore, he was the first to develop a dynamic perspective of the interaction between vegetation and geological formations. The studies by Cowles were seminal for Frederic Clements who, almost 20 years later (1928), further developed the successional theory of plant communities.

Coastal dunes also represent an important cultural value. For example, in New Zealand the earliest human settlements occurred in coastal dunes (Hesp 2000). Thus, many of their dune areas contain archeological evidence of their cultural Maori heritage. In Peru, the early hydraulic civilizations extended down valley into the migrating coastal dune fields (Parsons 1968). In The Netherlands, the Dutch dunes have been portrayed by many painters, and the dunes also figure in some patriotic Dutch folk songs.

1.3 Current Conservation Status

The influence of humans on the coastal environment is large and has occurred for a long time. In particular, the widespread marketing of coastal recreation has increased drastically in the last 50 to 80 years, which has led to the deterioration of many previously scenic coasts and well-preserved coastal ecosystems. Currently, a large proportion of the worldwide human population lives within 10 km of the coastline. An example of the high degree of modification to coastal dunes occurs in New Zealand, where more than 115,000 ha of drifting dunes have been converted to forestry and agricultural activities during the last 80 years (Hesp 2000). In The Netherlands, large parts of the inner old dunes have been excavated, and the sand was used for the expansion of towns and cities into the low areas inland of the

dunes (Carter 1991). In the USA, 70 % of the population visit beaches when they go on vacation. In Australia, 83 % of the population lives near the coast, 25 % within 3 km, resulting in increasing pressure on the coast (Hesp 2000). These proportions probably hold true for many countries in the world. As a result, many coastal dune systems of the world are in advanced stages of degradation and in many cases native and endemic species have been eliminated and replaced by introduced exotics (Grootjans et al. 1997). Other coastal dunes have been completely removed in the process of providing living space for the encroaching human population. A consequence of this reduction and removal of coastal dune topography is that the potential for storm surge damage has increased noticeably in the coastal zone. Further, the rate of change associated with construction in the coastal zone (and the loss of irreplaceable ecosystems) is occurring several times faster (two to three times as fast in the US) than the changes occurring inland. Additional impacts on coastal dunes associated with human activities are water extraction, trampling, invasive species, grass encroachment, sea-level rise, and climate change. The result of this worldwide intensive and consumptive use of coastal dunes is that many dune systems are already irreversibly altered and lost. Fortunately, there remain impressive stretches of the world's coast that still preserve pristine or minimally-disturbed ecosystems, incorporating a wide variety of coastal dune settings and ecosystems. Because it is likely that human development and activities on the coast will continue, these minimally-disturbed areas are in urgent need for appropriate management and conservation policies to ensure that they will retain their characteristics and will be available to future generations.

1.4 Aims and Scope of the Book

The continuation of scientific investigations into the understanding of dune processes and the functioning of this portion of the coastal ecosystem will contribute important data necessary for the enlightened stewardship of these dynamic and naturally evolving coastal morphologies, and it will promote their conservation, protection, enhancement and wise utilization as appropriate. Because of their relative economic importance, sand dunes have been studied for a long time. The oldest known study on the vegetation of coastal dunes was performed in 1835 by Steinheil (van der Maarel 1993a). There are also a number of more recent books which either focus on coastal dunes (van der Meulen et al. 1991; Carter et al. 1992; van der Maarel 1993a, b; García-Novo et al. 1997; Grootjans et al. 1997; Packham and Willis 1997; Wiedemann et al. 1999; Hesp 2000) or mention them briefly (Seeliger 1992). However, an examination of the literature indicates that there is a strong emphasis on the mid-latitude dunal systems and a lack of attention given to low latitude situations,

those areas where much of the modern exploitation and coastal touristic development is occurring.

Until now, there have been no compilations of coastal dune system studies in which the geomorphology, community dynamics, ecophysiology, biotic interactions, environmental problems, and conservation were addressed, especially incorporating both tropical and temperate latitudes. The modest communication and collaboration among scientists studying coastal dunes in tropical and temperate latitudes are factors that generate scientific isolation and limit the potential for comparing data, performing interdisciplinary studies, and coordinating joint research programs. This book aims at narrowing the gap. The goal is to gather information on the state-of-the-art studies on coastal dunes, covering a range of topics from dune geomorphology and community dynamics to ecophysiology and the environmental problems and management strategies and policies that are necessary for their conservation. The basic idea is to bring this information to the attention of an international forum interested in coastal dunes. This volume does not pose the final answer. More likely, the diverse array of contributions contained herein will stimulate further research that will lead to a better understanding of these ecosystems and to the generation of improved conservation and management strategies.

This book is directed mainly to graduate students who are interested in biological and environmental sciences. It may be part of a reading list for undergraduates, but the discussion and insightful analysis will occupy the graduates rather than undergrads. The book will also be useful to those with an interest in conservation biology and coastal management that seek information on various topics, ranging from coastal sand dune distribution in the world, to plants and animals, biotic interactions, environmental problems, and different management tools. Protection and wise management of coastal sand dune systems can be achieved only if the ecosystem dynamics are better understood.

We have invited experts from throughout the world to contribute to the different sections of the book. Their enthusiastic response reveals the uniqueness of a book where researchers focused on temperate and tropical dunes are gathered for the first time.

The book is divided into six Sections: I. A general description of coastal dunes; II. The flora and fauna; III. Living in a stressful environment; IV. Biotic interactions; V. Environmental problems and conservation, and finally, VI. The coastal dune paradox: conservation vs. exploitation?

Section I begins by defining and describing in detail coastal dunes, which are always changing in shape and location because of the dynamics of the coastal system. Their complex and changing topography generates a high environmental heterogeneity. Norb Psuty describes the geomorphology of coastal dunes and illustrates the fundamental control of sediment supply in the system. Patrick Hesp, in turn, focuses on the distribution of coastal dunes

in the mid-latitudes and tropics and revisits if there really is a paucity of dunes in the tropics.

The high environmental heterogeneity of the dune environment provides specialized habitats for many organisms. There are many adapted plant and animal species (native or even endemic) that occur in these environments. Many of these species are currently rare or endangered. Dune vegetation is very diverse: lichens and bryophytes abound in Europe and the polar regions, whereas plants with seeds (especially palms) are more diverse in the tropics. Arthropods, mollusks, amphibians, reptiles, birds and mammals are the animal groups best represented. In each community, recognizable sets of species appear and disappear along typical marine gradients, making zonation a common feature.

Section II addresses dune vegetation as a characteristic and a formational agent. Al Wiedemann and Andrea Pickart integrate the information from temperate latitudes, and present a case study from North America; Roy Lubke focuses on the vegetation dynamics in the tropical dunes and the role of invasive vs. non-invasive species, and Ab Grootjans and colleagues analyze the vegetation dynamics and processes of the most humid places within the dunes: the slacks. The information on dune vegetation has proven to be highly relevant for conservation programming. In contrast with the relatively well studied dune vegetation, the paucity of data on dune animals is evidence that the fauna of dune environments have been less well studied than the vegetation. In spite of this limitation, innovative data are presented by Rudy van Aarde and collaborators, who relate habitat rehabilitation to the conservation of vertebrates inhabiting these ecosystems.

Flora and fauna found in coastal dunes are greatly affected by substrate mobility, extremely high temperatures, drought, flooding, salinity, and a scarcity of nutrients. They show morphological, physiological, and behavioral responses to these limiting conditions. The different mechanisms required to survive in such stressful environments are addressed in Section III, which, because of the lack of information for animals, focuses only on plants. Anwar Maun contributes a thorough review of the different responses of plants to burial, whereas Brad Ripley and Norm Pammenter pursue the understanding of plant responses to the restricted budgets of water and nutrients, especially for dune pioneer species. Francisco García-Novo and his colleagues bring together a set of plant responses to the dune environment by using plant functional types in relation to environmental constraints.

In addition to the important role of the abiotic environment, interspecific interactions between the organisms that live on these ecosystems play a key role in community dynamics. Biotic interactions, explored in Section IV, cover a wide variety of plant and animal relations, ranging from arbuscular mycorrhizae (Rick Koske et al.), to algae and phanerogams (Gabriela Vázquez), plant–plant interactions (M. Luisa Martínez and José García-Franco) and ant-animal interactions (Víctor Rico-Gray et al.).

The need of management and conservation policies for coastal dune and barrier island ecosystems becomes evident from the studies above and has led to the implementation of different strategies and technologies throughout the world. Environmental problems and their potential solutions are diverse, and they are the purview of Section V. Annemieke Kooijman discusses the effectiveness of nature management options in the dune environment, especially when grass encroachment depletes biodiversity. Frank van der Meulen and co-authors, in addition, suggest a more flexible approach for coastal conservation, allowing geomorphological processes to occur, and they evaluate the costs and benefits of this decision. Gert Baeyens and M. Luisa Martínez, in turn, cover the issue of exploitation and protection of introduced animal life on sand dunes. Ileana Espejel et al. propose the usage of different indicators (environmental, functional, and structural) as feasible decision-making tools. Patricia Moreno-Casasola analyzes the current conservation status of coastal dunes in the tropics and presents a case study of coastal zone management in which local inhabitants are actively involved.

Finally, Section VI presents a discussion of the conflict common to all natural systems: the balancing of conservation with exploitation. The spatial continuum of the dune environment establishes the basis of the energetics framework of coastal ecosystems and is responsible, to varying degrees, for primary production, habitat formation, and shoreline evolution. Prior to human interference, coastal dune habitats were evolving and they will continue to evolve even with human husbandry. However, what is important in coastal conservation is to allow the natural systems to evolve, to change, and to do so in a natural pace. When humans interfere, the natural dynamics of the system are altered. Any change in the system may lead to an upending of the balance and to an exacerbation of the rate of change of the coastal dune system as a whole as well as in its components.

Therefore, the challenge is to manage the parts as well as the entirety of the system better. Each community is vital to the ecological integrity and functioning of the coastal dune complex. An improved understanding of this interaction is vital because modern coastal area management and planning strategies have increasingly adopted the systems approach as a basis for habitat preservation and enhancement. Based on the above, Heslenfeld and coauthors present general principles regarding evaluation criteria on an international level. Lastly, the final chapter is a discussion on the theme of dune conservation as a viable option given the current status and trend of the coastal environment.

The vast information generated in this book covers a wide variety of themes. Our aim and scope are to bring forth concepts on the physical basis for coastal dune development and the trend of the spatial and temporal evolution of the foredune and the inland dune continuums. We also intend to show that only through an integrated approach of the physical system in which geomorphology and inventories of the flora and fauna are comple-

mented by information on the ecophysiological responses and the role of biotic interactions can we strive to attain an integrated coastal zone management. Certainly, a flexible and multidisciplinary approach is fundamental for coastal conservation, and the costs and benefits of conservation should be considered. Further, coastal management must integrate the needs and the participation of all of the local and regional stakeholders in the development of appropriate strategies and policies.

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