# 21 The Fragility and Conservation of the World's Coastal Dunes: Geomorphological, Ecological, and Socioeconomic Perspectives

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## 21.1 Current Worldwide Status

Coastal dunes have a worldwide distribution and are comprised of a variety of forms going through successional changes in geomorphology and ecological association. Some changes are driven by natural processes whereas other changes are products of human endeavors. Coastal dunes are highly valuable multifunctional ecosystems that occupy a unique natural niche. Further, these same systems are ideal locations for recreation, replenishment of local aquifers, and coastal defense (van der Meulen et al., Chap. 16, this Vol.). However, in spite of their many valuable attributes, these ecosystems share a history of exploitation and mismanagement. The greatest threat to their survival is overuse, urban expansion, urban sprawl, mining, and pollution. Frequently, these systems and their functions are completely replaced by high rise buildings, residential development, cottages, tourist resorts, and recreation parks. The eventual consequence of such activities is the destruction of a fragile ecosystem. Tourism, in particular, has become an important activity with economic benefits that have resulted in severe environmental degradation of dunes. For example, hotels and houses are built directly on the dunes and trampling by people kills the stabilizing vegetation, thus exacerbating the process of sand movement and dune erosion. These changes in sediment supply and the regional sand budget produce extensive geomorphological and ecological damage with important economic consequences (Psuty, Chap. 2, this Vol.). As a result, there is the net loss of coastal dunes, their dynamics, and their natural biological diversity. Dune slacks have been similarly subjected to systematic alteration through overexploitation by grazing, hay making, and growth of crops.

Slowly, this alarming trend is reaching decision-makers, politicians, and the public in general, and, gradually, coastal dunes are becoming protected

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ecosystems (mostly at mid-latitudes). Nevertheless, many important questions remain regarding management approaches and techniques for preserving form and function. For example, how much do we know about the methods of preservation of the form and function of coastal dunes? What remains to be studied? How should they be managed so that their evolving geomorphological and ecological systems are preserved for future generations? In the following sections we will address these questions and discuss whether dune conservation is a possibility. We will first consider current research trends and then examine different ways of managing and preserving fragile dune systems.

## 21.2 Current Research Trends (What Do We Know?)

Recent studies on coastal dune systems have focused on the spatial and temporal variations of morphologies, the sequences of biological succession in dune types, adaptations to the environmental stresses, and comparison between the patterns and processes in coastal dunes of the tropics and mid-latitudes. Different aspects of these topics were addressed widely in various sections of the book. This final chapter summarizes the complex topics covered in the book.

### 21.2.1 Variable Morphologies

Coastal dune systems are highly variable in form and dimension. Psuty (Chap. 2, this Vol.) and Hesp (Chap. 3, this Vol.) establish that the present-day morphological systems have been evolving through the most recent period of Holocene sea-level transgression and they have waxed and waned in their development as sediment supply has fluctuated and sequences of stabilization and destabilization have characterized regions. There is no one dune system, there are patterns, trends, and episodes that describe the creation of regional coastal dune forms and systems. As morphologies pass through sequences dependent on ambient sediment supply, wind conditions, stabilizing vegetation, and human interaction, they form the variable physical base that constitutes the coastal foredune in the beach profile and the inland extension of the dune fields. Whereas there is considerable progress accomplished in the mechanics of eolian sand transport, the specific association of quantities of transport and coastal dune form remains a fertile area of inquiry. Further, there is a very significant and difficult research topic regarding the dichotomy between the active dune-beach system (which may be eroding, accreting, or stable) and the highly variable equally dynamic dune topography inland of the beach.

### 21.2.2 Succession

Ever since the early studies performed by Henry Chandler Cowles, more than a century ago (1899), succession on coastal dunes has been the focus of many researchers. Importantly, the studies by Cowles were seminal for Frederic E. Clements who, almost 20 years later (1916), proposed the successional theory of plant communities, a key concept in current ecological theory.

Recent studies demonstrate that local environmental characteristics and heterogeneity affect successional trends (Lubke and Avis 1988; Grootjans et al. 1997;, Chap. 6, this Vol.). An array of complex interactions affects the successional process, namely: local hydrological and topographical conditions, nutrient availability, amount of precipitation, and freshwater discharge (Grootjans et al. 1991; Houle 1997; Vázquez et al. 1998; Lichter 2000; Martínez et al. 2001; Grootjans et al., Chap. 6, this Vol.; Vázquez, Chap. 12, this Vol.). There is evidence that the rate of vegetation succession is largely controlled by the productivity of the ecosystem, the decomposition of organic matter, and the recycling of nutrients within the ecosystem (Koerselman 1992). In addition, the increased atmospheric input of nitrogen, because of industrialization, automobile combustion, and increasing population size may accelerate the successional pathway (Maun and Sun 2002; Kooijman, Chap. 15, this Vol.).

More recently, it has become evident that biotic interactions play a key role during community succession. Facilitation of these interactions is especially important during the earlier successional stages (Vázquez et al. 1998; Lichter 2000; Shumway 2000; Martínez 2003; Lubke, Chap. 5, this Vol.; Grootjans et al. 1997 and Chap. 6, this Vol.; Martínez and García-Franco, Chap. 13, this Vol.; Vázquez, Chap. 12, this Vol.) when both phanerogamous species and algal mats ameliorate the environmental extremes and facilitate colonization by later successional species. However, biotic interactions are not restricted to a specific seral stage because facilitation and competition have both been observed during early and later stages of succession (Kellman and Kading 1992; Callaway and Walker 1997; Martínez and García-Franco, Chap. 13, this Vol.).

It is also important to note that the traditional explanation of dune succession usually overlooks the role of mutualistic fungi which facilitate the invasion of bare areas. Certainly, many dune-building plants are incapable of establishment in the absence of arbuscular mycorrhizal (AM) fungi (Koske and Polson 1984; Sylvia 1989; Corkidi and Rincón 1997; Koske et al., Chap. 11, this Vol.). This association is of particular ecological relevance since the fungi enhance nutrient uptake, soil aggregation, increase plant tolerance to drought and salt stress, and protect them from soil pathogens (Gemma and Koske 1997; Tadych and Blaszkowski 1999; Gemma et al. 2002). Thus, although overlooked, AM fungi certainly play a significant role in community dynamics. Further studies are needed to examine the role of AM fungi in ecological interactions during succession.

Vegetation succession is also known to affect animals and their interactions with plants (McLachlan 1991; McLachlan et al. 1987; van Aarde et al., Chap. 7, this Vol.). For example, in the case of birds, species richness and diversity are positively correlated with structural heterogeneity of vegetation and habitat (Kritzinger and van Aarde 1998). Alternatively, spatial and temporal variability in habitat, community structure, and plant height determine the occurrence of rodents in coastal dune forests (Ferreira and van Aarde 1999; Koekemoer and van Aarde 2000).

Different animal species also exhibit definite successional trends. They are dominant during the different seral stages. For example, the rodent, *Mastomys natalensis* was most abundant during the first few years of vegetation establishment and regeneration, while *Saccostomys campestris* was dominant in sites older than 15 years (van Aarde et al., Chap. 7, this Vol.). Similarly, birds were closely associated with different stages in succession because of changes in food sources, protection from predators, nesting sites, and plant community structure (van Aarde et al., Chap. 7, this Vol.; Kritzinger and van Aarde 1998).

Many sand dune systems around the globe are used for grazing by cattle and sheep. Such grazing is highly detrimental to dune systems because trampling by animals may arrest or revert succession by killing vegetation and enhancing erosion by wind action. Grazing by rabbits does not allow vegetation to increase in height and prevents shrubs and trees from sprouting and growing. When rabbit populations drop, shrubs and trees begin to flourish and bird populations change (Baeyens and Martínez, Chap. 17, this Vol.).

In brief, studies on successional changes on coastal dunes indicate that in addition to local abiotic conditions such as topography and hydrology (De Jong and Klinkhamer 1988; Grootjans et al. 1991 and Chap. 6, this Vol.; Houle 1997; Lammerts et al. 1999; Martínez et al. 2001), biotic interactions are integral to dune system development (Shumway 2000; Rico-Gray et al., Chap. 14, this Vol.; Vázquez, Chap. 12, this Vol.; Grootjans et al., Chap. 6, this Vol.; Martínez and García-Franco, Chap. 13, this Vol.). The understanding of the the concept of successional sequence (whether in accretional, erosional, or stable systems) and the interactive processes are of immense value in dynamic management plans aimed at maintaining the natural dynamics of dune systems.

### 21.2.3 Adaptations

Sand dune habitats are highly heterogeneous and offer a wide variety of microhabitats in which species utilize different strategies. The major environmental condition in foredunes is burial of plants by sand, initially supplied by wave action and then – episodically transported inland by onshore wind. This recurrent burial acts as a strong selective force that affects plant community composition and dynamics especially in the early stages of succession (Disraeli 1984; Davy and Figueroa 1993). Soon after burial of a plant its photosynthetic capacity may decrease but many dune species are able to withstand and even benefit from certain threshold levels of burial and the associated delivery of nutrients (Disraeli 1984; Maun 1994, 1998;, Chap. 8, this Vol.; Martínez and Moreno-Casasola 1996). Some foredune species are so well adapted that they require regular burial to maintain high vigor. In the absence of sand deposition, a marked decline in vigor and density of these populations has been observed after sand stabilization (Maun, Chap. 8). When this occurs, early pioneers may be eventually replaced by plants of later stages in succession.

Many factors limit the establishment and growth of plants in sand dune ecosystems. However, the major factors are high wind velocities, sand blasting, salt spray, salinity, and the scarcity of water and mineral nutrients. In particular, some dune plants are especially efficient in water utilization (Ripley and Pammenter, Chap. 9, this Vol.; Martínez et al. 1994). During dry spells, stomata are closed thus reducing transpiration and some plants have access to moisture in the form of internal dew. Some dune species also have the ability to re-cycle nutrients, suggesting that at the shoot meristem level, cell division and growth are not limited by nutrient availability (Ripley and Pammenter, Chap. 9, this Vol.). An efficient nutrient utilization has also been observed in tropical species (Valverde et al. 1997; Martínez and Rincón 1993).

In contrast, dune slacks have excessive moisture and may behave like temporary wetlands with cycles of flooding and dry periods. The species growing here are tolerant to both dry and wet (flooded) conditions (Grootjans et al., Chap. 6, this Vol.). Nevertheless, anoxic conditions during flooding may prevent the establishment of all but species with a well-developed aerenchyma (such as *Schoenus nigricans* and *Littorella uniflora*) which counteracts anoxia by active radial oxygen loss (Grootjans et al., Chap. 6, this Vol.). Many dune slack species also require very low amounts of nutrients.

The specific responses to environmental fluctuations generate functional groups (or types) (FTs) that contain species from different biogeographic and ecological zones but possess a common life strategy that enables them to thrive in a given environment (García-Novo et al., Chap. 10, this Vol.). The grouping of plants according to functional types is a useful approach that facilitates the recognition of patterns in species response to the environmental variability in coastal dune vegetation. The analyses of FTs not only helps to understand community functioning at the local scale but also facilitates the comparison between communities (with few species in common) exposed to similar environmental constraints at the regional scale.

### 21.2.4 Tropical vs. Mid-Latitude

There is a general scarcity of studies on tropical beaches and dunes; only recently are scientific publications emerging in Mexico, (Moreno-Casasola 1988, 1999) Cuba (Aguila et al 1996; Borhidi 1996) Brazil, Venezuela, and Chile

(Araujo 1992; Seeliger 1992). This is probably one of the reasons why earlier publications on coastal dunes stated that tropical coasts lacked extensive dunefields (Ranwell 1972; Carter 1988). However, current studies (Moreno-Casasola 1982) have demonstrated that coastal dunes are not only abundant along tropical latitudes but also have definite latitudinal variation among them.

The vegetation of coastal dunes has been thoroughly studied in temperate latitudes and less intensively in the tropics (van der Maarel 1993a, b). Although species and genera differ with latitude, in general, those occupying the upper beach and foredunes are tolerant of salt spray, substrate mobility, and strong winds. Farther inland, the vegetation varies depending on the microclimate and local conditions and there is less latitudinal similarity. Arboreal vegetation shows a closer resemblance to the regional flora.

Hesp (Chap. 3, this Vol.) suggests that there may be morphological differences between tropical and mid-latitude dunes, possibly the product of vegetation and weather conditions.

He indicates that, contrary to earlier publications (e.g., Jennings 1964), eolian coastal dunes are neither very poorly developed nor largely absent in the humid tropics. Certainly, dunes may be uncommon in many tropical coasts, probably due to frequent storm surges during typhoons and hurricanes, abundant rainfall coinciding with periods of strong winds, and a general lack of sediment supply. However, there are areas with large dunefields in the humid tropics, specifically in those regions with a positive sediment budget and strong winds during a marked dry season. Coastal dunes in these arid and semiarid tropical areas frequently extend into adjacent inland dunefields. Further, latitudinal coastal dune characteristics may vary because the many coralline shorelines and the abundant fine-grained deposits of the tropical rivers offer a different type and quantity of source material to the beach-dune system. In general, taller grasses and sedges are dominant on temperate foredunes whereas low creepers dominate the humid tropics. Creepers also occur in the dry tropics, but grassy species tend to be dominant along these coasts. In addition, colonization and stabilization rates are faster in the tropics which may lead to a reduced opportunity for changes in the original duneform. Given the above, coastal dunes in the tropics are apt to be more stable than their temperate counterparts, although outstanding exceptions probably occur in both regions.

Additional latitudinal convergences in dune vegetation and dynamics are (1) similar successional pathways (facilitation) (De Jong and Klinkhamer 1988; Kellman and Kading 1992; Shumway 2000; Martínez et al. 2001; Martínez 2003) and (2) a high susceptibility to invasion by exotic species (Castillo and Moreno Casasola 1996; Wiedemann and Pickart, Chap. 4, this Vol.; Lubke, Chap. 5, this Vol.). Furthermore, post-burial stimulation of plant growth has been observed in both temperate and tropical dune species alike (Maun 1994, 1998 and Chap. 8, this Vol.; Martínez and Moreno-Casasola 1996; Baskin and Baskin 1998).

## 21.3 Fragile Ecosystems?

Aspects of dune dynamics are driven by naturally occurring disturbances. However, even though recurrent disturbances are common disrupting forces in these environments, either a higher intensity or frequency of such disturbances or their absence may alter community dynamics. When too intense or highly frequent, mobility of sand may increase and stabilized dunes (such as forested areas) may be lost to erosion or sand deposition. When natural disturbances are absent, the early successional stages which are dependent on high substrate mobility may disappear. In brief, coastal dunes are dynamic and heterogeneous environments where naturally occurring patch dynamics maintain their diversity. They are considered fragile because only a slight disruption (either natural- or human-induced) may lead to change and long-term progressive alteration (Carter 1988) and their natural diversity might be compromised rather easily.

In addition to natural disturbances, the dune communities are exposed to different types of human-related disturbance events which cause both direct (trampling, grazing, sand and water extraction, leveling of dunes) and indirect damage (climate change, sea-level rise, and alterations in soil, moisture regimes, and sediment supply). The historical record of coastal Europe has a litany of coastal dune stabilization and destabilization conditions which are apparently related to a combination of natural and human-caused events (Sherman and Nordstrom 1994). The full range of these events has had a significant impact on natural dune dynamics and should be addressed in management practices.

## 21.4 Management Practices

On a worldwide basis, during the last two or three decades the public has become increasingly aware of their deteriorating and diminishing coastal recreational environment. Slowly, efforts at coastal protection and improved management are becoming priorities for the public and Government authorities, thus leading to a greater respect and urgent need for conservation of coastal dunes. Management practices have changed during the last decades depending on the use to which dune systems were subjected and their impact on human activities. For example, thirty years ago dunes were stabilized when they were encroaching on adjacent farm land. Bare sand surfaces were stabilized against deflation and inland engulfment. Because of its effectiveness in stabilizing active dunes, surface stabilization was achieved by introducing *Ammophila arenaria* (marram grass) into almost every temperate coast of the world. In time, this grass became invasive in some regions. For instance, following the introduction of marram grass along the western coast of the USA in 1869, the species flourished, spread quickly, and brought about major changes in the dunescape. Native dune-forming species were eliminated and the extensive grass cover stabilized the foredune, thus cutting off sand supply from the beaches to the back dunes. Early successional stages disappeared (Wiedemann and Pickart, Chap. 4, this Vol.) and indigenous taxa were suppressed (Richardson et al. 1992, 1997). The overall result was a reduction in biodiversity. Grass encroachment has also become an important environmental problem on European coasts (Veer and Kooijman 1997; Kooijman, Chap. 15, this Vol.; Grootjans et al., Chap. 6, this Vol.). At present, the pioneer stages are rare in most western European dunes, although large mobile systems can still be found in Spain (Coto Doñana); Poland (Slowinski National Park); France (Landes district); Denmark; the German Wadden Sea island of Sylt; and the Dutch Wadden Sea island of Texel (Kooijman, Chap. 15, this Vol.). Similar trends in spread by exotic species seem to occur in the tropics (for instance Mexico) where tall and dense stands of grasses (*Schizachyrium scoparium*) gradually replace local endemic vines and creepers (Martínez and García-Franco, Chap. 13, this Vol.; Martínez et al. 2001). Interestingly, *A. arenaria* has not become an invasive species in South African coastal dunes (Lubke and Hertling 2001; Lubke, Chap. 5, this Vol.).

Currently, numerous control programs exist on several continents that are aimed at eliminating *A. arenaria* and restoring the natural dune processes without sacrificing stability. Several activities such as (a) removal of aboveground biomass by annual mowing and grazing by cattle and (b) sod cutting and stimulation of eolian activity have been used to lower the vigor of alien species. Both measures seem effective, although their effectiveness depends on local soil characteristics (Kooijman, Chap. 15, this Vol.). However, these programs are costly. An eradication program of 10 ha of *A. arenaria* population cost US$ 350,000 over a four-year period (Wiedemann and Pickart, Chap. 4, this Vol.). Clearly, the correction of the problem of invasive species exceeds the resources available.

It is now evident that dune stabilization is not always a necessary and suitable management tool because it may create many new problems. First, artificial stabilization alters the eolian processes and may have a major impact farther inland or downwind. Second, stabilization can be very costly, and third, mobile dunes may be part of the natural successional landscape and should be allowed to function normally. In fact, recent management trends are directed towards an acceptance of these systems as valuable wilderness areas. Nature conservation policies have changed from a focus on rare and endangered species to biotic and abiotic processes and landscape functioning. That is, management is best done in accordance with the natural processes (Avis 1992; Avis and Lubke 1996), preferably in areas of at least several hundreds of ha in size (Bal et al. 1995). Given this scenario, when trying to conserve native dune species it should be considered whether stabilization is necessary and, if it is, under what circumstances and what are the species that should be used (preferably, native).

Based on the above emerging concerns, artificial stabilization measures in some parts of The Netherlands have been stopped, because they are no longer considered necessary. Dune fixation is now limited to special parts of the foredunes which are endangered by the sea, not the wind, and fixation is done mostly with hedges of branches or native marram grass without deleterious ecological consequences. This has saved the coastal management authorities millions of dollars, and has resulted in a much more beautiful and natural dune landscape (Heslenfeld et al., Chap. 20, this Vol.). Within the framework of the European Union of Coastal Conservation all countries except France are following the Dutch example. In other countries such as the USA, Canada, and South Africa, dune stabilization programs are selectively applied. Dune stabilization programs in other parts of the world are rare. In any case, any stabilization program should only be initiated when the need has been carefully ascertained through detailed studies. Whenever possible, natural dynamics should therefore be maintained and restored.

Ideally, management plans of coastal dunes should embrace the planting and maintenance of the natural vegetation, conservation of wildlife, control of visitors, the zonation of activities, and provision of amenities. When managing and preserving coastal dunes, it is important to bear in mind that species richness and habitat diversity in dune systems, which by their nature are highly dynamic, are greatest when a full sequence of successional stages is represented. Management should aim at maintaining this diversity and the natural dynamics of these ecosystems (Avis 1992; Davy and Figueroa 1993).

Management practices should also include animal populations. In a fashion similar to what occurred with coastal vegetation, the attitude of humans towards dune mammals and birds has changed throughout history (Baeyens and Martínez, Chap. 17). Initially, wild animals were used as sources of food and fur. Their populations were manipulated in several ways: (1) some populations (rabbits) were artificially fed and enlarged to facilitate hunting activities; (2) species of interest (deer) were protected from their natural predators; (3) new species were introduced and bred. However, at the beginning of the 20th century, birds started to receive special protection that led to habitat protection and the protection of wild animals in general. In addition, trends in both bird and rodent communities indicate that habitat rehabilitation is a management tool that could potentially reverse the negative impact of habitat loss and fragmentation that threatens the viability of species populations (van Aarde et al., Chap. 7, this Vol.). However, there is evidence that changes in food webs result in domino effects in many links of the food chain (Baeyens and Martínez, Chap. 17). In this case, mitigating measures aimed at controlling shrub and grass encroachment do not always restore the breeding densities of locally extirpated birds (Baeyens and Martínez, Chap. 17, this Vol.). It is thus evident that the relevance of biotic interactions should also be considered in restoration projects, because species reintroduction will not restore communities, given that interactions need to be restored as well.

Finally, it is important to bear in mind the importance of long-term monitoring. The systematic recording of the geomorphology, flora, and fauna over long periods of time is of particular value to detect ecosystem and community changes such as invasive plant species and their potential impact. Monitoring is important to establish trends, periodic variations, and aperiodic events in the history of change. Monitoring will lead to the establishment of a baseline which is essential to assess locally endangered species, and can only be achieved through long-term studies (Lubke, Chap. 5, this Vol.; van Aarde et al., Chap. 7, this Vol.; Grootjans et al., Chap. 6, this Vol.; Martínez et al. 2001).

## 21.5 Future Trends and Perspectives

Is it possible to preserve the form and the functions of coastal dunes? Based on current global trends and aspirations, the future looks bleak. For example, it is projected that (1) agriculture will intensify in these sandy, well-drained habitats; (2) ports will expand and urbanization will continue; (3) infrastructure will increase, especially near the airports and tourist resorts; (4) pressure from tourism will increase; (5) in some countries, a return to more natural ecosystems (forests) is likely to be promoted; and (6) sea level rise will displace the beach-dune system and narrow the protected dune zone; erosion rates will be exacerbated (Heslenfeld et al., Chap. 20, this Vol.). Thus, it seems that human development along the coast will continue, and it would be wise to do so in a proper and sustainable manner. This necessarily implies agreement with the philosophical supposition that conservation and development are not irreconcilable, and efforts must be made to strike a balance between them.

In light of the above, conservation efforts should be aimed at solving several problems of preservation, restoration, and management (which should include actions to prevent further species invasions) (Wiedemann and Pickart, Chap. 4, this Vol.). Because coastal defense mechanisms that fail to consider the natural processes are highly costly and ineffective, management towards maintaining dune dynamics should be promoted. All too often, however, management objectives focus on static solutions, such as securing the shoreline against erosion, maintaining a constant channel depth, or cultivating a continuous dune grass sward. Such solutions place an unwanted stress on many coastal environments and may, in some instances, promote a catastrophic event. In fact, it is known that the more diverse the systems are, the better able they are to withstand change. A dune system with diverse vegetation, morphology, and relief is more resilient to changing conditions. Indeed, the concepts raised in this book indicate that dune systems are often in a developmental stage of instability and migration as part of the natural system. Permitting some degree of mobility should be part of a holistic management strategy. Thus, the application of adequate standards of resource use, coupled with proper management and conservation policies will sustain these environments and maintain a wide variety of living organisms.

Heslenfeld et al. (Chap. 20, this Vol.) proposed the following recommendations to restore and preserve coastal dunes:

1. Generate an international long-term strategy for coastal management and development.
2. National policies of coastal countries should include an Integrated Coastal Zone Management (ICZM) approach.
3. Include all actors (local inhabitants and authorities) involved in the decision making process of ICZM.
4. Dunes should not be artificially fixed or afforested: they should be promoted as dynamic self-sustained systems.
5. Promote international exchange of knowledge and expertise.
6. Use international funds for dune conservation projects.

In addition to these recommendations, it is also important to bear in mind that:

7. Mobility and succession are dune formational processes and functions
8. Tropical dunes should be included in the above-described actions.
9. Finally, adequate legislation to protect coastal environments, generally lacking in tropical countries, needs to be addressed in the near future.

In particular, in the case of ICZM, zoning is a major management tool through which coastal functions are allocated to meet the economic and leisure demands without influencing their ecological well being (van der Meulen and Udo de Haes 1996). Segregated activities help to absorb the high numbers of visitors, and overall, the dune system is preserved. This is particularly important because the overall carrying capacity of dunes is relatively low (less than 100 persons per hectare) (van der Meulen et al., Chap. 16, this Vol.). Zoning operates on two embedded scales, one covering the entire coastline (and the countries involved) and the other within individual dune systems.

Biotic interactions: plant-plant, predators, herbivores, and seed dispersers should all be considered to make the ICZM effective. Because of their high relevance in community dynamics (Rico-Gray 2001; Rico-Gray et al., Chap. 14, this Vol.; Grootjans et al., Chap. 6, this Vol.; Vázquez, Chap. 12, this Vol.; Martínez and García-Franco, Chap. 13, this Vol.), coastal zone management should consider impact of the activity on biotic interactions as much as possible. However, when the impact of major changes in the food chain (appearance or disappearance of species), is not diminished, additional restoration measures will be required (Baeyens and Martínez, Chap. 17, this Vol.).

A complementary tool for ICZM plans is the use of different ecological indicators (compositional, structural, and functional) which are potentially helpful in measuring the environmental quality of dune systems (Espejel et al., Chap. 18, this Vol.). Such tools are particularly useful in conservation and restoration programs, since they provide quantitative values through which sites or regions can be compared and monitored. These ecological indicators are potentially very useful when planning to perform environmental quality assessment and regional coastal zone management. Furthermore, the adequate and sufficient knowledge of the functioning of coastal dunes will provide proper tools that will enable decision-makers to properly conserve and restore these ecosystems for future generations. Long-term monitoring studies should thus be promoted.

Coastal dune conservation provides a major challenge in densely populated areas, but it can be achieved. Two examples of extensive and protected dune systems lying next to large industrial and densely populated areas are the Sefton coast dunes near Liverpool (England) and Meijendel dunes near The Hague (The Netherlands) (van der Meulen et al., Chap. 16, this Vol.). In Mexico, conservation efforts are being planned by taking into confidence all stake-holders, local inhabitants, academic institutions, and Government authorities. The objective is to agree upon the necessary actions to utilize the natural resources without affecting their integrity and ecological balance (Moreno-Casasola, Chap. 19, this Vol.). Nevertheless, the total cost of dune management can be very high. For instance, in the Meijendel dunes, surveillance by 15 wardens plus management costs 3.2 million Euros per year (van der Meulen et al, Chap. 16, this Vol.).

Definitely, good design based on sound scientific research can contribute significantly to the management of dunes, but it must be emphasized that environmental education is an essential adjunct to planning and design. Public participation and awareness of the environmental problems are essential prerequisites to preserve important coastal features and processes for the present and future generations. At the onset of the 21st century, managers and society should no longer be considered separate entities. Managers are required to offer a product that is in accordance with nature and meets the needs of the society at large. Finally, the issues of enlightened conservation along with increasing coastal development should reflect on the fact that maintenance of the status quo of coastal dunes may not be attainable because of their natural dynamism and the changes wrought by humans.

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