

# Contents

|          |  |           |
|----------|--|-----------|
| <b>I</b> | <b>What Are Sand Dunes?</b>  |           |
| <b>1</b> | <b>A Perspective on Coastal Dunes</b> . . . . .  | <b>3</b>  |
|          | M.L. MARTÍNEZ, N.P. PSUTY, and R.A. LUBKE  |           |
| 1.1      | Coastal Dunes and Their Occurrence . . . . .   | 3         |
| 1.2      | Relevance of Coastal Dunes . . . . .   | 3         |
| 1.3      | Current Conservation Status . . . . .  | 5         |
| 1.4      | Aims and Scope of the Book . . . . .   | 6         |
|          | References . . . . .   | 10        |
| <b>2</b> | <b>The Coastal Foredune: A Morphological Basis<br/>for Regional Coastal Dune Development</b> . . . . . | <b>11</b> |
|          | N.P. PSUTY   |           |
| 2.1      | Conceptual Setting . . . . .   | 11        |
| 2.2      | Dichotomies of Inquiry . . . . .   | 12        |
| 2.3      | Dune Morphology Related to Sediment Supply<br>and Dune–Beach Exchange . . . . .                        | 15        |
| 2.4      | Continuum Scenario . . . . .   | 17        |
| 2.4.1    | River Mouth Discharge . . . . .  | 18        |
| 2.4.2    | Scenario Complexity . . . . .  | 20        |
| 2.5      | General Model . . . . .  | 22        |
| 2.6      | Humans as a Variable . . . . .   | 24        |
| 2.7      | Conclusions . . . . .  | 24        |
|          | References . . . . .   | 25        |

|           |   |           |
|-----------|---|-----------|
| <b>3</b>  | <b>Coastal Dunes in the Tropics and Temperate Regions:<br/>Location, Formation, Morphology and Vegetation Processes</b> | <b>29</b> |
|           | P.A. HESP   |           |
| 3.1       | Introduction . . . . .  | 29        |
| 3.2       | Climatic Conditions in the Tropics . . . . .  | 29        |
| 3.3       | The Location of Coastal Dunes in the Tropics . . . . .  | 30        |
| 3.4       | Are There Differences Between Tropical<br>and Temperate Coastal Dunes Types and Processes? . . . . .                    | 33        |
| 3.5       | Foredunes . . . . .   | 34        |
| 3.5.1     | Flow Dynamics in Vegetation . . . . .   | 34        |
| 3.5.2     | Tropical Versus Temperate Foredune Trends<br>and Morphologies . . . . .   | 35        |
| 3.6       | Gross Dune-Field Morphology . . . . .   | 37        |
| 3.7       | Rate of Dune-Field Vegetation Colonisation<br>and Re-Vegetation Processes . . . . .                                     | 39        |
| 3.8       | Types of Dune-Field Vegetation Colonisation<br>and Dune Morphologies . . . . .  | 40        |
| 3.9       | Conclusions . . . . .   | 44        |
|           | References . . . . .  | 45        |
| <br>      |   |           |
| <b>II</b> | <b>The Flora and Fauna of Sand Dunes</b>  |           |
| <br>      |   |           |
| <b>4</b>  | <b>Temperate Zone Coastal Dunes . . . . .</b>   | <b>53</b> |
|           | A.M. WIEDEMANN and A.J. PICKART   |           |
| 4.1       | Coastal Temperate Zone Climates . . . . .   | 53        |
| 4.2       | Coastal Dunes of Western North America . . . . .  | 56        |
| 4.3       | Conservation and Management . . . . .   | 60        |
|           | References . . . . .  | 64        |
| <br>      |   |           |
| <b>5</b>  | <b>Vegetation Dynamics and Succession on Sand Dunes<br/>of the Eastern Coasts of Africa . . . . .</b>                   | <b>67</b> |
|           | R.A. LUBKE  |           |
| 5.1       | Introduction . . . . .  | 67        |
| 5.2       | Successional Change Along the Southern African Coast . . .  | 67        |
| 5.2.1     | Studies on Prograding Dune Fields . . . . .   | 68        |
| 5.2.2     | Studies on Transgressive Dune Fields<br>and Partially Eroding Coastlines . . . . .                                      | 73        |

|            |  |            |
|------------|--|------------|
| Contents   |  | XI         |
| 5.2.3      | Studies on Rocky Shores and Eroding Coastlines . . . . .   | 76         |
| 5.3        | Changes in Dune Succession Due to Invasive Aliens . . . . .  | 76         |
| 5.3.1      | The Effect of <i>Ammophila arenaria</i> as a Dune Pioneer<br>on the Southern Cape coast . . . . .  | 76         |
| 5.3.2      | The Effect of Invasive Communities of <i>Acacia cyclops</i><br>in the Southern and Eastern Cape . . . . .  | 78         |
| 5.3.3      | Introduction of <i>Casuarina equisetifolia</i> as a Dune Stabiliser  | 79         |
| 5.4        | Discussion . . . . .   | 80         |
| 5.4.1      | Distinguishing the Mechanism of Succession<br>with Indigenous Pioneers . . . . .   | 80         |
| 5.4.2      | Effects of Aliens and the Need for Dune Stabilisation . . . . .  | 81         |
| 5.4.3      | Conservation of Biodiversity and Dune Ecosystems,<br>and Future Studies . . . . .  | 81         |
| References | . . . . .  | 82         |
| <br>       |  |            |
| <b>6</b>   | <b>Why Coastal Dune Slacks Sustain a High Biodiversity . . .</b>   | <b>85</b>  |
|            | A.P. GROOTJANS, E.B. ADEMA, R.M. BEKKER,<br>and E.J. LAMMERTS  |            |
| 6.1        | Introduction . . . . .   | 85         |
| 6.2        | The Dune Slack Environment . . . . .   | 86         |
| 6.2.1      | Hydrological System . . . . .  | 86         |
| 6.2.2      | Adaptations to Flooding and Low Nutrient Supply . . . . .  | 87         |
| 6.3        | Succession in Dune Slacks . . . . .  | 87         |
| 6.3.1      | Nutrient Limitation During Succession . . . . .  | 89         |
| 6.3.2      | Seed Banks and Succession . . . . .  | 89         |
| 6.3.3      | Stability of Pioneer Stages . . . . .  | 92         |
| 6.4        | Impact of Human Disturbances on Ecosystem Functioning  | 95         |
| 6.5        | Restoration of Dune Slacks . . . . .   | 97         |
| References | . . . . .  | 99         |
| <br>       |  |            |
| <b>7</b>   | <b>Coastal Dune Forest Rehabilitation:<br/>A Case Study on Rodent and Bird Assemblages<br/>in Northern KwaZulu-Natal, South Africa . . . . .</b> | <b>103</b> |
|            | R.J. VAN AARDE, T.D. WASSENAAR, L. NIEMAND, T. KNOWLES,<br>and S. FERREIRA   |            |
| 7.1        | Introduction . . . . .   | 103        |
| 7.2        | Study Area . . . . .   | 104        |
| 7.2.1      | Indian Ocean Coastal Dunes . . . . .   | 104        |
| 7.2.2      | The Coastal Sand Dune Forests of KwaZulu-Natal . . . . .   | 104        |

|       |   |     |
|-------|---|-----|
| 7.2.3 | The Post-Mining Rehabilitation of Coastal Dunes . . . . . | 105 |
| 7.3   | Materials and Methods . . . . .                           | 107 |
| 7.3.1 | Rodents . . . . .   | 107 |
| 7.3.2 | Birds . . . . .   | 107 |
| 7.4   | Results and Discussion . . . . .                          | 108 |
| 7.4.1 | Rodents . . . . .   | 108 |
| 7.4.2 | Birds . . . . .   | 112 |
| 7.5   | Conclusions . . . . .                                     | 113 |
|       | References . . . . .                                      | 114 |

### III Living in a Stressful Environment

|          |  |            |
|----------|--|------------|
| <b>8</b> | <b>Burial of Plants as a Selective Force in Sand Dunes . . . . .</b> | <b>119</b> |
|          | M.A. MAUN  |            |
| 8.1      | Introduction . . . . .   | 119        |
| 8.2      | Storm Damage of Foredunes – A Case History . . . . .                 | 120        |
| 8.2.1    | Return . . . . .   | 121        |
| 8.2.2    | Re-Establishment . . . . .   | 123        |
| 8.3      | A Conceptual Model of Plant Response to Burial . . . . .             | 124        |
| 8.4      | Post-Burial Responses of Plants . . . . .                            | 125        |
| 8.4.1    | Seeds and Seed Bank . . . . .  | 125        |
| 8.4.2    | Seedlings . . . . .  | 127        |
| 8.4.3    | Adult Plants . . . . .   | 128        |
| 8.4.4    | Plant Communities . . . . .  | 128        |
| 8.5      | Burial – The Primary Cause of Zonation . . . . .                     | 129        |
| 8.6      | Degeneration Response . . . . .                                      | 130        |
| 8.7      | Stimulation Response . . . . .                                       | 131        |
| 8.8      | Summary . . . . .  | 132        |
|          | References . . . . .   | 133        |

|          |   |            |
|----------|---|------------|
| <b>9</b> | <b>Physiological Characteristics of Coastal Dune<br/>Pioneer Species from the Eastern Cape, South Africa,<br/>in Relation to Stress and Disturbance . . . . .</b> | <b>137</b> |
|          | B.S. RIPLEY and N.W. PAMMENTER  |            |
| 9.1      | Introduction . . . . .  | 137        |
| 9.2      | A Conceptual Model of Resource Limitation<br>and Plant Performance . . . . .  | 138        |
| 9.3      | Study Site, Species and Parameters Measured . . . . .   | 140        |

|          |  |      |
|----------|--|------|
| Contents |  | XIII |
| 9.4      | Water Relations . . . . .                | 141  |
| 9.5      | Mineral Nutrients . . . . .              | 144  |
| 9.6      | Photosynthetic Characteristics . . . . . | 144  |
| 9.7      | Growth Rates . . . . .                   | 146  |
| 9.8      | Stress and Disturbance . . . . .         | 150  |
| 9.9      | Conclusions . . . . .                    | 152  |
|          | References . . . . .                     | 153  |

|           |  |            |
|-----------|--|------------|
| <b>10</b> | <b>Plant Functional Types in Coastal Dune Habitats . . . . .</b>                                 | <b>155</b> |
|           | F. GARCÍA NOVO, M.C. DÍAZ BARRADAS, M. ZUNZUNEGUI,<br>R. GARCÍA MORA, and J.B. GALLEGO FERNÁNDEZ |            |
| 10.1      | Plant Functional Types . . . . .   | 155        |
| 10.2      | Dune Habitats as Environmental Islands . . . . .   | 157        |
| 10.2.1    | Adverse Interactions . . . . .   | 159        |
| 10.3      | Some Examples of Applications of Plant FTs<br>to Dune Vegetation Analysis . . . . .              | 159        |
| 10.4      | Dune Habitat Confinement . . . . .   | 164        |
| 10.5      | Conclusions . . . . .  | 166        |
|           | References . . . . .   | 167        |

**IV Biotic Interactions**

|           |   |            |
|-----------|---|------------|
| <b>11</b> | <b>Arbuscular Mycorrhizas in Coastal Dunes . . . . .</b>  | <b>173</b> |
|           | R.E. KOSKE, J.N. GEMMA, L. CORKIDI, C. SIGÜENZA,<br>and E. RINCÓN                                     |            |
| 11.1      | Introduction . . . . .  | 173        |
| 11.2      | Life History of AM Fungi in Coastal Dunes . . . . .   | 174        |
| 11.3      | AM Fungi in Sand Dunes . . . . .  | 176        |
| 11.4      | Seasonality of AM Fungi in Coastal Dunes . . . . .  | 177        |
| 11.5      | Effects of Arbuscular Mycorrhizas on the Establishment<br>and Growth of Coastal Dune Plants . . . . . | 178        |
| 11.6      | Arbuscular Mycorrhizas and Coastal Dune Succession . . . . .  | 181        |
| 11.7      | Arbuscular Mycorrhizas in Coastal Dune Restoration<br>and Stabilization . . . . .                     | 183        |
|           | References . . . . .  | 184        |

|           |  |            |
|-----------|--|------------|
| <b>12</b> | <b>The Role of Algal Mats on Community Succession<br/>in Dunes and Dune Slacks</b> . . . . .       | <b>189</b> |
|           | G. VÁZQUEZ   |            |
| 12.1      | Introduction . . . . .   | 189        |
| 12.2      | Hydrological Dynamics of Slacks<br>within Coastal Dune Systems . . . . .                           | 189        |
| 12.3      | Algal Communities in Slacks and Other Coastal Zones . . .  | 190        |
| 12.4      | The Role of Algae During Primary Succession<br>in Coastal Dunes . . . . .                          | 193        |
| 12.5      | A Case Study on the Gulf of Mexico . . . . .   | 197        |
| 12.6      | Importance of Algae for Slack Conservation . . . . .   | 200        |
| 12.7      | Conclusions . . . . .  | 201        |
|           | References . . . . .   | 202        |
| <br>      |  |            |
| <b>13</b> | <b>Plant-Plant Interactions in Coastal Dunes</b> . . . . .   | <b>205</b> |
|           | M.L. MARTÍNEZ and J.G. GARCÍA-FRANCO   |            |
| 13.1      | Introduction . . . . .   | 205        |
| 13.2      | Facilitation . . . . .   | 207        |
| 13.3      | Competition . . . . .  | 209        |
| 13.3.1    | Grass Encroachment . . . . .   | 210        |
| 13.3.2    | Invasive Plants . . . . .  | 212        |
| 13.4      | Epiphytes . . . . .  | 213        |
| 13.4.1    | Non-Parasites . . . . .  | 213        |
| 13.4.2    | Parasites . . . . .  | 216        |
| 13.5      | Conclusions . . . . .  | 217        |
|           | References . . . . .   | 218        |
| <br>      |  |            |
| <b>14</b> | <b>Ant-Plant Interactions: Their Seasonal Variation<br/>and Effects on Plant Fitness</b> . . . . . | <b>221</b> |
|           | V. RICO-GRAY, P.S. OLIVEIRA, V. PARRA-TABLA,<br>M. CUAUTLE, and C. DÍAZ-CASTELAZO                  |            |
| 14.1      | Importance of Interspecific Interactions . . . . .   | 221        |
| 14.2      | Richness and Seasonal Variation of Ant-Plant Interactions .  | 222        |
| 14.3      | Importance of Nectar to Ants in Tropical Seasonal<br>Environments . . . . .                        | 225        |
| 14.4      | Effect of Ants on Plant Fitness . . . . .  | 227        |
| 14.4.1    | <i>Myrmecophyla (Schomburgkia tibicinis) christinae</i><br>(Orchidaceae) . . . . .                 | 229        |

|  |     |
|--|-----|
| Contents   | XV  |
| 14.4.2 <i>Paullinia fuscescens</i> (Sapindaceae) | 231 |
| 14.4.3 <i>Opuntia stricta</i> (Cactaceae)        | 232 |
| 14.4.4 <i>Turnera ulmifolia</i> (Turneraceae)    | 234 |
| 14.5 Conclusion                                  | 235 |
| References                                       | 236 |

## V Environmental Problems and Conservation

|           |  |            |
|-----------|--|------------|
| <b>15</b> | <b>Environmental Problems and Restoration Measures<br/>in Coastal Dunes in the Netherlands</b> | <b>243</b> |
|           | A.M. KOOIJMAN  |            |
| 15.1      | Introduction   | 243        |
| 15.2      | Differences Between Renodunaal and Wadden Districts  | 244        |
| 15.3      | Impact of Availability of P on Biomass Production<br>and Successional Trends                   | 245        |
| 15.3.1    | Renodunaal District  | 245        |
| 15.3.2    | Wadden District  | 247        |
| 15.4      | Effect of Mineralization of Nitrogen   | 247        |
| 15.4.1    | Impact of Litter Production  | 247        |
| 15.4.2    | Impact of Litter Decomposition   | 249        |
| 15.5      | Role of <i>Ammophila arenaria</i> in the Wadden District                                       | 250        |
| 15.6      | Restoration  | 250        |
| 15.6.1    | Effect of Grazing and Annual Mowing  | 251        |
| 15.6.2    | Effect of Sod Cutting  | 253        |
| 15.6.3    | Effect of Increased Aeolian Activity   | 254        |
| 15.7      | Concluding Remarks   | 255        |
|           | References   | 256        |
| <b>16</b> | <b>The Costs of our Coasts: Examples of Dynamic<br/>Dune Management from Western Europe</b>    | <b>259</b> |
|           | F. VAN DER MEULEN, T.W.M. BAKKER, and J.A. HOUSTON   |            |
| 16.1      | Introduction   | 259        |
| 16.2      | Coastal Dunes: Dynamic Systems and Management  | 259        |
| 16.3      | Examples from Western Europe: England<br>and The Netherlands                                   | 261        |
| 16.4      | The Sefton Coast (England)   | 262        |
| 16.4.1    | Area   | 262        |
| 16.4.2    | Management   | 263        |

|          |   |     |
|----------|---|-----|
| 16.4.3   | The Sefton Coast in the 21st Century . . . . .  | 264 |
| 16.4.4   | Recreation . . . . .  | 266 |
| 16.4.4.1 | Visitor Research . . . . .  | 266 |
| 16.4.4.2 | Visitor Typology . . . . .  | 266 |
| 16.4.5   | Costs of Management . . . . .   | 267 |
| 16.5     | The Meijendel Dunes (The Netherlands) . . . . .   | 268 |
| 16.5.1   | Area . . . . .  | 268 |
| 16.5.2   | Management by the Dunewater Company . . . . .   | 269 |
| 16.5.3   | Recreation: Better Possibilities for People to Enjoy Nature . . . . .   | 269 |
| 16.5.4   | Meijendel and the Production of Drinking Water . . . . .  | 272 |
| 16.5.5   | Development of a Natural Core Area . . . . .  | 272 |
| 16.5.6   | Costs of Management . . . . .   | 274 |
| 16.5.7   | Visitors Appraisal . . . . .  | 275 |
| 16.6     | Dune Management in a Changing Society . . . . .   | 275 |
|          | References . . . . .  | 276 |
| <br>     |   |     |
| 17       | <b>Animal Life on Coastal Dunes: From Exploitation<br/>and Prosecution to Protection and Monitoring</b> . . . . . | 279 |
|          | G. BAEYENS and M.L. MARTÍNEZ  |     |
| 17.1     | Introduction . . . . .  | 279 |
| 17.2     | Cropping Stock and Game: The Medieval Coastal Dunes<br>as a Store of Animal Goods . . . . .                       | 280 |
| 17.3     | Nature Conservation Starts with Bird Protection . . . . .   | 281 |
| 17.4     | The Complexity of Biotic Interactions . . . . .   | 284 |
| 17.5     | Coastal Zone Management: Can Animals be Integrated? . . . . .   | 290 |
|          | References . . . . .  | 293 |
| <br>     |   |     |
| 18       | <b>Coastal Vegetation as Indicators for Conservation</b> . . . . .  | 297 |
|          | I. ESPEJEL, B. AHUMADA, Y. CRUZ, and A. HEREDIA   |     |
| 18.1     | Introduction . . . . .  | 297 |
| 18.1.1   | Environmental Indicators . . . . .  | 297 |
| 18.1.2   | Ecological Indicators . . . . .   | 298 |
| 18.2     | Methods . . . . .   | 301 |
| 18.2.1   | Ecological Indicator Selection . . . . .  | 301 |
| 18.2.2   | Calculation of Ecological Indicators . . . . .  | 304 |
| 18.3     | Results . . . . .   | 306 |
| 18.3.1   | Environmental Indicators for the Region<br>(Landscape-Scale Indicators) . . . . .                                 | 306 |



|   |  |            |
|---|--|------------|
| 18.3.2                                    | Ecological Indicators for Coastal Dunes<br>(Plant-Community Scale) . . . . .                                       | 306        |
| 18.4                                      | Discussion and Conclusion . . . . .  | 309        |
| Appendix: Floristic List of Northern Baja |  |            |
|   | California Coastal Sand Dune Systems . . . . .   | 311        |
|   | References . . . . .   | 316        |
| <br>                                      |  |            |
| <b>19</b>                                 | <b>A Case Study of Conservation and Management<br/>of Tropical Sand Dune Systems: La Mancha-El Llano . . . . .</b> | <b>319</b> |
|   | P. MORENO-CASASOLA   |            |
| 19.1                                      | Introduction . . . . .   | 319        |
| 19.2                                      | Dune Conservation and Management . . . . .   | 319        |
| 19.3                                      | Beach and Dune Biodiversity and Protected Areas in Mexico  | 320        |
| 19.4                                      | Community Management for the Conservation of Coastal<br>Resources: La Mancha-El Llano Case Study . . . . .         | 325        |
|   | References . . . . .   | 332        |
| <br>                                      |  |            |
| <b>20</b>                                 | <b>European Coastal Dunes: Ecological Values,<br/>Threats, Opportunities and Policy Development . . . . .</b>      | <b>335</b> |
|   | P. HESLENFELD, P.D. JUNGERIUS, and J.A. KLIJN  |            |
| 20.1                                      | Introduction . . . . .   | 335        |
| 20.2                                      | Distribution of Coastal Dunes along Europe's Coast:<br>A Short Geography . . . . .                                 | 336        |
| 20.3                                      | Ecological Values Related to Biodiversity . . . . .  | 338        |
| 20.4                                      | Trends, Threats and Opportunities . . . . .  | 340        |
| 20.4.1                                    | Agriculture: Intensification as well as Marginalization . . .  | 340        |
| 20.4.2                                    | Urbanisation, Industries, Harbour Development . . . . .  | 340        |
| 20.4.3                                    | Infrastructure . . . . .   | 341        |
| 20.4.4                                    | Tourism/Recreation . . . . .   | 341        |
| 20.4.5                                    | Forestry . . . . .   | 342        |
| 20.4.6                                    | Coastal Processes, Climate Change and Sea Level Rise,<br>Aeolian Processes . . . . .                               | 342        |
| 20.4.7                                    | Coastal Defence Works . . . . .  | 343        |
| 20.5                                      | Policy Analysis of Dune Conservation in Europe . . . . .   | 343        |
| 20.5.1                                    | Bern Convention . . . . .  | 344        |
| 20.5.2                                    | EU Policy . . . . .  | 344        |
| 20.5.3                                    | National Policies . . . . .  | 346        |
| 20.6                                      | SWOT Analysis . . . . .  | 347        |
| 20.7                                      | Conclusions . . . . .  | 347        |

|        |                               |     |
|--------|-------------------------------|-----|
| 20.7.1 | EU Countries . . . . .        | 347 |
| 20.7.2 | Accession Countries . . . . . | 349 |
| 20.7.3 | Non-EU Countries . . . . .    | 349 |
| 20.8   | Recommendations . . . . .     | 349 |
|        | References . . . . .          | 350 |

## VI The Coastal Dune Paradox: Conservation vs Exploitation?

|    |   |            |
|----|---|------------|
| 21 | <b>The Fragility and Conservation of the World's Coastal Dunes:<br/>Geomorphological, Ecological and Socioeconomic<br/>Perspectives . . . . .</b> | <b>355</b> |
|    | M.L. MARTÍNEZ, M.A. MAUN, and N.P. PSUTY  |            |

|        |  |     |
|--------|--|-----|
| 21.1   | Current Worldwide Status of Coastal Dunes . . . . .  | 355 |
| 21.2   | Current Research Trends (What Do We Know?) . . . . . | 356 |
| 21.2.1 | Variable Morphologies . . . . .                      | 356 |
| 21.2.2 | Succession . . . . .                                 | 357 |
| 21.2.3 | Adaptations . . . . .                                | 358 |
| 21.2.4 | Tropical vs. Mid-Latitudes . . . . .                 | 359 |
| 21.3   | Fragile Ecosystems? . . . . .                        | 361 |
| 21.4   | Management Practices . . . . .                       | 361 |
| 21.5   | Future Trends and Perspectives . . . . .             | 364 |
|        | References . . . . .                                 | 367 |

|  |                                  |            |
|--|----------------------------------|------------|
|  | <b>Taxonomic Index . . . . .</b> | <b>371</b> |
|--|----------------------------------|------------|

|  |                                |            |
|--|--------------------------------|------------|
|  | <b>Subject Index . . . . .</b> | <b>379</b> |
|--|--------------------------------|------------|