Beaches and Dunes of Developed Coasts

Karl F. Nordstrom
Institute of Marine and Coastal Sciences
Rutgers University
New Brunswick, USA

Cambridge University Press

PUBLISHED BY THE PRESS SYNDICATE OF THE UNIVERSITY OF CAMBRIDGE
The Pitt Building, Trumpington Street, Cambridge, United Kingdom

CAMBRIDGE UNIVERSITY PRESS
The Edinburgh Building, Cambridge CB2 2RU, UK http://www.cup.cam.ac.uk
40 West 20th Street, New York, NY 10011–4211, USA http://www.cup.org
10 Stamford Road, Oakleigh, Melbourne 3166, Australia
Ruiz de Alarcón 13, 28014 Madrid, Spain

First published 2000

Printed in the United Kingdom at the University Press, Cambridge

Typeface Lexicon (*The Enschedé Font Foundry*) 10/14 pt *System* QuarkXPress® [SE]

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication data
Nordstrom, Karl F.
Beaches and dunes of developed coasts / Karl F. Nordstrom.
p. cm.
Includes bibliographical references and index.
ISBN 0 521 47013 7 (hardback)
1. Coastal zone management. 2. Coastal ecology. 3. Coasts.
I. Title.
HT391.N58 2000
333.91′7–dc21 99–13766 CIP

ISBN 0 521 47013 7 hardback

Contents

1

The developed coastal landscape: temporal and spatial characteristics

Introduction

Human-altered coasts vary greatly in appearance, from landscapes where human impact is significant but barely perceptible (Figure 1.1) to landscapes where cultural features visually dominate the landscape (Figure 1.2). No one would deny the prominent role that humans play in altering the coastal landscape (Walker 1984). The more difficult tasks involve identifying: (1) how human-altered landforms may be defined; (2) whether humans are or should be the dominant agent in landscape evolution; and (3) whether human needs or actions should determine the characteristics and values of the resulting landforms. These broad issues can be separated into several areas of investigation (Table 1.1) that are examined in detail. It is assumed here that the landforms of interest (beaches and dunes) and the habitats within them are desirable for both their natural and human values, and that it is better to have these landforms than not to have them. Human actions are then evaluated in terms of loss, gain or conversion of these landforms.

This chapter addresses the first two areas of investigation identified in Table 1.1 by providing a historical perspective on the human forces that drive coastal development and the processes and stages of alteration from natural shorelines to artifacts in attempts to maximize human values. The focus is on long-term and large-scale transformations of landscapes within which individual landforms are altered. The most obtrusive human modifications are highlighted, along with some of the economic and social reasons for the conversion. Evolution at the scale of individual landforms and at shorter temporal scales are evaluated in greater detail in subsequent chapters.

The historical perspective is based largely on activities in western Europe and the USA, because of the availability of information for those locations. Recent economic and social forces are evaluated to show how improvements in communication and transportation, increases in expendable income and

Figure 1.1 Manzanita Oregon, USA. The natural-appearing dune in the foreground has been transformed from its natural appearance as a result of the introduction of European beach grass (*Ammophila arenaria*). This vegetation was first planted in the nineteenth century. It spread rapidly along the Pacific coast and provided a more complete trap to blown sand than the native vegetation and created a higher, more linear, and better vegetated foredune than existed previously.

Figure 1.2 Arma di Taggia, Italy, showing onshore and offshore structures and beach grading operations that have changed the appearance and function of the coast by altering the energy of the waves, the topography of the beach and the natural vegetation and habitat.

Table 1.1 *Major areas of investigation addressed in this book*

How do developed coasts evolve?
How do landforms and landscapes change due to changes in social and economic processes?
How are landforms altered to achieve specific human needs?
How are landforms enhanced to retain their utility?
What are the physical characteristics of the resulting landforms?
What are the temporal scales of evolution of coastal landforms?
Under what conditions are humans intrinsic or extrinsic agents of landscape evolution?
How effective are regulations affecting landforms?
What are the viable alternative approaches to restoring landforms?
How can human alterations be made compatible with natural processes?
What are the ways that natural values can be maintained while accommodating human use?
What is the significance of using static or dynamic approaches to management?
What are the research requirements for beaches and dunes on developed coasts?

creation of global economies have made human alterations an international phenomenon, contributing to an exponential increase in the pace and scale of development. Much emphasis is placed on the evolution of tourism, because it has been a driving force in altering beaches and dunes, and on the implementation of shore protection projects that have extended the impact of humans beyond the initial modifications to the landscape that were designed to accommodate tourism activities.

Perspective on some of these trends is provided in an assessment of a case study of the shoreline of New Jersey, USA, a location that is examined in some detail throughout the rest of the book. The New Jersey coast has the longest history of stabilized barrier island shoreline in North America; it has the most developed coastal barriers and the highest degree of stabilization in the USA; and it has been identified as a template by which developing barriers can be evaluated to show the incompatibility of shorefront development (Pilkey 1981; Nordstrom 1987a; Mitchell 1987; Pilkey and Wright 1988; Hall and Pilkey 1991).

The impact of humans through time

Finding detailed information on the impacts of humans on beaches and dunes through time is a difficult task. There is less information on these landforms than on many other aspects of the environment because these features were of little value in traditional economies. There is little doubt that some human impact on coasts dates back tens of thousands or even hundreds of thousands of years in some areas. Human presence along the coast of Italy, for example, is described as occasional, beginning about 300 000 years BP, and the first settlement is documented about 40 000 years BP (Torresani 1989).

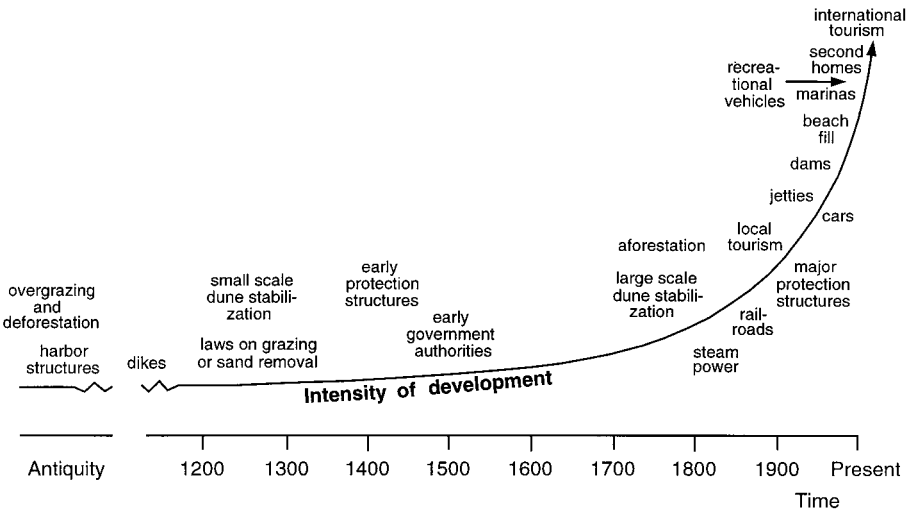


Figure 1.3 Idealized representation of the intensity of human development through time with contributing human actions or features.

Evidence of human influence in the past is obscured due to sea level rise. Most coastal and nearshore archaeological sites are less than 6000 years old because of the rapid rise in sea level prior to that time (Walker 1981a; Bird and Fabbri 1987). Real influence on the coastal landscape in Italy apparently started with the Etrurians from the ninth century BC (Torresani 1989), and there is a rich assemblage of archaeological and geomorphological evidence in Italy and other parts of the Mediterranean in the past 2000 years (Bird and Fabbri 1987).

Figure 1.3 presents an idealized representation of the intensity of development in historical times (revealed in the trend line) along with the principal human actions or features for which there is adequate documentation. The figure is based largely on reports of activities in western Europe and North America. The time of initiation of human activities is generalized because data prior to about 1800 are spotty and site-specific, but the figure does reveal the general change from incidental or accidental actions to direct modification in response to changes in population pressures, perception of resources, income, leisure time and technological advances. Other locations may have gone through similar phases of landscape conversion, but the phases may have been at different dates or have had different durations.

The trend line in Figure 1.3 is portrayed as smooth because it represents a global curve. A site-specific curve would show considerable short-term fluctuations. The impacts of humans on the coast have always undergone periods of greater and lesser impact. In the distant past, periods of declining human use

have been related to piracy, war and disease (Torresani 1989). Pronounced cycles of shoreline advance and retreat are associated with changes in social and demographic characteristics on the Mediterranean coast (Innocente and Pranzini 1993), and at least one and perhaps several phases of active deposition of sediment and advance of the shoreline occurred on the Mediterranean coast in classical antiquity as a result of human activity (Paskoff 1987).

There is a pronounced change in the slope of the curve beginning about two centuries ago corresponding to the availability of steam power that enabled large modifications to the landscape (Marsh 1885; De Moor and Bloome 1988; Terwindt *et al.* 1988; Meyer-Arendt 1992). The slope of the curve has increased with increases in the size and availability of machinery, with development of the internal combustion engine, and with the growth of tourism as a major industry.

Overgrazing and deforestation

Overgrazing and deforestation of drainage basins leads to increased quantities of sediment delivered to the coast. These human actions were likely the earliest causes of major changes to coasts (Walker 1985), and they have undoubtedly had great impact in the Mediterranean, where there has been a long history of human settlement. Deforestation in Italy occurred at a modest scale during the Roman period (Fabbri 1985a; Postma 1989). Deforestation there accelerated in the Middle Ages when people migrated from the coast to higher and drier regions and needed new land for agriculture and settlement; and large areas were deforested by the middle of the nineteenth century when farming reached its maximum extent (Postma 1989). Deforestation associated with settlement in the USA led to delivery of considerable volumes of sediment in the nineteenth and twentieth centuries, leading to locally high rates of accretion on the Pacific coast where rivers flowed directly to the ocean.

Overgrazing and deforestation had a more direct effect on coastal landforms when these activities were practiced in the dunes themselves. Historical perspective on problems of dune destabilization are presented in Sherman and Nordstrom (1994). Human activity in dune fields in Cornwall, England exists from the Neolithic that occurred from about 6500 to 4500 BP (Lewis 1992). There is evidence of Bronze Age occupation of dune fields in Europe (Higgins 1933). Actual reports of wind blown sand and sand drift date back to the tenth century in continental Europe (Klijn 1990) and prior to 1066 in Wales (Higgins 1933). Dune mobility has been increased by human activities associated with grazing, such as burning plant species to produce more desirable vegetation cover and cutting wood in trees to supply shelter or fuel for shepherds (Corona *et al.* 1988). Problems of dune destabilization appeared to

reach their greatest extent in Europe in the eighteenth and nineteenth centuries, when actions at the national scale were taken to stabilize the dunes.

Dune stabilization

Stabilization of drift sands with vegetation plantings was practiced in Great Britain after the stormy periods of the fourteenth and fifteenth centuries (Ranwell 1972). Aforestation occurred as early as the early part of the sixteenth century in Japan (Hotta *et al.* 1991). Aforestation took place in the Doñana Dunes in Spain in 1737 using *Pinus pinea*, but, since then, many other species were used all over the Mediterranean and Portugal using mainly non-indigenous species (van der Meulen and Salman 1996). Aforestation led to commercial activities to make use of the new resources, including lumbering and charcoal-making (Corona *et al.* 1988). The relative success of dune aforestations led to the belief that dunes had to be stabilized with trees whether they were mobile or not (van der Meulen and Salman 1996). Large-scale measures were taken to stabilize drift sand in the eighteenth century in Prussia, Denmark and France (Marsh 1885) and in the nineteenth century in Poland (Piotrowska 1989) and The Netherlands (Klijn 1990). Foredunes for controlling wind blown sand were widely built in European countries in the eighteenth and nineteenth centuries in Europe and in the 1920s in Japan (Hotta *et al.* 1991). Active measures to stabilize drift sand in the USA occurred at Cape Cod, USA before 1775 (Marsh 1885). Stabilization of present-day Golden Gate Park in San Francisco began in 1869 Lamb (1898). Large-scale stabilization projects began on the Oregon coast of the USA in the early twentieth century.

Water regulation activities

Water regulation activities affect coastal sediment budgets, leading to erosion and accretion at the shoreline. These activities may include reclamation, stream channel diversion and stream damming. It is likely that attempts to reclaim land and control flooding have occurred for millennia in population centers near ports. Fabbri (1985a) notes that patterns of canals of Roman Age (2200 to 2000 BP) still exist on the landscape in the plain of the Po River, and he speculates that artificial levees built by the Romans along channels of the Po River affected sedimentation rates on adjacent beaches. A dramatic increase in human influence on European coasts occurred on the Dutch coast between 1100 and 1300 (Berendsen and Zagwijn 1984). This is about the time when dikes are identified on maps in France (Lahousse *et al.* 1993) and when dikes became common in Britain and Germany (Doody 1996; Garniel and Mierwald 1996).

Large-scale stream diversion occurred near the end of the sixteenth century

in northeastern Italy when the Venetians diverted several rivers near their city, including the Po and the Piave (Zunica 1990; Bondesan *et al.* 1995). Diversion of the Po was extensive, involving relocation of a portion of the channel more than 5 km long (Bondesan *et al.* 1995).

Dramatic change in coastal sediment budgets occurred in the twentieth century owing to reduction in river sediment supply because of upstream dams and mining of sediment from river beds (Ferrante *et al.* 1992; Marabani and Veggiani 1993). Major periods of dam building affecting coastal sediment budgets occurred prior to World War II in many industrial countries and after World War II in many others (Paskoff 1992). The recent increases in sedimentation rates at dams have reduced the amount of sediment delivered to the coast and reversed the accretional trends that formerly occurred in many areas due to overgrazing and deforestation.

Navigation improvements

Navigation improvement structures are among the earliest human features used to directly control coastal processes, and they are among the earliest structures identified in inventories of human alterations (Leidersdorf *et al.* 1994). Harbor works that are still functioning may be traced back to antiquity (Inman 1974). These structures have great longevity because of their scale (that results in a high degree of survivability) or because of their importance (that justifies rebuilding if they are damaged).

The most profound changes to coasts due to navigation improvements have occurred since the mid nineteenth century, when advances in power machinery facilitated opening and closing of inlets and enabled construction of massive jetties and channel dredging projects to stabilize them. Many jetties were constructed at inlets on the coast of the USA from the late nineteenth century to present. Nearly every harbor in southern California is artificial, being either dredged in low sandy areas, followed by jetty construction, or created by building breakwaters in the nearshore (Wiegel 1994). The coast of New South Wales has over 30 jettied river entrances (Druery and Nielsen 1980). The effects of these human actions extend far beyond the limits of the navigation channels themselves because the alterations affect the sediment exchanges and shoreline fluctuations at a larger spatial scale than the site of the navigation improvement.

Early regulations

Early laws to preserve littoral defences by prohibiting cattle on dikes or removing sand and vegetation date from the thirteenth century in Italy (Franco and Tomasicchio 1992). Laws to control migrating sand date from the

thirteenth century in The Netherlands (van der Meulen and van der Maarel 1989) and the sixteenth century in Denmark and Great Britain (Marsh 1885; Gray 1909; Ranwell 1959; Jensen 1994). Government authorities designed to deal with coastal hazards and erosion problems date back to the fifteenth century with formation of the Dutch water boards and the Venetian Water Committee (Franco and Tomasicchio 1992). Laws regulating activities on dikes and in dunes appear to have been the principal actions taken to control activities in coastal landforms prior to the twentieth century and were driven by the need to control specific types of coastal hazard, rather than to protect natural components from irreversible losses. The late twentieth century saw passage of many laws that attempt to reduce losses from coastal hazards and protect the natural environment in the face of dramatic increases in the pace of coastal development.

The growth of tourism

There was little or no interest in direct use of the exposed part of the coastal zone in many countries up to the mid nineteenth century due to the difficulty of traversing lagoons and marshes and the occurrence of malaria (Cencini and Varani 1989). The second half of the nineteenth century saw the beginning of relatively large-scale coastal tourism and development of seaside resorts in many locations (Meyer-Arendt 1990; Ehlers and Kunz 1993; Grechischev *et al.* 1993; Kelletat 1993; Nordstrom 1994a; Fabbri 1996). Contributors to increased use of the coast and change in the character of resorts during that time period were expansion of steamship service and railroad systems, changes in the organization of time between working and non-working hours, reduction in the number of hours in the work week, reduction of time devoted to religious practices on Sundays, and formation of an urban middle class with money and mobility (Fabbri 1990).

Mass tourism occurred after World War II, due to a general increase in national incomes and its distribution to different social levels, combined with increased free time (Cencini and Varani 1989; Ridolfi 1989). The diffusion of tourism has turned many ports and fishing villages into resorts (Fabbri 1989; Meyer-Arendt 1991; Anthony 1997). Automobile access has been the primary stimulus for development in many areas, extending the zone of development beyond centers of mass transit. For example, construction of the Trans-peninsular Highway in Baja California, Mexico in 1973 increased tourist arrivals 500 percent (Fermán-Almada *et al.* 1993).

Second homes have become more popular in recent decades, resulting in a greater amount of environmental degradation and exposure to coastal hazards than occurred in formerly clustered hotel-dependent activities

(Ridolfi 1989; Good 1994). Spaniards vacationing in Cantabria, for example, prefer to buy or rent flats in new high-rise hotels rather than stay in hotels or camping areas, contributing to the extension of urbanization into areas formerly occupied by farms (Fischer *et al.* 1995). Many new homes are detached single-family or duplex structures that use considerably greater space than condominiums. Many homes often are used only for a few weeks a year, raising questions as to whether their cost is worth their use (Fabbri 1989). In other cases, older weekend cottages are torn down and replaced by larger homes (Griggs *et al.* 1991b).

A large number of marinas have been built in recent years, particularly on the Atlantic coast of France and in the Mediterranean, where they are considered a means of drawing income to a municipality and contributing to its prestige (Miossec 1988; McDowell *et al.* 1993; Anthony 1994, 1997). Pleasure boating in Italy was limited and elitist up to the end of the 1960s but has expanded greatly since then as a result of increased leisure time, leveling of standards of living, widespread increase in income and perception of yachting as a less exclusive pastime (Rizzo 1989). The average distance between harbors on the northern Adriatic coast is now 6 to 7 km (Rizzo 1989), yet demand often exceeds mooring capacity (Ridolfi 1989). There are up to 50 marinas on the French coast, where they are considered a threat to the natural environment (Miossec 1993). There are over 4000 harbors in Japan, or about one for every 8 km of shoreline; many of them are built out from shore into the open sea (Walker 1985).

Mobile homes (or caravans) have increased in numbers over the past several decades. These units may be static and rented on site, towed or self-propelled. The direct impact of vehicles varies according to whether they are confined to regulated camping sites or allowed to drive to undeveloped sites where their subsequent use is uncontrolled. Their indirect impact is related to: (1) the increased access of a larger number of beach and dune users to relatively undeveloped areas; (2) increases in the number of pedestrian trips across dunes as users make return trips to their caravans; and (3) damage to surface cover and substrate as users create burial pits for disposal of refuse (Mather and Ritchie 1977).

Off-road vehicle use has increased as well. Small off-road vehicles, "dune buggies," were a novelty at Sand Lake, Oregon, USA until the 1960s, but they numbered in the thousands on weekends in 1979 (Wiedemann 1990). Off-road vehicle registrations at Cape Cod National Seashore USA grew from 966 in 1964 to 5843 in 1978, and 33 378 vehicle passes were made through access points in this seashore between June and September 1976 (Godfrey and Godfrey 1981). The Aberffraw sand dune system in Anglesey, Wales had 3.2

km of vehicle tracks and 2.2 km of footpaths in 1960 and 11.7 km of vehicle tracks and 16.5 km of footpaths in 1970 (Liddle and Grieg-Smith 1975a).

Stages of landscape conversion through tourism

The relationship between natural coasts and human-modified coasts may be presented in terms of generic scenarios, representing the results of applying different human values and levels of investment. Most coastal communities undergo incremental development that progresses through stages. The stages in many resorts in Thailand, for example, include: (1) construction of simple low-budget visitor dwellings; (2) upgrading of these structures as visitor numbers increase; (3) selling of land to developers; (4) construction of hotels to meet increasing demand; and (5) expanding buildings and infrastructure while ignoring legislation on zoning and land use (Chou and Sudara 1991). Models for growth of European and North American resorts present growth in terms of: (1) an exploration stage; (2) a period of commercial involvement and infrastructure development; (3) a settlement-expansion stage; and (4) an increase in intensification of sites already developed (Butler 1980; Meyer-Arendt 1990, 1993a). The end of the settlement stages is a maturation stage when all potentially developable land has been developed as either low or high density, and levels of tourist visits have stabilized (Meyer-Arendt 1993a). By this stage, human-induced environmental degradation is often recognized and translated into government controls (Meyer-Arendt 1993a). Levels of maturation vary from site to site, reflecting a combination of physical and cultural attributes, land use regulations and market demands; locations that developed prior to restrictive legislation can mature within the stage of land use intensification, whereas locations that developed more slowly may have been halted in earlier stages (Meyer-Arendt 1993a).

Meyer-Arendt (1985, 1990, 1991, 1992, 1993a) reviews the characteristics of seaside resorts and how their form has changed since the nineteenth century. Resorts in the nineteenth century reflected an urban spatial structure attributed largely to the mode of access (steamship or railroad), resulting in a concentration of tourists at nodes. Concentric zones of human activity and infrastructure emanated from locations where transportation routes ended, either near the shorefront or at docks or railroad stations somewhat inland from the beach. These zones (Figure 1.4) have been subject to redefinition through time, but they include: (1) the core central business district (CBD), often of compact shape; (2) the recreational business district (RBD), usually of linear shape, corresponding to the orientation of the beach and swash/surf zone that is the principal attraction of coastal resorts; (3) an accommodation

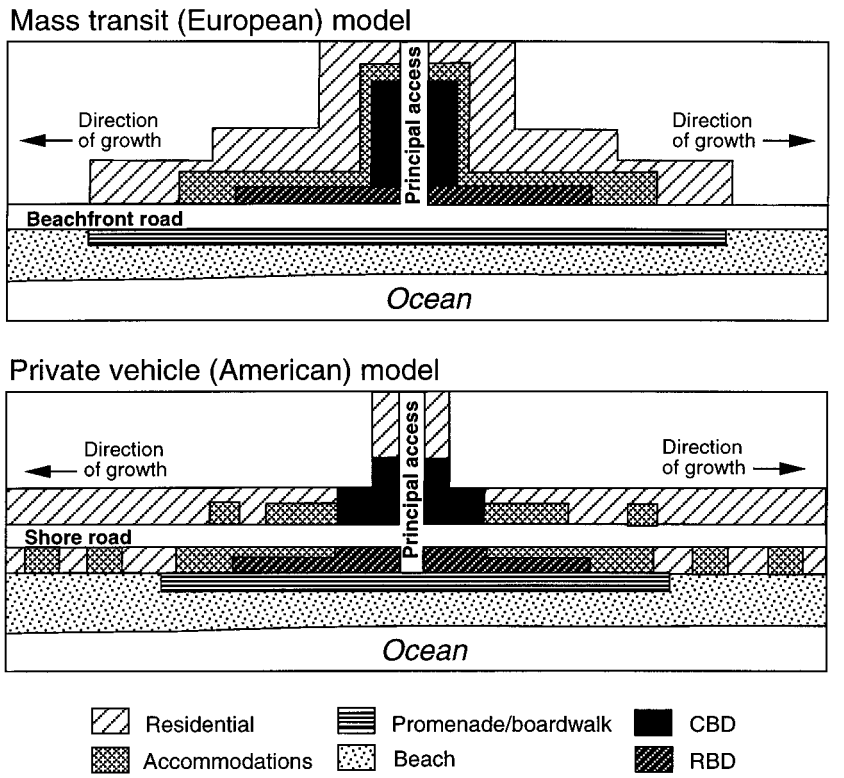


Figure 1.4 Relationship of recreational business district and central business district to beach and transportation routes. Synthesized from models presented in Meyer-Arendt (1990) and visual observations of seaside resorts.

area (hotels, boarding houses) around both the central business district and recreational business district; and (4) a residential zone for non-tourists or (more recently) owners of second homes. The recreational business district may be distinguished from the central business district in both form and function. The central business district may offer a full range of retail goods and be centrally located with respect to permanent residents; the recreational business district is located close to the beach with maximum accessibility to lodging facilities and travel routes (Stansfield and Rickert 1970; Meyer-Arendt 1990).

The tourist structures in the recreational business district were often (as now) separated from the beach itself by a pedestrian promenade, a highway, or both (Figure 1.5). Many resorts on the northeast coast of the USA have an elevated boardwalk instead of a ground-level promenade. Promenades (and boardwalks) may be built out onto the landward portion of the beach (Fernandez-Rañada 1989), and they usually end at the longshore termini of

Figure 1.5 Nice, France showing linear recreational business district, beachfront promenade and thoroughfare.

the recreational business district and do not extend along the shoreline fronting isolated residential structures.

The nodes of developments were T-shaped where reliance on mass transit produced a limited number of routes or disembarcation points (Figure 1.4). Initially, automobile access created a T-pattern of development, with the focus being one or two central beach hotels with amusement facilities. The recreational business districts expanded by increasing concentration of businesses in these core areas and lateral elongation along the shoreline as a recreational frontier (Meyer-Arendt 1990, 1991). Expanded use of private vehicles resulted in elimination of railroads as a principal mode of access, and many rail lines to seaside resorts have closed (Gale *et al.* 1995). The use of air travel by international tourists has created a large-scale pattern where high-value, low-density leading-edge development in the form of villas are farthest removed from the airport, with low-value, high-density properties in high-rise apartments and condominiums closer to it (McDowell *et al.* 1993).

Lateral elongation can occur as contiguous development or leap to new nodes that represent *loci* of speculative development or conversion of pre-existing coastal communities that add tourism to traditional economies. Development and expansion of resort communities is strongly tied to developments in transportation. The new transportation links can be built under

speculation, specifically for tourism, such as at Atlantic City, New Jersey (Nordstrom 1994b) or they can be built for economic values that precede demand for tourism, such as at Progresso, Mexico (Meyer-Arendt 1991).

Seaside resorts have changed considerably when compared with their nineteenth-century counterparts in that they have diversified to incorporate retail residential and industrial functions akin to inland towns and cities. Increased mobility allowed by private vehicles and proliferation of shopping chains into resorts have blurred the sense of place and quality of resorts as an exclusively coastal experience (Gale *et al.* 1995).

The user population can come from local non-coastal urban areas or can be international, and much of the character of coastal resorts reflects the mix of user populations. Former characteristics associated with folk culture and specific characteristics of the natural environment are altered by the imprint of popular culture, creating a new landscape layer (Meyer-Arendt 1990). For example, ports that were part of the tourist folklore and considered part of the landscape have been replaced by massive developments driven by tourism and fueled by competition among seaside resort communities trying to capture readily available private investment (Anthony 1997).

Stages of shore protection

Towns threatened by erosion in the distant past were allowed to succumb when their time came, or they essentially migrated inland with the new coastline (Paskoff 1987). Written reports of shore protection works date back to AD 537 in Italy (Franco and Tomasicchio 1992). Seawalls built of timber piles and stones were common on the coastal barriers near Venice in the seventeenth century and were built to large scale in the mid eighteenth century (Franco and Tomasicchio 1992; Marchi 1992). Protective works on the Nile Delta coast began as early as 1780 (Fanos *et al.* 1995). Groins were built more than 200 years ago on the Dutch coast (Pluijm *et al.* 1994). Groin building activities began at Atlantic City, New Jersey between 1857 and 1876 (Weggel and Sorensen 1991), at Norderney, Germany beginning in 1857 (Kunz 1990), the west coast of Denmark in 1875 (Laustrup 1993), Hawaii in 1900 (Fletcher *et al.* 1997).

Large-scale shore protection projects became common in the past 100 years as availability of heavy machinery and the benefit–cost ratio of protecting infrastructure of ever-increasing scale became more favorable. The first large-scale shore protection project in the USA occurred early in the twentieth century with construction of the Galveston seawall and raising of the height of the island near the beach (Wiegel 1991).

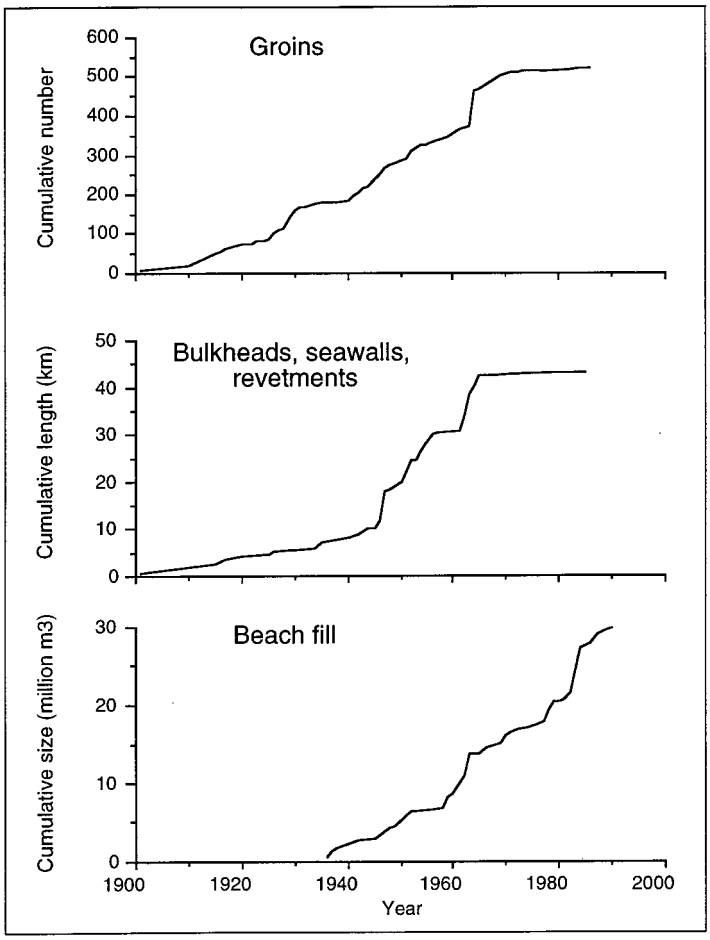


Figure 1.6 Trends in the implementation of shore protection projects in New Jersey since 1900. Modified from Nordstrom (1994a).

Shore protection methods change in frequency of implementation, depending on changing preferences of residents and attitudes of planners and engineers. Examination of these changes (Figure 1.6) often reveals an early preference for groins, followed by a period of construction of shore-parallel structures, to a period of beach nourishment that is currently favored (Caputo *et al.* 1991; Kana 1991; Paskoff and Kelletat 1991; Nordstrom 1994a). In some locations, such as Italy and Japan, offshore breakwaters have been in vogue, with submerged breakwaters becoming popular relative to traditional emergent structures (Lamberti and Mancinelli 1996). The number of detached breakwaters in Japan increased from 2305 in the early 1980s (Toyoshima 1982) to about 4800 by 1989 (Silvester and Hsu 1993). Sawaragi (1988) reports

a growth rate of offshore detached breakwaters at about 10 times the growth rate for construction of dikes and seawalls from 1970 to 1985.

In some locations, different types of structures are added to the protective infrastructure through time as erosion proceeds. The shoreline of Kaike, Japan has undergone the following stages: (1) a series of groins built from 1947 to 1955; (2) a seawall built from 1955 to 1961; (3) emplacement of concrete blocks in front of the seawall in the 1960s; and (4) a detached breakwater system built seaward of all of these structures from 1971 to 1981 (Toyoshima 1982). In other cases, a similar type of structure is used, but its dimensions and cost increase through time as each structure fails (Pilkey 1981; Kana 1983; Reynolds 1987). Structures built initially as backup protection are replaced by structures designed to provide the principal defense, as has occurred on the east coast of the USA, where bulkheads have been replaced by seawalls.

Relatively large-scale beach nourishment projects were used to improve urban resorts in the USA as early as 1922 (Dornhelm 1995). Nourishment became popular in the USA in the 1950s (Domurat 1987). The first large-scale beach nourishment project in Europe was on Norderney, Germany in 1951–52 (Kunz 1993a). The first planned nourishment in France was in Cannes in 1960–61 (Anthony and Cohen 1995). Nourishment became popular at the end of the 1970s in Poland (Zawadzka-Kahlau 1995) and in the 1980s in Georgia (Zenkovich and Schwartz 1987). Since the 1970s, 90 percent of the US federal appropriation for shore protection has been for beach nourishment (Sudar *et al.* 1995). Over 60 percent of all sand emplaced on the Gulf Coast of the USA was emplaced during the past 16 years, with approximately 25 percent of all sand emplaced within the past 6 years (Trembanis and Pilkey 1998). Beach nourishment is increasingly favored because of the decreasing real cost of sand (Laustrup 1993).

Use of shore protection structures has increased along with the increase in construction of buildings and support infrastructure. A total of 80.9 km of seawalls, 11 km of breakwaters and 914 groins over a length of 54.8 km have been constructed on the Russian Black Sea coast between Tuapse and Psou since the 1950s (Grechischev, *et al.* 1993). 178 groins were built over an 8.8 km reach in Yucatan in Mexico (Meyer-Arendt 1991). 1300 groins extend over a distance of 125 km in France (Monadier *et al.* 1992). Over 130 groins were built on the 4.4 km long Tybee Island, Georgia since the late 1800s (Olsen 1996). The percentage of the California, USA coastline protected by structures increased from 42.9 km in 1971 to 210.6 km in 1989 (Griggs 1995).

The proportion of coastline that is protected against flooding and erosion or that is significantly affected by human development varies from high estimates of about 100 percent for Belgium (De Moor and Bloome 1988; De Wolf

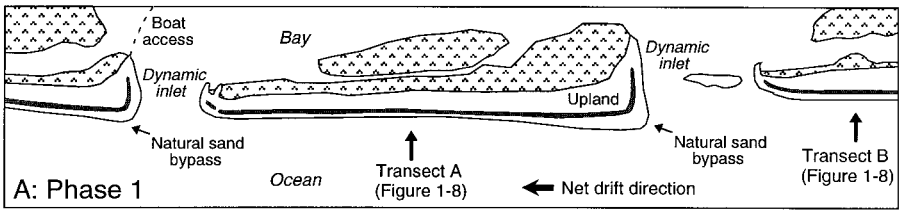
et al. 1993) to low estimates of about 12.9 percent for Italy (Cencini and Varani 1988). The national averages may obscure the intensively developed and protected shorelines where low coastal formations and desirable beaches have been foci for resort development. Coastal defense structures have been built along 60 percent of the coast of northeastern Italy from Grado to Rimini, including 56 km of groins and breakwaters and 55 km of seawalls (Bondesan *et al.* 1995).

The coastline of Japan has been drastically altered by massive engineering projects (Nagao 1991; Watanabe and Horikawa 1983). As many as 10 043 groins were reported in Japan by the early 1980s, along with 5579 km of seawalls and 2838 km of dikes (Toyoshima 1982). The total length of protection structures along the coast of Japan is over 10 000 km (Nagao 1991). Many coastal areas in Japan have been built as human artifacts and bear little resemblance to the coast that formerly existed (Kawaguchi *et al.* 1991; Nagao and Fujii 1991).

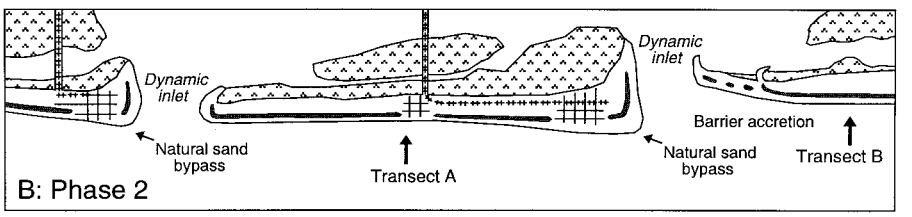
Case study: development of an intensively developed coast

The preceding sections provide a brief survey of only a few of the large-scale landscape conversions that have occurred over millennia in a variety of different locations characterized by different user populations and different economic and social constraints. This section identifies trends in one segment of coast, the State of New Jersey, USA, focussing on activities that have occurred since human alterations became dominant (corresponding to the steep rise in the curve on Figure 1.3).

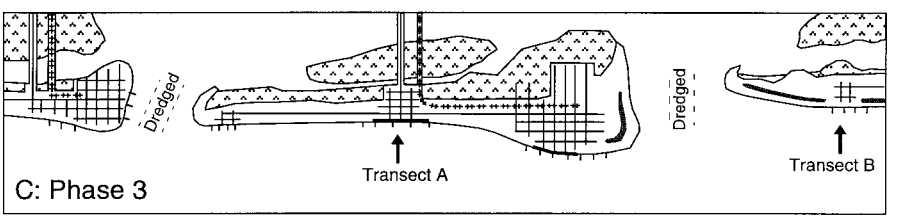
Figures 1.7 and 1.8 synthesize changes that occurred to the barrier islands of New Jersey since early development initiatives in the mid nineteenth century. Beaches at the New Jersey shoreline had some limited use as a recreational resource as early as 1790 (Domurat 1987), but only a few hunting cabins, homesteads and boarding-houses existed on the islands prior to the mid and late nineteenth century (Sea Isle City 1982; Koedel 1983). This period corresponds to the exploration stage, when access is initially difficult, and human impact on the physical environment is limited to access paths to the beach (Meyer-Arendt 1993a). The barriers were low and narrow prior to intensive human modification, and they were backed by salt marsh and fronted by foredunes that formed broad-based ridges in relatively stable portions of the barriers (Transect A, Figures 1.7 and 1.8 at Phase 1) and hummocks in more dynamic areas, such as near inlets (Nordstrom 1994a). The upland portions of the barriers had lush growth of cedar, holly and other trees and a variety of grasses (Sea Isle City 1982). Several New Jersey barriers appeared to be highly mobile prior to human development; one of these barriers migrated across its



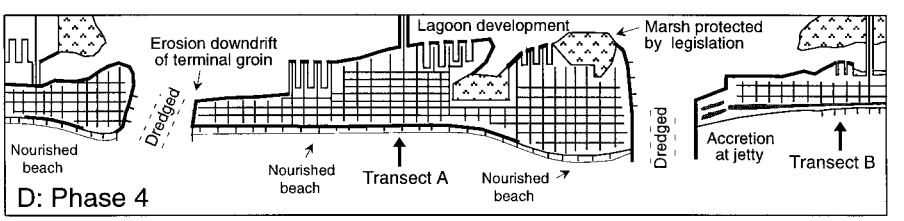
Access by boat
Scattered buildings
Paths to water



Railroad building
initial development at access nodes
Local elimination of dunes



Construction of road networks and new settlement nodes
Widespread elimination of dunes
Beginning of marsh filling
Dredging of inlets
Emplacement of groins and bulkheads at eroding settlements



Construction of lagoon residences
Widespread use of groins and bulkheads
Beach nourishment in intensively developed areas
Jetty construction at inlets
Restrictive environmental regulations

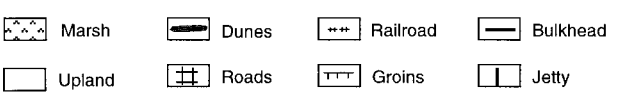


Figure 1.7 Plan view of phases representing the development and protection of coastal barriers in New Jersey, USA through time. Transects A and B are presented in profile view in Figure 1.8 Modified from Nordstrom (1994a).

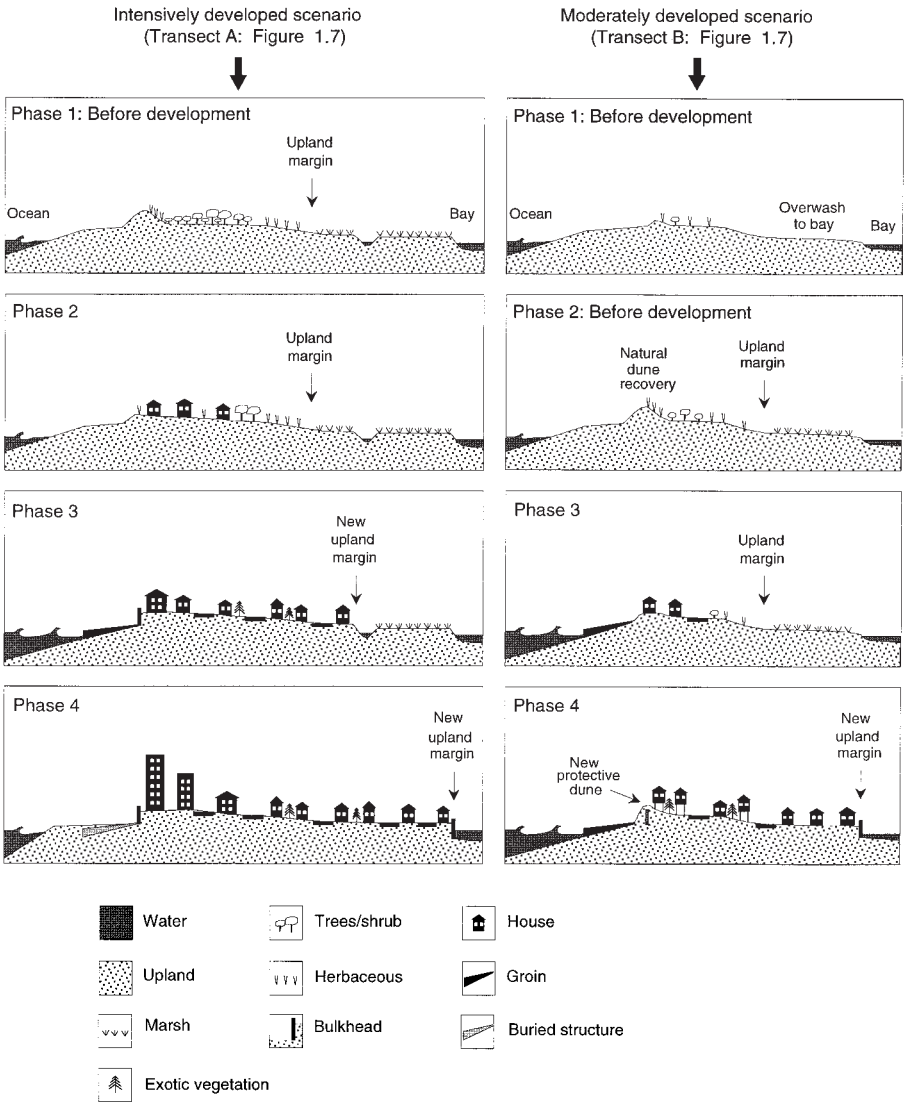


Figure 1.8 Profile view of phases representing the development and protection of coastal barriers in New Jersey, USA through time. Transects A and B are presented in plan view in Figure 1.7 Modified from Nordstrom (1994a).

width in no less than 200 years (USACOE 1957). Locations adjacent to inlets were especially mobile (Figure 1.7, Phases 1 and 2).

Railroad lines, built to support real estate speculation ventures, extended along 57.8 percent of the New Jersey shoreline by 1885–86 (Nordstrom 1994a). The resulting land use pattern reflected a clustering of recreational business districts near railroad stations on the upland portions of the barriers (Figure 1.7B). The infrastructure development stage is a time when landscaping often

is accompanied by removal of geomorphic features and replacement of upland vegetation by introduced species (Meyer-Arendt 1993a). Modifications on the New Jersey barriers included grading dunes to a flatter form to facilitate construction of buildings and roads (Figures 1.7 and 1.8, Transect A in Phase 2 and Transect B in Phase 3) and destruction of the natural vegetation, that was often dense shrub.

The settlement expansion stage in growth of coastal resorts was rapid following construction of railroads and the first permanent business districts. The permanent population of Atlantic City was nearly 5500 by 1880 (Funnel 1975). Land values at Atlantic City grew from almost nothing in 1854 to $50 million in 1900 (Domurat 1987).

The barrier island resort industry in New Jersey developed rapidly in the early twentieth century, due primarily to increased use of private automobiles (Koedel 1983), accelerating the pace of the settlement expansion phase. New isolated communities appeared, in some cases linked by roads rather than railroads. Growth then extended outward from these locations, both alongshore on the upland portion of the barriers and bayward onto the marsh surface. Filling of the marsh behind the upland occurred on several barriers between 1886 and 1902 (Figure 1.7C), and the marsh at Ocean City was filled all the way to the edge of the backbay by 1907 (Nordstrom 1994a).

The settlement expansion stage involves the transformation of the physical environment into a cultural one (Meyer-Arendt 1993). Shore protection measures begin to be employed in the settlement expansion stage, although the intensity of development may be too limited early in this stage for public works to be cost-effective (Meyer-Arendt 1993a). Efforts were made to control erosion in New Jersey as early as 1847 at Cape May (USACOE 1957). The widespread use of protection structures came in the settlement expansion phase after 1900 (Figure 1.7C).

Dredging of channels into the backbarrier marsh to accommodate boats occurred in the larger settlements between 1905 and 1913. Large-scale conversion of the marsh to lagoon developments for private housing and their associated boat docks (Figure 1.7D) occurred on many of the barriers after World War II. Most of these projects placed materials dredged from the new waterways on the marsh surface to provide a substrate for houses and roads. Construction of lagoon housing is now severely restricted by regulations governing use of wetlands, but marshland is now found only in isolated enclaves on the back sides of the developed portions of barriers in New Jersey (Nordstrom 1994a).

Many inlets that existed in 1885–86 and all inlets that formed since that time were closed artificially by the US Army Corps of Engineers or kept from reopening after natural closure to eliminate undesirable shoreline fluctua-

Figure 1.9 Atlantic City, New Jersey, showing juxtaposition of high-rise buildings and beach. A geotextile tube that will form the core of an artificial dune is seen on the beach at lower right.

tions, facilitate land transportation or increase the hydraulic efficiency of nearby controlled inlets. Navigation improvement projects at inlets were undertaken to maintain a predictable navigation channel and a static shoreline. Five of the 12 New Jersey inlets that now exist are stabilized by jetties, constructed since 1911. Two of the unjettied inlets are maintained by dredging, changing the amount of sediment transferred across the inlets and the location of accretion and erosion on adjacent shorelines.

The stage of land use intensification (including construction of high-rise condominiums and hotels and replacement of pre-existing structures with structures of higher density) is not a requisite stage of resort evolution, but it is characteristic of resorts of high recreational demand (Meyer-Arendt 1993a). The proximity of the New Jersey shoreline to the large urban population centers of New York City and Philadelphia provided the stimulus for further intensification. Restrictions to the number of units per building in New Jersey have limited high-rise constructions to only a few locations, such as Atlantic City (Figure 1.9), where the buildings are so large and so close to the beach that they profoundly affect wind processes and aeolian transport. Other communities are characterized by a high density of multiple-unit low-rise structures. Most communities are moderately developed in detached houses that are fronted by a narrow dune (Figure 1.10), a bulkhead or both.

A level of development such as that portrayed along Transect A (Figure 1.8)