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The role of human actions in evolution and management of foredunes in The Netherlands and New Jersey, USA

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Abstract. The rationale and methods of construction of foredunes in The Netherlands and New Jersey, USA are identified and used to explain their genesis, locations, mobility, internal and external characteristics and temporal scales of evolution. Dunes are then ranked according to the degree they are modified by human processes. The lower level of protection required of foredunes in New Jersey and the greater amount of modification by municipal managers and shorefront residents results in smaller dunes and greater variety of sizes, shapes, methods of construction and alterations. As a result, humans are considered intrinsic agents in evolution of dune landforms and landscapes. Higher, wider, better vegetated foredunes occur in The Netherlands due to greater frequency of onshore winds and greater emphasis on sea defence at the national level. Natural processes play a greater role in the evolution of landforms. Human actions are considered extrinsic at this scale but intrinsic at the scale of landscapes. The change in foredunes from natural features to artifacts reveals the significance of humans in the modification of coastal landforms and reflects the changing perception of the role of these landforms in the coastal landscape.

Keywords: Aeolian transport; Beach; Coastal policy; Foredune; Landform; Management; Sediment; Shore protection.

Introduction

The location of coastal foredunes landward of the beach and seaward of most human development has made these landforms subject to considerable human modification. Despite the widespread influence of humans on the evolution of foredunes, there are no genetic studies that evaluate the variety of human processes and forms that these landforms can have on developed coasts. Most previous morphologic or sedimentologic evaluations of foredunes influenced by humans have concentrated on foredune characteristics and evolution under primarily natural processes (Nordstrom et al. 1986; Psuty 1989, 1990; Gares 1990; Pye 1990; Arens & Wiersma 1994; Pye & Neal 1994) or on strategies for modifying them to optimum dimensions to fulfill specific protective functions (Anon. 1984; Godfrey 1987; Hallermeier 1987; Adriani & Terwindt 1974; van de Graaff 1986). Knowledge of the genesis, form and location of the many other foredune types that owe their origin primarily to human action is important in defining the concept of a dune in a human-altered context.

The characteristics of foredunes in different developed locations reflect differences in: (1) the nature of natural inputs into coastal systems (winds, waves, sediment and biota); (2) the perception of the value of the dunes for human use (sea defence, ecological value, recreation); (3) the degree that activities in the dune are controlled (the laws and the administrative levels for management decisions); and (4) the latitude allowed for natural processes to shape the human-altered landforms. This paper examines foredunes in The Netherlands and the state of New Jersey, in the northeastern USA, to identify the role of humans as agents of foredune evolution and to describe the characteristics of foredunes as artifacts. These two locations were selected because the period of human alterations is relatively long, and there is a great variety in the resulting landforms. The two locations are within the zone of prevailing westerly winds, but they have important differences in exposure (windward and leeward coasts) and different management strategies due to different perceptions of the resource values of the dunes.

The rationale for human alterations of foredunes and the methods used to create and alter them are identified. The resulting effects on the mobility of dunes are described, along with the internal and external characteristics and temporal scales of evolution. Dunes are then ranked according to the degree that they are modified by human processes. We use a broad definition of the term ‘dune’ as a convenient way of describing both the ridges of sediment formed by aeolian processes and the ridges placed at that location by humans. The significance of using this term to refer to both natural and human altered forms is evaluated in the discussion after the variety of origins and characteristics of foredunes are described.

Study areas

New Jersey

The ocean shoreline of New Jersey is ca. 205 km long and consists of barrier spits and barrier islands (Nordstrom & Jackson 1995) and two low (<7.5mhigh) headlands composed of unconsolidated sediments. Dominant winds blow from the northwest (Fig. 1 inset), although northeasterly winds are strong during storms. Most of the coast is accessible to residents and visitors by shore-parallel access roads, and the shorefront is intensively developed in one- and two-story private residences, with hotels in the more intensively developed communities. Most of the natural vegetation and original dunes were eliminated in the early stages of development (beginning in the mid-19th century). Dunes in developed communities have been artificially re-created using sand fences, vegetation plantings or earth moving equipment. These dunes often form a single low narrow ridge. Dunes do not persist in many locations, but these locations are protected by bulkheads and seawalls. Over 100 beach nourishment operations have been conducted, most of which have involved placing sand on the subaerial beach, creating a higher, wider berm. Over 300 groins have been built, and 5 of the 12 inlets are fixed by jetties.

The present design standard for protective dunes in the USA is a dune volume provided by the Federal Emergency Management Agency (FEMA) for protecting against 100-yr floods. This level of protection is only likely to be adopted by municipalities in New Jersey if required as a condition of economic support from FEMA, and dunes, if they exist at all, are often lower than FEMA standards. State regulations prohibit direct disturbance to dunes that would reduce their dimensions, but sand can be added to dunes by bulldozing, and vegetation may be planted. Controls over development landward of mean high water are executed through municipal regulations that vary considerably in permissible activities. Periodic maintenance of beaches and dunes is performed at the municipal level using beach cleaning equipment, bulldozers and other types of earth moving equipment. Most municipalities have a municipal budget for sand fences, and they may have programs for planting, utilizing volunteer labor (Mauriello & Halsey 1987; Mauriello 1989). The first shore-parallel road in municipalities in New Jersey is usually landward of the seaward-most property lines, and the foredune often exists on private property. Residents affect dune forms by trapping, relocating or totally removing sand from their property.

The Netherlands

The coastline of The Netherlands is ca. 350 km long and consists of a chain of barrier islands in the north, a 118-km mainland coast in the center and a series of peninsulae in the south that are intersected by estuaries, sometimes connected by a dike (e.g. Arens & Wiersma 1994; Doing 1995). The strongest winds are onshore (Fig. 2). Dunes now represent ca. 75% of the principal line of shore protection features. Access to these dunes is greatly restricted, due to the limited number of roads to the shore. Development in houses and hotels landward of the beach occurs only in isolated coastal resort

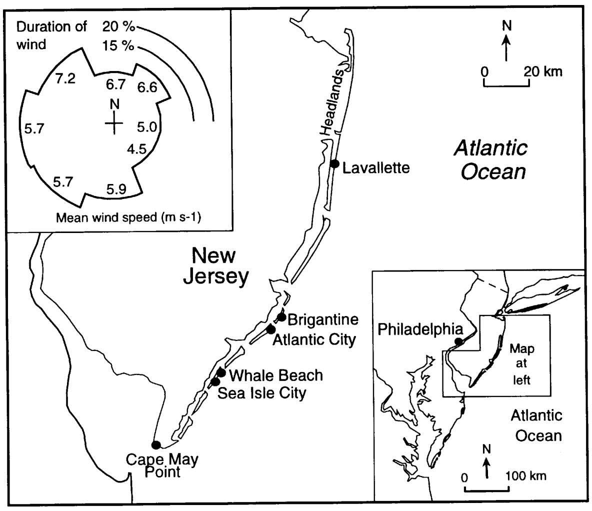

Fig. 1. Study area and sites in New Jersey, USA.

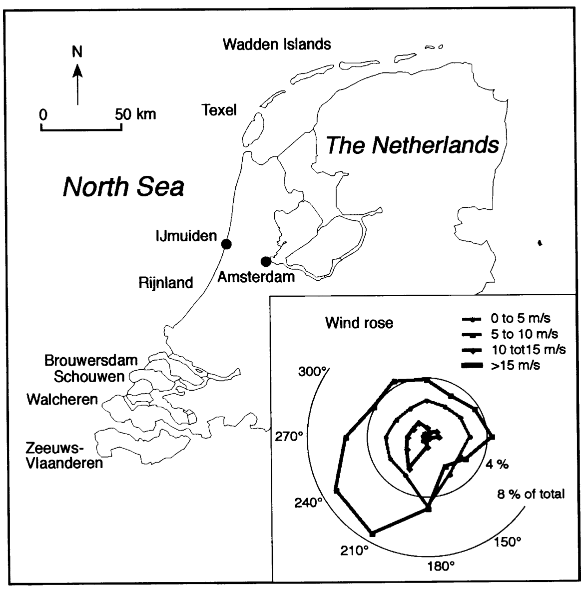

Fig. 2. Study area and sites in The Netherlands.

communities. Foredunes have been managed since at least the 15th century (Schoorl 1973), but large-scale stabilization has occurred only since 1850 (Klijn 1990). Impermeable groins, permeable groins constructed of pilings and static dune toe protection are used in places where the dune is the principal sea defense (Anon. 1991). Jetties have been constructed at IJmuiden, and on the island of Texel (Eijerland).

The principal standard for protective structures (including dunes) is Delta Strength as presented in the Delta Act of 1958. This refers to a specified minimum volume of sand, termed the border profile (Du: grensprofiel). Sea defences on the central and southern coasts are now designed to withstand a storm surge level of one in 10000 years; other sections of the coast have safety standards related to the value of the real estate and infrastructure of the shore (Koster & Hillen 1995), but the lowest prescribed level of protection on the developed coast is against a once in 2000 year event (Anon. 1990). In 1990, the national policy was formulated to preserve the coastline at its 1990 position, while allowing the natural dynamics and character of the coast to be preserved through large scale nourishment projects. The spatial scale of management has shifted from a line to a zone, with the foredune still considered as an important element in the sea defence zone.

The Water Boards in The Netherlands are responsible for reshaping the dune, vegetating it, and making all subsequent repairs. They provide permits for use of the dune and for construction of recreation facilities in accordance with provincial plans. The outer appearance of the dune in a given region is essentially determined by the perceptions and preferences of managers in the water boards. Municipalities may act as consultants, but they do not have specific tasks related to dune construction or maintenance (Koster & Hillen 1995). No residents have property rights in the foredunes, and few houses are located right behind it. In developed areas, a boulevard often separates the active shorefront environment from buildings, greatly reducing the potential impacts that residents may have on the foredune.

Methods of constructing foredunes

Fences and other sand barriers

Nearly all fences in New Jersey are 1.2 m high and have ca. 8 by 35 mm wooden slats spaced 60 to 70 mm apart (meaning ca. 65 % porosity). The slats are held in place by wires that are usually strung between steel posts. Most communities use a single or double row in a straight alignment, although zig-zag configurations are common. Fences are usually placed on the seaward side of the dune, but they are often placed on the landward side of the accretion area to keep pedestrians off the dune and keep the dune from migrating into boardwalks and private properties (Fig. 3). Use of fences in New Jersey is often a secondary action taken after the primary structure is created using bulldozers. Fences then help stabilize the bare sand surface and help prevent besanding of property landward of the dune. Fences are most often emplaced at the end of the summer tourist season in preparation for the winter storm season, but they may also be constructed at the beginning of summer to keep people out of the dune zone.

Fencing materials in The Netherlands are branches (usually common willow) or reed stakes, placed close together and forming barriers from 1 to 2 m high after emplacement. Sometimes reed stakes are placed in a grid. Rows placed parallel to the foredunes are most common, with cross-rows facing into the dune. Short rows may be placed perpendicular or oblique to the foredunes depending on the most active wind direction. All materials used are natural, to assure breakdown after the barriers have accomplished their trapping function or are eroded by waves. Fences are used to either: (1) create a sand buffer to protect the larger foredune behind; (2) stabilize the surfaces of nourished areas; or (3) create an entirely new dune ridge (termed a stuif-dike). In the first case, fences are usually placed in spring at the end of the storm season. Growth rates of up to 10 to 20 $m^3 m^{-1} yr^{-1}$ occur at fences. This rate is greater than under natural conditions and is concentrated in a smaller zone than occurs with natural vegetation.

Planting vegetation

Planting of stabilizing vegetation is often accomplished at the community level in New Jersey. Dunes created using bulldozers are rarely planted immediately because they are considered short-term, sacrificial features. Foredunes built in state and federal projects are planted (usually with *Ammophila breviligulata*), but maintenance of vegetation is left to communities, and the success of maintaining this cover varies considerably with local commitment. Except for experimental plots, all dune modifications in The Netherlands are accompanied by planting programs, using *Ammophila arenaria* or *Ammocalamagrostis baltica*. There is less bare sand in the Dutch foredunes than in the New Jersey ones (Fig. 4); this may be as much due to the density of *A. arenaria* relative to *A. breviligulata* as to active management.

Mechanical placement

Sand dredged from backbays, tidal channels or offshore deposits may be used to build dunes. It is moved to the site by pipeline as a slurry. Emplacement of sediment

Fig. 3. Linear dune created for shore protection at Lavallette, New Jersey. The fence between the landward side of the dune ridge and the boardwalk was emplaced subsequent to the dune construction project to prevent besanding of the boardwalk.

on the beach has been the usual practice, with subsequent reshaping by bulldozers. Dune-building projects in New Jersey and The Netherlands using dredged sand have been conducted independently of beach nourishment projects, but separate dune building projects are not likely to occur in The Netherlands in the future because dunes have been built to Delta height. Priority is now given to nourishment of the beach, allowing dunes to form by aeolian action.

Trucking operations are common in New Jersey for supplying sand from upland quarries and for recycling sand that inundates yards and roads back to a convenient access point on the beach or dune. Trucking operations in The Netherlands are limited to this kind of recycling operation. Bulldozers are often used to construct foredunes in New Jersey because the narrow beaches restrict the potential source of wind-blown sand. Use of bulldozers to create dunes is common following storms using sediment from beach, overwash and aeolian deposits or from other sources that are brought to the site in trucking operations. Ad hoc operations may be conducted during non-storm periods, and sediment skimmed

Fig. 4. Representative Dutch foredune on the mainland coast of Rijnland.

from the top of the beach in cleaning operations also may be deposited in the dunes. Bulldozers are used in The Netherlands to reshape existing dunes and cover the front slope with a layer of sand from the beach following beach nourishment operations.

Locations of human-altered foredunes

New protective foredunes in New Jersey created in locations where dunes already exist are generally placed in front of the existing dune line. Dunes created where none previously existed are generally placed on the landward portion of the backbeach (Fig. 3), but a gap of 5 to 20 m is often left between the dune and the bulkhead or boardwalk to reduce the likelihood of inundation of properties. Sediment is periodically removed from this location so it remains low and unvegetated.

Sand blown inland onto boardwalks, roads, patios and yards creates unwanted aeolian forms (here termed nuisance dunes) that are often eliminated by municipal workers and residents. Some of these dunes are allowed to survive and are incorporated into the cultural landscape. These dunes may be augmented by residents dumping sand removed from other portions of the property. The result of these highly localized activities is a complex mosaic of natural and semi-natural forms.

The locations of foredunes created for shore protection in The Netherlands are more variable than in New Jersey. They have been placed on the landward side of the crest, on the crest and on the seaward side of the crest (van Bohemen & Meesters 1992). Protective sand dams (Du: stuifdijken) are still created to extend the foredune seaward or to create valuable natural environments, notably dune slacks.

Reshaping existing foredunes

To enhance protection against coastal hazards

Dunes are most commonly reshaped for protection against wave overwash and flooding by increasing the height of low areas and increasing the volume of sediment to achieve a level of protection prescribed by regulatory guidelines (e.g. FEMA volume requirements, Delta height). Sediment may be bulldozed from peaks in the dune crest and placed in lower areas in The Netherlands at locations where peaks are above Delta height.

Dunes are often reshaped to reduce the hazard of wind blown sand. Sediment that accumulates against bulkheads in New Jersey is often removed but then placed on the beach where it can result in accelerated aeolian transport. Gaps in the foredune may be closed to reduce the potential for besanding of buildings and infrastructure. It is common policy that blowouts in the Dutch foredunes are smoothed by bulldozers to prevent wind erosion, but this may change under the new policy of dynamic preservation.

To facilitate recreation

The emphasis on beach recreation in New Jersey often takes precedence over protection in the summer, when the resident and tourist population increases dramatically. The need for wide beaches as recreation platforms and the need for ready beach access and views of the sea have led to elimination of dunes in many communities, especially where bulkheads provide back up protection. Reshaping often involves transfer of sediment from the dune to the beach in the summer and from the beach to the dune at the end of the tourist season, although this activity is not permissible under state regulations. Material removed from the surface of the beach in cleaning operations is placed in the foredune in some communities. The resulting deposits may be in isolated hummocks or in ridges that mimic the location and form of dunes (Fig. 5).

Bulldozers are used in The Netherlands to reshape dunes that have been scarped as a result of wave erosion to create access ramps and reduce the hazard of slope failure. Bulldozers also are used to create raised, flat, artificial berms on the backbeach (called bankets) to facilitate pavillions (mostly restaurants) and cabanas and to protect them against wave uprush. These landforms may be considered functional equivalents of either storm berms or dunes depending on their height above the backbeach. They can be built up to 3m above the backbeach surface. After the tourist season they serve as a buffer against wave erosion.

To enhance aeolian activity or subsequent evolution

Actions to reshape dunes to enhance aeolian activity are not taken along most of the coast of New Jersey because of the hazard in developed areas and the prevailing conservative approach to management of natural areas. Aeolian activity on Dutch foredunes that are not critical for protection has been artificially enhanced in places by creating gaps in the crest to allow the dune profile to move landward (Fig. 6). Mechanical removal of the vegetation on the foredune also has been practiced to allow the crest to migrate inland and create a more gentle foredune slope while retaining original beach width and dune volume. Such a feature is termed a rolling foredune (Arens & Wiersma 1994; van der Wal 1996). This practice is not likely to occur again because of the present national policy of maintaining the shoreline position.

Fig. 5. Disposal dunes formed from deposits of beach litter following cleaning operations at Brigantine, New Jersey.

Foredune characteristics

Internal characteristics

Dunes that form through aeolian processes around obstacles introduced by humans have been called artificially inseminated dunes (Goldsmith 1989). These dunes have sediment characteristics and internal structures found in natural dunes, and they are the most common type of foredunes created by aeolian transport in both New Jersey and The Netherlands.

Dunes created by bulldozing or dumping from trucks or beach cleaning equipment have poorly defined internal stratification. Landforms placed by pumping in a sediment and water slurry reflect sorting by hydraulic processes rather than aeolian processes. The sediments

Fig. 6. Irregular foredune crest at Julianadorp, The Netherlands (June 1995), resulting from cuts made in dune to mimick blowouts and enhance aeolian activity. These locations were subsequently artificially stabilized.

emplaced by these mechanical means may be too coarse or too fine to be of aeolian origin. Sediments used as nourishment in New Jersey are often from upland quarries that have a source in glaciofluvial outwash and are of a yellow-brown or rust color resulting from iron oxide weathering. Sediments used as nourishment in The Netherlands are often coarse grained and shell-rich relative to natural dunes (van Bohemen & Meesters 1992; van der Wal 1996). The sediments are usually derived from offshore (below -20 m depth and > 10 km offshore) and may also be yellow-brown from iron oxide. Regardless of source, foredune sediments may not be stratified if they are reworked by bulldozers (Fig. 7).

Dunes may be built with cores that are designed specifically to resist erosion. Clay cores have been used at Cape May Point, New Jersey; asphalt or concrete have been placed within the foredunes in The Netherlands to provide dune toe protection. Dunes also have been built to function as veneers over other protection structures, such as at Atlantic City, New Jersey (where bulldozed beach sand and vegetation cover tubes filled with sand) and at Zeeuws-Vlaanderen and De Brouwersdam in The Netherlands (where sand dunes cover asphalt dikes). Locally, in The Netherlands, World War II era bunkers are covered with sand-using bulldozers.

Dimensions and topographic variability

Human-altered dunes are usually more linear than their natural counterparts because a linear feature is less vulnerable, and management is simplified. Another conspicuous feature of human-altered dunes is the smooth profile of the crestline in the longshore direction (Fig. 3). The major exceptions to maintenance of a uniform crestline in New Jersey are at the ubiquitous gaps in the dune at street ends that are used for beach access. Exceptions in The Netherlands occur where the dune is artificially landscaped to mimick natural contours (van Bohemen & Meesters 1992) and the relatively infrequent gaps that provide public access to the beach.

Human-modified foredunes are low where recreational values are favored over safety considerations, and they are highest where safety is the principal value. The heights of dunes in many communities in New Jersey represent a compromise between these values; the bulk of the dune is built to adequate heights to provide protection against small storms but not interfere with views, and low points (often at the elevation of the backbeach) provide beach access. The highest crest heights are only about 6 m above the elevation of the backbeach. Attempts to achieve Delta Height in The Netherlands have resulted in average crest elevations higher than formerly occurred under natural conditions. Artificial fixation may result in peaks up to 43 m above the backbeach. Crest heights that are lower than pre-existing levels may result where the sediment in the peaks is used to augment low or narrow portions of the dune.

Deposition caused by both sand fences and bulldozing occurs in narrower zones than under natural conditions, often resulting in steeper gradients. The seaward

Fig. 7. 10 m high scarp in the artificial dune at Meeuwenduinen, Schouwen, The Netherlands, showing internal structure.

side of dunes in New Jersey is often initially created as steep as can be shaped by bulldozers (ca.40° when emplaced), and it stabilizes at the angle of repose of dry sand. The tops of dunes created or shaped by bulldozers may be flat to retain adequate volumes of sand while minimizing crest heights and to minimize initiation of blowouts. When a foredune is constructed in The Netherlands, the tendency is to create a gentle slope (1:3) by bulldozing the seaward side to facilitate planting and to reduce the likelihood of a large cliff forming during erosion events. Slopes of dunes created by sand fencing are determined by the angle resulting from trapping, creating slopes that are much gentler (ca. 20°) and rounder than natural dunes. Slip faces are common on the landward side of unvegetated dunes following strong onshore winds.

Dunes in developed areas in New Jersey are usually narrow (often <30 m), because of restricted beach widths due to the proximity of structures. Wider foredunes exist where accretion has occurred near inlets (both jettied and unjettied) and regulations have prevented new development from encroaching on these accretion zones. Accretionary dune fields in The Netherlands can be up to 500 m wide, and the active foredune itself can be a clearly distinguished ridge up to 200 m wide.

Sediments dumped at the dune line result in a hummocky surface that reveals the method of mechanical deposition. The piles may be placed either contiguous to the dune crest (creating a linear dune with a hummocky crest) or in isolated hummocks dumped at the closest suitable location. Piles placed landward of the dune crest (such as the hummocks created by disposing of beach litter at Sea Isle City) may be buried by subsequent aeolian activity, and the mechanical origin may be obscured. Disposal dunes placed in front of the foredune on a narrow beach may retain their hummocky appearance for months (Fig. 5).

Surface characteristics

The surface of a newly created ridge or mound built from non-indigenous materials will have a conspicuously different sediment texture from a dune created by aeolian transport because the material is too coarse or too fine to be moved by aeolian processes and remains exposed. Subsequent aeolian accretion may restore the natural appearance of much of the landform (landward ridge in Fig. 5), but the aeolian cap often does not cover the entire feature. Formation of lag surfaces on the windward dune slopes of nourished dunes in The Netherlands has kept some of these locations from retaining or gaining sand, leading to degeneration of Marram grass *Ammophila arenaria* (van Bohemen & Meesters 1992).

Native species are less diverse on artificially maintained foredunes than on natural foredunes in New Jersey because only one species, beach grass (*Ammophila breviligulata*) is used in planting programs, and there is limited variability in micro-environments because the dunes are narrow and they have little variation in topography. Greater variety is found in the vegetation in the dunes on private properties, because both exotic and natural vegetation is used for landscaping. Some of the exotics used on private properties have colonized portions of the foredune landward of where they are planted.

Species diversity has increased in some foredunes in The Netherlands because stability has allowed succession to occur. A special case in changing the growth environment in The Netherlands is the sprouting of willows, from branches planted as sand fences on a nourished dune. These new tree rows were conspicuous in the foredune at Walcheren soon after nourishment and they became permanent features in inner dunes at Schouwen.

Sediment sources and sinks and transport potential

Beach modifications

Roughness elements intentionally or unintentionally eliminated from, or added to, the beach and dune change the transport potential. Driving or walking on the backbeach or raking and bulldozing the backbeach may destroy vegetation, converting that location into a source of sediment for aeolian transport rather than a sink. Raking during beach cleaning has the greatest impact in New Jersey because it occurs frequently and it affects the entire surface of the backbeach. Raking loosens the surface by breaking up surface crusts (salt and algae); it breaks up lag elements (shells or gravel); it eliminates litter; and it smoothens topography.

The effects of bulldozing are more complex and spatially variable. Scraping exposes sediments lower in the beach matrix and brings the surface closer to groundwater level. It compacts the surface in places, although it can create small loose piles at the edge of the blade or where the blade is lifted. Surface roughness may be increased or decreased depending on pre-existing beach topography and litter.

Rates of aeolian transport are usually high after nourishment, resulting in increased dune dimensions and increased vitality of vegetation where new sand is deposited (van der Wal et al. 1995). Development of coarse lag deposits through time reduces further aeolian transport from the nourished beach, although the frequent raking of nourished beaches in New Jersey re-initiates aeolian transport.

Effects of structures

Buildings, such as cabanas, lifeguard structures, piers and shore protection structures on the beach create their own distinctive aeolian landforms, but these are usually eliminated by wave action in the winter storm season. More permanent buildings and shore protection structures replace the beach and dune, alter wind speeds, alter depositional patterns and separate sources from sinks. The dunes landward of buildings can be detached from their beach or foredune source where residents have removed intervening sediment or where closely spaced buildings accelerate flows past the structures, creating scour zones between them and deposition zones landward of them.

Streets in towns act as highly efficient surfaces for aeolian transport. Overwash from moderate-intensity storms in New Jersey may extend only as far as the first road, but aeolian transport often continues landward for several blocks (several hundred meters). Paved surfaces of dikes in The Netherlands allow sand to be transported inland to form new dunes on the landward side of the structure. The physical separation of the dune from the beach does not preclude aeolian transport because the dike is a highly efficient transport surface.

Shore protection structures or jetties can greatly increase beach widths and supply sand to form new foredunes near them. Groins act as a trap for aeolian transport moved parallel or oblique to the shoreline, while bulkheads function as traps for movement perpendicular to the shoreline. Foredunes in the accretion zone caused by jetties can form multiple ridges as the accretion moves the location of sand trapping offshore. These ridges are conspicuous updrift (north) of the jettied inlet that separates Atlantic City from Brigantine (Fig. 1) and at IJmuiden (Fig. 2).

Cycles of landform change

Shore protection cycles may have periodicities driven by natural events, such as storms, seasons or years or by economic or political forces. Bulldozing is often conducted by communities in New Jersey following storms that erode the dune. The periodicities of this kind of cycle may be greater or lesser than seasonal cycles depending on the initial vulnerability of the dune and severity of storms in a given year. Yearly repair of dunes for protection often occurs in the early fall in New Jersey and in the spring in The Netherlands. The destruction phase may be accomplished by natural processes or by recreation activities; the construction phase may be accomplished solely by human action (using bulldozers) or a combination of human action and natural processes (using vegetation plantings or sand fences).

A sacrificial-dune cycle occurs in developed areas where an attempt is made to maintain a dune in a vulnerable position seaward of the designed protective foredune to protect the investment of money and human resources used to create the established dune. The periodicity of this cycle is less than the recurrence interval of the storms that would erode the designated protective foredune. The sacrificial-dune cycle may follow a seasonal periodicity or it may occur more than once per year, especially in New Jersey communities where beaches are narrow and waves frequently reach the foredune.

The recreation-protection cycle described earlier is usually seasonal. The destructive (to dune) phase is normally accomplished at the end of spring by bulldozing. The constructive phase can be accomplished using bulldozers or fences (Mauriello & Halsey 1987). Clearing of deposits from small wind events from municipal recreation surfaces (boardwalks, parking areas) is often done prior to the summer tourist season, creating an annual cycle. Clearing of nuisance dunes from individual properties in New Jersey generally follows a cycle related to the recreational life style of the owner. These dunes are formed by the strong winds that occur in the winter and survive until late spring when most residents and managers of commercial properties return to actively use the buildings in the tourist season. Year-round residents may keep pace with aeolian accretion, resulting in cycles of deposition and removal at the temporal scale of strong-wind events.

Beaches may be nourished and dunes may be rebuilt after several years of erosion by means of expensive, large scale operations. The timing of these nourishment cycles in New Jersey depends on perceptions of the need for wider beaches, the political climate (affecting availability of funds) and delays associated with bureaucratic response at higher levels of government. The timing is thus highly variable because of the need to involve so many participants. Beaches in The Netherlands that need sand are nourished every five to seven years (Koster & Hillen 1995). The timing is more predictable because of the national emphasis on coastal defence and the commitment to maintain the border profile.

Discussion and Conclusions

Assessing degree of human input

The characteristics of foredunes in New Jersey and The Netherlands reflect differences in natural processes and management controls. One of the greatest differences affecting dune characteristics is the amount of freedom left to municipalities and residents in managing foredunes. The need to levy funds on a site-specific basis and the transmittal of political power to the communities and residents result in a great variety in activities in the dune zone, manifested in a great variety of sizes and shapes. Long-term instabilities inevitably result from manipulation of dune locations seawards of their equilibrium positions (Sherman & Bauer 1993). In the absence of wide protective beaches, cycles of foredune destruction and rebuilding occur frequently and often on an ad hoc basis. There is reason to expect that residents and municipal managers in New Jersey will continue to act on their personal perceptions of the resource value of dunes. Foredunes in developed areas are maintained as artifacts and are frequently manipulated, so humans must be considered intrinsic agents in both their formation and evolution.

Larger foredunes occur in The Netherlands due to the greater frequency of onshore winds, that have greater potential to deliver sediment to the dune (e.g. Arens 1997) and the greater emphasis on sea defence (that ensures maintaining beaches through nourishment, retaining higher standards of protection, vesting responsibility for maintenance of foredunes at the national level, and providing regular funding). Thus, the foredunes here are higher, wider, better vegetated and not subject to change at the hands of residents and municipal managers. Expectations in The Netherlands are that the large-scale dune-building projects that occurred in the recent past will not be conducted frequently in the future, because the Delta Height standard has been achieved in most locations; future protective efforts will come in the form of beach nourishment (van Bohemen & Meesters 1992). Designation of foredunes as backup protection allows managers great flexibility in their approach to management, allowing for greater acceptance of modification by natural processes. Human actions affecting foredunes may now be extrinsic at the scale of the landform itself, but the conditions that affect growth, maintenance and ability to survive wave attack are a direct result of human input, and humans may be considered intrinsic at the landscape scale.

Classifying human-altered dunes

The alterations to foredunes identified in this paper may not indicate all of the human actions that have occurred or can occur on developed shorelines, but they are believed to be sufficiently comprehensive to provide a basis for classifying human-altered foredunes. Human-altered dunes, like other landforms, could be classified on the basis of many factors, including character of material, dominant process, form, location, erosion/accretion status or stage of evolution. Research on developed coastal landforms is still too preliminary to provide the basis for a definitive classification based on a single set of criteria, but we think it is useful to identify the significance of aeolian processes vis-a-vis direct human agency.

A distinction can be made between foredunes that are created intentionally to provide specific utility functions (designed dunes) and those that form from natural aeolian erosion or accretion as a result of human activity conducted to accommodate other utility functions (opportunistic dunes). Fig.8 compares the degree that humans are intrinsic or extrinsic agents in foredune evolution with the types of activities that lead to this landscape conversion. The classification system is designed to provide perspective on the relationship between human involvement and the degree of naturalness of the dune. Dunes are sedimentary landforms, and the categories are structured to follow a general progression from top left to bottom right based on degree of human manipulation of the sedimentological and geomorphological process. The least amount of direct manipulation occurs where human actions that contribute to dune formation are unintended. The most natural types of dunes can result from activities outside the dune zone but within the adjacent beach zone (left side of top row). Aeolian processes play the most limited role in dunes that are artificially created through disposal of litter removed from the beach or through direct emplacement of fill material.

Fig. 8 represents an ordering according to the conditions that create the initial landform. Direct human action may affect the short term shape or relative position of the foredune on the beach profile. Either natural processes or human actions may dominate in the long term. There is considerable opportunity for aeolian processes to modify the foredunes after they are created, even in locations where exotic materials are dumped (Fig. 5). One season may be all that is required to establish an aeolian veneer over a landform that is initially created using earth moving equipment.

The appearance or functions (e.g. recreation, habitat) of the dunes are not evaluated in Fig. 8. It is likely that certain types of artificially-manipulated dune would have greater perceived natural value than certain types of dune that formed by natural processes. For example, a dune that forms through growth of exotic species may be perceived to be of less ‘natural value’ than the same dune that has been subsequently ‘improved’ by removing exotic species and planting indigenous species to create or maintain a specific biological inventory. A dune that is created directly by nourishment and planted with vegetation (a true artifact) may be perceived as having greater natural value than a dune that forms when sand blown across a natural beach is trapped at a

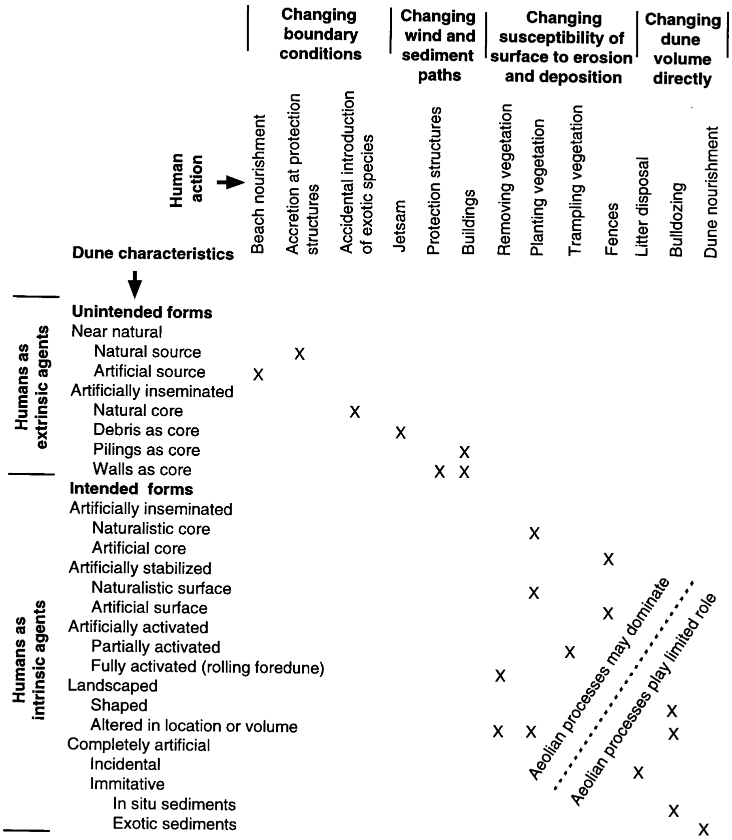

Fig. 8. Comparison of characteristics of dunes in developed areas ranked with the human actions leading to their formation or growth.

shore protection structure (a true dune). The classification in Fig. 8 could be rearranged to create a function-oriented continuum that would have greater use in interpreting the value of human-altered dunes for management and evaluating the rationale for the human processes leading to landscape conversion. Recognition of the many ways that human alterations contribute to our conception of a dune and its value will help in developing more sophisticated models for foredune evolution that place human alterations in their proper perspective.

Re-defining dunes on human-altered coasts

We have used the term 'dune' throughout the paper as a convenient way of describing the feature that occupies the position that a dune would occupy on a shoreline subject to only natural processes. This term is considered appropriate only if the landform has similar form and functions (natural and human) to the natural feature and if it is capable of modification by aeolian action, even if this action is restricted to a surface veneer. Other definitions of dunes in human-altered environments may be more or less dependent on the processes or functions of natural dunes. The 1982 Coastal Primary Sand Dune Protection Act of Norfolk, Virginia, USA defines a primary dune as a mound of unconsolidated sandy soil contiguous to high water that must rise sharply from the adjacent terrain and have one of a list of 10 species of plants on at least a part of it (Blair & Rosenberg 1985). This definition retains many of the characteristics of natural dunes. The state of Massachusetts, in contrast, has used a definition that can include gravel barriers - features that cannot be shaped by wind and that have different ecological and protective values from natural dunes and have different natural and human functions. Definitions of dunes that consider only a limited number of functions have little use as targets for managing or restoring coastal resources.

In our conception, foredunes on human-altered coasts should be defined as semi-natural, where humans provide conditions for their creation or survival, but their subsequent effect on geomorphological and biotic processes is primarily natural. The genesis of dunes in developed areas is affected by human design criteria (with planning and engineering inputs) in addition to the traditional genetic factors that shape natural landforms and habitats (winds, waves, and biota). The changing conception of the definition of foredunes from natural features to artifacts is part of the recognition of the role that humans play in the evolution of coastal landforms and the changing role that landforms have in the coastal landscape.

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