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CALIFORNIA'S COASTAL NATURAL HAZARDS

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THE EVOLUTION AND VALUE OF LANDFORMS ON HUMAN-ALTERED COASTS

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INTRODUCTION

Many studies call attention to the way human altered coasts differ from their natural counterparts in terms of loss of natural features, changes in sediment budgets, and changes in the degree of coastal hazard (Hall and Pilkey 1991; Finkl 1994; Morton *et al.*, 19,94; Nordstrom 1994), but there is little attention devoted to differences in coastal evolution at the scale of individual landforms. This paper presents a summary of results of a program designed to identify the variety of landforms created or altered by humans and to evaluate losses and gains in their resource potential. The purposes of the paper are to identify: 1) the ways landforms are altered initially to suit human needs; 2) the ways they are altered subsequently through interaction with buildings and shore protection structures; 3) the characteristics of human-altered landforms; 4) the relationship between the perceived resource value of landforms and the ways they are modified to maximize this value; and 5) the constraints to planning and policy controls that contribute to continued loss of natural landform characteristics.

ALTERATION OF LANDFORMS TO SUIT HUMAN NEEDS

Ways that landforms are altered to suit human needs (Table 1) vary from total elimination to subtle changes that affect their appearance or surface mobility but not their overall form or function.

Table 1. Ways that landforms are altered to suit human needs.

Elimination for alternative uses
- Buildings.
- Transportation routes and terminals.
- Alternative recreation surfaces.
- Non-coastal (landfills, farm fields).
- Mining.
    - Construction aggregate.
    - Minerals.
    - Liming material and substrate for crops.
    - For covering landfills.

Alteration through use
- Pedestrian trampling and vehicle use.
    - For access.
    - For direct recreation

Waste disposal
- From day use tourist activities.
- Random disposal of cars, machinery.
- From beach cleaning.
- From commercial activities.

Agriculture and harvesting.
- Planting forests.
- Gathering flowers, fruits, seaweed.
- Removing vegetation for fuel, thatch.
- Grazing.

Extraction and recharge
- Drinking water.
- Oil and gas.
- Watering gardens and waste-water disposal.
- Concentrating surface runoff.

Military
- Active uses (bombing, maneuvers).
- Fortresses and bunkers.
- Harbor structures.

Reshaping

Increasing levels of protection
- Scraping beaches.
- Bulldozing dunes.
- Breaching barriers to control flooding.
- Dredging inlet channels to cause deposition.

Preventing or alleviating sand inundation

Enhancing recreational or commercial use
- Widening beaches for recreation platforms.
- Eliminating obstacles to access.
- Providing or retaining views of the sea.
- Creating platforms for cabanas, pavillions.
- Clearing the beach of litter.
- Maintaining navigation channels.

Enhancing environmental values
- Creating more naturalistic landscapes.
- Altering environments for wildlife.

Altering landform mobility

Placing barriers to trap sand.

Armoring surfaces

Introducing new sediments into beach, dune.

Creating or closing inlets.

Relocating channels or altering cycles.

Altering natural vegetation
- Controlling density (mowing, grazing, fires).
- Planting species to increase diversity.
- Introducing exotics.
- Changing growth conditions by nourishment.

Altering external conditions
- Mining and damming streams.
- Reducing basin source area.
- Changing nutrient levels or acidity (pollution).

Beaches and dunes are eliminated to facilitate construction of buildings (Figure 1) (Kuhn and Shepard 1980; Healy *et al.*, 1990), public support infrastructure, such as roads and

Figure 1 Oxnard Shores, California, 1984, showing loss of dune and trucation of the beach due to construction of buildings and roads

railroads (Cencini and Varani 1989; Peña *et al.*, 1992), airports and landing strips (Mather and Ritchie 1977) and parking areas. They may be eliminated for recreational uses that do not require buildings, such as golf courses (Mather and Ritchie 1977; Doody 1989) or for uses that have little specific value in a coastal environment, such as landfills or fields for specialized farming (Cencini and Varani 1989). Landforms also may be eliminated through mining operations (Mather and Ritchie 1977; Hesp and Hilton 1996), mostly for construction aggregate or for beach and dune nourishment.

Landforms that are not completely eliminated can be altered through use (Table 1). The most widely reported alteration is trampling by pedestrians and off-road vehicles (Eastwood and Carter 1981; Godfrey and Godfrey 1981; Anders and Leatherman 1987; Bonner 1988; Andersen 1995). Trampling may occur because a landform is: 1) an access way to another location (e.g. trampling of dunes by visitors to the beach); 2) the destination for passive recreational activity (seeking seclusion in dunes); or 3) the direct target of consumptive use (sand sliding, dune busting).

Waste disposal can include items that are relatively inconspicuous and temporary (products from day use tourist activities) or items that are large, durable and not associated with beach use (cars and farm equipment) (Mather and Ritchie 1977). Waste products may comprise their own distinctive landforms, such as the disposal mounds associated with beach cleaning (Nordstrom and Arens in review) or mine waste (Bourman 1990; Paskoff and Petiot 1990; Humphries and Scott 1991; Smith *et al.*, 1994).

Some agriculture and harvesting activities, such as picking natural decorative plants (Olsauskas 1995), can have little effect on viability of coastal landforms; other activities, such as planting forests (Blackstock 1985; Sturgess 1992; Favennec 1996), can change the surface cover and mobility of landforms. Activities, such as harvesting kelp or removing vegetation for fuel and thatch (Randall 1983; Westhoff 1985; Skarregaard 1989; Hewett 1985) may have little impact when practiced on a small scale, but they may have pronounced cumulative effects. Grazing is an activity that may be seen as beneficial or harmful depending on the level at which it is practiced (Mather and Ritchie 1977; Hewett 1985; Westhoff 1985).

Extraction and recharge of drinking water and artificial drainage can alter vegetation in dune systems (Westhoff 1985; van Dijk 1989). Extraction of oil and gas (Inman *et al.*, 1991; Flick 1993; Wiegel 1994; Bondesan *et al.*, 1995) can increase flooding and wave action. Watering lawns and gardens, waste-water disposal and concentrating surface runoff can affect stability of slopes on high relief coasts (Kuhn and Shepard 1980; Dias and Neal 1992; Griggs 1994).

Active military uses (bombing, maneuvers) can have positive effects on landforms by excluding more destructive recreational uses (Doody 1989) or negative effects by destroying vegetation cover or landform shape through direct use or through efforts to remove unexploded ordnance (Demos 1991). Fortresses and bunkers that no longer have military value often survive for long periods to have a passive effect on coastal processes and landforms (Mather and Ritchie 1977; Guilcher and Hallégouët 1991; Jensen 1995). Many effects of military structures are highly localized and confined to military reservations, but the effects of harbor structures can change sediment budgets for many kilometers along the coast.

Landforms may be reshaped to accommodate a wide variety of uses (Table 1). Reshaping to increase levels of protection includes scraping beaches to change local sediment budgets (Tye 1983; McNinch and Wells 1992; Kana 1991), bulldozing dunes to create more effective barriers to flooding (Nordstrom and Arens in review), breaching barriers fronting lagoons to control flooding (Orford *et al.*, 1988) and altering navigation channels to change erosion/deposition cycles through artful dredging (Farrell and Sinton 1983; Kana 1983).

Inundation by sand that is washed (Bush 1991) or blown (Sherman and Nordstrom 1994) onto boardwalks, roads patios and yards may be alleviated by removing incipient sand deposits or excavating buried facilities. These actions can be highly localized and conducted manually, or they can occur at the regional scale and involve use of heavy equipment following major storms (Nordstrom and Arens in review).

Reshaping to enhance recreational or commercial use includes creating wider beaches as recreation platforms, eliminating dunes and other topographic obstacles to provide easy access or views of the sea (Nordstrom and Arens in review; Cortright 1987), raising the elevation of the backbeach to provide a platform for cabanas and pavilions (Cencini and Varani 1989; Paskoff 1992) and clearing the beach of litter (Hotten 1988; Bodge and Olsen 1992; Atherley *et al.*, 1993). Alteration of beaches and dunes to enhance environmental value is less common but has been accomplished to create naturalistic contours (van Bohemen and Meesters 1992), to create environments that encourage bird nesting or breeding (Randall and Doody 1995) or to flush pollutants or enhance target aqueous species (Tiffney and Andrews 1989).

Intentional alteration of landform mobility (Table 1) can be accomplished by restricting movement using barriers or by changing surfaces or internal characteristics to alter the effectiveness of the processes acting on them. Planting vegetation and placing sand fences to trap sand (Godfrey and Godfrey 1973) are among the most common means of restricting mobility, but a variety of other stabilizing materials are used, including straw (van der Putten and Kloosterman 1991), tires (Western Australia Department of Planning and Urban Development 1993), biodegradable matting (Demos 1991) and bitumen spray (Ritchie and Gimingham 1989). Introducing new sediments into the beach or dune matrix can change resistance to wave erosion and can be done intentionally to reduce erosion rates (Nelson 1991) or incidentally, when opportunistic sources are used in nourishment operations, rather than more costly sources that are compatible with native materials. Human actions change inlet characteristics by creating new inlets (Wiegel 1992; Bodge 1994), closing inlets (Sorensen and Schmeltz 1982; Louters *et al.*, 1991; Terchunian and Merkert 1995), preventing new inlets from forming (Ehlers and Kunz 1993), relocating inlets or channels (Kana 1989; Møller 1990) or altering the timing of natural cycles (Webb *et al.*, 1991). Natural vegetation may be altered by mowing (Hewett 1985; Westhoff 1985), setting fires (Chapman 1989), planting diverse species (Mauriello 1989), introducing exotics (Cooper 1958; Chapman 1989; Doody 1989; Sturgess 1992; Espejel 1993) and changing temperature and drainage through nourishment operations (Bodge and Olsen 1992).

Alterations of conditions external to the boundaries of landforms (Table 1) may affect their evolution by changing sediment budgets and viability of vegetation. Sand supply to the coast from fluvial sources may be reduced due to mining and damming streams and reducing basin area in land reclamation projects, resulting in a change from accreting shorelines to eroding shorelines (Postma 1989; Innocenti and Pranzini 1993; McDowell *et al.*, 1993; Niemeyer 1994). Changes to the viability of vegetation occur due to alterations in nutrient levels or acidity due to pollution in precipitation (Westhoff 1989; van Boxel 1997).

The categories of activities indicated in Table 1 are limited to those that have large-scale implications or are frequently reported. Many local human actions could be added, including inscribing graffiti and carving caves (Komar 1979; Lee 1980; Lee and Crampton 1980; Dias and Neal 1992) and using dunes for toilets or for cemeteries (Western Australia Department of Planning and Urban Development 1994; Mather and Ritchie 1977).

EFFECTS OF STRUCTURES ON PROCESSES, LANDFORMS AND SEDIMENT AVAILABILITY

Structures can have direct impacts on landforms in addition to the alterations associated with initial construction and use of structures identified in the previous section. Shore protection structures change wave refraction patterns and wave breaking, surf-zone circulation, swash velocity, duration and elevation, beach groundwater elevation and beach slope variability; these structures also can re-direct sediment transport, interrupt existing beach-bar systems, create rhythmic features on the beach and offshore and create differences in sediment characteristics updrift and downdrift (Orme 1980; Sherman *et al.*, 1990; Bauer *et al.*, 1991; Gayes 1991; Plant and Griggs 1992; Short 1992; McDowell *et al.*, 1993). Structures on the upper beach provide barriers that enhance deposition of aeolian transport and dune accretion (Nersesian *et al.*, 1992; Nordstrom *et al.*, 1986). Jetties cause migration of preexisting channels, displace ebb tidal deltas and associated bars, induce lower nearshore gradients, reduce breaker heights, change sediment budgets, change the likelihood of dune building and growth of vegetation, convert bidirectional (erosion-accretion) cycles to unidirectional cycles and eliminate inlet throat beaches and bare sand areas that provide habitat (Nordstrom 1987; Roman and Nordstrom 1988; Short 1992; Bodge 1994).

Piers and pilings create scour holes and cause differences in depth, slope, and vertical variation of beach profiles related to pile size and spacing (Miller *et al.*, 1983; Nicholls *et al.*, 1995). They also affect local longshore transport (Miller *et al.*, 1983; Weggel and Sorensen 1991) and can create a tombolo-shaped bulge in the shoreline (Weggel and Sorensen 1991). Shore-parallel promenades and boardwalks can provide local traps for wind blown sand. Minor beach structures, such as cabanas and pipes, locally alter accretion and erosion on the beach (Otvos 1993; Bandeira *et al.*, 1990) and create distinctive but temporary landforms.

Sand fences alter natural flow patterns and trap sand, thereby stabilizing bare sand surfaces, accelerating natural accretion rates and concentrating accretion over smaller zones than occurs with natural vegetation. These structures control dune morphology by adjusting porosity, height, orientation, type of opening, number and distance separating fence rows (CERC 1984; Hotta *et al.*, 1987, 1991; Snyder and Pinet 1981).

Buildings alter wind speeds, alter depositional patterns and separate aeolian sources from sinks. Their size and spacing affect flow directions and speeds, and they can create scour zones between them and deposition zones landward or in front of them (Nordstrom *et al.*, 1986). High rise structures can cause local reversals in regional wind direction and create pronounced upward flows and scour depressions (Gundlach and Siah 1987; Nordstrom and Jackson 1997). Buildings that end up in the swash and breaker zones obstruct or redirect waves and currents and can cause changes in the slope of the beach and the shapes of nearshore bars (Gayes 1991). Buildings can remain on the beach and affect processes and beach response years after they are abandoned (Meyer-Arendt 1993). Swimming pools and septic systems provide obstructions to flow and increase turbulence and scour (Nnaji *et al.*, 1996; Yazdani *et al.*, 1997). Roads and parking lots provide impermeable and unobstructed pathways for overwash and entrained sand (Hall and Halsey 1991; Fletcher *et al.*, 1995) and can act as transport surfaces separating sources from sinks.

Marinas and harbors replace natural coastal environments, break up shoreline orientation, change wave patterns, trap sediment, deflect sediment offshore and starve adjacent beaches. They also have indirect effects, such as changes in bottom configuration caused by dredging and accelerated erosion and accretion of adjacent beaches caused by construction of jetties or breakwaters built to enhance navigation (Wiegel 1994; Anthony 1994).

Specialized landforms can be created that have little large scale impact but may be of great local interest, including artificial islands and tombolos (Leidersdorf *et al.*, 1990; Nagao and Fujii 1991), artificial shoals to enhance surfing (Wiegel 1993) and sand seawalls to protect mining operations (Smith *et al.*, 1994). These artificially-created coastal landscapes can evolve naturally, once built.

ALTERATIONS OF CHARACTERISTICS OF COASTAL LANDFORMS BY HUMAN ACTION

The locations of human altered landforms are dictated by human preference, not the interplay of natural processes (Nordstrom 1994), resulting in spatial relationships different from those that would occur under natural conditions (Table 2).

Table 2. Characteristics of human-altered coastal landforms.

Location
- Created in places where they may not occur naturally.
- Eliminated in places where they would occur normally (sand drift, overwash).
- Displaced (e.g. location of breakers, surf, accretion and erosion zones.

Sedimentology
- Introduced sediments may differ in size, sorting, shape, mineralogy, texture, color.
- Aeolian transport on introduced sediments may create a lag surface layer.
- Drainage may be changed by impermeable layers and compaction by vehicles.
- Bulldozed dunes have poorly defined internal stratification.
- Dunes emplaced by pumping in a slurry reflect sorting by hydraulic, not aeolian processes.
- Substrate deposited artificially lacks roots and filaments.

Orientation
- Structures transform natural beaches into smaller drift cells.
- Beaches affected by structures achieve a new planform
- Nourishment can fill reentrants, creating a continuous beach.
- Erosion hot spots on nourished beaches create local crenulations.
- Dunes often more linear to function as continuous barrier to flooding.

Height
- Nourished beaches are built higher to achieve protection goals.
- Backbeaches may be built higher to accommodate use structures (cabanas, restaurants).
- Dramatic elevation differences occur on opposite sides of protection structures.
- Low beaches occur where shore-parallel walls restrict development of upper beach profile.
- Dunes are often lower to maintain views of the water from shorefront homes.
- Dunes are higher where safety is the principal value.
- Lower dune heights may result where sediment in peaks is used to fill low portions.
- Low points may be created in dunes at intervals alongshore to favor beach access.

Topographic variability
- Low cross-shore variability where:
  - Simple profile shape is adopted to facilitate construction and calculation of fill volumes.
  - Recreation beaches are graded flat to facilitate beach access and use.
  - Beach cleaning eliminates incipient dunes.
  - Truncation by landward structures limits formation of storm berms and dunes.
- Variability alongshore may be increased by shore-perpendicular structures.
- Dune creation by sand fences and bulldozing causes steeper gradients.
- Dunes are of consistent height to minimize blowouts or retain predictable level of safety.

Width

Construction on or near the beach creates narrower beaches.

Nourished beaches may be temporarily wider.

A single narrow ridge is preferred for dunes in developed communities.

Surface characteristics

Removal of wrack eliminates biomass and nutrients and disturbs eggs.

Beach cleaning produces a featureless beach with an artificial look and little natural value.

Native species on stabilized protective dunes are usually less diverse.

Landforms on landward side of dune may be planted with exotics.

Mobility

Most protection structures are designed to reduce mobility.

- Reduction of long term erosion rates.
- Truncation of short term cycles of erosion and deposition.

Dunes shaped according to human needs are usually protected in place.

Coarse surface lag resists deflation.

Human attempts to maintain a sand-free surfaces prevent landward accumulations.

Aeolian transport may be increased during construction, when vegetation is removed.

Mobility due to beach nourishment can greatly exceed natural rates.

Timing of cycles of landform change

Protection projects introduce cycles related to administrative or logistical constriants.

Cycles of dune destruction and rebuilding are shortened to annual or storm periodicities.

- Dunes eliminated to provide beach space in summer and re-built for winter protection.
- Regularly scheduled repair of dunes usually creates an annual cycle.
- Sacrificial protective dunes are rebuilt soon after small storms.
- Clearing of deposits from small wind events may occur at periodicities of small storms.

The sediments introduced in beach nourishment and dune building operations and the methods used can change both the surface and subsurface characteristics dramatically (Hotten 1988; Rouch and Bellessort 1990; Adriaanse and Choosen 1991; Wiegel 1992; van der Wal 1997). Landform orientation changes as structures transform natural beaches into smaller drift cells (Byrnes *et al.*, 1993). Nourishment operations can create a more continuous beach planform between groins or result in a less continuous planform, such as through creation of erosional hot spots associated with beach fill operations (Hamilton *et al.*, 1996). Dunes often become more linear, due to a conservative, protective approach to management based on the value of dunes for protection. Human-altered beaches and dunes can be either higher or lower than pre-existing natural beaches, depending on the rationale for the landform conversion (Table 2).

Human-altered beaches usually have less topographic variability measured across the shore, but topographic variability alongshore may be increased by shore-perpendicular structures as a result of trapping sand or redirecting it offshore. Deposition caused by sand fences and bulldozing usually occurs in narrower zones than under natural conditions,

resulting in steeper gradients, although some bulldozed foredunes may be constructed with a gentle slope to facilitate planting and reduce the likelihood that erosion scarps will form (Nordstrom and Arens in review). Tops of dunes shaped by bulldozers may be of consistent height and shape to provide a predictable measure of safety against wave overwash and flooding or minimize blowout formation. Small hummocks, resulting from mechanical deposition, may occur on the surface of bulldozed dunes that are not subsequently re-shaped to provide a smooth surface. Surfaces of artificial dunes can be shaped to simulate natural dunes (Adriaanse and Choosen 1991; van Bohemen and Meesters 1992), but most artificial dunes are built to be more linear than their natural counterparts for ease of management (Nordstrom 1990).

Variations in beach width may be more a function of landscaping efforts and use of protection structures than natural factors (Kana 1993). The width of human altered landforms is usually narrower than natural landforms. Construction on or near the beach and prevention of subsequent onshore migration of the beach profile usually results in narrow beaches, although nourishment may temporarily create a wider beach than under natural conditions. A single narrow ridge may be considered the optimum shape for dunes in developed communities (Mauriello 1989) to maximize beach width, allow easy access and retain views of the sea from shorefront residences.

The surface characteristics of recreation beaches (Table 2) can be altered by removing wrack and flotsam, thereby eliminating biomass and nutrients and disturbing eggs (Hotten 1988). The clean, processed look of raked beaches (Figure 2) appears artificial and has

Figure 2. Atlantic Beach, New York, showing flat, bare sand beach considered optimal for recreational use in urban environments and suburban conception of landscaping on backbeach

little natural value. Native species are often less diverse on protective foredunes because a single species is preferred for stabilization. Landforms that are allowed to survive on the landward side of the dune often are planted with exotic species (Nordstrom and Arens in review).

Most direct human actions are designed to reduce landform mobility to protect buildings and infrastructure or provide more predictable navigation channels and recreation surfaces, although mobility can be increased during construction phases, when stabilizing vegetation is removed (González-Yajimovich and Escofet 1991) or when landforms are adjusting to achieve a new equilibrium configuration just after structures are in place. Mobility due to beach nourishment can greatly exceed natural rates (Pilkey and Clayton 1987), although this mobility is an unwanted byproduct of these operations.

Human actions dramatically change the cycles of landform change. The timing of nourishment projects is prescribed by the administrative time of government projects rather than conditions at the site (Kana 1993). These cycles may be longer than natural cycles of beach change, but they are aperiodic and may have no direct relationship to natural cycles. Dunes in developed areas may be eliminated in summer to provide a recreation platform and re-built in the autumn to provide storm protection, resulting in a seasonal cycle. Regularly scheduled repair of dunes is usually conducted on an annual basis. Dunes in developed areas are often closer to the water than in natural areas and are eliminated by smaller storms than would eliminate them in natural areas; they are usually rebuilt immediately after the storm rather than waiting for natural processes to restore them. As a result, sacrificial dunes may have several cycles per year. Clearing of deposits from small wind events by residents may occur at periodicities of small storms. All of these dune cycles are of shorter term than natural cycles that are related to destruction during major storms and subsequent rebuilding by natural processes (Nordstrom and Arens in review).

VALUES VS DEGREE OF NATURALNESS

The potential for modifying natural beaches and dunes to artifacts and for reversing this process in order to restore coastal landscapes to more naturally-functioning systems depends on human values for coastal resources and the perceived role of natural components in providing these values. The most commonly occurring human values and their associated alterations or uses may be placed in a continuum (Figure 3) to highlight

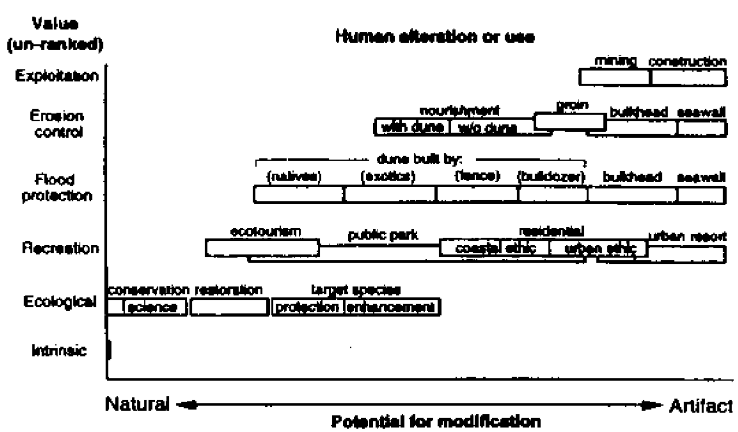

Figure 3. Potential for modification of coastal landscapes from naural to artifact based on perception of values for coastal resources.

those that are most natural. The alterations are presented as mutually exclusive categories in Figure 3 for simplicity of portrayal, although they would not be considered mutually exclusive by many coastal planners and managers. The values in the left column represent nominal data and cannot be ranked quantitatively, but they have been placed in the figure according to the degree to which they contribute to, or enhance, "naturalness." If managers of a segment of the coast wish only to address one value, the most natural of these will be to the left of each row on the diagram. If alternative values are considered, the most natural of these will be on the lowest row considered appropriate.

Intrinsic (inherent or essential) value (Figure 3) refers to the value that a component in nature has in itself. It is not a human-use value, although it is a useful concept to use in developing a management ethic about natural landforms and ecosystems (Nordstrom 1990). Actions taken to protect ecological values vary considerably in their potential for modifying coastal environments. Conservation of ecological resources for scientific study may be distinguished from conservation without scientific study (Figure 3) in that landscapes that are preserved for study of nature are used directly by humans. Restoration results in a less natural landscape than the original that was altered. Protection for target species may be viewed as distinct from enhancement for target species in that protection, if conducted properly, involves less direct alteration of the natural system.

Recreation (Figure 3) can be accommodated with small impact on natural beach and dune environments or it can result in their complete elimination. Ecotourism is one way to incorporate environmental conservation and tourism development in a single strategy (Pearsall 1993). Public parks (national, state, county and municipal) can be developed to accomplish similar goals. Coastal parks vary greatly in emphasis on human and natural features. Some parks may be managed to include urban recreation activities, and beaches and dunes may be altered dramatically to accommodate parking and pedestrian access; other parks may be managed for environmental values, where no recreation facilities are provided and there is no attempt at landscaping, other than use of sand fences in the foredune.

Residents directly alter the characteristics of the shore within the limits of their properties according to personal preference, and they indirectly alter the characteristics of municipally maintained segments by means of their collective participation in community level decisions. The least natural environments occur where residents grade dunes to retain views of the sea, remove sand blown into yards and replace natural vegetation with exotics. These actions are most likely to occur in locations where individual property rights are held in high regard; the owners are seasonal users of the property; or the owners have a landscape ethic that reflects greater familiarity with urban and suburban environments than coastal environments. In many cases, management practices in moderately-developed residential communities may be similar to those used in neighboring intensively developed shorefront communities (coastal resorts), where coastal landforms and vegetation are modified to accommodate mass use. The resulting landscape in these coastal suburbs bears little resemblance to a natural one in topography and vegetation.

Flood protection (Figure 3) involves constructing and maintaining a continuous barrier at prescribed height. The degree to which natural processes are allowed to create and maintain this barrier depends on how critical the need for protection has become. A dune can be constructed by natural aeolian accretion around vegetation where time and space are available, as on nourished shorelines, but bulldozed dunes may be the only landform option in highly erosional areas, where beaches are narrow. The value of a naturally-constructed dune for both flood protection and ecological value argue for combining flood protection and erosion control projects using beach nourishment. Bulkheads are built primarily for backup protection on high-energy coasts that still have a beach; the availability of sand for aeolian transport and the relatively low elevation of bulkheads allows wind-blown sediment to pass over them or bury them, creating the potential for dunes to survive. Seawalls are larger structures that are built as primary protection, and they restrict the landward migration of both the beach and dune and prevent the upland from functioning as part of the dynamic coastal system. There is limited potential for formation of natural landforms where seawalls are the principal form of protection for either flooding or erosion control.

Artificial beach nourishment designed to provide erosion control benefits (Figure 3) has great potential for restoring coastal landscapes, but this potential is usually not realized. Nourishment in many communities is perceived as a means of providing protection to shorefront buildings and providing a recreational platform rather than a means of restoring natural interactions or ecological values. Most nourished beaches are graded into "slabs of sand." In some cases, a low, flat, linear sand dike is constructed on them to provide flood protection. This feature can bear little resemblance to a natural dune.

Groins are artifacts, and the beaches and dunes that accumulate as a result of their placement reflect human impact in terms of their location and shape. The mechanisms of sediment erosion, transport and deposition mimic natural processes, and the landforms created at groins may be considered more natural than bulldozed forms. The perception of groins as structures to be avoided stems from their local effect on the sediment budget, but they have considerable value as habitat, and they do not constitute as great a threat to natural processes as bulkheads and seawalls.

LIMITATIONS OF MANAGEMENT PROGRAMS

Many problems associated with past coastal development projects cannot occur today because of more stringent regulations and increased knowledge about detrimental impacts (Shipman 1993), but there are still many problems that can occur in implementing planning and policy programs that are compatible with maintenance of beaches and dunes (Table 3).

Table 3. Problems of implementing planning and policy programs compatible with maintenance of natural beaches and dunes.

Problems of implementation
- Many parties cause difficulties of coordination and cooperation.
- Modern management is still lacking in some countries.
- Regulations may apply only to new development, not improvements.
- Court-ordered penalties may be too low.
- Illegal activities occur despite regulations.
- Existing environmental management policies may be rescinded or amended.
- Support for rebuilding damaged structures favors property owners.
- Value of shorefront property argues against preventing development.
- Requirement to purchase threatened properties at market value cannot be met.
- Approved initiatives may lack of funding for implementation.

Problems of conflicting goals
- Incompatible or contradictory policies occur in different regulatory agencies.
- Residents and developers have different perception of the resource.
- Uses that eliminate the beach may be considered compatible with a coastal location.
- Water-dependent uses that do not require a beach or dune may have priority.
- Cooperation at local level is often dependent on personalities, not optimal solutions.
- Dredged sediment is lost due to failure to combine navigation and erosion projects.
- Programs may favor public facilities over natural values.
- Individual species rather than landscapes often targets of conservation.
- Sites of geomorphic interest are less significant than sites of ecological interest.

Problems of spatial coverage
- Management may emphasize stability, not sustainability or spatial and temporal flexibility.
- Control zones may not coincide with physiographic units or coastal dynamics.
- Policies may not establish coastal construction setbacks, or setbacks may be too small.
- Degradational activities may be displaced to jurisdictions where there are no controls.

Problems in technical expertise
- Jursdictions usually lack the staff to make technical and scientific evaluations.
- Undeveloped environments may be managed as natural, but they may not be natural.

Problems in timing
- Land-use management may take decades to reveal benefits.
- The process of nourishing a beach can take up to 15 years.
- Waiting for erosion to become an emergency often results in structural solutions.
- Prescribed lifetimes of structures do not reflect their longevity.
- The life of engineering projects exceeds programs of local sponsors.
- Timing of nourishment projects is determined by administrative factors, not beach width.
- Politicians respond readily to emergencies but lose interest in long term projects.
- Long-term study of effects of projects is unappreciated by politicians.

Many of these problems are administrative, but even where environmentally friendly regulations are in place, landform viability may be threatened by the perception that landform mobility is bad or that a less environmentally-compatible value (Figure 3) is more desirable.

Mobility is the key to ensuring the value of coastal environments for ecological values and most human use values, in the sense that the dynamism of beaches and dunes is responsible for their physical characteristics and aesthetic appeal. It is a paradox that stability of beaches becomes the goal once humans attach specific values to them. Attention is often directed toward preserving the inventory of natural features within management units rather than the processes that created them. The mobility is often the characteristic most worthy of conservation, requiring more flexible approaches towards conserving landforms in a dynamic state, based on the significance of landforms for maintaining ecological productivity, preserving rare species and ensuring diversity of habitat (Wanders 1989; Westhoff 1989; Bray and Hooke 1995; Jones *et al.*, 1995).

IMPLICATIONS

Coastal landforms have many values, including intrinsic, ecologic, scientific, recreational, protective, exploitive and positional (i.e. good building sites). Many of the problems in management of coastal landforms stem from a focus on only one or two of these values, resulting in uses that restrict landform size or mobility. Coastal landforms that are perceived as developable properties are landscaped and maintained according to suburban aesthetics (Figure 2). Dunes that are perceived as valuable primarily for their protective qualities are maintained as narrow linear ridges, often planted with a limited number of vegetation species. Beaches that are viewed as recreational platforms rather than resources having intrinsic, ecological, or aesthetic value are graded into flat, featureless surfaces and maintained that way by raking during beach cleaning operations (Figure 2).

Landforms on human altered coasts can be said to evolve, but this evolution follows a progression of construction (or destruction) and maintenance, with changes manifested more in the size of the landform than in its mobility, shape or species diversity as occurs on natural landforms. It would be fruitful and prudent to examine ways to develop or use the shoreline in a manner that maintains or restores natural sediment transfers and accommodates mobility of landforms and their tendency to grow and be altered. Specification of the ways human altered systems differ from natural systems provides perspective on losses and gains associated with development, but it is not likely that an evaluation that simply underscores the ways these systems differ will provide the insight needed to restore natural components of coastal landscapes in developed communities and reinvigorate our sense of coastal heritage. It is important to examine activities in communities that have adopted successful compromise solutions that accommodate human uses and landform mobility and maximize future options for natural environments while retaining an image of the coast that reflects the natural processes that provide its special appeal.

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