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Temporal scales of landscape change following storms on a human-altered coast, New Jersey, USA

Nordstrom, Karl F.[1] & Jackson, Nancy L.[2]

[1]*Rutgers University, New Brunswick, NJ 08903, USA;* [2]*New Jersey Institute of Technology, Newark NJ 07102, USA; Tel. +1 908 932 6555; Fax +1 908 932 1820*

Abstract. Cycles of storm destruction and rebuilding of human facilities are as much a part of a predictable cycle of shoreline change as destruction and re-establishment of landforms and wildlife habitat by natural processes. An evaluation of the human-induced and natural geomorphic responses to three storms in two vulnerable developed areas in New Jersey reveals that storms can have limited effect in re-establishing a natural coastal resource base of lasting significance. Reconstruction of coastal landscapes by human action may be more rapid than natural restoration, decreasing the likelihood for geomorphic features to develop based on natural processes. Reliance on storm processes to create new natural habitat in locations where there is human investment in buildings and support infrastructure is not realistic unless a proactive stance is taken to include naturally-functioning characteristics of the coastal system in reconstruction efforts. By striving to control construction of shorefront buildings to reduce their potential for damage, managers may be taking attention away from the separate but critical issue of ensuring that post-storm reconstruction efforts include the potential for replacing loss of natural geomorphic features and wildlife habitat.

Keywords: Barrier island; Beach; Dune; Geomorphology; Overwash; Restoration; Structure; Vegetation; Wave.

Introduction

Scientists and managers often view destruction of landforms and loss of vegetation and fauna due to coastal storms as part of a normal cycle of events that also includes subsequent restoration by natural processes (Godfrey & Godfrey 1973; Gardner et al. 1991). Destruction of shorefront buildings and infrastructure, in contrast, is usually viewed as a disaster and evidence of the vulnerability of human alterations, although the cultural landscape too will be restored (Nordstrom 1994 in press). Seeds and culms in the storm wrack lines and vegetation buried by overwash provide the basis for regrowth of vegetation and re-establishment of habitat in natural areas; political pressure, the availabililty of capital, heritage of ownership, and preference for structures that enhance coastal recreation provide the basis for renewal of cultural landscapes. Without a perspective on the degree to which the coastal landscape is converted to a human artifact following storms, conservationists and managers may overestimate the ability of coastal storms to restore critical natural features, or they may overlook the opportunity to incorporate human actions to restore natural values during post-storm reconstruction programs.

This paper is a preliminary assessment of effects of major storms on the morphology and surface cover of a developed coast over temporal scales that include restoration of storm-altered landscapes and is designed to identify how restored landscapes reflect the imprint of natural and human processes. The purpose of the paper is to illustrate that cycles of storm destruction and rebuilding of human facilities are as predictable as destruction and re-establishment of wildlife habitat but that human-induced reconstruction may be more rapid than natural restoration and may dominate the landscape.

Previous analyses of coastal storms and human-altered landscapes

There is no lack of studies of the geomorphological and related engineering implications of specific storms (Nichols & Marston 1939; Hayes 1967; Dolan & Godfrey 1973; Morton 1976; Penland et al. 1980; Dean et al. 1984; Nakashima 1989; Finkl & Pilkey 1991; Kraus 1993; Finkl 1994; Stone & Finkl 1995). At least one major study of shoreline changes is published following each hurricane in the USA (Morton 1976). Most of these studies are conducted within a few months of the storm and published within a few years, well before the lasting effects of the storm are apparent. Most evaluations of post-storm landscapes are reconnaissance-level investigations that include descriptions of dramatic changes in landforms, inventories of damage to buildings and infrastructure and suggestions for actions required to prevent damage from subsequent storms. Descriptions of post-storm recovery are often limited to a paragraph or

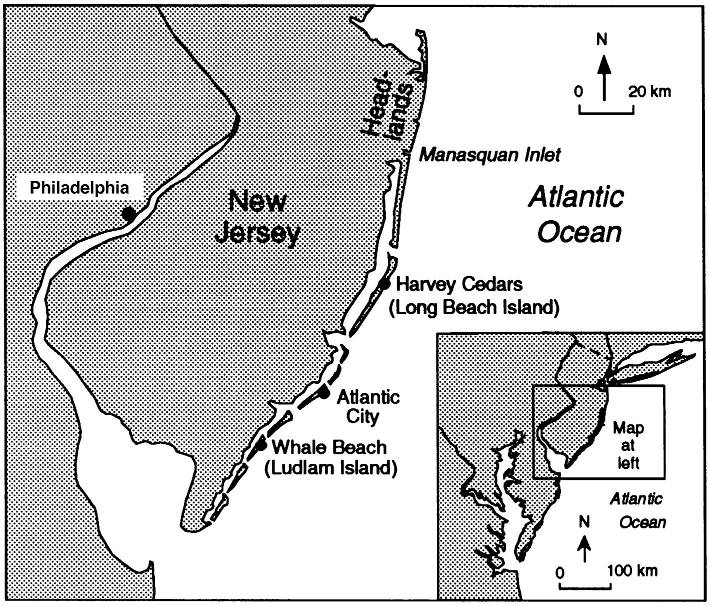

Fig. 1. Study area.

two near the end of a litany of damages, and the elapsed time following the storm is too short to obtain meaningful conclusions about the recovery process. Geomorphic effects of storms have been studied in the context of long-term geological scale investigation of natural areas (Hayes 1967; Morton et al. 1994), and decadal scale studies of biological succession exist (Hosier & Cleary 1977), but these studies are not conducted in developed areas. Studies have been conducted on developed coasts at temporal scales of decades, but the data subsume storm effects rather than concentrating on them (Gares 1990; Nordstrom 1988a; Anthony 1994).

Our investigation differs from previous assessments of storm effects in that we concentrate on: (1) identifying changes to the morphology of the developed coastal landscape over a longer time interval than the traditional evaluations (that are often less than a year) to include restoration efforts; and (2) evaluating the susceptibility of the restored landscape to changes resulting from subsequent storms. Examples are provided of two locations on barrier islands in the state of New Jersey on the northeast coast of the USA - Harvey Cedars, on Long Beach Island and Whale Beach on Ludlam Island (Fig. 1). These sites were selected because they have been among the most vulnerable locations in New Jersey to storm damage in recent decades, and they represent locations where reversion to natural environments following storms could be considered a potential management option.

Study area

Average annual significant wave height in New Jersey is 0.82 m with an average wave period of 8.3 s (Thompson 1977). Tides are semi-diurnal with a mean range of 1.3 m (Anon. 1994). The dominant winds blow from the northwest, but storms bring strong onshore winds, predominantly from the northeast.

Beaches on Long Beach Island are quartz sand with a median diameter of 0.35 mm (Ramsey & Galvin 1977). Long Beach Island is densely populated with single family houses on small lots. The level of development here typifies many islands along the Gulf and Atlantic coasts of the USA (Titus 1990). Island width at Harvey Cedars varies from a maximum of 760 m to a minimum of 210 m, although the width of the upland above the marsh is less than 120 m in places. Vegetation on the foredune is primarily American beach grass (*Ammophila breviligulata*). The surface of the barrier island landward of the foredune is primarily unvegetated gravel that the residents favor as a landscaping agent, with pine trees introduced to break up the monotony of the cultural landscape.

Beaches on Ludlam Island are quartz sand with a median diameter of 0.23 mm (Ramsey & Galvin 1977). Whale Beach is sparsely populated. Island width, including salt marsh, varies from 700 m to 310 m, but the width of upland is less than 120 m in places. The dune is artificially maintained by importing fill material and by bulldozing. The most conspicuous vegetation cover on the low upland landward of the dune is made up by the introduced reedgrass (*Phragmites australis*).

Methods

The effects of storms are illustrated using data for the three most damaging recent events for which there is good photographic coverage and written post-storm assessments, including the storms of 6-7 March 1962 (Anon. 1962, 1963), 28-29 March 1984 (Anon. 1985), and 11-12 December 1992 (Anon. 1993). Comparative process data for these storms are available from records taken at Atlantic City (Fig. 1). Storm effects and post-storm recovery are illustrated at the two communities by examining vertical air photos at 1:4800 and 1:9600 scale. Photos for Harvey Cedars portray four different conditions through time including: the year before the March 1962 storm; the day after the March 1962 storm; 8 years after the storm; and 3 days after the December 1992 storm. Photos for Whale Beach portray conditions prior to the 1962 storm; a week after the 1962 storm; the day after the 1984 storm; and 3 days after the December 1992 storm. Post-storm human activities to rebuild the coastal landscape are determined from these air photos and from federal and state project reports. The physical imprints of the most damaging storms were examined in the field by observing flood levels and debris lines; characteristics of overwash sediments and bulldozed sediments; fate of sediment removed from streets, yards and driveways; and surface characteristics of landforms (natural and exotic vegetation, pavement).

Storm characteristics and post-storm changes

Effects of the March 1962 storm

Significant wave heights for this storm were estimated at between 6.1 and 9.1 m; the fastest wind gust observed at Atlantic City was 25.9 m s^{-1}; maximum water level elevation was 2.19 m above mean sea level (Anon. 1962). The storm passed New Jersey slowly, coinciding with five high tides, and damages were severe. Damage assessments for the shoreline counties of New Jersey south of Manasquan Inlet (Fig. 1) were $ 105 055 000 in 1962 US dollars (Anon. 1963).

The greatest geomorphological changes and damage to buildings throughout the state occurred where beaches were narrow and dunes were low prior to the storm. Storm washover and aeolian transport created a veneer of fresh sand well inland on much of the shoreline, with the major overwash deposits occurring at shore-perpendicular streets. Many oceanside bulkheads failed, but there was little wave effect landward of locations where bulkheads remained intact (Anon. 1962). Five breaches occurred in Long Beach Island; 5361 residences were damaged by flooding; and 998 had structural damage. Four of the breaches occurred at Harvey Cedars. Comparison of pre-storm photos (Fig. 2a) with photos taken the day after the storm (Fig. 2b) reveals that overwash penetrated all the way to the bay in places, and numerous buildings were destroyed. This storm caused extensive overtopping and leveling of the dunes along most of the community. (The tops of the dunes prior to the storm varied in elevation from 4.6 m to 7.6 m above mean sea level.) A 180 m long segment, within the area where complete dune destruction occurred, was not overtopped because the property owners had built a protective dune prior to the storm using sand fences and vegetation plantings.

A total of 2272 residences were damaged by flooding on Ludlam Island (Fig. 1), with 668 suffering structural damage. Nearly all of the dunes along the entire island were destroyed, and all public utility systems failed (Anon. 1962, 1963). At Whale Beach (Figs. 3a and 3b), all of the buildings on the seaward side of the main shore-parallel road were destroyed; overwash penetrated up to 185 m inland from the shorefront road; and underlying peat layers were exposed on the beach.

Activities after the March 1962 storm

The President of the USA declared coastal New Jersey a disaster area on 9 March, only 2 days after the storm reached its height. Emergency restoration and construction activities were in progress after only a few days under authority of Public Law 875, which authorized public agencies to perform protective work essential for the preservation of life and property, including clearing debris and wreckage and repairing public facilities. Even boardwalks, primarily recreation structures, were eligible for federal funds for repair because they were considered usable for emergency transportation. Closure of breaches in the barrier islands to safeguard federal navigation channels and restoration of protective value of beaches and dunes were priority actions. Closing of the breaches at Harvey Cedars was initiated by the Corps of Engineers on 9 March and was accomplished in only 2 days.

The Corps felt that beaches and dunes should be restored to provide protection against a storm having a frequency of one in 10 years, and that projects should be finished prior to the following hurricane season (late summer), allowing about 4 months to accomplish the protective effort (Anon. 1963). Most of the sand emplaced on the New Jersey shore after the 1962 storm was dredged from bays and channels behind the barrier islands.

The Corps placed 2 847 000 m^3 of sediment along the entire New Jersey shore; 547 000 m^3 of sediment were placed on Long Beach Island, much of it in the

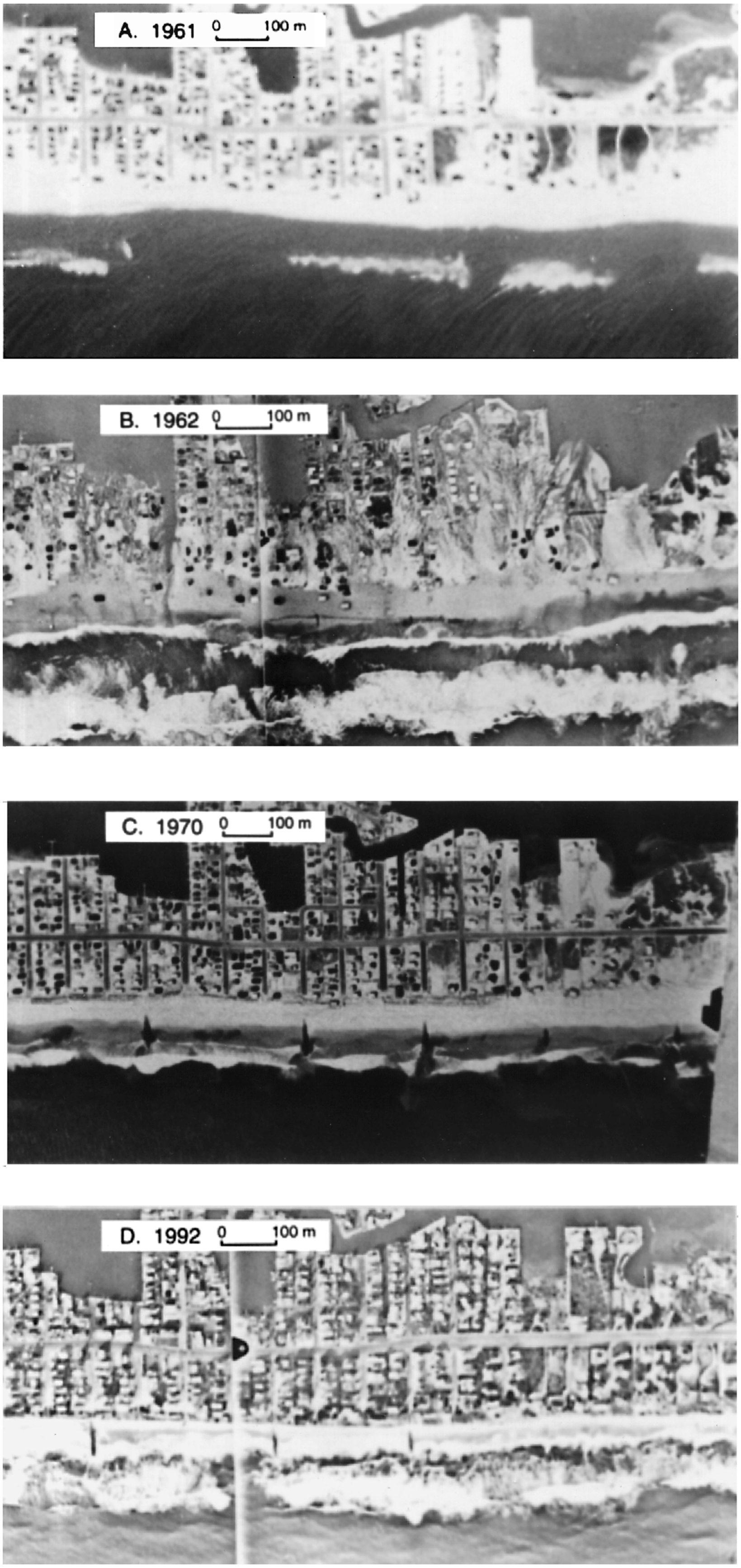

Fig. 2. Conditions at Harvey Cedars representing:

A. Before the March 1962 storm (Photo taken 17 March 1961).

B. The day after the March 1962 storm (Photo taken 8 March 1962).

C. 8 years later (Photo taken 7 March 1970).

D. After the December 1992 storm (Photo taken 15 December 1992).

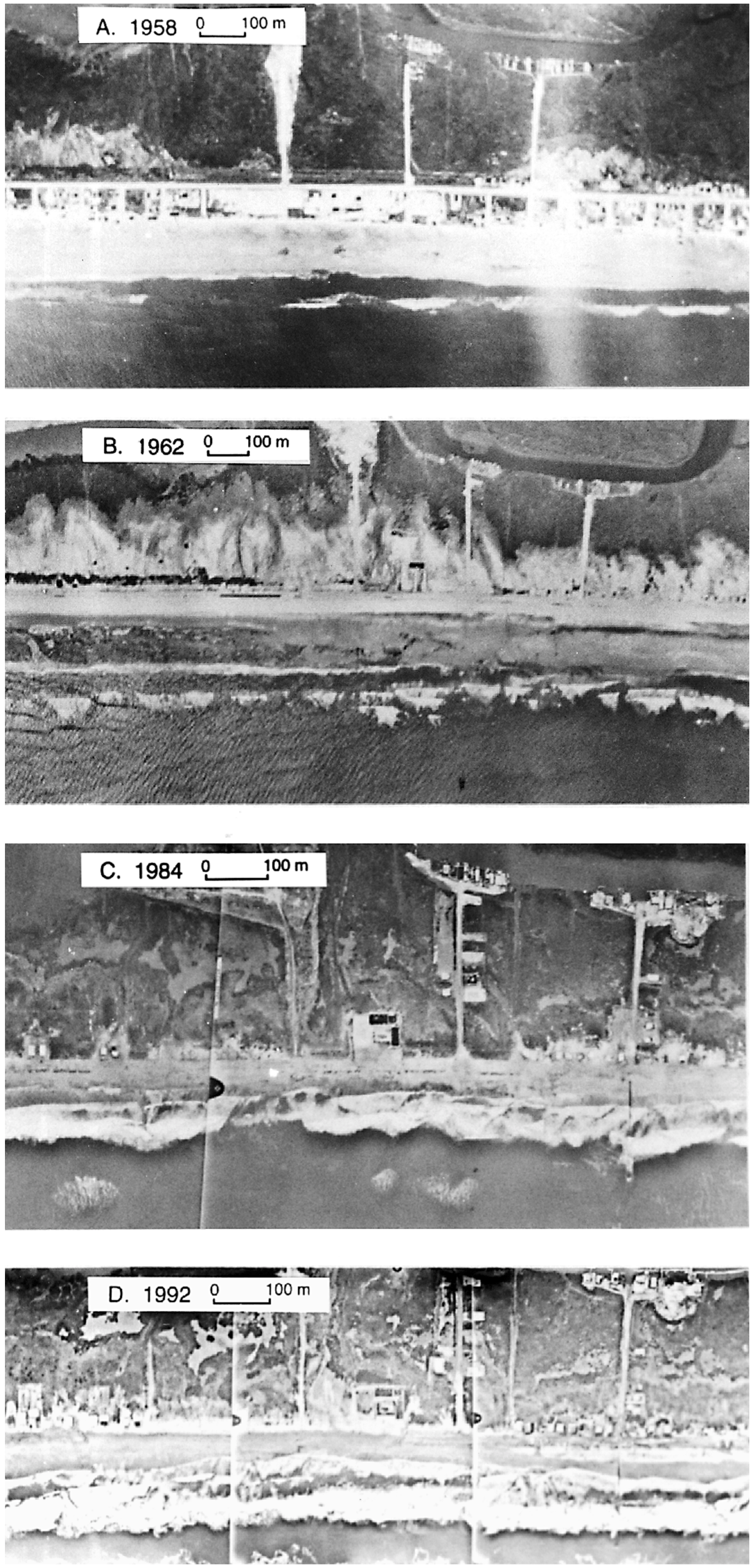

Fig. 3. Conditions at Whale Beach representing:

A. Before the March 1962 storm (Photo taken 11 October 1958).

B. One week after the 1962 storm (Photo taken 17 March 1961).

C. After the 1984 storm (Photo taken 30 March 1984).

D. After the December 1992 storm (Photo taken 15 December 1992).

vicinity of Harvey Cedars (Anon. 1993). The crest of the design dune at Harvey Cedars was only 3.7 m above mean sea level, but the municipal government placed a sand fence atop the dunes to trap additional sand. New groins were built by the Corps at an average spacing of every 300 m along the entire shorefront of Harvey Cedars and adjacent communities. 83 of the 110 groins in existence on Long Beach Island in 1972 were built or rebuilt following the 1962 storm (Everts & Czerniak 1977). The Corps nourishment project at Harvey Cedars was completed 27 April 1962. Natural beach recovery delivered sediments to the beach and dune in addition to these artificially-emplaced volumes. The emergency beach and dune restoration efforts implemented after the 1962 storm at Harvey Cedars and Whale Beach were considered to offer only a low to moderate level of protection; and Harvey Cedars was considered to rank among the 10 most vulnerable shoreline locations in New Jersey (Anon. 1993).

Fig. 2c identifies the condition of Harvey Cedars 8 years after the storm. Many houses had been built or rebuilt by this time, and many of the houses were farther seaward than in 1962. Data from topographic surveys (Miller et al. 1980) indicate that the beach was 20 m wider in 1970 than it was in September 1962. The groins constructed after the storm represent an attempt to achieve greater shoreline stability than existed prior to the storm. Although 77 storm events (determined by high water levels, coastal flooding or coastal erosion) occurred from September 1962 to June 1973, many beach profiles taken along Long Beach Island during that period showed relative stability or accretion (Miller et al. 1980).

Post-storm activities by the Corps of Engineers on Ludlam Island included emplacement of 692 4000 m^3 of fill, as well as construction of sand fences to build a higher dune. This protection project was completed 16 August 1962. No attempt was made to rebuild houses back in locations seaward of the shorefront road at Whale Beach. The dune at Whale Beach experienced progressive erosion and wave attack during small storms that occurred between the March 1962 storm and the March 1984 storm. Improvements were made to the dune by the state, including repair of the dune in 1983 using fill materials from a source outside the area.

Effects of the March 1984 storm

Peak wind velocities and storm surge levels for this storm were similar to the 1962 storm (significant wave height was 6.1 m; maximum wind gust at Atlantic City was 32.0 m s^{-1}; maximum water level elevation was 2.19 m above mean sea level) (Anon. 1985). The system passed New Jersey quickly, coinciding with only one high tide, and damages ($ 8 045 023 in 1984 US dollars for the three coastal counties) were not as severe as in 1962 (Anon. 1985).

Damages at Harvey Cedars were not severe: washovers occurred in several places in the dunes, and a breach occurred at the south end of the community, damaging some homes. Whale Beach (Fig. 3c) had some of the worst erosion and washover of any community along the New Jersey coast. The dune system was almost completely destroyed; underlying peat layers were exposed; the shorefront road was inundated with sand; cars were buried; numerous residences were inundated and had structural damages; flooding was up to 1.8 m above the ground surface in low-lying areas (Anon. 1985). The post-storm cultural landscape at Whale Beach bore a resemblance to the landscape after the 1962 storm, mainly due to the lack of construction of many new buildings following the former storm. The landward limit of overwash was not as great as occurred in 1962, presumably due to the rapid passage of the storm.

Activities after the March 1984 storm

The President declared the New Jersey coastal counties a disaster area (Federal Register 19 April and 27 April 1984), although damage was slight. Sand washed onto roads and storm debris were quickly cleared, and the majority of the affected communities in New Jersey were ready for the tourist season, only 2 months after the storm. A beach fill project was in progress at Sea Isle City when the storm occurred. The damages from this storm caused the state to expand the scope of that work to include rebuilding the dunes there, thus saving on mobilization costs. A beach fill and dune construction project was later implemented by the state between September and December 1984 at Sea Isle City and Whale Beach, involving 453 000 m^3 of fill (Anon. 1985). The new dune at Whale Beach was larger than it had been prior to the storm, but it bore little resemblance to a natural dune in location and physical characteristics (Fig. 4).

Effects of the December 1992 storm

The December 1992 storm was comparable in strength to the 1962 storm in terms of peak wind velocities, storm surge levels and storm duration (five high tides); wave energies were considered higher, but the effects of the storm were not as severe as the 1962 storm, in part because wind direction shifted to the north, resulting in energy loss through refraction (Anon. 1993). Significant wave height was estimated at 7.6 m; maximum wind gust at Atlantic City was 24.7 m s^{-1}; maximum water level elevation was 2.25 m above mean sea level. The storm caused erosion of dune lines and

Fig. 4. Artificial dune constructed at Whale beach November 1987 and eliminated in the 1992 storm.

overtopping of low dunes. Overwash occurred in the dunes at street ends and on shore-perpendicular streets that acted as conduits for overwash. Damage assessments for the coastal counties south of Manasquan Inlet (Fig. 1) were $11 878 523 (Anon. 1993).

This storm damaged signs, pavilions, recreational benches and docks throughout Harvey Cedars and deposited flood debris on properties and blocked sewer lines. The storm caused severe erosion of the dune along the entire town, with an estimated dune loss of 91 800 m^3 of sand. Some dunes were completely eroded, exposing the foundations of oceanfront homes; other houses were in the surf zone. The entire dune was eliminated at Whale Beach (Fig. 3d), resulting in a post-storm landscape similar to the one occurring after the March 1984 storm.

Activities after the December 1992 storm

The President declared the New Jersey shoreline a disaster area 18 December 1992. The State and National Guard supplied 20 dump trucks, a front-end loader and three bulldozers to transport an undetermined amount of sand to Harvey Cedars from an upland source (Anon. 1993). Earth-moving equipment was also used to plow sand from the beach into the dunes to create a new barrier against overwash. This new foredune was constructed in a few weeks. The state implemented a nourishment operation at Harvey Cedars autumn 1994 to spring 1995, involving transport of approximately 368 600 m^3 of sediment by truck from an upland source.

Post-storm activities at Whale Beach included bulldozing sand from the road back to the former location of the dune. The state also planned a dune-building project for implementation in 1995, involving approximately 34 000 m^3 of fill sediment.

Net effect of storms

There is little topographic variability or species diversity in the coastal landscape at Harvey Cedars. The location that bears the greatest resemblance to a natural coastal landscape is on the landward side of the dune crest (Fig. 5a). Here, the hummocky topography and vegetation cover of *Ammophila* mimic conditions on a natural dune, but other natural species, such as seaside goldenrod (*Solidago sempervirens*), are missing, and the width of the backdune zone is narrow (due to truncation by human activities). Growth of the seaward side of the foredune is aided by bulldozing; thus the dune face is more linear than would occur under natural aeolian transport, and the surface of the dune near the crest has conspicuous gravel deposits that are too coarse to be transported to this location by aeolian transport. The

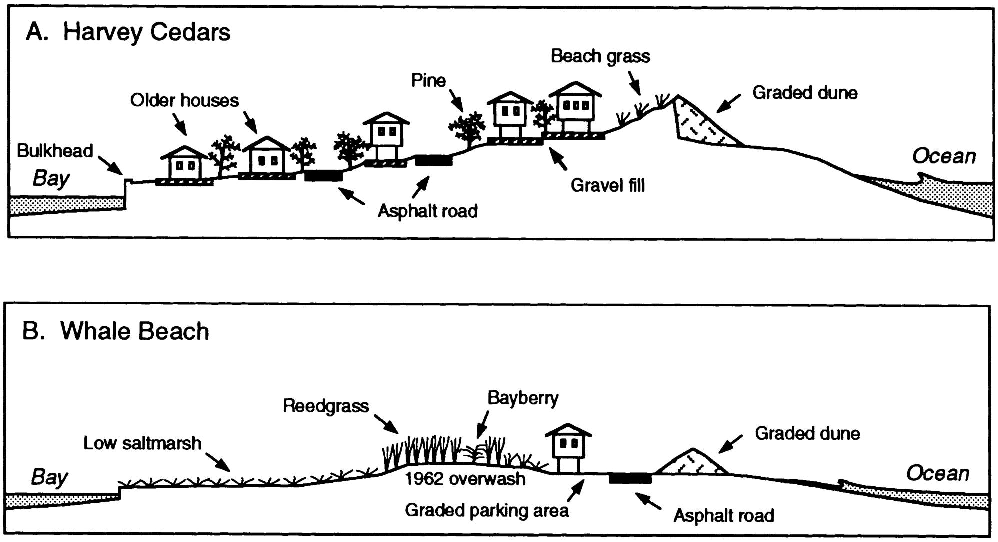

Fig. 5. Schematic representation of present characteristics of the cross-island profile at Harvey Cedars (a) and Whale Beach (b).

surfaces of most building lots are graded flat and supported by retaining walls on the landward side, creating a terraced landscape. Pine trees are the most conspicuous vegetation; these trees are isolated or form monospecific stands. Most lots are too small and intensively managed for significant growth of shrubs to form between them. Wooden timbers are frequently used to demarcate property lines.

The present seaward construction line at Harvey Cedars (Fig. 2d) is nearly at the same location it was prior to the 1962 storm. The net effect of that storm and all subsequent storms in altering the location of the shoreline, re-creating natural landforms or re-initiating new cycles of natural landform evolution was negligible. The beach and emergency dune constructed after the 1992 storm was considered to provide a low to moderate degree of protection to the oceanfront buildings in Harvey Cedars, and damage to these buildings was considered probable during a severe long-duration storm (Anon. 1993). However, precedents established in post-storm reconstruction efforts indicate that if a severely damaging storm does occur, the buildings and infrastructure would be rebuilt to a scale rivaling pre-storm conditions.

The net effect of the March 1962 storm at Whale Beach was elimination of numerous shorefront buildings and creation of new substrate over the marsh landward of the shorefront road, but the storm did not re-establish the dominance of natural processes. The overwash platform created at Whale Beach by the 1962 storm remains a conspicuous feature in the coastal landscape (Fig. 5b), but this feature is not as dynamic as it would be under natural conditions. The artificial dune has limited further modification of the overwash platform by both overwash and aeolian transport, and there have been no new cycles of landform evolution or vegetation growth and no inland migration of the barrier island. The overwash platform is colonized by *Ammophila*, *Solidago*, high saltmarsh species, such as saltmeadow cordgrass (*Spartina patens*) and woody shrubs, such as bayberry (*Myrica pennsylvanica*), but the dominant vegetation cover is *Phragmites*. This species is not commonly found at this density at this location on naturally migrating barrier islands, and it appears to be a result of human occupancy. Although *Phragmites* is not the most naturally-compatible species, it does have greater value as habitat than the sparse vegetation at Harvey Cedars.

Developed lots at Whale Beach are graded flat (as at Harvey Cedars), and the lots in the zone of overwash have been graded to lower elevations (Fig. 5b) to correspond to the elevation of the shorefront road, that is approximately the elevation of the backbeach. The only high portions of the coastal landscape other than the artificially-created dune and the overwash platform are hummocks of sand between properties that are created by humans as a means of disposing of sand washed into driveways and lots by storm waves.

Many of the new structures at Whale Beach and Harvey Cedars are now more elaborate than those built prior to 1962, and they are elevated on pilings to reduce the potential for damage during storms. The elevated buildings provide less interference with natural processes than buildings on the ground, and this aspect makes them more compatible with restoration to a natural setting, but active human alterations to the ground surface override any ecological or geomorphic benefit of constructing the buildings above the surface of the ground.

Discussion

Comparison of the post-storm geomorphic landscape with the human-restored landscape determines the degree to which the geomorphic imprint of storm alterations and post-storm recovery is dominated by natural or human processes. Analysis of the effects of subsequent storms on the human-restored landscape reveals the degree to which human alterations change the susceptibility of the developed coast to storm modification.

The incompatibility of human structures with the damaging effects of storms is dramatically revealed in comparison of the pre-1962 and immediate post-1962 storm photographs (Figs. 2a, b; 3a, b), but the significance of this storm in reestablishing the physical landscape was never realized, even after several storms of similar magnitude occurred. Although it can be argued that the subsequent storms were potentially less damaging from a meteorological standpoint, it is also apparent that human activities reduced the likelihood that these storms could achieve their full potential in modifying the coastal landscape.

Table 1. Temporal scales of selected storm changes and post-storm alterations in New Jersey and other locations as noted.

Natural alterations	*Restoration time*
Beach recovery	Several weeks (Davis et al. 1972)
Litter cleanup	N/A
Filling of erosional scarps	Weeks to months (Sexton & Hayes 1991)
Formation of small dunelets	Several months (Sexton & Hayes 1991)
Creation of dune ridges	1 year (Sexton & Hayes 1991)
Recovery of dunes resistant to overwash	5-10 years (Hosier & Cleary 1977; Ritchie & Penland 1988)
Re-establishment of incipient vegetation	< 1 year (Sexton & Hayes 1991)
Inlet closure	< 1 year to > 1 year (Sexton & Hayes 1991)
Human-induced alterations	*Restoration time*
Removal of sand from roads	Within 3 weeks (this study; Meyer-Arendt 1991)
Emplacement of sand bags	During storms
Emplacement of rip-rap	During storms and subsequent weeks (Griggs & Johnson 1983)
Litter cleanup	< 2 months (Anon. 1985)
Beach scraping to create berms and dunes resistant to overwash	Days to weeks (Katuna 1991)
Replanting vegetation	Months
Installing sand fences	Months (Katuna 1991)
Construction of groins, bulkheads	<2 years
Inlet closure	Days (Anon. 1963)

Temporal and spatial scales of landform changes

The time required to reconstruct the dune in developed areas may last a few days (using earth moving equipment), a season (using sand fences) or several years (using artificial vegetation plantings) (Nordstrom 1994). Although a new berm and dune may build up by natural processes after a year, these natural features may be smaller than their pre-storm size (Morton et al. 1994), and they may be ineffective in stopping periodic flooding that reactivates and increases the landward extent of washovers formed during the earlier storm (Sexton & Hayes 1991). The slower recovery time of natural landscapes to loss of dunes during large storms can perpetuate overwash conditions during smaller subsequent storms or contribute to continued net loss of dunes during subsequent storms (Hosier & Cleary 1977; Morton et al. 1994). Many human alterations are accomplished at a far more rapid pace than would occur under natural processes (Table 1) and they alter the degree of vulnerability of changes during subsequent storms, especially those of lower magnitude.

Events in New Jersey indicate that cycles of storm damage and reconstruction of both human structures and human-designed or human-enhanced geomorphic landscapes can be as little as one or two years for catastrophic storms. The human-altered post-storm landscape dominates over the natural post-storm landscape whether storm effects are prevented by human alterations or the storm obliterates the human-altered landscape and it is subsequently repaired.

Speed of reconstruction efforts may be a function of the economic importance and size of the market area for tourists (Meyer-Arendt 1991). Restoration of the value for tourism can be accomplished within a year after major storm damage with massive inputs of capital and labor, but activities as routine as removal of rubble can take several years where investment level is low (Meyer-Arendt 1991). Restoration of completely devastated cultural landscapes where economic investment is low may take years or even decades, but even formerly abandoned communities may undergo re-development when social and economic forces become more favorable (Meyer-Arendt 1992).

Impediments to environmentally-compatible policies

The examples from New Jersey that are highlighted in this paper are not unusual cases of developed shorelines maintained in a condition of extreme vulnerability. Lessons of previous storms are often forgotten or ignored (Nichols & Marston 1939; Podufaly 1962; Coch 1994), and people continue to locate in a high risk area.

Buildings damaged by storms are often rebuilt in the same location, often at larger scale (Waldrop 1988; Fischer 1989; Bortz 1991; Beatley et al. 1992; FitzGerald 1994). Many studies have suggestions for design of structures that will reduce damages during the following storm (Morton 1976; Rogers 1991; Saffir 1991; Nichols et al. 1993), contributing to the likelihood that structures will persist after major storms. There is an increase in the size of the new buildings and amount of support infrastructure (utility lines, widths of right-of-ways), making them less easy to be moved, and setbacks, if applied, often have inadequate widths (Rogers 1993).

Pre-storm planning for post-storm construction can occur, even at the municipal level, with cooperation between planning boards, advisory committees and elected officials (Bortz 1991), but for most communities, prevention of coastal construction or restrictions to reconstruction following storms based on geomorphic principles is likely an elusive goal. It is difficult to envision local governments and property owners accepting solutions that opt for retreat from coasts; most local residents would advocate an option that approaches the status quo (Titus 1990).

The USA has seen a dramatic increase in the number of plans, policies and personnel involved in environmental protection and reduction of hazards in the coastal zone since the early 1970s (Godschalk & Cousins 1985), but there are numerous state program components that have promoted development, especially tourism (Healy & Zinn 1985). There is no comprehensive national policy in response to coastal hazards, and development of a policy is obstructed by two dogmas of the US political system - privatism, whereby owners are entitled to use their land largely as they wish, and localism, whereby planning and management of coastal resources is considered within local government purview (Platt 1994). The evolution of public policy is not a linear process and public decision makers may reject or rescind environmentally favorable management initiatives (Nordstrom 1988b; Platt 1994). Damage assessments and economic support for rebuilding damaged structures are liberally interpreted in favor of property owners (Beatley et al. 1992). Arguments to prevent coastal development or convert developed areas to natural environments because of economic or social costs (e.g. Pilkey 1981) hold little weight because of the enormous value of shorefront property (Titus 1990). Planners and policy makers continue to recommend changes in federal policy and state programs to end public subsidies to private development in hazard areas and break the build-destroy-rebuild cycle (Godschalk et al. 1989), but the problem of increasing vulnerability continues.

Implications

Specific human structures may be incompatible with storm processes, and they can be readily destroyed, but this incompatibility is independent of the ability to rebuild the same structure; build new (and more storm-proof) structures; and alter landscapes to reduce the geomorphic impact of subsequent storms. By striving to control construction of shorefront buildings in terms of their loss potential, managers may be taking attention away from the separate but critical issue of directing attention toward preventing loss of natural geomorphic features and habitat that should be a principal focus of conservation-oriented scientific efforts.

Storm-related features that are prevented from occurring or are removed from the post-storm landscape and lose their ecologic significance as a result of human efforts include breaches in dunes and overwash lobes. Breaches in dunes create a hummocky dune crest and favor development of blowouts that can, in turn, provide avenues for wave overwash during subsequent storms. Overwash lobes create platforms on the barrier islands and shallow areas in the bay behind the barrier islands that form substrate for formation of new vegetation. These features can be preserved or artificially produced by human processes if policies and monies are in place to accomplish these goals. Reliance on storm processes to create new natural habitat in locations where there is heavy human investment is not likely to occur unless a pro-active stance is taken to include naturally-functioning characteristics of the coastal system in reconstruction efforts. Natural scientists may find profit in analyzing human process variables in addition to physical process variables to explain landform assemblages and facilitate finding procedures for incorporating natural ecosystem characteristics and values into public and private capital investment decisions and environmental praxis. Variables derived from the coastal geomorphology literature and coastal management literature that identify important growth management issues that would influence societal adjustments to coastal landform changes have been identified (Houlahan 1989; Paterson et al. 1991) as have research variables associated with geomorphological and engineering variables (Kochel et al. 1985; Anthony 1994). Scientific input is required to ensure incorporation of ecological values in decisions relating to human factors, such as beach ownership (public or private), ground cover (including decisions about exotic species in vegetated areas), land use type (residential, commercial, open space for both recreation and ecological values), building density (and use of space between buildings), permit variances (e.g. number granted over time interval), land use controls (presence of setbacks, dune ordinances), location of public roads, utility lines, water and sewer facilities. Coastal research has placed an increasingly important role in shaping legislative response by strengthening environmental perceptions of decision makers concerning the effects of disasters (Platt 1994). We can take steps to incorporate environmental values in the restoration process at both large and small temporal and spatial scales, but perhaps we must be both more creative and modest in our reconstruction of naturally-functioning environments.

Analysis of storm effects and post-storm human inputs, viewing humans as intrinsic to the coastal landscape is an important step in determining future conservation efforts. This holistic view will: (1) clarify changes that are not explainable under theories of natural evolution and conflicting theories about causes of these changes; (2) place shore protection strategies in perspective by identifying their cumulative long-term role in altering the effects of storms in terms of coastal evolution rather than the traditional way of viewing them in their local, short-term effects on beach changes; (3) better define the reason for the inability of successive storms to restore or maintain natural features; (4) provide a set of guidelines for planning and regulating construction of buildings that considers these buildings integral components of the coastal system; and (5) stimulate creative ways to re-establish natural or naturally-functioning components in a human-altered landscape.

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