Constraints on restoring landforms and habitats on storm-damaged shorefront lots in New Jersey, USA

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ABSTRACT

Removal of shorefront houses following storm damage can provide opportunity to restore landforms and habitats and reduce risk to people and property. This opportunity was evaluated on the ocean coast of New Jersey, USA, following Hurricane Sandy, which occurred 29 October 2012. Houses were removed from 79 of 339 private shorefront lots in the 9 km-long segment having the greatest damage. Sixty lots remained empty four years after the storm. Mean dimensions of these empty lots were 66.3 m across shore and 23.4 m alongshore. Mean area of vegetation cover was 49.8% prior to the storm and 17.7% after the storm. The lots showed little indication of active landscaping after debris clearance, and the lots lacked topographic and vegetation diversity. The real estate value of empty lots appears too great for public purchase, and lots are weak points in shore protection plans when left to evolve naturally. A new bulkhead and extension of a pre-existing seawall built after the storm now isolate the former dune from the active backshore, eliminating natural sediment exchange between beach and dune on 47 of the 60 lots. Loss of the linkage between the backshore and dune caused by shore-parallel walls need not prevent restoration of native vegetation typical of the more stable backdune environments. Restoration actions that do not require buyout of properties for public use can contribute to the diversity, aesthetic appeal and resilience of the dune. The natural image may influence acceptance of natural vegetation and favor acceptance of managed retreat in the future when occupation of the shorefront becomes less tenable.

Keywords: coastal storms, dune restoration, managed retreat, protection structures

1. Introduction

1.1 Purpose

Coastal development has eliminated much natural ocean beach and dune habitat worldwide (Defeo et al., 2009). Elimination can occur by constructing buildings and infrastructure directly on coastal landforms or indirectly by progressive erosion of landforms located between the shoreline and fixed human structures. Shore protection structures, such as seawalls, bulkheads and revetments, protect buildings and infrastructure but restrict space for natural landforms and habitats to form or survive (Dugan and Hubbard, 2006; Dugan et al., 2008, 2011; Pilkey and Cooper, 2014). Sandy beach ecosystems can adapt to storms and sea level rise by retreating landward and maintaining structure and function over various spatial and temporal scales (Berry et al., 2013). The advantages of allowing landforms and habitats to evolve by natural processes are acknowledged, but actual responses by removing human structures are limited and often resisted by the public (Ledoux et al., 2005; Abel et al., 2011; Luisetti et al., 2011; Morris, 2012; Niven and Bardsley, 2013; Cooper and Pile, 2014; NRC, 2014; Costas, 2015; Harman et al., 2015). Removal of structures occurs mostly on rural lands on low energy coasts to restore marshlands farther landward in managed realignment projects (French, 2006; Rupp-Armstrong and Nicholls, 2007). Managed realignment by removing structures is rarely implemented on exposed sandy coasts because of the great public interest in beach recreation and the human-use value of beaches (Nordstrom et al., 2015) and the great economic value of land already in private ownership. Nevertheless, coastal communities are experiencing rising sea levels and increased frequency and severity of coastal storms (FitzGerald et al., 2008; Boon, 2012; Stocker et al., 2013), requiring reevaluation of practices for managing coastal properties.

Post storm evaluations of damage to developed coastal communities reveal ample evidence of the vulnerability of houses and infrastructure to storm damage (Saffir, 1991; Sparks, 1991; Platt et al., 2002; Kennedy et al., 2011; Hatzikyriakou et al., 2016; Hu et al., 2016; O'Neil and

Van Abs, 2016). Destruction of houses during storms provides an opportunity for previously developed land to evolve naturally, if property owners resist developing the land further and avoid selling it for future development. Despite this opportunity to restore natural values and calls for implementing strategies for reducing the number of people and buildings at risk (Rabenold, 2013; NRC, 2014), this landscape conversion rarely occurs. Post storm human actions are conducted under extreme pressure of time, media attention and public sympathy for owners of damaged structures, resulting in rapid attempts to reestablish pre-storm uses (Platt et al., 2002), often including structures of greater unit value than the former ones (Nordstrom and Jackson, 1995).

The purpose of this paper is to identify constraints to reestablishing natural landforms and habitats on lots in private ownership frontin ocean beaches and identify opportunities for restoring some of the natural values. Storm damage of shorefront houses provides an incentive for change, but human desire for shorefront property and market value do not favor retreat from the coast. We acknowledge the advantages of reducing the exposure of people and property to hazards, but our emphasis is on restoring natural environments. This potential was evaluated by examining the fate of lots in the first (shorefront) row in northern New Jersey, USA, where houses were destroyed as a result of Hurricane Sandy, occurring 29 October 2012. Damage and removal of houses occurred farther landward than the shorefront, but our attention was on the seaward row of houses, where restoration of critical shore-dependent habitat would have the greatest value. Lots that remained abandoned four years after the storm were examined to see if they showed conspicuous evidence of evolving natural features. Most studies of the effects of damaging storms are conducted within a few months of the storm and published soon thereafter (Nordstrom and Jackson, 1995). We wanted to evaluate conditions several years after a storm when reconstruction of buildings is still occurring and implementation of plans to protect against future storms is in progress.

1.2 The issue

The condition of shorefront lots must be placed in the context of the natural gradient of processes and landforms and the restrictions caused by human actions. The first row of buildings in the study area and in many other developed shores throughout the world is located where the dune would be under natural conditions, greatly restricting the size, shape and mobility of dunes that are allowed to form. Dunes on naturally-functioning sandy ocean beaches undergo cycles of sediment exchange with the beach and backshore. Dune erosion by storm waves moves sediment offshore, but sediment is moved back to the beach after storms, providing a source for wind-blown sand for dune building.

Dunes provide many non-consumptive ecosystem functions and services. These include protection for human structures landward of them, aesthetic and therapeutic opportunities, cultural/environmental heritage, educational resources, filter for pollutants, retention area for groundwater, ecological niche for plants adapted to dynamic conditions, habitable substrate for invertebrates, refuge areas for wildlife, nest or incubation sites, food for primary consumers and higher trophic levels, synergistic benefits of multiple habitat types (e.g. corridors), and intrinsic value (Lubke and Avis, 1998; Arens et al., 2001; Peterson and Lipcius, 2003; Everard et al., 2010; NRC, 2014). The full expression of many of these functions and services is restricted in developed areas because of spatial constraints or emphasis on active recreational uses and the perceived need for buildings and infrastructure to facilitate these uses (Nordstrom et al., 2011). The value of dunes for shore protection (providing sediment and a physical barrier or resistant vegetation to address wave runup and erosion) is well known and often provides the basis for land use regulations. The natural values of dunes, in contrast, are generally under-appreciated in developed areas (Martinez et al., 2013).

The composition and number of species of vegetation on natural beaches and dunes are related to gradients of salt spray, wind stress, aeolian transport and wave inundation that differ with distance from the water and topographic sheltering (Doing 1985; Moreno-Casasola, 1986; Barbour, 1990; Ehrenfeld, 1990; Wilson and Sykes, 1999; Lortie and Cushman, 2007). Only a few species that tolerate the stresses of sand mobility and salt spray near the beach occupy the upper backshore above normal wave attack. In New Jersey, these include sea rocket (*Cakile edentula*), Russian thistle *Salsola kali*, seaside spurge (*Chamaesyce polygonifolia*), and the endangered seabeach amaranth (*Amaranthus pumilus*) and seaside knotweed (*Polygonum glaucum*)(Kelly, 2016; Wootton et al., 2016). Vegetation on the backshore contributes to formation of embryo dunes, while grasses form foredune ridges in locations farther landward (Hesp, 1989; Seabloom and Wiedemann, 1994). American beachgrass (*Ammophila breviligulata*) is the dominant dune builder in New Jersey. Seaside goldenrod (*Solidago sempervirens*) occupies a more landward portion of the foredune zone. Farther landward within the dune (here called the backdune), increased protection from physical stresses favors woody shrubs, with trees and upland species in the most landward portions. The transition from pioneer beach plants to fully mature forests on natural dunes can extend over gradients of hundreds to thousands of meters (McLachlan, 1990). The few extensive backdune environments in New Jersey are in natural parks and refuges. These locations can have multiple ridges with dry swales or wetland swales close to the ground water and blowouts created following dieback or grazing of vegetation. Bayberry (*Myrica pensylvanica*), beach heather (*Hudsonia tomentosa*), beach plum (*Prunus maritima*), poison ivy (*Toxicodendron radicans*) and Virginia creeper

(*Parthenocissus quinquefolia*) are common species. Differences in height and morphology and local zones of accretion and scour in natural dunes contribute to variety of microhabitats, leading to considerable variety of insects, birds, mammals and reptiles. The gradient of processes and habitats found across the beach, foredune and backdune in nature is often managed in developed areas as three distinct shore-parallel zones.

The encroachment of human facilities can severely restrict the space available for natural landforms and vegetation, and environmental gradients can be truncated, fragmented or compressed (Nordstrom, 2008). Regulations in New Jersey and many other jurisdictions now limit construction of permanent facilities on the backshore and confine human uses to day-use recreation, although pedestrian trampling, vehicle driving and mechanical raking can reduce or eliminate beach vegetation cover and wrack (Kelly, 2016; Wootton et al., 2016). Human uses in foredunes are more severely regulated because of the acknowledged value of foredunes for shore protection. Sand fences and vegetation plantings are authorized and are used to stabilize the foredunes, but their width is often greatly restricted by buildings and infrastructure landward and their height is restricted as a result of resident demands to keep top elevations low to allow for views of the sea from their properties. The foredunes are often kept in the same location and maintained in a consistent shape by installing sand fences, planting stabilizing vegetation and shaping with bulldozers (Jackson and Nordstrom, 2011).

Backdune environments on developed shores, can fare worse than backshores and foredunes because they are often completely eliminated to facilitate construction of houses and infrastructure, and the land not devoted to structures is maintained according to suburban conceptions of landscape taste, using lawn grass and ornamental exotics or crushed gravel that is kept unvegetated (Mitteager et al., 2006). The free interplay of natural processes that has value for maintaining natural diversity is restricted by stabilizing the foredunes, and the natural vegetation that could take advantage of the reduced mobility is replaced by exotics. Removal of houses provides space for natural cycles of beach and dune change to occur, space to accommodate landward migration of the active beach and foredune and space for characteristic backdune habitats to form. The amount of space required to maintain coastal habitats in the future will have to be wider across the shore-land transition than single lots (Burger et al., 2017), but we feel that acceptance of change to a more natural system will not be immediate and will depend in large part on precedents established for the first row of developed lots.

2. Study sites and storm effects

The shorefront lots in New Jersey where the greatest numbers of damaged houses were removed per unit length of shoreline were in a 9.0 km length of shoreline between the northern portion of Bay Head and Chadwick Beach in Ocean County (Fig. 1). This portion of the shore consists mostly of single-family residences that occupy a strip of land between a narrow beach and artificially maintained protective dune on the seaward side and a paved shorefront road on the landward side. Access to the beach is restricted to designated public walkways at the seaward end of shore-perpendicular roads and other municipally-designated walkovers created between some of the private lots. The dunes seaward of houses may occur on private property, but actions on this seaward portion of the dune are often regulated by municipal ordinances and actions that include use of sand-trapping fences and vegetation plantings for shore protection.

Hurricane Sandy was a classic late-season hurricane in the southwestern Caribbean Sea that grew in area but weakened in intensity as it took an unusual path northward. It made landfall as a post-tropical cyclone in New Jersey, but its large size resulted in an extremely high storm surge; minimum central pressure in New Jersey was estimated at 945 mb (Blake et al., 2013). Winds were not especially strong for a storm that caused such conspicuous damage, with a peak gust of 40.7 m s^{-1}; the defining characteristic was the high surge level, which was 1.31 m above the previous century level (Decker and Robinson, 2016). Water level at the nearest tide gage was 2.61 m above normal tide level when the station failed and stopped reporting (Blake, et al., 2013). Landfall coincided with a high spring tide. Physical damage was extensive, with house destruction extending up to 5 lots landward of the beach. Whole communities were inundated by water and sand; houses were washed from foundations; and boardwalks were destroyed. Two new inlets were created through the barrier spit in Mantoloking (Blake et al., 2013).

Emphasis on reconstruction in New Jersey was on rebuilding user facilities in pre-storm locations (but more resistant to erosion), rather than reducing the human footprint and making the shore more naturally sustainable, although repair and rebuilding of homes was delayed by slow insurance payments and confusion over new regulations related to new flood insurance rate maps (Andrews, 2016; Holcomb, 2016). Artificial dune nourishment and bulldozing were used all along the 9 km-long segment to create a protective dune after the storm (Fig. 2). A seawall at Bay Head that pre-dated Hurricane Sandy (Irish et al., 2013) was extended 320 m farther alongshore after the storm, and a new 5.6 km-long bulkhead was built in Mantoloking and Brick Township. These three municipalities now have a hard structure buried under an artificial bulldozed dune to provide extra protection against wave erosion. A Federal beach nourishment project has been authorized for this segment of coast. The U.S. Army Corps of Engineers is preparing to award a contract and begin construction, with the work expected to begin in winter of 2017-18 (USACOE, 2016). Island Beach State Park (Fig. 1) is the closest location managed as a natural area. Dune characteristics at that location (here called the natural area) were measured to provide a comparison with developed lots. Sand fences and vegetation plantings are not used to repair breaches in the dune in the northern portion of the park. Blowouts are common there, and the dune is subject to considerable mobility through time.

3. Methods

The dimensions of lots and density of cover in vegetation or human structures within lots were identified by comparing Google Earth aerial images before the storm (September 2010), a month after the storm (3 November 2012) and 3 ½ years later (16 April 2016). Data represent the 60 lots remaining empty several years after the storm where owners had not rebuilt and therefore might be more amenable to allowing the lots to evolve naturally.

Cross-shore depths and alongshore lengths of the 60 lots and the widths of the dry beach fronting them were determined to the nearest meter from the 16 April 2016 images using the Google Earth measuring tool at the scale of 1:1000. Lot dimensions were differentiated on the landward side by roads and sidewalks, on the seaward side by the dune crest, and alongshore by fences or change in vegetation at the margin of neighboring lots. Private ownership often extends onto the beach, but beaches are maintained by the municipalities, not by private owners. Beach widths were measured from the wetted uprush limit to the dune crest in the lots and in the natural area. Distance from the foredune crest to dense vegetation was also measured in the natural area to determine how far landward vegetation typical of the backdune would be expected if natural processes were allowed to occur unfettered by human action.

Estimates of vegetation cover and dense vegetation cover in the dune environment were made for each of the 60 lots on the 2010 pre-storm and 2016 post-storm images. These values represent percentage of lot area to the nearest 5%. Total cover included grasses, shrubs and trees. Dense cover is the percentage of lot with shrub thicket and trees; these values are not mutually exclusive of total vegetation cover. The percent cover occupied by houses and other structures (all termed structures) in 2010 was measured to the nearest 5%. The percentage in structures is mutually exclusive of vegetation cover. The percentages of cover that are not total vegetation cover or structures are considered bare ground capable of being vegetated. The aerial data were restricted to times when images were available, which was from late September through April. The growing season for annual beach plants is June through early September, so most of the annual beach and dune plant species are not visible. The data thus reflect perennial vegetation cover rather than total cover and underestimate total vegetation cover during the growing season. Annual plants are the first to colonize after storm damage and typically take a minimum of 4-6 years to be replaced by perennial species (Kelly 2014, Dugan and Hubbard 2010, Godfrey and Godfrey 1981). Since these are sparse plant communities compared to the perennial dune and woody vegetation that formerly occupied the sites, the general trends described are believed representative overall. The perennial species are what is growing during the critical storm season.

Empty private lots were visited on the ground in October 2016, four years after the storm. Estimates of the economic value of empty lots offered for sale were gathered from www.zillow.com in February 2017 and used to evaluate the feasibility of buying properties for conservation or public use. The largest listed lots were selected because they had the greatest restoration potential.

4. Results

Fewer than 20 shorefront lots were vacant in the 9 km-long segment prior to Hurricane Sandy; 339 lots in that segment had houses. Houses were completely removed from 79 of the lots because of storm damage. Sixty lots that formerly had houses remained empty as of April 2016. Summary data on these lots in 2016 (Table 1) indicate that the cross-shore depths of lots was nearly three times the widths of beaches fronting them. The narrowest beaches (0 m) were at the newly-constructed bulkhead. The greatest alongshore extent of any lot was 44 m (Table 1), but the greatest alongshore extent of contiguous empty lots was 243 m along 9 lots.

Beach widths in the natural area were unconstrained by human attempts to retain a fixed position by structures or dune-building programs and varied from 41-73 m with a mean of 56 m. The distance from the dune crest to the seaward-most beginning of the shrub zone in the natural area varied from 36 m to 70 m, with a mean of 57 m. The combined width of beach and depth of empty lots averaged 89.6 m, which is less than the average distance to shrubs under natural conditions. The implication is that the first row of many properties would be too close to the water to provide the dense vegetation found in the backdune zone if left to evolve naturally.

Site visits in October 2016 revealed that large cultural debris was removed from all empty lots. Fig. 2 is typical of the appearance of empty lots four years after the storm. Wooden-slat sand fences (Fig. 2) were the most conspicuous cultural features. Fences were used to control aeolian transport, build foredunes and demarcate property boundaries. Evidence of stewardship of the municipally-managed seaward foredune was occasionally seen in new vegetation plantings (Fig. 2), but the privately-managed portion of most lots showed no indication of active landscaping after clearance of debris. The most conspicuous native vegetation was American beach grass (*Ammophila breviligulata*), planted on the foredune, and isolated patches of seaside goldenrod (*Solidago sempervirens*), apparently occurring through natural colonization landward of the foredune (Fig. 2). The density of native vegetation was often in small patches at the margins of lots where the surface was not graded following removal of structures or where sand had accumulated against fences, creating incipient dune forms on an otherwise deflated surface (Fig. 2, left foreground).

Empty lots that had for sale signs showed no sign of actions to improve the environmental image. The three lots identified as available in Mantoloking were 21-30 m wide and listed at US$2.899-$3.799 million. The 21 m wide empty lot in Fig. 2 was listed at $3.375 million; the two neighboring lots with houses intact were $4.5 and $4.74 million.

Before Sandy, many lots were well vegetated landward and seaward of houses and within vegetated strips along boundaries between lots (Fig 3a), with much of the vegetation being woody shrubs (densely vegetated category in Table 1). Much of the pre-existing vegetation was disturbed by overwash or aeolian transport from the storm (Fig. 3b). By 2016, undeveloped lots were mostly devoid of woody shrubs (Table 1) or pre-existing topographic diversity (Fig. 3c). Some of the vegetation that survived the storm was removed mechanically along with the remnant structures to expedite clearance of debris. Decrease in vegetation cover through time on developed lots where houses were not removed or were rebuilt by 2016 (Fig. 3d) implies that little human attention was given to aid reestablishment of vegetation, whether the lots were occupied or not. The stabilization of foredunes seaward of lots restricted transport of sand inland from the beach to create new incipient dunes on the lots, and no attempts were made to reestablish topographic diversity using earth-moving equipment.

The lots that were large enough to accommodate houses but were vacant in the study area prior to Hurricane Sandy provide perspective on the potential for evolution of the new undeveloped enclaves between developed lots. The largest of these pre-existing undeveloped enclaves is at Bay Head (Enclave A Fig. 4). The vegetation in this enclave and on the undeveloped Enclave B, north of Enclave A, was not as dense prior to the storm as typically occurred on developed lots. The storm eliminated the dune and its vegetation in undeveloped and developed lots alike. Enclave A remained as an undeveloped backshore used for beach recreation, rather than being fenced and planted to encourage dune growth. This use prevented a vegetated dune from occurring where the pre-storm dune was. Enclave B, in contrast, was planted after the storm and had greater vegetation cover and topographic diversity by April 2016 (Fig. 4d). The extension of the seawall (Fig. 4d) isolated the former backshore and remnant dune from the active foreshore along this whole segment. Sediment was subsequently bulldozed on top of the seawall to create an artificial dune (Fig. 5).

The new bulkhead in Mantoloking was also covered by a bulldozed dune. Subsequent winter storms exposed the face of the bulkhead to a maximum depth of 7.25 m. Accretion subsequently occurred, but portions of the bulkhead are exposed periodically, creating a barrier between the beach and dunes (Fig. 6). Beach plant communities, embryo dunes, shore bird and sea turtle nesting sites are normally concentrated in the landward portion of the backshore (Kelly, 2016), but this space is restricted or eliminated by construction of walls seaward of the line of shorefront houses. The two new protective walls in the 9 km-long segment eliminated the potential for full evolution of the backshore on 47 of the 60 lots that remained undeveloped as of April 2016. Sediment bulldozed on top of the bulkhead and seawall creates an artificial dune, but winter storms periodically expose the walls and separate the beach from the dune. Natural evolution of the morphology of the dune landward of the walls may be precluded, but the shelter provided by the wall can facilitate establishment of backdune species that require some shelter from salt spray and wind stress.

5. Discussion

Natural coastal landforms are dynamic, and this dynamism contributes to the diversity of morphology and surface conditions and the coexistence of different stages of landscape evolution that provide landscape mosaics contributing to the sustainability of flora and fauna. In contrast, a flat, raked backshore, a linear well-vegetated dune, and a graded backdune planted with non-coastal species or kept free of vegetation is what many residents and municipal managers see. Storms offer the opportunity to reestablish some of the natural values lost in developed areas. The impossibility of returning to pristine nature should not deter efforts to regain elements of the natural environment. Compromise solutions must be found if residents and visitors will not give up traditional uses of the beach, if the foredune is primarily valued as a protection structure and if private property owners will not abandon the land they now occupy (Nordstrom, 2008).

We focus on the backdune environment in private ownership, where the rationale and guiding principles for managing dune resources are poorly developed relative to the publicly managed beach and dune (Mitteager et al., 2006; Nordstrom, 2008). The assessment of conditions four years after Hurricane Sandy indicates that return to a natural system is not going to occur, requiring a fresh approach to management on the part of private land owners. Topographic diversity, sand burial and landform mobility may be key to formation of backdune habitats and their variety under natural conditions, but at least species that are less dependent on mobile landforms need not be eliminated or prevented from occurring.

The reasons land remains vacant can be many and varied. Some owners could be waiting for the optimum price before selling their lots; potential buyers may be reluctant because of an unfavorable economic climate; some owners who wish to stay could be waiting for insurance payments to defray expenses; some owners could be waiting for implementation of the planned beach nourishment project before building structures. The reason the lots remain vacant is beyond the scope of this paper. Our interest is in whether the lots can be purchased for public use or, if not, how nature can be accommodated on them.

Home buyout programs are becoming popular as mitigation (Binder et al., 2015), but application of buyout programs is limited by reluctance of homeowners to relocate, reluctance of local governments to reduce their tax base, and expectation that public funds will prevent the market from discounting the value of properties at risk (Kousky, 2014). Changes in coastal governance would also be needed to ensure program success (Abel et al., 2011). We propose that demonstrating the natural value of coastal habitats can help retain species diversity in the short term while providing a basis for acceptance of natural vegetation that will facilitate decisions to convert to more dynamic natural landscapes in the future when occupation of the seaward row of buildings becomes less tenable.

Market and policy incentives for development and redevelopment in coastal communities with great tourism potential presently overwhelm attempts of planners to discourage development (Andrews, 2016; Holcomb, 2016). The high cost of lots may be more of a deterrent to purchase by public agencies and environmental organizations for conservation than to private developers, who can recoup their expenses in rebuilding and resale. The political need to direct most or all public funding directly to human constituents can also constrain actions to improve environment and wildlife benefits (Van Abs and O'Neil, 2016). No action has been taken by public agencies to purchase empty lots, and the lots are likely to be developed in the future because of their great economic value. If the area occupied by new buildings is similar to the area devoted to buildings prior to the storm (Table 1), just over ¾ of the area of lots could be devoted to natural vegetation. The task involves finding ways to underscore the value of adding natural vegetation to lots, whether houses are built on them or they remain vacant.

Shores unconstrained by structures can develop wider beach/dune gradients than portions of the developed shores adjacent to them. A wide beach provides greater protection against wave runup and a greater source area for delivery of sediment to the dune by winds (Keijsers et al., 2014; Davidson-Arnott et al., 2005). Beach plant communities, embryo dunes, shore bird and sea turtle nesting sites concentrated in the landward portion of the backshore (Kelly, 2016) would also be favored by a wide beach. Space is restricted or eliminated by protective walls. Construction of the new bulkhead as a post-storm response indicates that naturally-evolving lots were viewed as weak points in protection plans for the houses and infrastructure adjacent to them and landward of them.

Hard shore protection structures are likely to become increasingly important to reduce coastal risk in densely populated segments of coast (NRC, 2014), even in locations where beach nourishment is presently preferred (Pilkey and Cooper, 2014). Protection structures may prevent natural evolution of the undeveloped enclaves, but they need not preclude establishment of native species landward of them. Lack of vegetation cover by April 2016 reflects the initial storm changes to the soil conditions and the short time for natural succession to occur, especially given the lack of good seed sources in the highly developed area. These constraints to establishment of vegetation can be offset by human actions. Property owners can contribute to restoring habitat and ecosystem services in developed areas (Mitteager et al., 2006; Cerra, 2017), but regulations based on safety considerations or incentives based on aesthetic appeal, appreciation of natural heritage or economic benefits may be required to get owners to take action.

Vegetated enclaves in urban areas have aesthetic and therapeutic value (Ulrich, 1986; Nordh et al., 2009). Vegetated dunes provide a sense of nature that can be appreciated by residents (Feagin, 2013). Interventions through landscape management and enhancing people's knowledge and experiences can help establish desirable relationships between aesthetics and ecology and help achieve ecologically beneficial landscapes that are culturally sustainable (Gobster et al., 2007). Aesthetic appeal can provide a sense of nature, not degradation. The portion of coast most severely damaged by Hurricane Sandy lacked aesthetic appeal and vegetation diversity, four years after the storm.

A case can be made for the value of applying natural landscaping to shorefront properties to assure viability of species in the dune environment and reduce the high maintenance costs associated with exotic species that are not adapted to the stresses (Mitteager et al., 2006). This case can be made for properties where houses survived but ground cover was eliminated. Vegetation reduces net erosion on the dune, making its role in coastal defense an important ecosystem service (Silva et al., 2016). Vegetation also restricts the amount of sediment blown from the beach inland onto private properties, as do fences, seawalls and bulkheads. Actions to create a new foredune begin immediately after major storms, so there is little opportunity for wind-blown sand to re-create hummocky topography on empty lots farther landward. Where sediment input from the beach is not possible, planting must be devoted to the more stable backdune species.

Post-storm improvements are often piecemeal and the work of individuals, not the whole community (Andrews, 2016). Planting vegetation on the seaward portion of the foredune is a municipally-supported action that contributes to dune growth. Beaches and dunes on private lands are not accessible to the public, but restoration of ecosystem functions and services can be considered a common good worthy of public action. Linking market and human wellbeing outcomes to ecosystem protection and restoration offers hope for sustaining ecosystem benefits, although these options are relatively untested (Ruckelshaus et al., 2013). Achieving restoration goals on private lots may be enhanced by initiatives by local governments or environmental groups that do not require buyout of properties. These initiatives include extending municipal planting programs to private properties, educating residents and the professional landscapers they hire about the advantages of planting natural species, providing tax credits or permit exemptions for natural landscaping, or requiring use of native coastal species in municipal ordinances. Ordinances based on safety could highlight the value of the species in trapping and stabilizing sand, resisting erosion and being more tolerant of salt spray than exotics.

Planting suggestions, including species that should not be planted, are often available, even if they are not presently used (e.g. Mitteager et al., 2006; Wootton et al., 2016). The landward side of the foredune could be planted with coastal grasses, wildflowers and shrubs. *Ammophila breviligulata* is often used as the sole vegetation planted by coastal municipalities in New Jersey. This species helps promote establishment of other plants sown along with it, but it is unlikely to persist landward of the foredune. Accordingly, reliance on this species alone (as is often practiced) is not recommended (Wootton et al., 2016). Native species such as *Solidago sempervirens*, *Myrica pensylvanica*, *Prunus maritima* and *Panicum amarum* (coastal panic grass) could be retained outside the footprint of a new house constructed on the lot. Not all species that have natural value are likely to be well received. *Toxicodendron radicans* produces berries eaten by a variety of birds, provides good nesting and hiding places for animals, and is a good stabilizer (Wootton et al., 2016), but it can create rashes on people. *Parthenocissus quinquefolia* occupies a similar niche and can be substituted for *T. radicans*. Dune wetlands, may not be well received, especially because they are perceived as breeding ground for insects. Trees have a positive effect on preference (Ulrich, 1986), so the native red cedar (*Juniperus virginiana*) and American holly (*Ilex opaca*) could be used to contribute to diversity and aesthetic appeal.

Aesthetically pleasing native species have many advantages over lawn grass and other non-coastal vegetation or gravel as ground cover. Obtaining greater familiarity with natural landforms and habitats may facilitate acceptance of plans for adapting to sea level rise that are more compatible with natural processes when shorefront properties are damaged by future storms.

6. Conclusions

Storm damages provide an incentive for homeowners to leave the coast, but economic and institutional constraints can prevent this from occurring. Our investigation of effects of Hurricane Sandy indicate that storm damage and post-storm clearance operations both contribute to loss of topographic and vegetation diversity. Revegetation of storm damaged lots appears slow, but can be aided by human efforts. Municipally-managed foredunes are often planted, but private owners appear to take little action to revegetate their properties landward of that zone. Programs to encourage native vegetation plantings on private lands offer a relatively inexpensive means to restore some of the natural values lost in the development process. Undeveloped lots can be perceived as weak points on a developed coast and lead to extension of protection structures alongshore, preventing natural evolution of the beach and dune as linked geomorphic features. Loss of this linkage need not prevent native vegetation typical of backdune species in stable environments to be established on private lots landward of protection structures. Revegetating lots can offer an image of nature that can favor acceptance of managed retreat in the future when occupation of the shorefront becomes less tenable.

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Table 1. Summary statistics for the 60 lots where houses were removed and not rebuilt by 2016.

	mean	Min.	Max.
Post-storm (2016)			
Beach width (m)	23.4	0	54
Lot depth across shore (m)	66.3	31	102
Lot length alongshore (m)	23.4	12	44
Vegetated area (%)	17.7	0	60
Densely vegetated area (%)	8.1	0	45
Pre-storm (2010)			
Vegetated area (%)	49.8	10	80
Densely vegetated area (%)	34.8	0	80
Structures (%)	24.3	15	45

List of figures

Fig. 1. Study sites on the ocean coast of New Jersey.

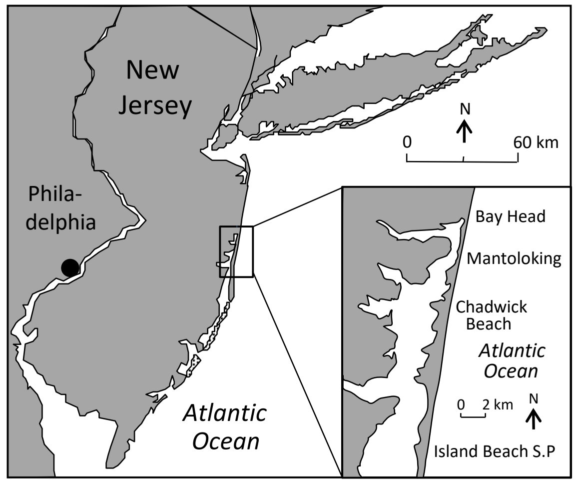
Fig. 2. Bay Head, NJ in October 2016 (looking southeast), showing a lot left empty after destruction of the house during the storm (foreground) and a house to the right that survived the storm. Both lots were for sale October 2016. The bare sand between the two lots is a municipal access path. The vegetated dune ridge to the left rear was built by bulldozing sand over a seawall.

Fig. 3. Mantoloking before and after Hurricane Sandy. Sources: Google Earth images.

Fig. 4. Bay Head before and after Hurricane Sandy. Sources: Google Earth images September 2010, November 2012 and April 2016.

Fig. 5. Undeveloped enclave at Bay Head (Enclave A, Fig 4) on 5 October 2016. The bulldozed and planted dune in the center of the photo covers a new seawall.

Fig. 6. Exposed portion of steel bulkhead in October 2016, looking south. The narrow beach provides little protection against wave attack from small storms creating a scarp that persists to interfere with transfers of sediment and fauna between beach and dune.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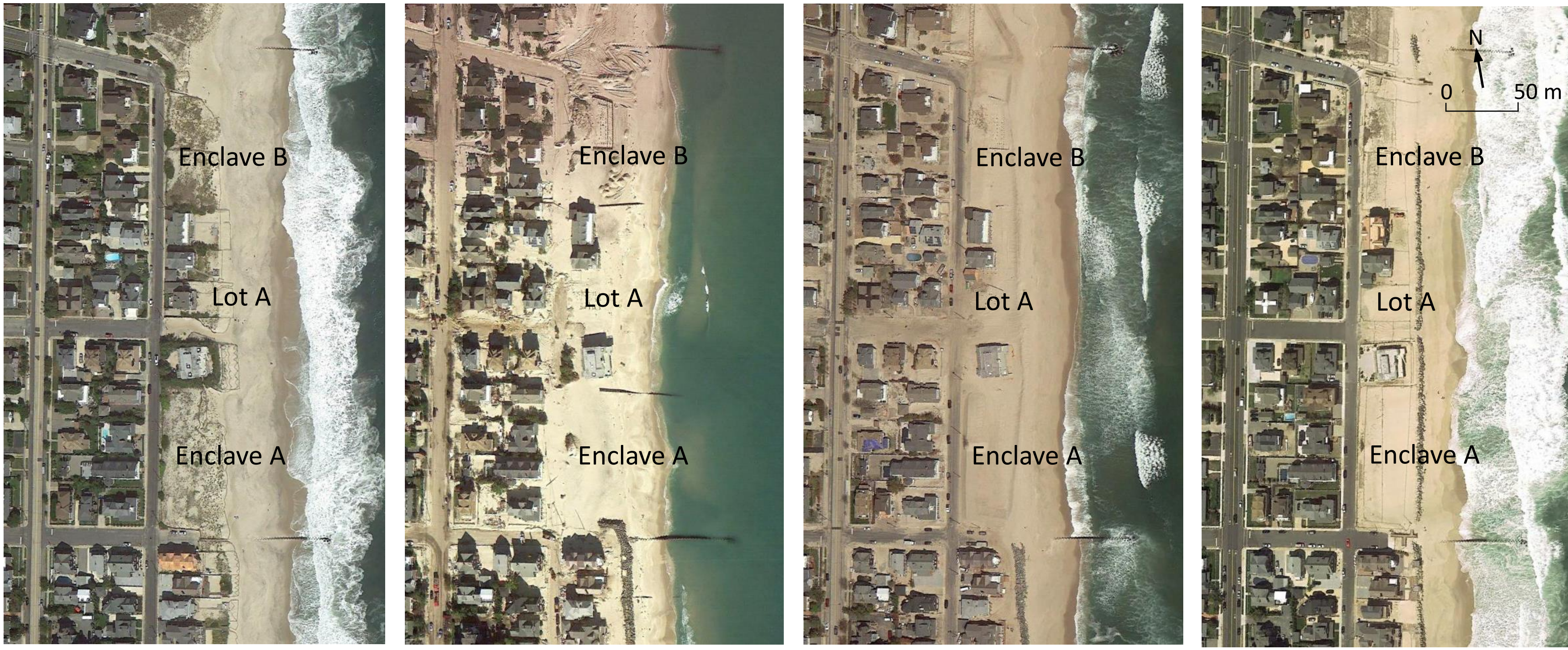
a. 20 September 2010 b. 3 November 2012 c. 25 April 2013 d. 16 April 2016



a. 20 September 2010 b. 3 November 2012 c. 25 April 2013 d. 16 April 2016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