First-Year Research in Earth Sciences: Dunes

Evaluating Sand Fence Placement, Purpose, and Efficacy on West Michigan Dunes

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Abstract

Adding sand fences to a dune can significantly impact morphology, ecology, and human interactions with the landscape. Although the effects (intended and unintended) of sand fences have been documented on ocean coasts, no such study has focused on the Great Lakes region. In autumn 2015, we visited four Ottawa County Parks along Lake Michigan's coast to map the locations of fences and unmanaged trails. We photographed each site to capture fence settings and conditions. We estimated porosity and recorded damage intensity and type for each fence. We categorized the amount of deposition near each fence using a ranking system. Our results show that fence locations affect human accessibility and sand deposition. Unmanaged trails often appeared to be a byproduct of fence placement. The greatest deposition on average was observed at the least vegetated site closest to the shore. Most fences were damaged, lowering their ability to deter human traffic or trap sand. Our study results add to the body of knowledge on sand fence location, orientation, and condition, providing information that can aid management practices to promote a healthy dune environment.

Introduction

Sand fences are human-made structures that are placed on a dune landscape primarily with the intent to alter or control dune morphology (Grafals-Soto and Nordstrom 2009). While sand fences often effectively perform this task, they may have additional unanticipated effects on the dune landscape. Documentation of fence placement and condition can be a part of monitoring their effect on dunes. Multi-site studies of sand fences have been conducted in other settings in the past, but no such study has focused specifically on dunes in west Michigan. The objectives of this study were as follows:

a) Document and map sand fences on dunes in four coastal parks
b) Compare characteristics of sand fences at each site
c) Determine the intended and unintended effects of the sand fences on the surrounding dune environment.

Background

Purpose of Sand Fences

The placement and purpose of sand fences reflect different means of altering dunes. A primary function of a sand fence is to stop sand from moving (Zaghloul 1997; Lee *et al.* 2002; Alghamdi and Al-Kahtani 2005; Khalil 2008). Still others may control traffic, protect vegetation, or do a combination of different tasks (Mascarenhas 2008; Grafals-Soto and Nordstrom 2009; Grafals-Soto 2012). Main purposes for installing fences include the creation of wider dunes for shore protection, the need to keep people off dunes, and preventing inundation of infrastructure (Grafals-Soto and Nordstrom 2009).

Sand Fence Efficacy

Fences have varying levels of effectiveness in achieving the original intent of their placement, and different factors contribute to their success, including porosity, height, and placement (Miller *et al.* 2001; Dong *et al.* 2006; Khalil 2008; Grafals-Soto and Nordstrom 2009; Tsukahara *et al.* 2012; Lv *et al.* 2013; Quan *et al.* 2014; Li and Sherman 2015). Studies have also examined the efficacy of fences at achieving their intended outcomes both in reducing sandblasting and in preventing erosion (Dong *et al.* 2006; Li and Sherman 2015). Fences with porosities of 0.3-0.6 are most effective at sheltering vegetation, confirming the findings of a previous study on the ideal porosity for a sand fence to prevent erosion (Dong *et al.* 2006). The study of sand fence efficacy is important as they are altering the natural environment in ways both expected and unexpected (DeJong *et al.* 2014), and fences often are placed near residential or commercial areas of significance that interact with, or risk interaction with the natural coastal landscape (Grafals-Soto and Nordstrom 2009).

Fences also affect dune vegetation (Grafals-Soto 2012). Research suggests that vegetation responds to topographic variables most likely affected by the sand fences (Grafals-Soto 2012). Such variables include the degree of sheltering provided by the fence (Grafals-Soto 2012). Recent research has also indicated that fences can somewhat mimic the function of vegetation and wrack when placed at the foredune slope and at the seaward toe of the dune respectively, enhancing deposition and reducing scour (Jackson and Nordstrom 2013). When placed on the foredune slope, however, fences can limit the delivery of sediment farther inland (Jackson and Nordstrom 2013).

Multi-site studies of sand fence placement are quite limited, with little research of this type having been done on Great Lakes dunes. A 2009 study by Grafals-Soto and Nordstrom examined the heavily modified dune landscape on the New Jersey shore in order to determine the intended and unintended effects of fences on the landscape character. The study compared a video record from 2002 with field reconnaissance in 2008, including interviews with municipal managers and site visits, in order to determine changes over time in the landscape and fences on the shore (Grafals-Soto and Nordstrom 2009).

Management Techniques

Studies have found that some fence management techniques work better than others (Grafals-Soto 2012). Multiple fence rows will form foredunes more effectively than single-row fences (Hotta *et al.* 1991), while fewer fence rows placed further apart will represent a more natural topographical variation (Grafals-Soto 2012). Shore-perpendicular orientations are less compatible with natural processes than are shore-parallel orientations (Grafals-Soto and Nordstrom 2009). Fence placement also plays a role. While fences are often placed at the dune toe, they can create a higher dune if placed on the foreslope of an existing dune, that is, landward of the dune toe (Grafals-Soto and Nordstrom 2009).

The pattern of an individual sand fence may also contribute to or detract from its efficacy (Hotta *et al.* 1991; Grafals-Soto and Nordstrom 2009). Straight fences require less fence material per shoreline length, are more quickly built by fewer people, are easier to repair, and allow for easier removal of the deposition that accumulates next to them (Grafals-Soto and Nordstrom 2009). Zigzag fences are preferred for trapping sand coming from different directions (Grafals-Soto and Nordstrom 2009). Fence height is an indicator of the barrier potential of the fence (Grafals-Soto 2012), with higher fences presenting greater barriers to wind. After installation, sand fences may remain in place until completely buried by sand. This allows the rate of deposition to decrease at a more natural rate than would removal of the fence (Grafals-Soto 2012).

Study Areas

Our study focused on four parks in Ottawa County on the eastern coast of Lake Michigan (Figure 1). We chose an area within each park and mapped all of the fences in that area.

The *North Beach dune* site is located in North Beach Park and the southwest corner of North Ottawa Dunes in Ferrysburg, MI. North Beach Park is 0.03 km^2 (7 acres) in total area, with 227 meters (745 feet) of shoreline (OCPRC 2016c). North Ottawa Dunes is an adjacent park with wooded dunes accessible by hiking trails; it also contains the large parabolic dune known as the North Beach dune which overlooks North Beach Park, but is separated from the beach by a road and parking lot. Our study focused on the beach and large parabolic dune.

Kirk Park is located in West Olive, MI. Its landscape includes over 500 meters (0.3 miles) of coastline, as well as 0.275 km^2 (68 acres) of beach, bluffs, and dunes (OCPRC 2016b). The park also features trails and stairways through wooded dunes.

Mt. Pisgah is a part of the Historic Ottawa Beach Parks, a collection of 12 parks located in Holland, MI (OCPRC 2016a). It is a large parabolic dune that features a wooden stairway to the top of the dune. The stairway provides access to viewing platforms and connections to Holland State Park trails.

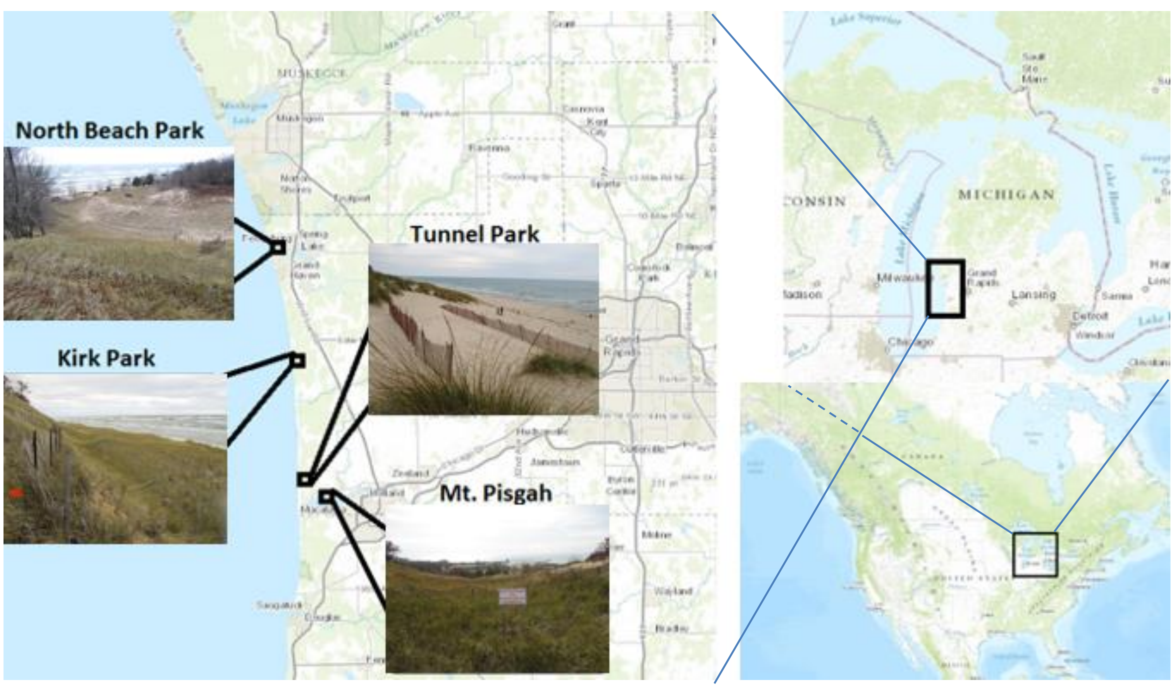

Figure 1: Study area locations in Michigan, USA.

Tunnel Park is located in Holland, MI, and is 0.09 km^2 (22 acres) in total area (OCPRC 2016d). It features a tunnel through a dune, a playground, and dune stairway. The park also includes beach volleyball courts and beach shelters.

Methods

Data was collected in October and November 2015. Upon arrival at each park, we decided on an area within which we could reasonably document all the fences during our allotted time. Each team member recorded one or more specific aspects about each fence. For North Beach Dune, our data set was supplemented by additional fence location data that had been previously collected. Wind speed and direction, as well as temperature, were recorded at each site.

We assessed characteristics of wooden slat sand fences and their surrounding environment at each study site. Each observed fence was assigned a number and was marked with a flag (Figure 2). Documentation included mapping the fences, measuring fence height to calculate amount of deposition (Figure 3), measuring slope angle, estimating porosity, categorizing fence damage and deposition, qualitatively documenting surroundings and fence condition, and photo-documenting the fences and their settings (Table 1).

A Trimble Juno GPS unit was used to collect line data for each fence and point data for areas with significant damage. Line data was also collected for unmanaged trails. Additional points of interest (the edge of a boardwalk, for example) were also collected.

Figure 2: A numbered flag was placed near each fence in order to ensure consistency.

Figure 3: A team member uses a meter stick to measure the height of a fence above the sand.

Variable	Procedure	Purpose of Measurement
Location	Mapped with GPS Took photos	Document presence and spatial patterns Capture general surroundings, significant damage, and deposition
Setting	Observed vegetation and setting Mapped nearby unmanaged trails	Assess impact of location Evaluate traffic control effectiveness
Orientation	Analyzed with GIS software Measured slope angle	Assess arrangement Assess impact of slope
Purpose	Estimated fence purpose	Identify motivations for installment
Deposition	Ranked deposition amount Measured fence height	Evaluate deposition near the fences Document patterns of deposition
Damage	Estimated porosity Ranked damage amount	Assess sand-trapping capability Evaluate efficiency in erosion prevention
Slope Angle	Measured with clinometer	Evaluate slope angle across sites
Material	Recorded material of each fence	Assess choice of fence material across sites

Table 1: Methods used to examine fence characteristics.

Custom ranking scales were developed to estimate deposition and damage to fences. Fence damage was assessed on a scale of 0-5, where 0 is no damage, 1 is little damage, 2-3 is moderate damage, and 4-5 is significant damage. Deposition near fences was categorized on a scale of 0 to 5, with 0 indicating no deposition and 5 indicating substantial deposition. Rankings were performed at each site by the same team member for consistency.

Post-processing of the GPS data included uploading it to ArcGIS in order to visualize spatial relationships. Maps allowed for observation of the relationships between fences, unmanaged trails, and points of interest, such as damage. Additionally, ArcGIS was used to record and categorize the orientation of each fence and to measure the lengths of the fences.

Results

Overall Patterns

We documented 32 fences in total across the four sites (Figure 4) and included GPS data only of 14 additional fences at the North Beach dune. The longest fence was 116 meters and the shortest was 0.6 meters, both at the North Beach dune.

The number of fences varied from park to park. We recorded the most fences at the North Beach dune and the fewest fences at Tunnel Park.

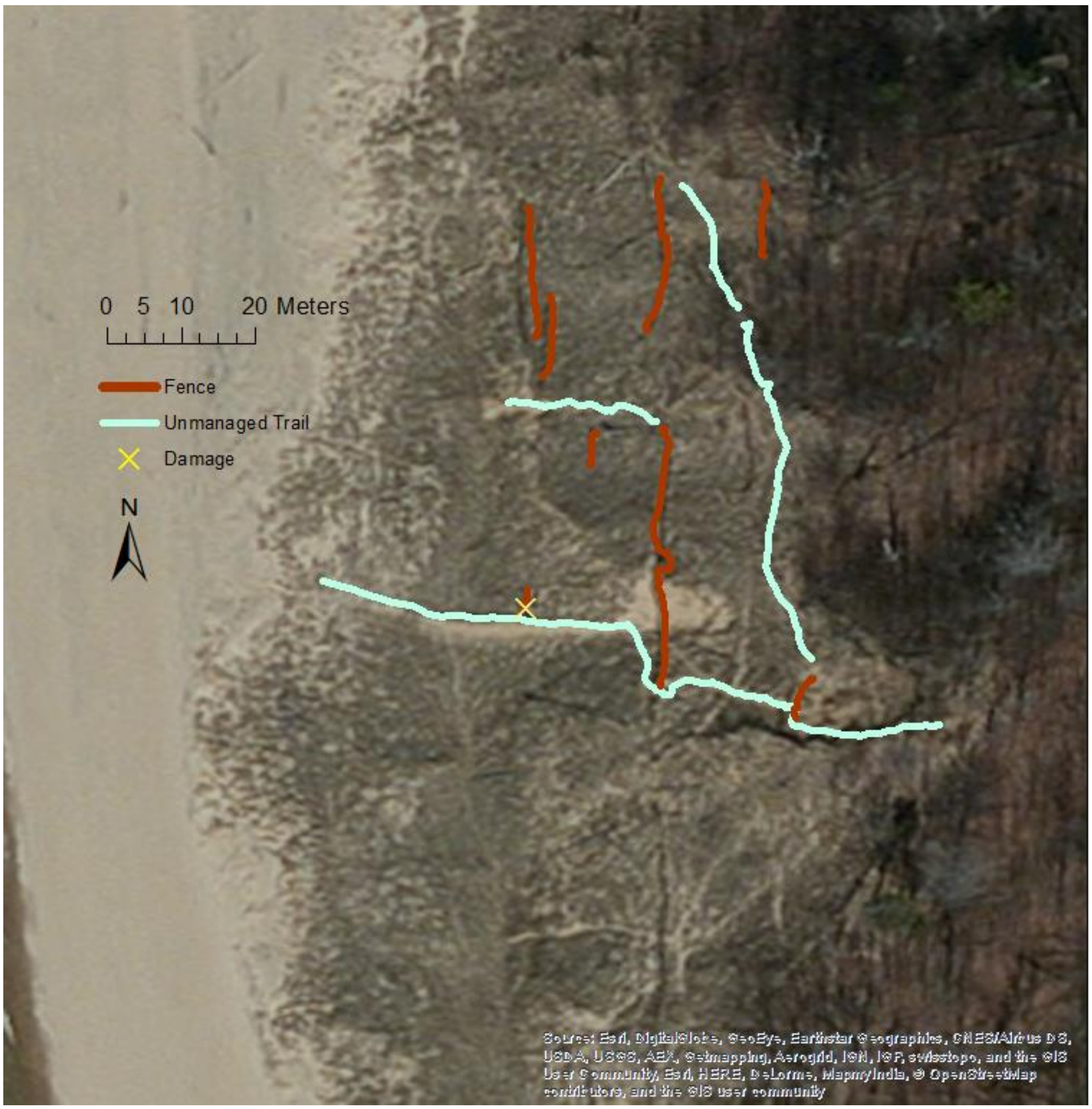

Figure 4a: Fences, unmanaged trails, and damage at Kirk Park.

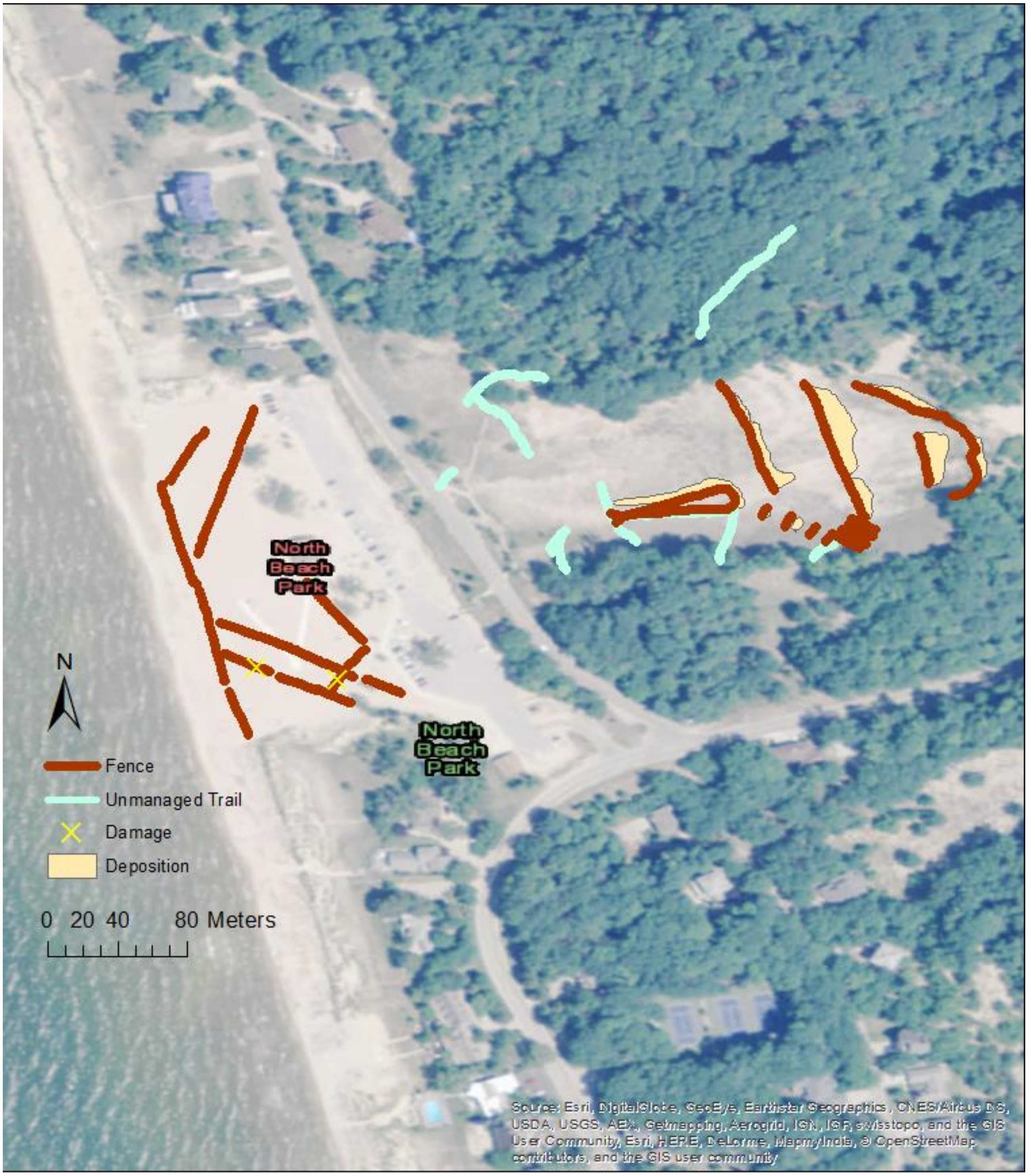

Figure 4b: Fences, unmanaged trails, damage, and deposition at the North Beach dune.

Figure 4c: Fences, unmanaged trails, damage, and boardwalk platform at Mt. Pisgah.

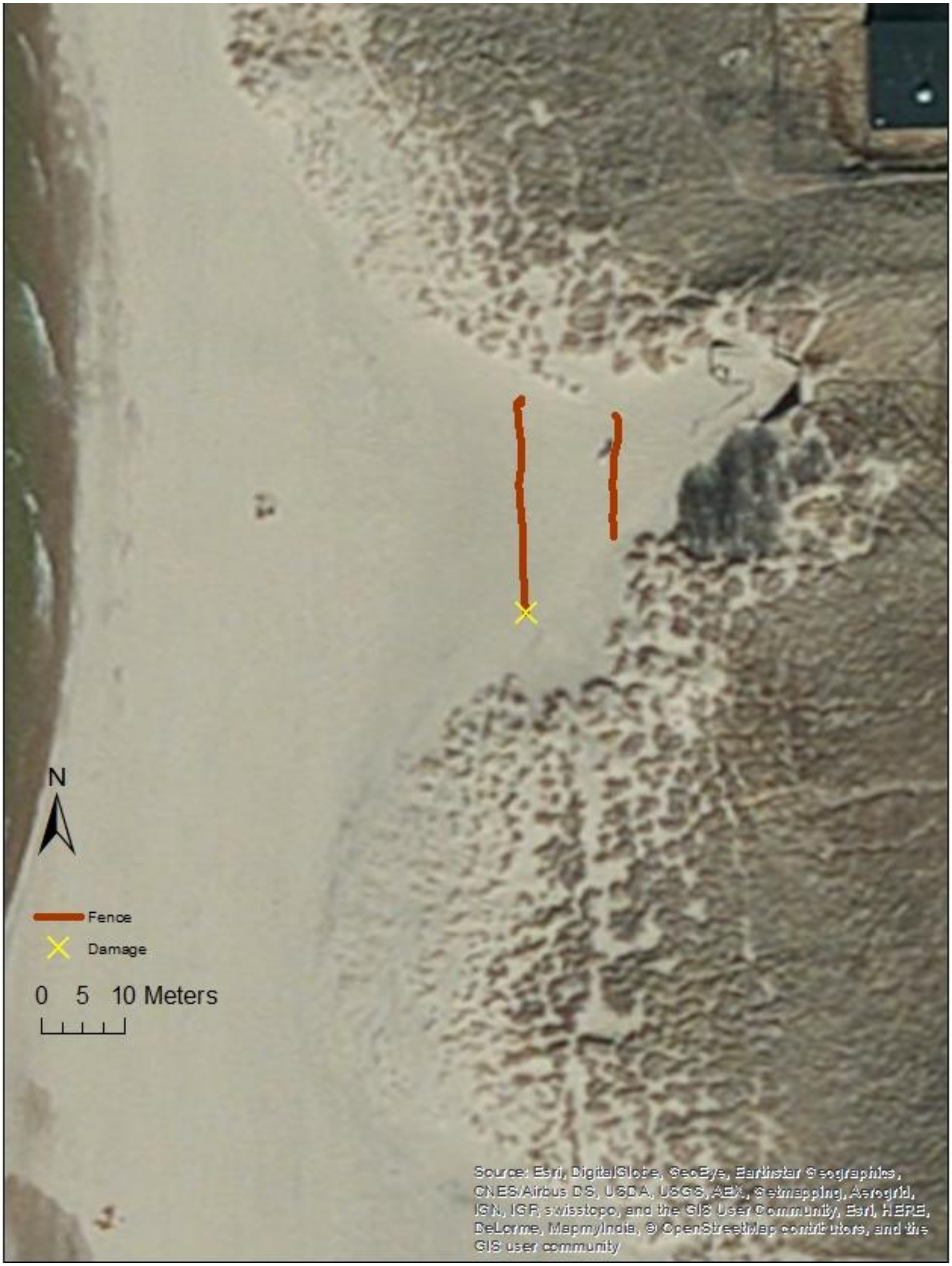

Figure 4d: Fences and damage at Tunnel Park.

Fence Locations

All of the fences were either on the beach or on the windward side of a dune. At the North Beach dune, the team documented fences in two settings: on the beach and on the windward slope of a large parabolic dune. The beach was bare of vegetation but there was some debris present. The fences on the beach appeared to be seasonal, i.e., installed in the fall and removed in the spring. Inland from the beach and across a parking lot was the large parabolic dune. A boardwalk created a loop that went up both arms of the dune and along the crest. Signs asked that people stay off the dune.

Tunnel Park held an equal measure of vegetation and sand. The beach was large, and a tunnel went through the middle of the dune. There were no unmanaged trails. Two fences, thought to be placed seasonally, were observed near the entrance to Tunnel Park.

At Kirk Park, the setting was mostly vegetated and close to the shore, with signs surrounding the area telling people to keep off the dune. The majority of Kirk Park's foredune was vegetated and 5 to 7 meters away from the shoreline. The majority of the fences we observed were surrounded by vegetation. The dune's elevation was high and contained boardwalks near the crest of the dune. Litter and unmanaged trails were visible on the dune.

Mt. Pisgah was very high in elevation, providing stairs and boardwalks to walk on. There was a large blowout at the top of the dune and trees surrounded the leeward side of the dune where a boardwalk provided access to the crest. Mt. Pisgah was separated from the beach by houses and roads in a small neighborhood. All of the fences we documented were located within or along the edge of the blowout.

Unmanaged Trails

We observed 16 unmanaged trails in total. The majority were located at the North Beach dune, where we observed 10 unmanaged trails. At all sites, the unmanaged trails were often present around the edge of a row of fences or along the length of a fence. Some unmanaged trails went through damage in fences.

At Kirk Park, a long unmanaged trail went around the southern edge of a row of fences. At Mt. Pisgah, one unmanaged trail extended from the boardwalk platform and through a break in a fence. Traffic also appeared to have caused some damage going through another intact fence. Another unmanaged trail was located just west of the edges of two fences. At the North

Beach dune, more unmanaged trails were observed around the edges and at the base of the blowout than within the blowout itself. No unmanaged trails were observed at Tunnel Park.

Orientation and Purpose

Fence orientation could fit into one of five categories: parallel to the shore, 45-degree angle to shore (either SW to NE or NW to SE), perpendicular to the shore, or assuming the shape of the blowout. Of all fences observed, more meters of fence were oriented parallel to the shore than in any other direction (Figure 5).

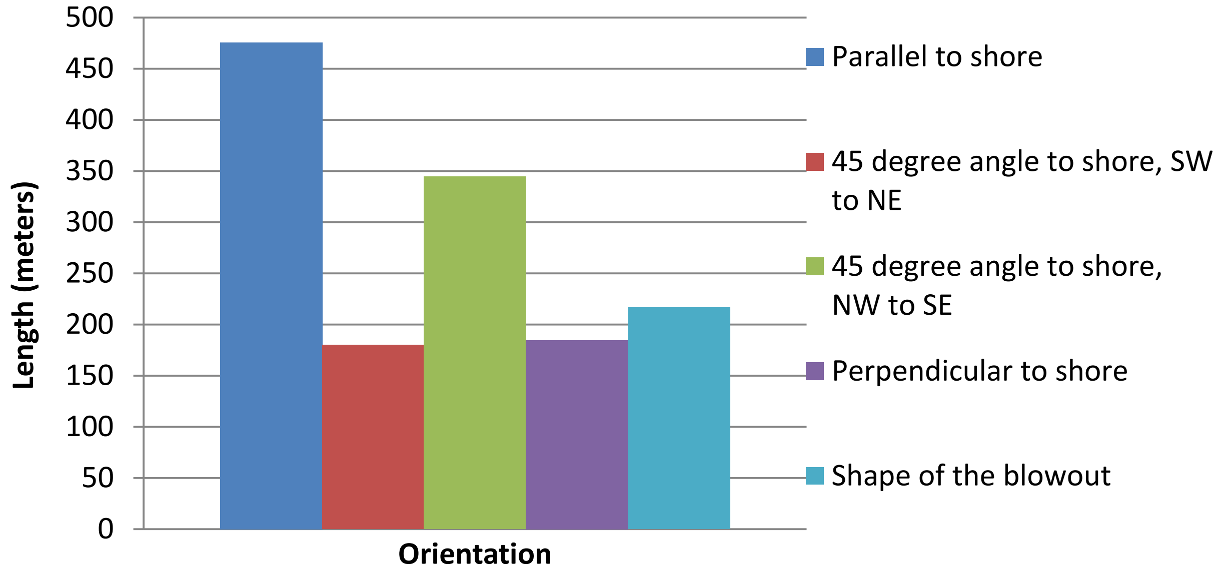

Figure 5: Length of fences observed for each orientation to the shore.

We estimated 3 purposes for installing fences: to slow sand, to control access, and to protect vegetation. Of the three, slowing sand was the most common (Table 2). At Mt. Pisgah, signs indicated that managers were attempting to restore the deflation area on the dune, and the majority of fences were estimated to be put in place to control access (in addition to other purposes). This purpose was estimated for 8 out of 10 fences at Mt. Pisgah. Signage instructing people to stay off the dune was also observed at Kirk Park and the North Beach dune.

Purpose	Frequency
Slow Sand	32
Protect Vegetation	17
Control Access	16

Table 2: Frequency of purposes for installing fences.

Deposition

Most of the fences had some amount of deposition near them. Measured at the point of highest deposition, the majority of fences had a height between 20 and 40 cm above the sand (Figure 6). Newly installed fences have heights of approximately 60 cm. The average deposition ranking observed across the sites was 2.55 out of 5.

The greatest deposition on average was observed at the least vegetated site close to the shore in North Beach Park (Figure 7). At that site, a comparison of the sand deposition caused by the fences on the beach found considerable deposition near the shore, close to the fences thought to be more recently installed. These fences had an average deposition ranking of 3.5 out of 5. However, on the windward side of the dune, east of the parking lot, the fences appeared older and more damaged. The lowest average deposition ranking was observed at Mt. Pisgah, at 1.9 out of 5.

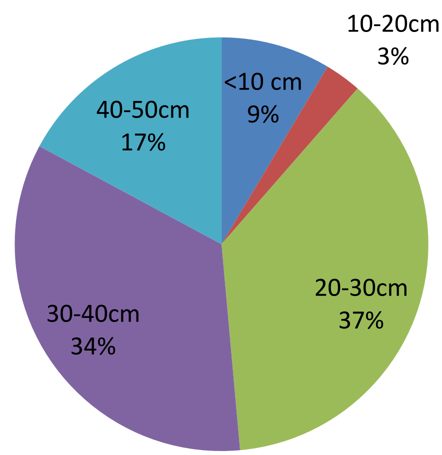

Figure 6: Distribution of fence heights above sand at point of greatest deposition.

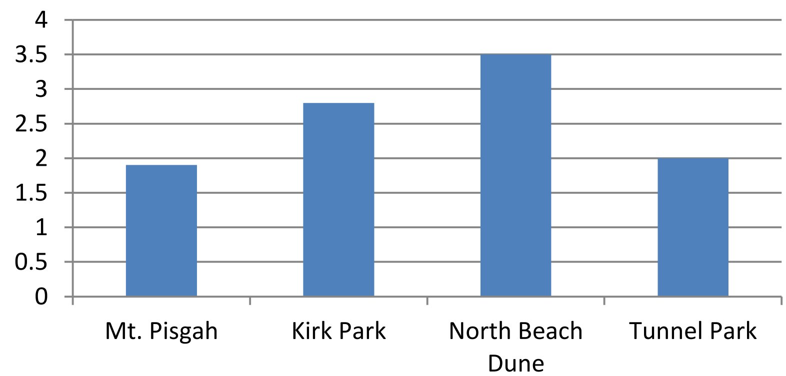

Figure 7: Average amount of deposition at each site (ranked on a scale of 1 to 5).

Porosity

The porosity documented for the newest fences was 50%. The most frequent fence porosity observed was 60% (Figure 8), slightly more than that of a brand new fence. The most frequent reason for an increase in fence porosity appeared to be damage.

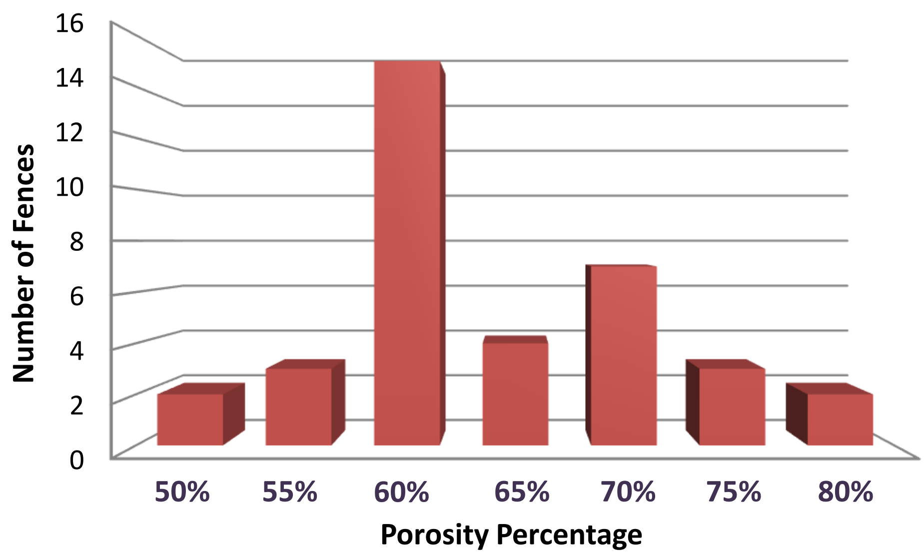

Figure 8: Estimates of sand fence porosity across all parks.

Damage

Most of the fences we observed were damaged in some way (Table 3). The most common causes were human traffic and weather conditions. The most common level of damage was "Moderate", with 41% of fences observed demonstrating a level of damage ranked between 2 and 3 on a scale of 1 to 5 (Figure 9). The highest level of damage was observed at Kirk Park, with an average of 3.2 out of 5. The lowest level of damage was observed at the North Beach dune, with an average of 1 out of 5.

Types of Damage	Probable Causes
Slats broken or snapped	Human traffic, weathering
General weathering	Weathering, vegetation growth, sand erosion
Slats missing	Human traffic, weathering, falling trees/branches
Slats fallen over	Human traffic, weathering, sand erosion
Slats detached from wire	Human traffic, weathering, sand erosion
Fence completely detached from poles	Human traffic, weathering

Table 3: Types of fence damage and probable causes.

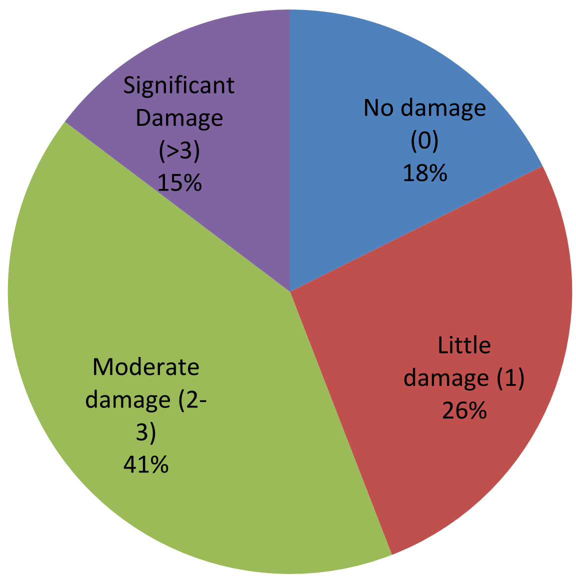

Figure 9: Amount of damage to each fence (ranked on a scale of 1 to 5).

Discussion

Efficacy

The sand fences appear to have mixed efficacy at keeping people off dunes. Signs at the sites suggest that managers want people to keep out of sensitive dune areas, and they may have placed fences to encourage people not to walk on the dunes. The location of unmanaged trails relative to fences suggests the fences may restrict access to certain areas, but not always to the dune as a whole.

At Kirk Park the fences appeared to have been unsuccessful at keeping people off of the dunes, based on the amount of damage observed combined with the presence of unmanaged trails. At Mt. Pisgah the fences appeared to have successfully kept people off the dune. The signs showed that management was attempting to restore the large blowout on the dune, and the fences appeared to be contributing to stabilization.

Further research could examine the dunes for evidence of deer presence. At this point, we cannot know for sure whether the trails we observed had been produced by deer, humans, or some combination of animal and human presence.

While fences' effectiveness at reducing traffic on the dunes were mixed, the fences appeared to have been at least somewhat successful at meeting goals for slowing sand. The most likely estimated reason for fence installation was to slow sand, and most of the fences appeared to be causing some level of deposition. However, the amount varied from site to site. Future investigation could involve interviews with the dune managers in order to better understand the rationale behind fence placement.

Damage

Damage to fences is likely reducing their effectiveness. As observed at North Beach Dune, the age of fences varied. Some appeared to have been installed fairly recently, while others appeared to be much older, with the older fences appearing to have withstood more damage and weathering over time. Most of the fences were damaged and could not trap as much sand as newly installed fences. Measured porosity was generally higher than the 30-60% porosity identified by previous research as ideal for the prevention of wind erosion (Dong *et al.* 2006; Tsukahara *et al.* 2012).

Collecting further information about the fences, such as their installation dates, could help to analyze the effects of weathering over time. Weathering was one of the forms of damage we observed; it visibly affected fence porosity, and ultimately the fences' ability to trap sand.

Orientation

The variety of fence orientations that were not parallel to the shore may be affecting the dune environment in unnatural ways. Previous research suggests straight fences parallel to the shore encourage more natural dune morphology than do angled fences (Grafals-Soto and Nordstrom 2009). While our study observed the greatest number of fences were oriented parallel to the shore, the combination of all the fences from other orientation categories surpasses this number. Further research could focus on the effects of these fences in particular on the landscape. Additionally, a future study could document fences at additional dune sites to see whether sand fence trends observed by this study are representative of the Lake Michigan dunes as a whole.

Conclusion

Our study documented and compared 32 fences across four Ottawa County Parks sites. Most of the sand fences we studied were oriented parallel to the shore and likely intended to slow sand. The fences seemed to have mixed effectiveness in controlling traffic. Our observation of fence damage suggests better maintenance could lead to more erosion prevention. Other studies of this kind have not previously been performed on Lake Michigan dunes, so future studies could help to shed more light on the particular situation of fences in this geographic location. Furthermore, the patterns in fence placement and condition suggested by this study warrant more research to see if the trends at our study sites are indicative the region as a whole.

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