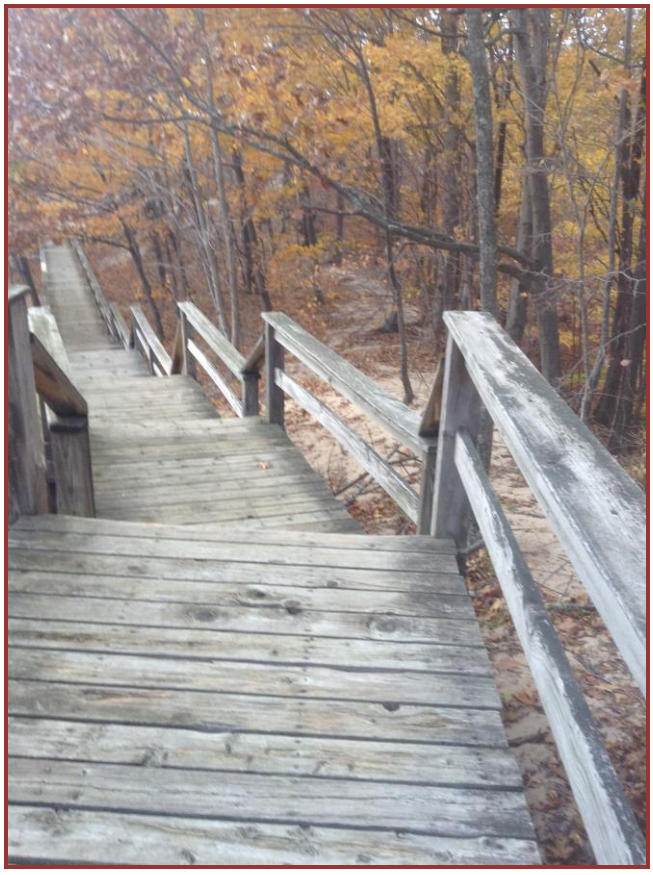
First-Year Research in Earth Sciences: Dunes



Boardwalk Interactions with a Lake Michigan Dune System

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ABSTRACT

Boardwalks enable visitors to enjoy dunes in a way that protects sensitive dune environments from human impacts, but a tension remains as a boardwalk itself alters a dune system. This study investigates how a boardwalk in Hoffmaster State Park, Michigan affects human interactions with a Lake Michigan coastal dune system. In autumn 2014, the boardwalk was mapped and the quality of its features assessed. Human impacts were investigated by documenting unmanaged trails and interviewing park staff. Ecological communities were mapped, and vegetation conditions near the trails were recorded. The boardwalk is part of a managed trail system connecting a visitor center with the beach; the boardwalk gives visitors access to a high dune lookout over Lake Michigan. The boardwalk ends at two viewing platforms and is worn but functional. A network of unmanaged trails indicate that people leave the boardwalk. The boardwalk and the unmanaged trails interrupt the ecological communities. The study results suggest that the boardwalk enables enjoyment of the dune and protects vulnerable environments, but it also affects the formation of unmanaged trails and influences dune processes. Understanding the spatial patterns of human interaction with the dune can inform the planning process as park staff work towards reconstructing the boardwalk in the next few years.

INTRODUCTION

Boardwalks provide people with experiences of fragile natural areas while simultaneously protecting vulnerable environments. Managers of coastal dune environments often build boardwalks to preserve these fragile systems and to allow access by visitors. The boardwalks form an infrastructure that influences how humans interact with the coastal environment, yet very little research has been done on this relationship.

This case study of a boardwalk in a Lake Michigan dune system is guided by the question: How does infrastructure affect human interaction with dunes and their processes? To answer the question, four research objectives were pursued:

- To document the boardwalk and its features,
- To document dune characteristics,
- To investigate recent dune changes in the topography and ecology, and
- To investigate human interactions with the dune.

BACKGROUND

The beach and dune environments of the West Michigan coast are popular attractions for visitors. One of the most popular areas to visit, Holland State Park, has more than 1.5 million visitors each year (van Dijk and Vink 2005). The tourism industry is a valuable part of the Michigan economy; in 2014, 113.4 million visitors generated $37.8 billion in total business sales (Tourism Economics 2015). Natural resources remain a key factor in drawing visitors to the state. The Pure Michigan campaign's 2012-2017 Michigan Tourism Strategic Plan presents this vision: "Maintaining access to these resources, while simultaneously preserving their integrity, is critical to their long-term sustainability and integral to conserving the quality of life that makes Michigan a great place to live and a premier travel destination" (Nicholls 2013). The challenge is not unique to Michigan, as managers of coastal environments around the world seek to preserve natural areas while allowing public access (Carlson and Godfrey 1989).

Though many use the word "preserve," dunes are naturally changing landforms that defy static preservation (Carlson and Godfrey 1989), as exemplified in the Lake Michigan dunes (van Dijk 2004). Lake Michigan dunes are composed of quartz sand blown from the beach inland by prevailing winds from the west (Cowles 1899; Hansen *et al.* 2009). Fluctuations in lake levels in the last 6,000 years caused periods of activity and periods of stabilization and have been a main factor in the current condition of dune topography (Hansen *et al.* 2010). During low lake levels, exposed beach sand is deposited by the wind in coastal vegetation, forming foredunes (van Dijk 2004). Older and taller dune ridges are inland and often well stabilized with vegetation (van Dijk 2004). When the vegetation is disturbed in areas of high wind energy, blowouts occur, sometimes growing to form parabolic dunes that bury vegetation beneath them (Hansen *et al.* 2009). The parabolic dunes travel inland, often piling up onto older dune ridges and stabilized parabolic dunes (Olson 1958).

After a blowout occurs or a slipface buries an area of vegetation, the ecological process of succession restarts. Pioneering species may colonize areas of bare sand, beginning the complex processes of ecological succession that may result in forest development (Cowles 1899; Olson 1958; Lichter 1998). The pioneering species are typically succeeded in order by conifers, black oaks, and mixed forest as disturbance decreases and a soil develops (Cowles 1899; Olson 1958; Lichter 1998). The path of succession is variable and is dependent on topography, type of disturbance, sources of seed, and other factors (Figure 1; Olson 1958).

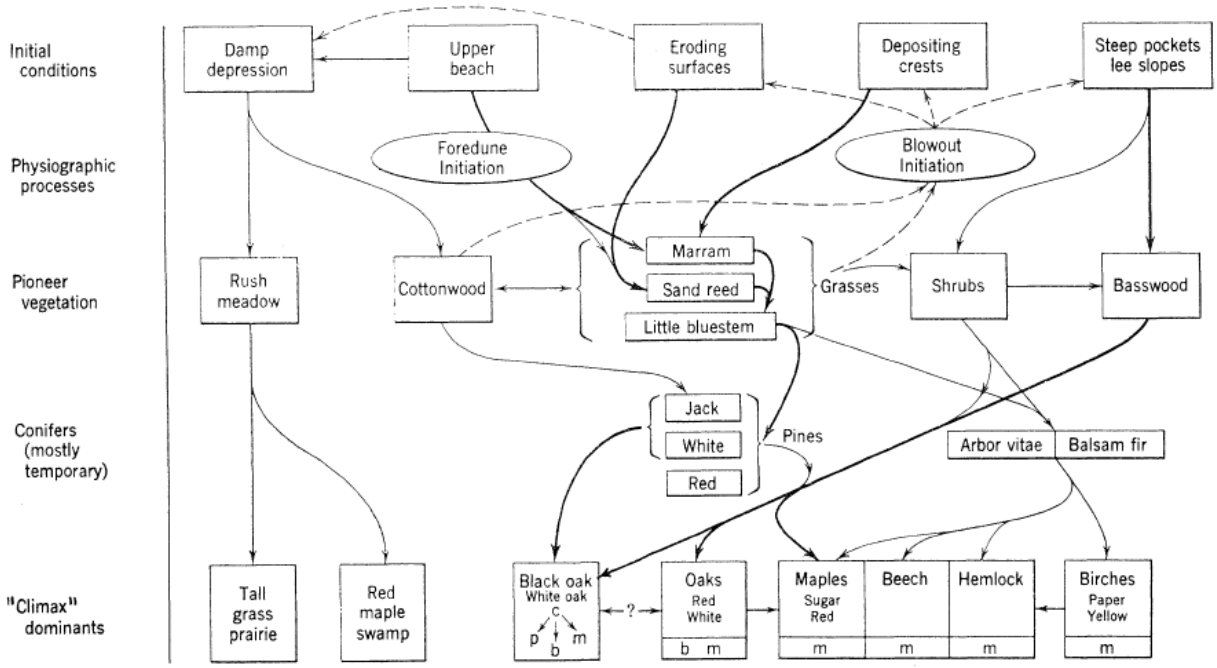

Figure 1. Different initial conditions result in different paths of ecological succession (from Olson 1958, p. 152).

Due to their parent material and dynamic nature, coastal dunes are among the most fragile environments in regards to human trampling (Talora *et al.* 2007). Research shows that excessive human trampling will decrease plant diversity and density, compact the soils, decrease organic matter, and create paths (Andersen 1995; Santoro *et al.* 2012). Large amounts of visitors may also cause a notch in the dune crest and lower the dune height (van Dijk and Vink 2005). Trampling may increase sand movement and cause blowouts (Burkley *et al.* 2014). The impacts of trampling are dependent on the time of year, the topography, and the intensity of the trampling (Hylgaard and Liddle 1981). While a small amount of human trampling may benefit certain plant species which depend on disturbance, excessive human trampling in areas of early successional stages such as bare sand or dune grasses will alter or prevent ecological succession (Andersen 1995).

Effective management can allow for both public enjoyment and protection of the dune system (Carlson and Godfrey 1989). A primary strategy is the construction of maintenance features. According to Randall and Newsome (2008, p. 24), "Maintenance features are engineering or educational solutions (i.e. steps or signs) that help to counteract walk trail degradation or increase user comfort". Maintenance features include sand fences, trails,

boardwalks, signs, boot cleaning stations, and benches. Managed trails are pathways that are planned and maintained by natural area managers to provide access to specific environments. A well-managed trail can be important for limiting erosion and protecting plant communities (Randall and Newsome 2008). Because of the dynamic nature of dune environments, an effective management plan must account for and allow change (Carlson and Godfrey 1989).

Boardwalks are a management technique proven to reduce human impacts on fragile environments (Carlson and Godfrey 1989; Randall and Newsome 2008). They are built walkways, usually wooden, which can be designed to allow for change in a dune environment. Leaving 3cm space between the boards and elevating the walkway at least 0.5 m above the sand can allow sunlight through to plants and leave room for sand accumulation (Carlson and Godfrey 1989). A different method, used in this case for vehicles, involves placing a ground level wooden ramp which can be easily lifted and reset after sand accumulation (Carlson and Godfrey 1989). Boardwalks often provide educational information about the dunes which can increase visitor respect for the fragility of the environment and the rules of an area (Carlson and Godfrey 1989).

STUDY AREA

Dune 4 of Hoffmaster State Park, Michigan provides a case study for the research question. The park is located on the coast of Lake Michigan in north Ottawa County and south Muskegon County (Figure 2). Dune 4 is a system of several dunes, including a large nested parabolic dune, a dune ridge, a foredune, and several blowouts (Figure 3). The managed trail from the Gillette Sand Dune Visitor Center leads to a large blowout on the first dune ridge, the foredune, and the beach. A branch of the managed trail system, known as the Dune Climb, leads to a boardwalk that climbs to the highest crest of the parabolic dune.

Figure 2. Location of Hoffmaster State Park

Figure 3. Location of Dune 4 in Hoffmaster State Park and focus areas A, B, and C.

Three areas were identified for specific focus. Area A refers to the beach, foredune, and first dune ridge. Area B refers to the nested parabolic dune is used by the park for dune education. Area C refers to the largest parabolic dune east of the nested parabolic dune and is the main area of analysis.

This study took place as the management of Hoffmaster State Park was planning to rebuild one of their boardwalk structures within the next year, provided they receive funding (Brockwell-Tillman 2014). The current boardwalk was built in 1975 with the help of the Michigan National Guard, who used a helicopter to airlift lumber from the parking lot to the top of the dune (Brockwell-Tillman 2014). At the time of this study, the boardwalk was almost 40 years old. A greater understanding of the boardwalk's impacts on how humans interact with and affect the dune may help guide future boardwalk designs.

METHODS

Field data was collected during site visits on October 23, October 30, and November 6, 2014. A variety of methods were used to meet the four research objectives.

Documenting the Boardwalk and Its Features

To document the boardwalk and its features, the whole managed trail system, its length, and its features were recorded using a GPS Trimble Unit. The full length of the trail system connecting the Visitor Center to the beach and the dune crest was mapped using lines. Polygons were used to map viewing platforms and points were used to denote trail management features such as benches and signs.

Documentation of boardwalk characteristics was focused on the Dune Climb, which was divided into the upper wing, the lower wing, and the stairs. The quality of the boardwalk was observed by noting the condition of the walking area, the railing, and management features. Two observers separately estimated the condition of each area and category, rating it on a sliding scale between 0 (unusable condition) and 1 (excellent condition). The number of unmanaged trails leading from each section of the boardwalk was recorded, and the percentage of bare sand underneath each section was estimated. The two observers averaged their estimation of each area's condition, count of unmanaged trails, and estimation of bare sand percentage.

Documenting Dune Characteristics

Physical characteristics of the study area were documented. Dune crests, arms, blowouts, slipfaces, and dune types were identified. The height of the dune crests and the distance of each crest from the lake was identified using an online elevation profile application found in the Michigan Dunes Inventory GIS at http://gis.calvin.edu/MDI/ (VanHorn *et al.* 2014). Photos of the dune area were taken.

Different ecological communities in Area C were mapped using a GPS Trimble Unit. The chosen communities are a simplified version of the complex framework of ecological succession in dune environments developed by various ecologists and dune researchers (Table 1). Each category was mapped as a polygon within Area C. Categories of a higher successional stage were mapped in polygons which could include vegetation from categories of a lower

Ecological Community	Successional Stage	Examples of Species
Bare sand	Pre-succession	None present
Pioneering vegetation	First stage	*Ammophila breviligulata* (American beach grass)
Conifers	Second Stage	*Pinus strobus* (white pine), *Pinus banksiana* (jack pines)
Black oak forest	Climax	*Quercus velutina* (black oaks)
Mixed forest	Climax	*Fagus* (beech), *Tsuga* (hemlock), *Sassafras* (sassafras), *Acer* (maple)

Table 1 Categories for classifying ecological communities in the study area. Categories are based on work by Cowles (1899), Olson (1958) and Lichter (1998).

successional stage. In areas A and B, types of ecological communities were observed but not mapped.

Identifying Recent Changes in the Topography and Ecology

Changes in dune activity over the last century were recorded using aerial imagery dating back to 1938. Aerial images of Dune 4 from 1938, 1950, 1955, 1968, 1974, 1981, 1988, and 1996 (Appendix A) were studied to see if any major changes in form or land cover have occurred. Alterations in topography such as blowout and nested parabolic dune locations and the changes in land cover were recorded to understand if the topography of the dune was changing or stabilizing. Significant changes in vegetation were recorded according the ecological framework described above.

Each aerial photo was analyzed according to a standardized classification of dune activity known as the Dune Features Inventory (DFI) Activity Classification (Table 2; Appendix B). The entire Dune 4 was analyzed together using a series of 5 yes or no questions (Appendix B). The questions determine whether the dune is stable and entirely vegetated, very active with large areas of bare sand and early colonizers, or somewhere in between.

Activity Classification	Key Descriptor
Inactive (Stable)	Dune is almost 100% vegetated
Slightly Active	One or more active blowouts are present on the dune
Moderately Active	Substantial dune activity (blowouts) but dune is not advancing
Active	Dune is advancing
Very Active	Dune is advancing quickly (e.g., 1 m/year or more)

Table 2. Summary of Dune Features Inventory activity classes (see Appendix B for more detail).

Investigating Human Interaction with the Dune

To understand the human impact on Dune 4, unmanaged trails in the study area were mapped. Unmanaged trails were identified as linear breaks in the vegetation and ground cover or lines of trampled vegetation which signify human traffic. Trails were mapped as segments between intersections and numbered in the order they were recorded. For each segment, the amount of litter, a short description of vegetation and ground cover, and comments were recorded.

Direct reporting of how humans interact with the dune environment was obtained using a questionnaire and an informal interview with park naturalist, Elizabeth Brockwell-Tillman. The questionnaire was a single, 2-sided sheet of paper asking questions about perceptions of management practices and activities engaged when visiting the park (Appendix C). Copies of the questionnaire were placed in the Visitor Center for a period of two weeks with a sign inviting visitors to participate. A "ballot box" enabled visitors to return the completed questionnaire quickly and confidentially. Researchers also carried copies while at the study site and asked people encountered to participate. Brockwell-Tillman visited the study site with the researchers on October 30 where she answered prepared questions and discussed her experience of the study area.

RESULTS

Boardwalk and Managed Trail

The managed trail system is 0.85 km long including all segments (Figure 4). The trail is designed to allow visitors to move between the Visitor Center, the beach, and the two viewing platforms and to safely enjoy the space in between (Figure 5). The Dune Climb, the section of trail leading to the highest crest of Dune 4, has a steep section of stairs and comes to two endpoints at the viewing platforms.

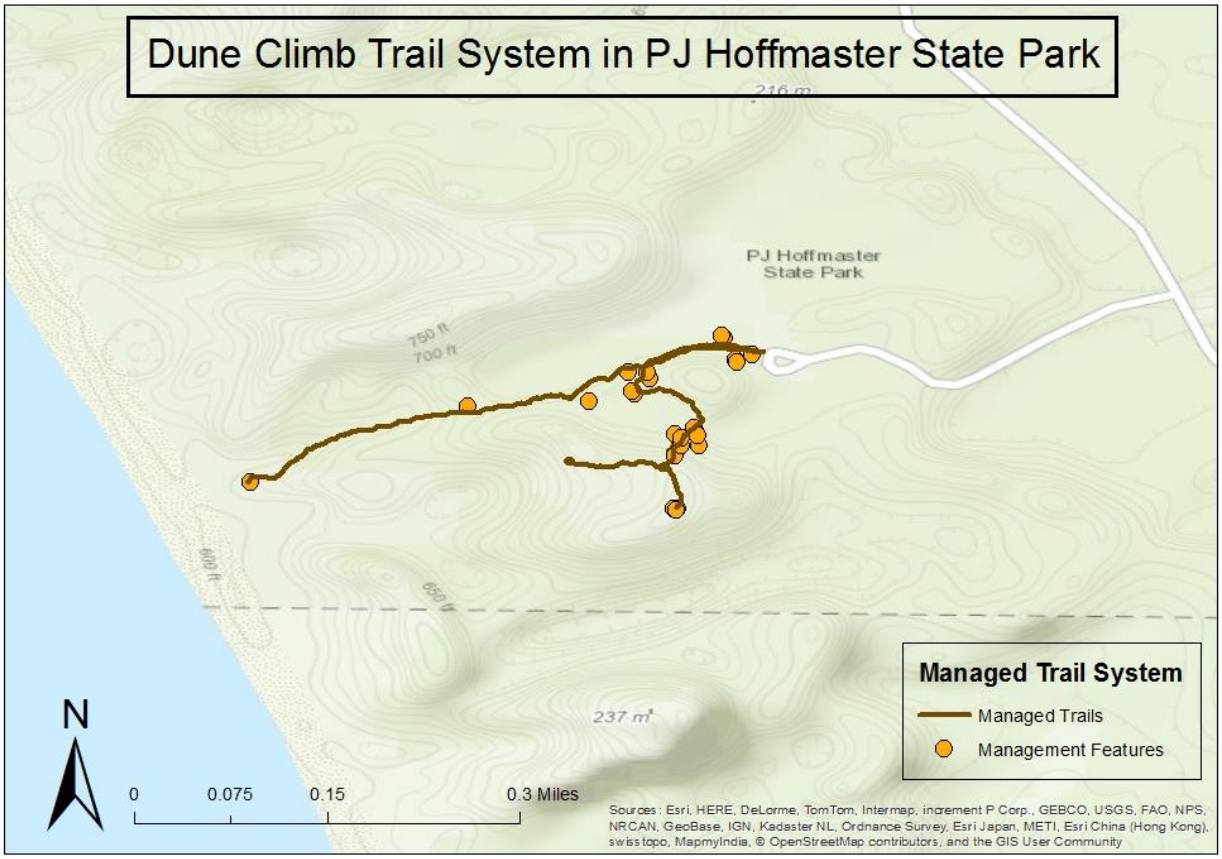

Figure 4. Managed trail system and locations of management features.

Figure 5. (A) Boardwalk on the dune crest. (B) Southern viewing platform.

The managed trail system is made up of a mix of raised boardwalk and other managed trail sections. Trail sections have surfaces of earth, sand, or gravel, and they often have railings and wooden supports to create steps or to stabilize slopes beside the trail. The raised boardwalk is a metal or wooden platform raised above the surface of the dune or the backdune area. The metal section is near the Visitor Center (Figure 6) while the rest of the boardwalk is wooden. The boardwalk typically has railings and is elevated above dune surface. Spaces between the boards are less than 3cm.

Figure 6. Metal section of the boardwalk.

Management features include benches, signs, and a boot cleaning station. The benches are most concentrated on the steep section of stairs leading to the dune crest, but a bench is also found on the highest viewing platform. Signs are both informational and cautionary. They provide facts about the dune environment, warnings of hazards to visitors, and warnings against leaving the trail (Figure 7). Some signs are weathered and in need of replacement. A boot

Figure 7. (A) The stairs which lead to the highest crest of Dune 4 on the leeslope of the parabolic dune. (B) An informative sign at the southern viewing platform in need of replacement. (C) Some of the hazards of the backdune forest.

cleaning station provides a place at the entrance to the Dune Climb for visitors to scrub their shoes to prevent the spread of invasive species.

Forty years after its construction in 1975, the boardwalk is showing signs of wear. In particular, the upper portion of the stairs shows evidence of being moved by the pressure of sand piling at the dune crest. Yet, the boardwalk is functional. The condition of both wings and the stairs as estimated between 1 and 0 can be seen in Table 3. The railings are stable but do not stop visitors from climbing off the boardwalk and forming unmanaged trails. Very little space exists between the boards of the boardwalk, allowing little light beneath and less vegetation to grow. The slope beneath the stairs shows signs of erosion.

	Boardwalk Section		
Question	**Upper Wing**	**Lower Wing**	**Stairs**
Condition of Walking Area?	0.83	0.63	0.60
Condition of Railing?	0.75	0.60	0.70
Condition of Misc.?	0.60	0.80	0.55
# of Unmanaged Trails	3.00	4.50	0.00
% Bare Sand	48%	78%	90%

Table 3. Classification of conditions for different boardwalk sections, as averaged from estimates by two researchers. Conditions closer to 1 are excellent while conditions closer to 0 are unusable.

Dune Characteristics

Dune 4 is a parabolic dune system involving several parabolic dunes, a dune ridge, blowouts and a foredune. The elevations above lake level and distances from the water of the dune crests are shown in Table 4. In Area A, there is a foredune and a dune ridge with a large blowout. Area B consists of a nested parabolic dune and Area C includes the upper windward slope and crest of the largest parabolic dune of the system. Sand movement is evident in depositional lobes downwind from blowouts.

Dune Crests:	**Foredune**	**Area A**	**Area B**	**Area C**
Elevation above Lake Level (m)	5 m	7m	23m	57m
Distance from Water (km)	0.05km	0.1km	0.2km	0.5km

Table 4. Elevations above Lake Michigan and distances from shoreline for dune crests in different Dune 4 areas. Elevations and distances were calculated using the Elevation Profile Application in the MDI GIS (VanHorn *et al.* 2014). Dune crests increase in height with distance from the shore making for excellent views from the viewing platform in Area C.

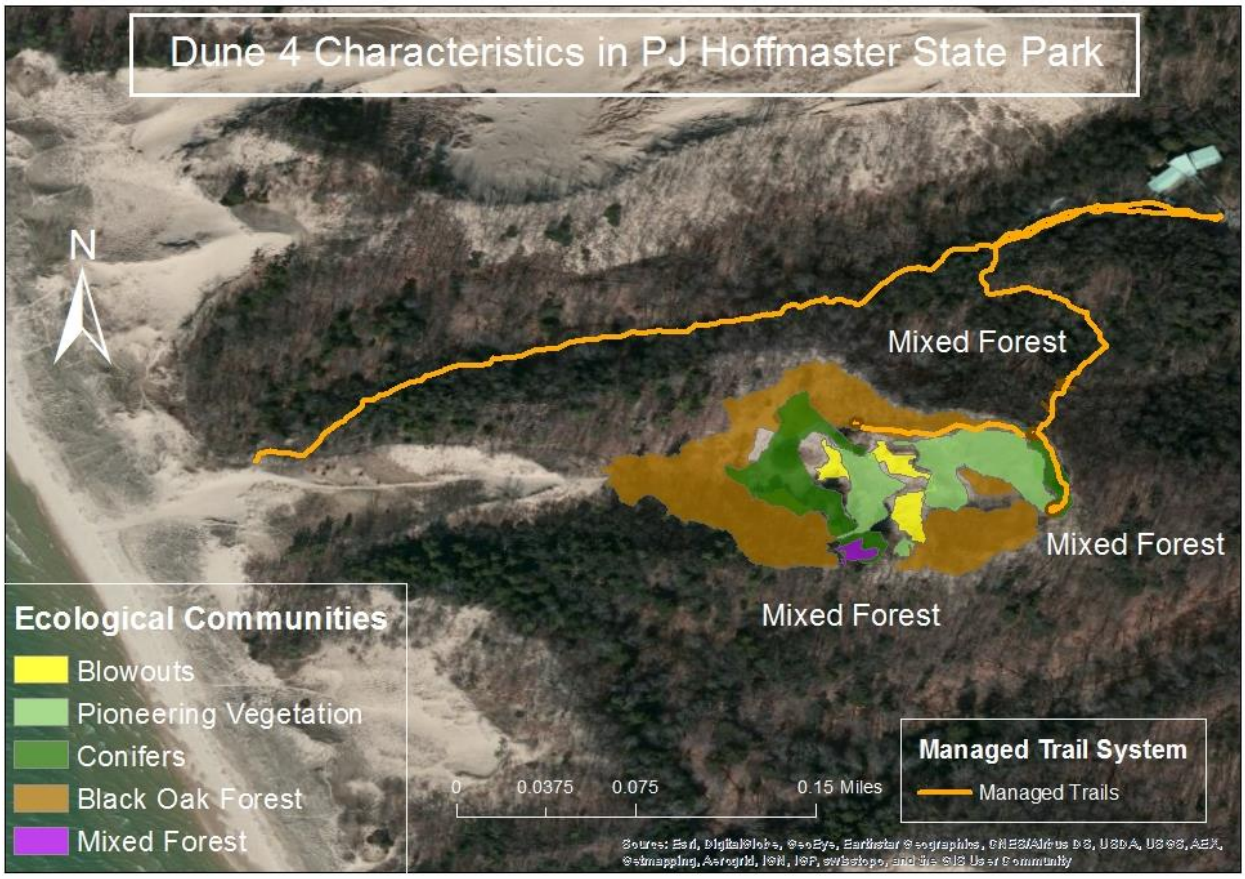

Figure 8. The ecological communities in Area C of Dune 4.

Dune 4 exhibits each of the main ecological successional stages known for West Michigan dunes, from bare sand blowouts to well-developed mixed forest (Figure 8). In Area C, blowouts are found towards the middle of the windward slope, about halfway between the top and the bottom. Between the blowouts and on the upper windward slope, pioneering vegetation dominates, especially *Ammophila breviligulata* (American beach grass.) Conifer species are found mostly on the lower windward slope but also at the crest of the dune. Pioneering species cover the ground between the conifer trees in both areas. Areas of predominantly black oak (*Quercus velutina*) forest are found at the bottom of the windward slope and along the north and south dune arms. On the south side of the upper windward slope, the black oak forest protrudes into the area of pioneering vegetation, separated by an unmanaged trail and an area of pioneering vegetation. On the north arm, black oak forest is found on the north side of the boardwalk, except for a few younger trees growing south of it. Conifers can be found within the black oak forest areas, especially in the southwest of Area C. A patch of young beech trees, indicative of a mixed

forest, can be found on the southern arm of the dune and a single young beech tree is growing on the north arm just south of the boardwalk on the upper windward slope. Beyond the crest and arms of the dune and surrounding the black oak forest on the lower windward slope is mixed forest, including hemlocks, beech, sassafras, and maples.

Area B has a much larger blowout on the upper windward slope of the nested parabolic dune with pioneering vegetation and conifers on the lower windward slope. The nested parabolic dune is also surrounded by mixed forest on the crest and the outside of its arms. Area A has a large blowout where the managed trail ends at the edge of the forest that extends all the way to the beach. Outside of the disturbed area is pioneering vegetation, including cottonwood trees.

Recent Changes in the Topography and Ecology

Air photo analysis shows that since 1938, the overall activity level of Dune 4 has changed very little (Table 4). Over the last 77 years, Dune 4 has never been entirely vegetated. Active blowouts have been present and substantial areas of the dune have been active. The aerial photographs provide no evidence that the dune has been advancing, though forest cover makes this difficult to assess. The photos also show that higher levels of ecologic succession than just bare sand and early colonizers cover parts of the dune surface. According to the Dune Features Inventory, Dune 4 is Moderately Active and has been for some time.

Though the activity level has stayed constant, internal changes to the dune have been significant. Since 1938, forest has pressed in on the edges of the dune, especially on the arms and crest of Area C. Black oak forest has developed on the north arm and the southeast corner of the study area where it had not been before. The lower windward slope of the Area C also developed

Year of Air Photo	Activity Classification	Comments:
1938	Moderately Active	Evidence of slipface
1950	Moderately Active	Slipface is half the size
1955	Moderately Active	Slipface is forested
1968	Moderately Active	Mid-slope vegetation disappeared
1974	Moderately Active	Dune C's windward slope appears vegetated. Dune A is bare sand.
1981	Moderately Active	
1988	Moderately Active	
1996	Moderately Active	

Table 4. Activity classification of Dune 4 from air photos (1938-1996).

a black oak forest where there had not been one before. The black oak forests are first noticeable in the 1981 photograph, which is the first photograph available after the boardwalk was constructed in 1975. Looking at the differences between the aerial photograph from 1968 and the recent Esri imagery, the nested parabolic dune in Area B has visibly moved eastward (Figure 9). On-site observations in 2014 reveal that the slipface is piling up on the forest which has developed there in the 30 years. Since 1968, the blowouts in the middle of the windward slope

Figure 9. With 1968 imagery on the left and recent Esri imagery on the right, the appearance of the boardwalk and changes in topography and vegetation are clear to see. The nested parabolic dune has visibly shifted during this period. The amount of vegetation and blowout activity in Area C has also changed significantly, possibly due to the boardwalk.

have moved east and been chased by the forest. There is visual evidence that human traffic from the managed trail has maintained and widened the blowout in Area A.

Human Interaction with the Dune

A network of unmanaged trails is present on Dune 4, connecting the boardwalk to the beach (Figure 10). The viewing platforms and sections of the boardwalk that are easier to climb over serve as end points for the trails. The trails either follow the arms of the dune between the crest, the beach, and a hidden lookout point on Dune 3.5, or the trails connect to a central trail, which joins the bottom windward slope of Area C and the beach via the nested parabolic dune.

State park naturalist Elizabeth Brockwell-Tillman shared some anecdotal evidence about how some unmanaged trails have developed. One cause has been park culture. Some park volunteers and regular visitors have made it a habit to take weekly dune ridge walks for many years now. Another cause is individual visitor activities. In 2014, Brockwell Tillman observed a

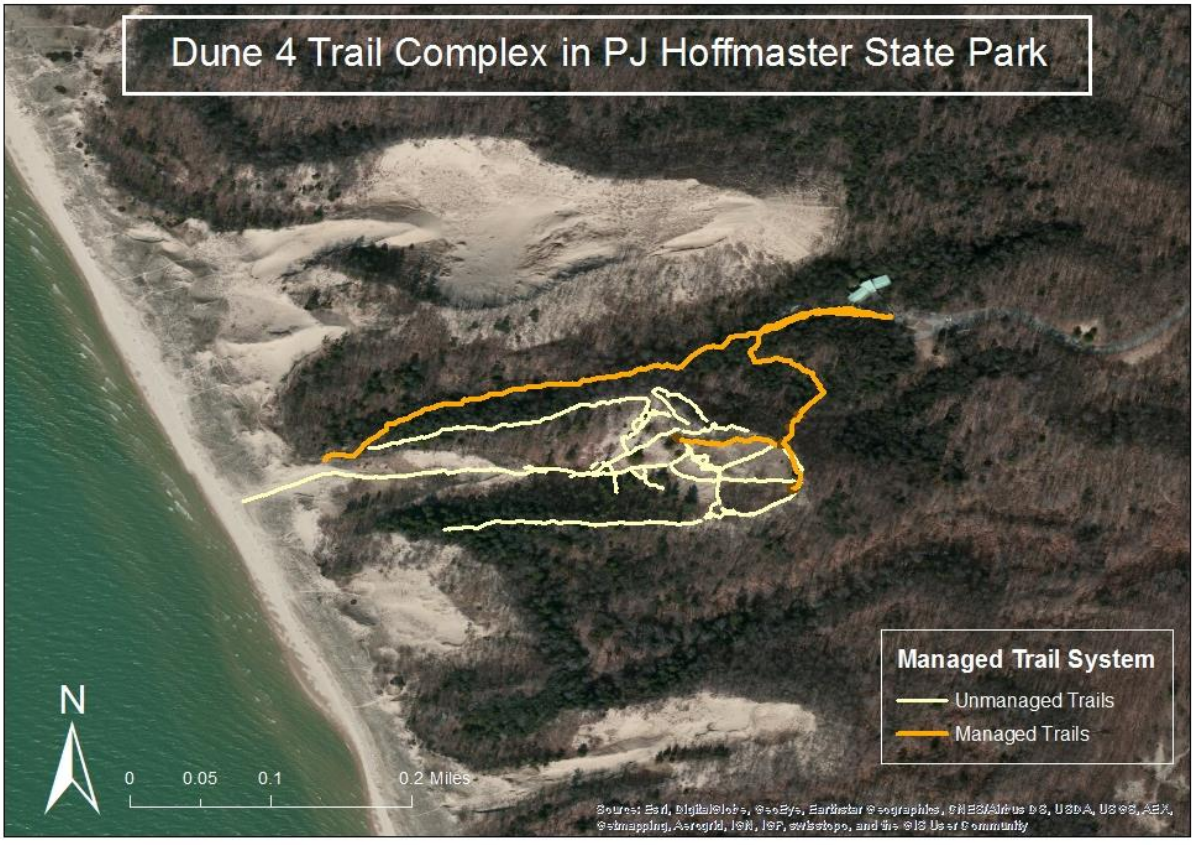

Figure 10. The unmanaged trail complex in relation to the managed trail system.

person regularly coming to the park to play fetch with a dog. Brockwell-Tillman notes that the prominent trail connecting the central viewing platform to the blowouts did not exist before this visitor's activity (Figure 11).

Figure 11. Unmanaged trail reportedly caused by dog

Public response to the questionnaire about human activity was limited. We received 5 completed questionnaires over the period of two weeks. 100% percent of those surveyed wrote that when they come to the dune they use the boardwalks and managed trails to enjoy scenery at the dune and 40% wrote they go to the dune to run down it. The last question showed that "access to scenic views," "make it easier to climb dune," "provides exercise opportunities," "protect dune vegetation/wildlife," and "increase enjoyment of dune" were 100% valuable to the 4 survey takers who answered this question. 60% of those surveyed have been to the dune many times. All people who took the survey were from west Michigan.

Other than the trails themselves, observable human impacts to the dune area were limited. The trails did affect the topography and ecology of the dune area, sometimes causing indents in the surface (up to 1 meter deep in one case) and creating areas of bare sand. Not much litter was left on the dune at the time of research; 15 pieces were found over the whole area. No signs of camping such as campfires were evident.

DISCUSSION

The park's built infrastructure influences the development of the unmanaged trail system and the processes of sand transport and ecological succession. Our results suggest several of these relationships warrant more attention: how the managed and unmanaged trail systems and the dune topography interact, how park culture can influence human impacts, and how the trail complex affects ecological succession.

Unmanaged Trails, Boardwalk, Topography, and Visitor Choice

The unmanaged trail system is a product of three influences: people's behavior, the dune topography, and the boardwalk. On one level, the unmanaged trail system is shaped primarily by the whims of human visitors to the park—where they want to walk is where trampling will occur and trails will form (Hyldaard and Liddle 1981; Talora *et al.* 2007). Typically, visitors seek ease of access and points of interest. However, the natural topography and human infrastructure also play distinct roles in determining where people want to walk.

The boardwalk connects to the unmanaged trail system in a number of ways. The boardwalk structure provides the easiest access to the dune crest and the best views and seating areas. It directs visitor traffic and reduces human impacts on the dune (Carlson and Godfrey 1989; Randall and Newsome 2008). Yet as visitors walk on the boardwalk, points where one may climb off the infrastructure with ease provide starting points for unmanaged trails. The visitors may be seeking to access points of interest that cannot be reached by the managed trail system. Boardwalk end points also serve as these starting points for unmanaged trails. Benches and viewing platforms with excellent views may serve as points of interest in themselves (Carlson and Godfrey 1989). If visitors find it easier to reach them from a location off the managed trail system, they may do so and create unmanaged trails. As a result, decisions of boardwalk design are crucial for determining how much and where humans impact the dune environment.

The dune topography also plays a critical role in shaping human impacts. The tendency of visitors to dune environments is to seek high points, good views, and places to walk (Arevalo *et al.* 2013). The dune arms provide the most stable and most gently-sloped ways to get to and from the beach and the dune crests, but the dune arms are also mostly hidden behind trees. The most visible unmanaged trail follows the center of Dune 4 connecting the beach, the crest of the

first dune ridge, the crest of the nested parabolic dune, and the lower windward slope of Area C. From there, the unmanaged trail splits in many directions directly to and from the points of interest on the dune crest and the boardwalk. The unmanaged trail along the north arm connects the northern viewing platform to where the managed trail from the visitor center exits onto the dune. The trail on the south arm leads from the southern viewing platform to a lookout on Dune 3.5 and an unstudied system of unmanaged trails. Visibility of the trails and their accessibility are a factor in their use.

Park Culture and Unmanaged Trails

Key to the creation and use of unmanaged trails is the human culture of the visitors and the park. Visitor decisions about whether to leave the boardwalk or not can be influenced by their understanding of how trampling affects dune vegetation and sand transport (Carlson and Godfrey 1989). Park rules, their enforcement, the possibility of punishment, and the amount of information provided by the park are critical factors as well. If park volunteers provide examples of leaving managed trails, rules do not exist, or rules are not known, then the creation of unmanaged trails is more likely.

Trail Complex and Ecology

The spatial layout of the managed and unmanaged trail systems relative to the patterns of ecological succession suggest two relationships. The first is that the infrastructure of the boardwalk, when placed along the boundary of ecological zones, may hinder seed dispersal and ecological development. Source of seed is a key factor in succession (Olson 1958, Lichter 1998). The north arm of the boardwalk appears to provide a barrier between black oak forest and pioneering species. This may be a matter of wind direction or soil development, but the abrupt boundary between the zones warrants mention.

The second relationship is that the trampling of unmanaged trails prevents ecological development, especially at the bare sand and pioneering stages (Hylgaard and Liddle 1981; Andersen 1995; Talora *et al.* 2007). Unmanaged trails are typically comprised of bare sand surrounded by the vegetation of the area. Even if the soil develops on either side of the trail, the trail itself remains disturbed by trampling. The effects of this are most evident on the upper windward slope of the main parabolic dune in Area C. The unmanaged trail leading from the

Figure 12. Separation between stands of oak trees from the southern viewing platform

southern viewing platform to the blowouts leads through two areas of black oak forest separated by the trail and an area of pioneering vegetation (Figure 12). While the surrounding areas were able to develop enough to sustain black oaks, the area near the trail consists of pioneering vegetation. More research is needed to further explore the potential ecological impacts of these trail systems.

RECOMMENDATIONS

As the park considers a new design for the boardwalk, several implications of this study may prove useful. The features of the boardwalk, its spatial layout, and certain additional management practices may further improve the infrastructure's effects on the dune environment.

One recommendation is to design the boardwalk to be adjustable to its dynamic environment. The structure itself can be built to be easily raised or lowered as the dune surface changes. The boards can be placed at least 3cm apart and the walkway elevated at least 0.5 m to allow sunlight to plants below (Carlson and Godfrey 1989). These design decisions would minimize impacts on ecological succession. Furthermore, a higher raised boardwalk would make it more difficult for visitors to create unmanaged trails.

A second recommendation is to create more loops rather than dead ends in the managed trail system to discourage the formation of unmanaged trails. The relative stability of the crests

and arms compared with the windward slope limits where the boardwalk can be safely built. A loop through the middle of the windward slope would be difficult and would be at risk of destruction by the recurring blowouts which form there. Continuing the managed trail with a mix of boardwalk and walking track along the stable dune arms may be a viable way of providing more legitimate access to the dune environment without more disturbance.

A third recommendation is to consider adding some simple management practices to limit human trampling. Educational signage about the dune environment can provide reasons to visitors for staying off the dune surfaces; positive messages are more effective than negative messages (Carlson and Godfrey 1989). Signs can be placed where people are most likely to leave the trail. In places where people are most likely to enter the dune system away from boardwalk—such as the beach—string and posts with small signs have proven effective in keeping people from fragile areas in other areas (Carlson and Godfrey 1989).

CONCLUSIONS

The 0.85 km managed trail system provides access to the beach and the dune crest and protection to the dune environment. The managed trails directly impact the dunes and their processes and affects how human visitors do the same. The 40-year old boardwalk is still functional but is showing signs of wear. Connections between the boardwalk and unmanaged trails suggest that boardwalk design is a significant factor in where unmanaged trails form.

Physical and ecological characteristics also provide context for people's interaction with the dune system and unmanaged trail formation. The dune system includes the foredune, the dune ridge, the parabolic dune and the nested parabolic dune. Area C has some signs of activity but shows more signs of stabilization than the very active nested parabolic dune and the large blowout on the dune ridge. Although Dune 4 is surrounded by mixed forest, the more-recently disturbed areas have younger stages of ecological succession. The most prominent blowouts are found on the upper windward slopes of the dunes. Pioneering species surround the blowouts while conifers and black oak forest are found on the edges of the dune areas. Certain trails appear to be boundaries between some ecological communities.

Investigation of recent history included 37 years before and 40 years after the construction of the boardwalk. Since 1938, Dune 4 as a whole has remained moderately active;

the large parabolic dune is not advancing but it retains internal activity. Internal changes include expansion of the forest which has pushed in on the edges and developed on the lower windward slope of the parabolic dune. The dune ridge and nested dune have remained very active and have moved eastward. Blowouts have come and gone from the upper windward slope of the parabolic dune (Area C). While overall dune activity has remained steady, Area C appears to have developed forest in several areas since the creation of the boardwalk.

Visitors to the dune have created an unmanaged trail network connecting points of interest along routes of easiest passage. The trails connect the beach with the highest points of the dune, leading along the arms of the parabolic dune and directly through the central axis. The viewing platforms and the boardwalk provide destination and departure points which influence the spatial layout of the trails. The existence of the trails themselves is influenced by park culture and lack of enforcement of rules against leaving the boardwalk. Regular visitors who disregard these rules can have the greatest impact on the dune environment.

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APPENDIX A: Aerial Photographs of Hoffmaster State Park Used in Analysis

Date	Photo Number	Approximate Scale
6/30/1938	BEI-IR-31	1:20,000
6/30/1938	BEI-IR-32	1:20,000
?-19-1950	BEI-4G-83	1:20,000
?-19-1950	BEI-4G-84	1:20,000
10/11/1955	BEI-5P-75	1:20,000
10/11/1955	BEI-5P-76	1:20,000
5/8/1968	BEI-2JJ-151	1:20,000
5/8/1968	BEI-2JJ-150	1:20,000
9/25/1974	A40 26121 174-131	1:40,000
9/25/1974	A40 26121 174-132	1:40,000
6/7/1988	MDNR 416-103-25	1:25,000
6/7/1988	MDNR 416-103-24	1:25,000
5/2/1996	MDNR PKS 36	1:12,000
5/2/1996	MDNR PKS 37	1:12,000

APPENDIX B: Dune Features Inventory (DFI) Checklist - Activity

D. Natural Features: Dune Activity

1. Is the dune 100% (or almost entirely) vegetated?
☐ Yes ☐ No

2. Are active blowouts present?
☐ Yes ☐ No

3. Are substantial areas of the dune active?
(Ex. large blowouts, sand moving over dune crest, etc)
☐ Yes ☐ No

4. Is the dune advancing?
(Evidence of sand deposits reaching bottom of slipface.)
☐ Yes ☐ No

5. Is the dune surface mostly composed of bare sand and early colonizers?
☐ Yes ☐ No

6. Classify dune activity level (see DFI Guide)
☐ Inactive/Stable
☐ Slightly Active
☐ Moderately Active
☐ Active
☐ Very Active

7. Classify foredune activity (see DFI guide)
☐ Active ☐ Stable

From the Guide to Completing the DFI: D. Natural Features: Dune Activity

Active blowouts have an area of bare sand (the deflation area) which serves as the area of wind erosion. You may also see a downwind area of sand deposition. Bigger or very active blowouts may have a visible slipface; for smaller or less active blowouts, the sand may be deposited on the slopes/vegetation downwind of the blowout.

Substantial areas of dune activity include:

- one or more large blowouts (10s of meters in size)
- a large number (>5-10) of small blowouts (<10 m in length or width)
- evidence that sand moves over the crest of the dune: this includes a bare sand area on the (upper) windward slope of the dune, bare sand areas on the dune crest, and a deposition area on the (upper) slipface of the dune
- evidence that sand has moved a significant distance from a sand source: deposition area of blowout(s) extends more than 10 meters from the blowout, fresh deposition on slipface reaches at least half-way down the slope or more.

Evidence of dune advance includes fresh sand deposits reaching the bottom of the slipface (ie without leaf litter or soils on the surface of the sand) and/or burial of vegetation/leaf litter/soils at the bottom of the slipface.

Level of Foredune Activity	Responses to Questions 1-5	Description of Dune Characteristics
Active	1. No or Yes 2. No or Yes 3. No or Yes 4. No or Yes 5. Yes	Active foredunes have evidence of sand movement (vegetation burial, fresh sand deposits, leaf/plant litter is buried by sand) and vegetation consists of pioneering species that may not completely cover the dune surface. Scarping of the windward foredune slope is an indicator of recent wave erosion.
Stable (Inactive)	1. Yes 2. No (possibly Yes) 3. No 4. No 5. No	Stable foredunes may have more complete vegetation coverage, less vigorous pioneering species (eg. duller color), greater species diversity from plant succession, and leaf/plant litter on ground beneath active plants. Another dune between the foredune and the beach is often an indicator of stability.

Classifying Dune Activity for dunes other than foredunes

Level of Dune Activity	Responses to Questions 1-5	Description of Dune Characteristics
Inactive (Stable)	1. Yes 2. No 3. No 4. No 5. No	Inactive (stable) dunes are fully vegetated with no locations of sand movement by wind. Dune surfaces have soils and leaf litter on them. Vegetation may be a climax forest community.
Slightly Active	1. No 2. Yes 3. No 4. No 5. No	Slightly active dunes have mostly stable (vegetated) surfaces with localized areas of sand movement. Sand movement occurs from small blowouts with sand deposition occurring within several meters of the blowout.
Moderately Active	1. No 2. Yes 3. Yes 4. No 5. No	Moderately active dunes have stable (vegetated) surfaces with substantial areas of activity in the form of large blowouts and/or sand moving over the crest of the dune. Deposition occurs on the slipface, but sand does not reach the bottom of the slope to cause dune advance. A dune may also be considered moderately active if it contains a very active nested dune on an otherwise stable surface.
Active	1. No 2. Yes 3. Yes 4. Yes 5. No	Active dunes show signs of substantial sand movement (large blowouts, sand moving over the crest of the dune) and the dune is advancing over the underlying landscape (shown by fresh sand deposits reaching the bottom of the slipface). Active dunes often have significant portions of the windward slope with little or no vegetation.
Very Active	1. No 2. Yes 3. Yes 4. Yes 5. Yes	Very active dunes have little or no vegetation and evidence of significant sand movement including significant dune advance. The windward slope and crest of the dune have substantial unvegetated areas for wind erosion and sand transport. The slipface shows many signs of activity (fresh sand deposits reaching the bottom of the slope, burial of vegetation, colonizing species of vegetation). Very active dunes will have rapid advance rates (> 1 m/year).

APPENDIX C: Hoffmaster Boardwalk Questionnaire

Please answer these questions related to a boardwalk in Hoffmaster State Park. You do not need to write your name on this questionnaire, and your answers will not be used to identify you personally. You may choose to answer all, some, or none of the questions. The results from this questionnaire along with other data gathered from the site will be incorporated into a final report to Hoffmaster State Park. This report may be obtained upon request. This study is being done by Calvin College students for a course called Geog 181 First-Year Research in Earth Sciences (FYRES) mentored by Gabe LePage, with faculty advisor Deanna van Dijk.

1. Approximately how often do you come to Hoffmaster State Park?
(Please check the corresponding box.)

- □ This is my first time
- □ Once a year
- □ Several times a year
- □ Once a month
- □ Several times a month
- □ Several times a week
- □ Every day
- □ Other _____

2. Where are you from? (*City, State/Province, Country)*_____

3. Which activities do you participate in when visiting the dunes in Hoffmaster State Park?
(Please check all that apply.)

- □ Go for a walk
- □ Walk the dog
- □ Climb a dune (not using stairs/boardwalk)
- □ Climb a dune to a viewing platform (using stairs/boardwalk)
- □ Enjoy scenery
- □ Play games
- □ Run down the dune (on the sand)
- □ Observe wildlife
- □ Read informational signs
- □ Other (*please specify*) _____

4. Approximately how often have you been on the Dune Climb boardwalk?

Branching off from the trail to the beach, this boardwalk provides access to a viewing platform which overlooks Lake Michigan from the top of a large dune.

□ Never □ Once □ A few times □ Many times

5. Did the Dune Climb boardwalk add to your enjoyment of the dune?

□ No □ A little □ A moderate amount □ A lot

Please answer the following questions whether or not you have been on the Dune Climb boardwalk.

6. How much do you value the following functions of a boardwalk on a dune?
(Please circle the corresponding number.)

	Do not Value	Slightly Value	Moderately Value	Strongly Value
Provides access to scenic views	1	2	3	4
Makes it easier to climb dune	1	2	3	4
Provides opportunity for exercise	1	2	3	4
Protects dune shape/activity	1	2	3	4
Protects dune vegetation/wildlife	1	2	3	4
Increases enjoyment of dune	1	2	3	4
Gives information about dune (interpretive signs/displays)	1	2	3	4
Other:_____	1	2	3	4

7. Additional Comments:
We would particularly welcome stories, poems, or drawings about your dune experience.

Thank you!