First-Year Research in Earth Sciences: Dunes

Characteristics of a Natural Vegetation Population on a Lake Michigan Foredune

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1.0 Abstract

Although Lake Michigan's coastal foredunes are predominantly vegetated with *Ammophila breviligulata* (American beachgrass), the natural characteristics of this species have not been documented. This study identified and analyzed the characteristics and environmental conditions of *A. breviligulata* populations in P.J. Hoffmaster State Park, Michigan. We analyzed three areas of vegetation growth on the foredunes: one with human influences (in the form of unmanaged trails), one with a steep scarp, created by wave erosion, and a control area with a slumped scarp and no significant human influence. In each area, we measured the height and density of *A. breviligulata*, recorded the presence of unmanaged trails and measured scarp characteristics. The greatest density of *A. breviligulata* was observed in the site of human disturbance, while the greatest height was recorded in the control site. Scarping affects the vegetation near the scarp, but does not influence the vegetation beyond the foredune crest. Unmanaged trails negatively influence the density of vegetation only near the trails. Understanding *A. breviligulata*'s natural characteristics could provide a model for assessing the success of vegetation plantings — a common technique for moderating sand movement in managed sites.

2.0 Introduction

Ammophila breviligulata (American beachgrass) is a dune-stabilizing grass species native to Michigan, and it is frequently planted to manage dunes in the Great Lakes region and other North American coastal areas (Woodhouse Jr. 2000). Despite its abundance and importance on the Great Lakes dunes (Maun 1985), *A. breviligulata* has not been thoroughly investigated in the region. While human impacts and foredune erosion have both been subjects of study in the Great Lakes dunes, neither has been analyzed in relation to the characteristics of a natural *A. breviligulata* population. This study identified and analyzed the characteristics and environmental conditions of *A. breviligulata* populations in P.J. Hoffmaster State Park, Michigan. We focused on three areas of *A. breviligulata* growth: an area with human impacts in the form of unmanaged trails, an area with a steep scarp and a control area with low human impact and a slumped scarp.

Our objectives were to (1) measure *A. breviligulata* height, density and health in each research area, (2) compare the characteristics of *A. breviligulata* between the three areas, and (3) determine whether a link exists between level of disturbance in a site (as caused by human impacts and scarping) and the natural characteristics (height, density, and health) of *A. breviligulata*.

3.0 Background

3.1 *Ammophila breviligulata*

Figure 1: *A. breviligulata*.

A. breviligulata (figure 1) is a pioneering grass species native to the Atlantic coast and Great Lakes coastal dunes, but it is listed as threatened in Illinois and Minnesota (Fant *et al.* 2008). The species is well adapted to the dynamic sand movement that characterizes foredunes in the Great Lakes region (Maun and Lapierre 1984; Fant *et al.* 2008). Mature *A. breviligulata* can survive annual burial of up to 1 m of sediment (Laing 1954), and seedling emergence is optimal at a burial depth between 2 cm and 4 cm (Maun and Lapierre 1986). The response of *A. breviligulata* to sand accretion and erosion is a key factor in the formation of the Great Lakes dunes (Disraeli 1984).

The direct correlation between vegetation cover and sediment deposition (Disraeli 1984; Arens *et al*. 2001) has contributed to dune management techniques employed in the Great Lakes region, where *A. breviligulata* is commonly planted to stabilize dune systems (Emery *et al.* 2010). The species is a common candidate for restoration efforts because it is native to the dunes and allocates a significant portion of its biomass to root systems, which anchor the plant firmly in the sediment (Maun 1984).

Figure 2: The rhizome is the belowground stem of a plant, which sends out roots and shoots as the plant grows.

A. breviligulata is described as particularly well suited to dune environments owing to its rhizome characteristics (figure 2). *A. breviligulata* rhizomes are reported to grow as much as 2.4 m annually, and are noted for growing both vertically and horizontally to establish the plant in a dynamic dune environment (Voss and Reznicek 2012). Rhizomes are also the primary method of reproduction in *A. breviligulata*.

Maun (1984) found that — even in natural conditions — *A. breviligulata* contributes very little biomass to sexual reproduction.

Despite *A. breviligulata*'s clonal nature (reproducing primarily through rhizome growth), Fant *et al*. (2008) found greater genetic diversity in native populations than in planted ones. In contrast, Emery *et al.* (2010) suggest that the commonly planted "Cape" variety of *A. breviligulata* is better equipped for drought tolerance and herbivory resistance than native populations. They observed a higher rate of *Epichloë*-type endophytic fungi — suggested to increase a plant's resistance to both drought and herbivory damage — in the "Cape" variety (Emery *et al.* 2010).

3.2 Unmanaged trails

Of all the anthropogenic effects on the dunes, trampling and paths have the greatest impact on vegetation communities (Ciccarelli 2014). Unmanaged trails (figure 3) — along with trampling damage and erosion — have been linked to degraded vegetation habitats on dunes (Ciccarelli 2014). The presence of even moderate human trampling in a dune ecosystem can reduce the density and diversity of vegetation communities (Ciccarelli 2014).

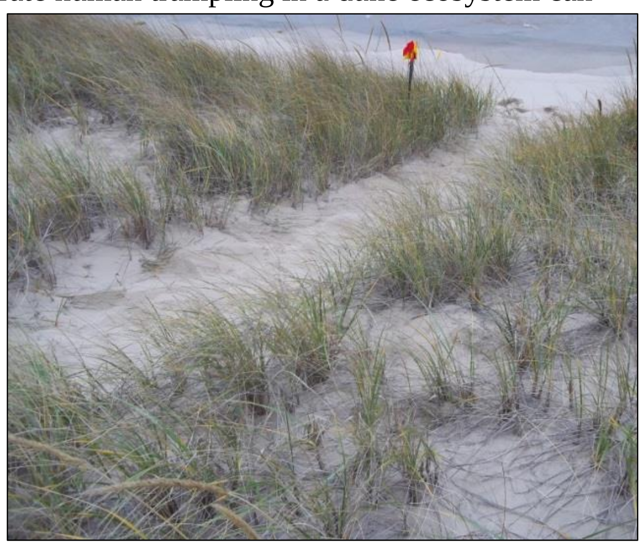

Figure 3: Unmanaged trails reduce the density of dune vegetation; plants are eliminated in a distinctive path when the trail is used regularly.

Kutiel *et al.* (1999) found that anthropogenic trails had varying impacts on local vegetation communities, depending on the intensity of trail use. In addition to its density and diversity, a vegetation community's soil organic matter was found to be lower on high-intensity trails than on low-use ones (Kutiel *et al.* 1999). Moderate trampling has been found to affect a vegetation community's composition more than its total ground cover, favoring *A. breviligulata* and other robust species to the exclusion or diminishment of more impact-sensitive plants (McDonnell 1981).

Persistent and significant trampling has been found to eliminate even more robust vegetation species over time (Hylgaard and Liddle 1981), resulting in unmanaged trails. As the number of passes over a trampled surface increases, path width and depth increase while vegetation cover decreases (Hylgaard and Liddle 1981).

3.3 Scarping

Vegetation populations in coastal environments are prone to spatial disturbances and density variability as their members are damaged and destroyed by periodic sediment erosion and deposition (Maun 1984). On foredunes, erosion can occur in the form of both wind and wave activity; the latter results in scarping (figure 4).

Figure 4: Scarping, due to wave activity at the lakeward edge of the foredune, pulls sediment out from underneath established vegetation.

Scarping is therefore intrinsically related to lake level, being a direct result of wave erosion on the windward slope of the foredune. Scarping has annually-variable effects on Lake Michigan foredunes and their *A. breviligulata* populations. Both the severity and rate of scarping occurrences are erratic (Johnson and Miyanishi 2010).

Minimal scarping is unlikely to result in substantial species composition changes, though it might eliminate a number of leading-edge plants (Johnson and Miyanishi 2010). Moderate to severe scarping may have more lasting effects, particularly if the scarping is recurrent (Johnson and Miyanishi 2010). Vegetated foredunes commonly exhibit slumped scarps (figure 5), which form when a block of sediment (anchored by vegetation) slides down the scarp incline, producing a gentler foredune slope (Johnson and Miyanishi 2010).

Figure 5: A slumped scarp forms a new windward slope from the collapse of a steep, vegetated foredune scarp.

4.0 Study Area

Our study took place in P.J. Hoffmaster State Park, located on the eastern shore of Lake Michigan, in Muskegon County, Michigan (figure 6). The park covers approximately 4.9 km^2 (1200 acres), including 4.8 km (three miles) of beaches and eight coastal dunes (State of Michigan 2001-2003). Study site A showed human impacts in the form of unmanaged trails. Study site B had a steep scarp, and study site C was the control area, having a slumped scarp and no unmanaged trails.

Figure 6: P.J. Hoffmaster State Park is located on the eastern shore of Lake Michigan (right). Study sites A, B and C were located on foredunes in the park (above).
* Note: Each study site measured 20m x the width of the foredune (red rectangles not to scale).

5.0 Methods

We observed *A. breviligulata* at the three study locations in P.J. Hoffmaster State Park during two site visits from late October to early November, 2014. At the beginning of each site visit, we performed a basic weather survey to determine maximum and average wind speeds, wind direction, and ambient temperature. We compiled average temperatures, precipitation measurements, and wind data recorded by Weather Underground for each week to compare our weather survey to regional data. We made field observations at each study site, noting species present and general environmental conditions using a Dune Features Inventory (Appendix A).

Figure 7: Quadrat measurements.

We measured *A. breviligulata* characteristics in different foredune zones at each site. To obtain *A. breviligulata* height, health, and density measurements, we threw fifteen quadrats in each site (figure 7); five each on the windward slope (if present), crest, and leeward slope. In site B, where no windward slope was present, quadrats were thrown on the scarp edge instead. Quadrats were thrown (rather than placed) to preserve sampling randomness in each of the foredune zones. We recorded the height of the tallest and shortest *A. breviligulata* leaf in each quadrat. Density was measured by extrapolating from the number of *A. breviligulata* plants within the 0.5 m x 0.5 m quadrat to determine density per square meter. We also made an estimate of *A. breviligulata* health (on a scale of 1-5) in each quadrat (Table 1).

We observed and recorded physical characteristics of each site, noting each site's extent and features. We mapped each of the study sites with Trimble Juno GPS units, recording the site boundaries, unmanaged trails, scarps, and quadrat locations.

	Category	Description
1	Poor	Complete discoloration, many missing stalks and/or significant trampling.
2	Below average	Considerable discoloration, missing stalks and/or some trampling.
3	Average	Occasional discoloration, parts of stalks missing stalks and/or minor trampling.
4	Good	Minimal discoloration, occasional missing stalk segment.
5	Exceptional	None of the above damage or discoloration.

Table 1: Scale used to estimate *A. breviligulata* health.

These data were downloaded and post-processed using ArcGIS software to produce site maps. We measured the height of the scarps (where present), and observed the incision of unmanaged trails in site A.

Plant height, health, and density data were compared between each of the three sites, as was the number of sessile species present at each. Statistical t-tests were performed to determine significance of differences in *A. breviligulata* height, health, and density between the sites.

Sediment characteristics were recorded in each site, along with foredune topography change due to scarp retreat. A surface sediment sample was collected from the scarp (if present, windward slope if not), crest, and leeward slope of each site, and analyzed for comparative moisture content between foredune zones (scarp, windward slope, crest, leeward slope). We extrapolated erosion pin data from a site approximately 469 m (1,538 feet) south of study site C to estimate scarp retreat during the week between the study periods (October 30 to November 5, 2014).

6.0 Results

6.1 Environmental conditions

Fieldwork took place over three consecutive weeks, with site visits on October 23, October 30, and November 6, 2014. Since observations occurred during the fall, average wind speeds were characteristically high (van Dijk 2014), ranging from 1.6 m/s to 5.7 m/s, while wind direction, temperature and precipitation were variable (Appendix B). Although unmanaged trails (observed in site A) and litter (observed in all three study sites) indicated human activity in the park, we did not observe other park visitors in the study area during our site visits.

Vegetation assemblages varied slightly between sites. *A. breviligulata* was observed in seed on the foredune crests (although it reproduces primarily by rhizomes (Fant *et al*. 2008)), and it was observed to a lesser extent on the lee slopes (Figure 8). *Artemisia campestris*

Figure 8: *A. breviligulata* in seed was primarily limited to the crest of the foredune, with slight infringement onto the leeward slope.

(Beach wormwood) was only present in the leeward slope and trough areas that exhibited at least moderate *A. breviligulata* density. The majority of the *A. campestris* observed was in seed.

Six sessile (immobile) species were observed in the study sites: five plant and one fungal (Figure 9). *A. breviligulata* and *Phallus hadriani* (Dune stinkhorn) were the only species found at all three sites.

Figure 9: Sessile dune species observed: *A. breviligulata* (sites A, B, and C), *Artemisia campestris* (Beach wormwood) (sites B and C), *Populus deltoides* (Eastern cottonwood) (site C), *Phallus hadriani* (Dune stinkhorn) (sites A, B, and C), *Salix (cordata or myricoides)* (sand dune or bayberry willow) (site C),and *Oenothera biennis* (Evening primrose) (site B).

6.2 *A. breviligulata* measurements: comparisons between sites

The composition of foredune vegetation in every study site was almost entirely *A. breviligulata.* The average plant density across all sites was 32.7 plants/m^2, while the health rating averaged 3.9 on a scale of 1-5 (see Table 1 on pg. 6 for categories). The average height of *A. breviligulata* was 79 cm.

All three sites exhibited high vegetation coverage: each was 75%-100% vegetated. No endangered, threatened, special concern, invasive, or exotic species were observed at any of the sites. No animal damage to vegetation, such as grazing or trampling, was observed, and we found no evidence of off-road vehicle use at any site. Trails (where present) were unmanaged.

Trails were observed only in site A. Two quadrats on the leeward slope intersected a trail, where *A. breviligulata* density was reduced. The largest trail intersecting the study site was evidently used frequently and was incised greater than 5 cm (figure 10a).

All three foredune sites were scarped by wave activity (figure 10b). The scarp was the highest at site B, averaging 119.25 cm. The scarp at site C was slumped: eroded sediment had fallen to form a new windward slope (figure 11). Scarp retreat averaging 2.21 m was noted at a foredune site 469 m (1,538 feet) south of site C from October 30 to November 5, 2014. It is likely that scarp retreat occurred throughout the park during this time, making the scarp active at the time of observation on November 6.

Figure 10: Disturbances such as unmanaged trails (a) and scarping (b) eliminate and damage vegetation in narrow regions of the foredune.


Figure 11: The slumped scarp at site C had fallen, forming a new windward slope.

Differences in *A. breviligulata* density were negligible between the three sites (figure 12). There were likewise no significant differences between plant health observed in the control, scarped, and human impact sites. However, the greatest average height of *A. breviligulata* was recorded at the control site, and was significantly greater than the average height observed at the human impact site (figure 13). The greatest number of sessile species (five of the six total) was also observed at the control site.

While overall *A. breviligulata* density and health were not significantly different between the sites, local effects of unmanaged trails and scarping resulted in decreased plant density (figure 10a) and health (figure 10b) in narrow regions of study sites A and B.

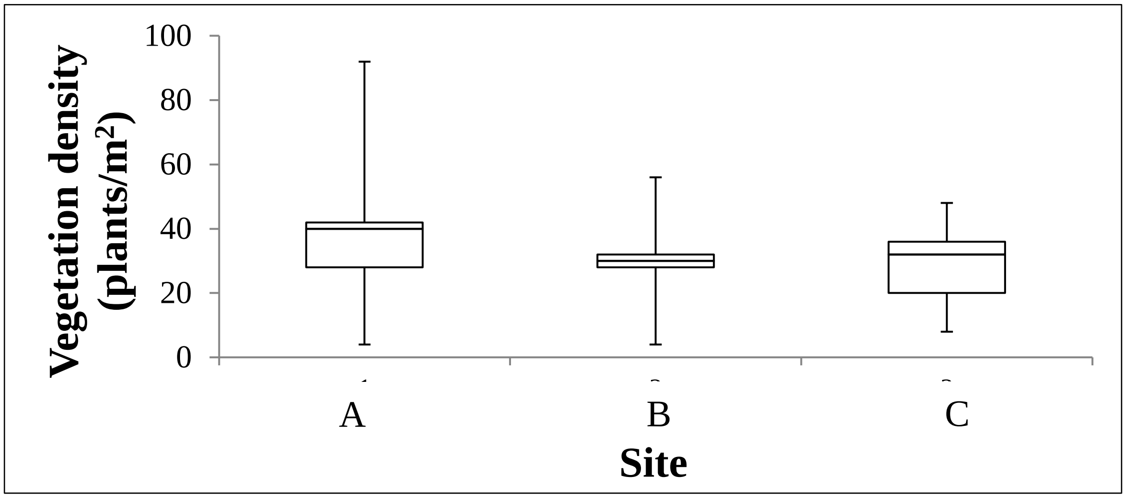

Figure 12: The median and quartile values for vegetation density at the human impact site (A) and scarped site (B) were not significantly different from those at the control site (C).

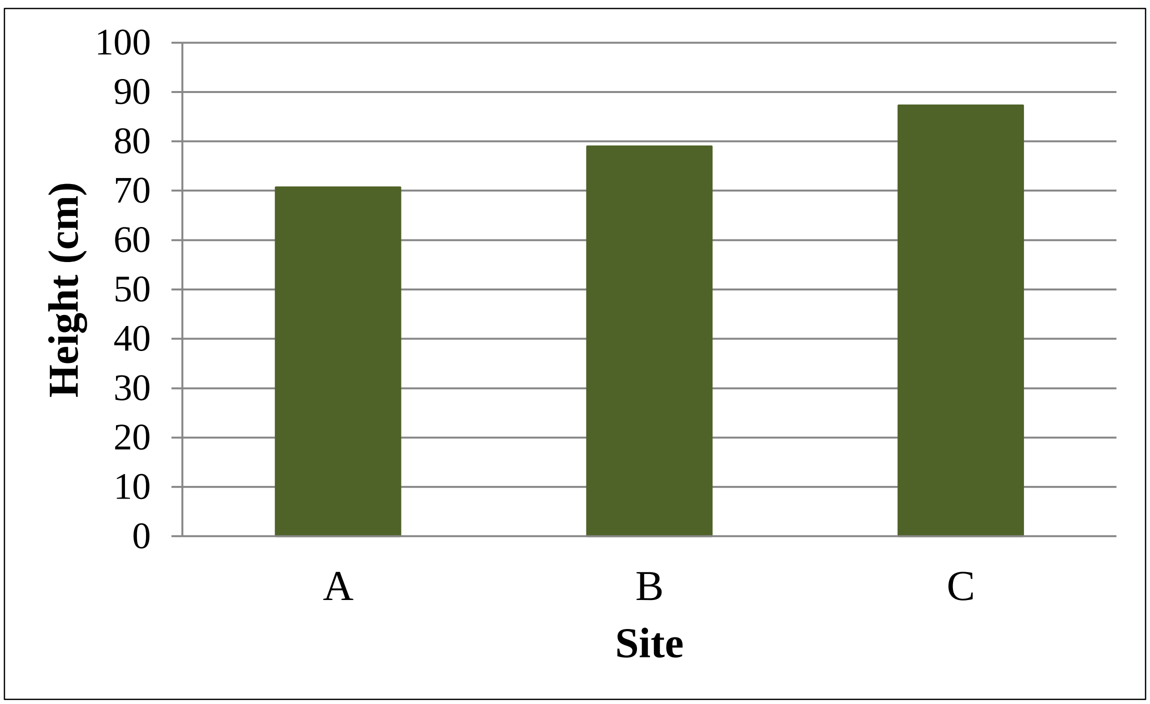

Figure 13: Average height of *A. breviligulata* as recorded at each study site.

7.0 Discussion

7.1 Environmental conditions

The autumn conditions observed at the study sites were consistent with those of the region: high wind speeds and fluctuating temperature, precipitation, and wind direction measurements (van Dijk 2014).

P.J. Hoffmaster State park annually receives more than 49,000 visitors (Harrison Wolffis 2011). As such, no site was completely free of human impacts; even sites without unmanaged trails had litter or the odd footprint. Likewise, no site was truly without a scarp, since the weather during the study period and the weeks leading up to it resulted in wave erosion along the entire shoreline of the park.

7.2 *A. breviligulata* measurements: comparisons between sites

The foredune vegetation populations appeared healthy, exhibiting few of the expected dune vegetation threats. Each foredune study area was predominantly vegetated, with no evidence of off-road vehicle use, herbivory damage, or invasive species. There was also no evidence of endangered or threatened species, or species of special concern. This was contrary to our expectation of finding Pitcher's thistle (*Cirsium pitcheri*), an endangered endemic (Gauthier *et al.* 2010) at sites B and C since we observed the species in other park locations. Dune vegetation dynamics are known to be affected by human influences such as trampling and unmanaged trails (McDonnell 1981); we therefore did not expect to find *C. pitcheri* in site A.

The greatest species diversity was observed in the control site, which was populated with five sessile species. The least variety was observed in the human impacts site. This suggests, in compilation with other studies (McDonnell 1981; Andersen 2000), that species composition is affected by human influences.

The presence of unmanaged trails (observed only in site A) invariably coincided with reduced *A. breviligulata* density. There is evidence that these trails were used frequently (the largest was incised greater than 5 cm), without sufficient time for *A. breviligulata* and other species to fill in trampled areas.

A more recent addition to the park's landscape is the scarp along its foredunes, which has corresponded with rising lake levels over the span of only the past year. All three sites, being located along the same shoreline, were scarped to some extent. It was the least noticeable at site C, where the scarp had slumped into a new windward slope, and was the most pronounced at site B, which exhibited the highest scarp.

A. breviligulata density did not vary significantly between sites. Decreased density due to unmanaged trails is confined to the trails, and does not seem to influence vegetation beyond them. The average height of *A. breviligulata* was greatest in the control site. This is consistent with research citing dune vegetation's vulnerability to human impacts (Ciccarelli 2014).

Figure 14: Vegetation on the scarp edge was more exposed and less dense than that farther removed from the shore.

The presence of scarping and unmanaged trails did not affect the overall health of *A. breviligulata*. However, vegetation exhibited exposed roots (and noticeably decreased density) on scarps (figure 14) and was trampled on trails. The observed scarp is less than six months old, and has not altered the vegetation composition or dune shape. However, long-term effects may be noted in future studies, as a dune's shape is associated with its vegetation assemblage (Arens *et al.* 2001).

The technique of planting *A. breviligulata* to stabilize dune systems in the Great Lakes region, and elsewhere (Woodhouse Jr. 2000), is common. Comparisons of planted *A. breviligulata* populations to the natural population at P.J. Hoffmaster State Park could assess the relative health of the former. However, Koske and Gemma (1997) suggest that, even after nearly six years, planted populations do not exhibit the significant hyphal (nutrient-transferring fungi) networks that are present in natural populations. This suggests that meaningful comparisons between planted and natural *A. breviligulata* may not be possible unless both populations are fully established—including the unseen fungal networks inherent in non-planted groups.

8.0 Conclusions

P.J. Hoffmaster State Park's foredunes are populated by *A. breviligulata* with an average density of 32.7 plants/m^2, height of 79 cm and health rating of 3.9. The control site displayed the greatest species diversity, with five sessile species observed at the time of the study.

All three of the foredune sites were highly vegetated (75%-100%), exhibiting no evidence of off-road vehicle use. No invasive or exotic species were observed in any of the sites, and none of the sites had threatened, endangered, or special concern species.

Measurements suggest that neither human impacts (in the form of unmanaged trails) nor scarping due to wave erosion has a significant influence on *A. breviligulata* over the entire foredune, although each disturbance has local — and visible — effects on the vegetation. *A. breviligulata* exhibited the greatest average height in the site with neither disturbance factor.

Since planting *A. breviligulata* is a common management strategy, an understanding of the plant's natural characteristics could serve as a model to analyze the efficacy of planted vegetation on managed dunes.

9.0 Acknowledgements

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10.0 Works Cited

Andersen, U. V. 2000. "Resistance of Danish vegetation types to human trampling." *Biological Conservation* 71 (3): 223-30.

Arens, S. M., A. C. W. Baas, J. H. Van Boxel, and C. Kalkman. 2001. "Influence of reed stem density on foredune development." *Earth Surface Processes and Landforms* 26: 1161-76.

Ciccarelli, D. 2014. "Mediterranean coastal sand dune vegetation: influence of natural and anthropogenic factors." *Environmental Management* 54: 194-204.

Disraeli, D. J. 1984. "The effect of sand deposits on the growth and morphology of *Ammophila breviligulata*." *Journal of Ecology* 72: 145-54.

Emery, S. M., D. Thompson, and J. A. Rudgers. 2010. "Variation in endophyte symbiosis, herbivory and drought tolerance of *Ammophila breviligulata* populations in the Great Lakes region." *American Midland Naturalist* 163 (1): 186-96.

Fant, J. B., R. M. Holmstron, E. Sirkin, J. R. Etterson, and S. Masi. 2008. "Genetic structure of threatened native populations and propagules used for restoration in a clonal species, American beachgrass (*Ammophila breviligulata* Fern.)." *Restoration Ecology* 16 (4): 594-603.

Gauthier, M., E. Crowe, L. Hawke, N. Emery, P. Wilson, and J. Freeland. 2010. "Conservation genetics of Pitcher's thistle (*Cirsium pitcheri*), an endangered Great Lakes endemic." *Botany* 88 (3): 250-57.

Harrison Wolffis, S. 2011. "P.J. Hoffmaster State Park, Gillette Visitor Sand Dune Center give Muskegon area residents reason to get outdoors." Muskegon Chronicle. Accessed April 16, 2015. http://www.mlive.com/living/muskegon/index.ssf/2011/10/pj_hoffmaster_state_park_gille.html

Hylgaard, T. and M. J. Liddle. 1981. "The effect of human trampling on a sand dune ecosystem dominated by *Empertrum nigrum*." *Journal of Applied Ecology* 18: 559-69.

Johnson, E. A. and K. Miyanishi. 2010. *Plant Disturbance Ecology: The Process and the Response*. Academic Press 720 p.

Koske, R. E. and J. N. Gemma. 1997. "Mycorrhizae and succession in plantings of beachgrass in sand dunes." *American Journal of Botany* 84 (1): 118-130.

Kutiel, P., Zhevelev, and R. Harrison. 1999. "The effect of recreational impacts on soil and vegetation of stabilised coastal dunes in the Sharon Park, Israel." *Ocean and Coastal Management* 42 (12): 1041-60.

Laing, C. C. 1954. "The ecological life history of the *Ammophila breviligulata* community on Lake Michigan dunes." Ph.D. University of Chicago.

Maun, M. A. 1984. "Colonizing ability of *Ammophila breviligulata* through vegetative regeneration." *Journal of Ecology* 72: 565-74.

Maun, M. A. 1985. "Population biology of *Ammophila breviligulata* and *Calamovilfa longifolia* on Lake Huron sand dunes. I. Habitat, growth form, reproduction, and establishment." *Canadian Journal of Botany* 63: 113-24.

Maun, M. A., and Lapierre, J. 1984. "The effects of burial by sand on *Ammophila breviligulata*." *Journal of Ecology* 72 (3): 827-39.

Maun, M. A., and Lapierre, J. 1986. "Effects of burial by sand on seed germination and seedling emergence of four dune species." *American Journal of Botany* 73 (3): 450-55.

McDonnell, M. J. 1981. "Trampling effects on coastal dune vegetation in the Parker River National Wildlife Refuge, Massachusetts, USA." *Biological Conservation* 21 (4): 289-31.

State of Michigan. 2001-2003. "79: P. J. Hoffmaster State Park." *Michigan Department of Natural Resources.* Accessed April 2, 2015. www.dnr.state.mi.us/publications/pdfs/wildlife/ViewingGuide/slp/79Hoffmaster/index.htm

van Dijk, D. 2014. "Short- and long-term perspectives on the evolution of a Lake Michigan foredune." in Fisher, T.G., and Hansen, E.C., eds., *Coastline and Dune Evolution along the Great Lakes: Geological Society of America Special Paper* 508: 195-216.

Voss, E.G. and A. A. Reznicek. 2012. *Field Manual of Michigan Flora.* Ann Arbor: University of Michigan Press. 990 p.

Weather Underground 2015. "Weather History for Muskegon, MI." Accessed March 18, 2015. http://www.wunderground.com/history/airport/KMKG/2014/10/29/WeeklyHistory.html

Woodhouse Jr., W. W. 2000. "Coastal sand dunes of the U.S." in Lewis, Roy R. III, ed. *Creation and Restoration of Coastal Plant Communities*. Boca Raton: CRC Press. 1-44.

Appendix A: Dune Features Inventory*

A. Site Information

1. Dune Name: ____

(If dune is unnamed, describe location.)

2. Dune is located on (check all that apply):

☐ Park Land	☐ Protected Land	☐ Private Land
☐ Municipality	☐ Conservation Easement	☐ Commercial Property
☐ County	☐ Land Trust	☐ Industrial Property
☐ State		☐ Other: __________________
☐ Federal		

3. Identify supplementary information collected for the site by completing the following checklist.

☐ Yes ☐ No ☐ Unknown a. Are there any known **publications, reports or other data** concerning this dune site? If yes, attach a list (bibliography) to the completed DFI.

☐ Yes ☐ No ☐ Unknown b. Are **aerial photographs** of the dune site available? If yes, attach a copy of the photograph(s) or list of reference numbers to the completed DFI.

☐ Yes ☐ No c. Was the **intensity of surrounding land uses** determined? If yes, attach the completed *Intensity of Surrounding Land Uses Worksheet*.

☐ Yes ☐ No d. **Location map**. Attach a copy of a county road map showing location of the DFI site.

☐ Yes ☐ No e. **Topographic map**. Attach a copy of a topographic map showing the DFI site.

☐ Yes ☐ No f. **Photographs** taken at the site. Label the photograph(s) and attach to the completed DFI.

4. Attach a landscape sketch or labeled aerial photograph. ☐ Completed ☐ Not completed
   a. Clearly indicate the site boundaries for this inventory.
   b. Label features of interest within the site (ex: dune components, management activities).
   c. Label natural (ex: beach, dunes) and human (ex: roads, buildings) features of interest near the study area.

B. Field Data Collection Information

1. Observer(s): ____

2. Date: ___________________________ Time: ____________________________

3. Walking time from vehicle to dune: ______________________

4. Weather conditions:

   Wind speed (avg): Wind direction:

5. Lake Level:_______________

Additional comments:

Last Revised: August 31, 2010

*Full DFI includes sections J-O, which were not applicable to our study.

C. Natural Features: Geomorphology

1. Site is a:
☐ Single dune ☐ Dune System

2. Dune environments present (check all that apply)
☐ Beach ☐ Blowout(s)
☐ Shadow dune ☐ Parabolic dune
☐ Incipient foredune ☐ Perched dune
☐ Foredune ☐ Interdunal wetland
☐ Dune ridge ☐ Backdune
☐ Dune and swale ☐ Other: _______________
☐ Hummocky dunes ____________________

3. Parabolic dune type (if present)
☐ Hairpin ☐ Digitate
☐ Lunate ☐ Nested
☐ Other: ___________________________________

4. Number of blowouts at site: ________________

5. Height of foredune (m):____________________

6. Orientation of foredune: ___________________
(Measure along crest)

7. Is wave action causing erosion to the dune(s)?
☐ Yes ☐ No

8. Is the foredune scarped?
☐ Yes ☐ No

9. Width of beach (m):_______________________

10. Height of dune (m):_______________________
(Measure at highest point of dune)

11. Orientation of dune: ______________________
(Measure along main axis)

12. Width (m):_______________________________
(Measure perpendicular to dune's main axis)

13. GPS location at lakeward center point of dune:

N: _____________ Elevation: ______________

W: _____________ Accuracy: ______________

14. Length (m):____________________________
(Measure along main axis)

15. GPS location at crest of dune:

N: _____________ Elevation: ______________

W: ____________ Accuracy: ______________

16. Dune Site Area (m^2): ______________________

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

Additional Comments:

E. Natural Features: Ecology

1. Ecological communities (check all that apply)
☐ Bare Sand
☐ Beach Grass/Early Colonizers
(Ex: American beach grass)
☐ Shrubland/Early Succession
(Ex: sand cherry, juniper, aspen, cottonwood)
☐ Forest
(Ex: pine, red oak, aspen, red maple)
☐ Interdunal Wetland
(Ex: St. John's-wort, shrubby cinquefoil, white-cedar)
☐ Great Lakes Barrens
(Ex: Jack pine, white pine, red pine, juniper)
☐ Other: _______________

2. Condition of the windward slope
(check all that apply and circle the most common)
☐ Bare sand
☐ Grasses/Early Colonizers
☐ Shrubland/Early Succession
☐ Scattered Trees
☐ Forest
☐ Interdunal Wetland
☐ Other: _______________

3. Condition of the dune crest
(check all that apply and circle the most common)
☐ Bare sand
☐ Grasses/Early Colonizers
☐ Shrubland/Early Succession
☐ Scattered Trees
☐ Forest
☐ Interdunal Wetland
☐ Other: _______________

4. Condition of the leeward slope
(check all that apply and circle the most common)
☐ Bare sand
☐ Grasses/Early Colonizers
☐ Shrubland/Early Succession
☐ Scattered Trees
☐ Forest
☐ Interdunal Wetland
☐ Other: _______________

5. Density of vegetation on the foredune:
☐ High (75%-100% vegetation cover)
☐ Moderate (25%-75% vegetation cover)
☐ Low (0%-25% vegetation cover)

6. Presence of Endangered, Threatened or Species of Special Concern
☐ None present
☐ Pitcher's thistle
☐ Lake Huron tansy
☐ Moonwort
☐ Other:

7. Presence of Invasive Species
☐ None present
☐ Lyme grass
☐ Garlic mustard
☐ Baby's breath
☐ Spotted knapweed
☐ Other:

8. Presence of Exotic Species
☐ None present
☐ Dandelion
☐ Chicory
☐ Bouncing bet
☐ Mullein
☐ Other:

9. How extensive was the plant survey?
☐ Complete
☐ Partial
☐ Slight
☐ Did not assess

10. Indicate the Floristic Quality Index of this site (optional):_______________________________

11. Evidence of grazing by animals (Ex: deer, rabbits)?
☐ Yes ☐ No

12. Evidence of trampling by animals (Ex: deer)?
☐ Yes ☐ No

Additional Comments:

F. Human Impacts: Human Pressure

1. Do any trails lead from a parking area to the dune?
☐ Yes ☐ No

2. Distance from trail to dune (m): _______________

3. Is the crest of the dune visible from any of the following?
☐ Not visible ☐ Road
☐ Beach ☐ Trail not on dune
☐ Parking lot ☐ Other: ________________

4. Cost of daily access to dune (in dollars): ________

5. Is an annual pass available?
☐ Yes ☐ No

6. Nearby infrastructure (give minute walk if known)
☐ Houses ____ ☐ Playground____
☐ Restrooms ____ ☐ Concession stands____
☐ Parking lot ____ ☐ Roads____
☐ Visitor center ____ ☐ Picnic shelters____
☐ Trash cans ____ ☐ Athletic areas____
☐ Swim area ____ ☐ Other: _________
Is it ☐ designated or
☐ undesignated?

7. Does infrastructure interrupt the dune system?
☐ Yes ☐ No

8. Is litter present on the dune (excluding trails)?
☐ No
☐ Scarce (e.g. 1 piece of litter approx every 50 m)
☐ Moderate amount (between scarce and common)
☐ Common (e.g. one piece of litter every 5 m)

9. Did you observe anyone on the dune?
☐ No ☐ Yes; number: _____
If yes, record number of people you saw during the inventory.

10. What were the observed people doing?
☐ Climbing dune ☐ Hiking
☐ Running down dune ☐ Observing wildlife
☐ Sunbathing ☐ Other: ________________

11. What evidence of human activities do you see?
☐ Footprints ☐ Tree forts
☐ Ski tracks ☐ Logging evidence
☐ Campsite remains ☐ Hunting evidence
☐ Campfire remains (ex: deer blinds, salt lick)
☐ Other(s): ___________________________________

G. Human Impacts: Off-Road Vehicles (ORVs)

1. Is there any evidence of ORV impacts at the site?
☐ No (*if no skip to next section*)
☐ Yes

2. Are ORVs legally permitted at the site?
☐ Yes ☐ No

3. Where are ORV impacts observed?
☐ On managed trails ☐ Off the trails
☐ On unmanaged trails

4. Are ORV marks recent?
☐ Yes ☐ No

5. Estimate the intensity of ORV use:
☐ Occasional- less than several times per year
☐ Intermediate
☐ Frequent- greater than 10 per day

6. Locations of the dune impacted by ORVs
(check all that apply)
☐ Beach ☐ Blowout(s)
☐ Foredune ☐ Parabolic dune
☐ Windward ☐ Windward
☐ Crest ☐ Crest
☐ Leeward ☐ Slipface
☐ Dune ridge ☐ Arms
☐ Windward ☐ Bottom of slipface
☐ Crest ☐ Perched dune
☐ Leeward ☐ Windward
☐ Dune and swale ☐ Leeward
☐ Ridge ☐ Interdunal wetland
☐ Trough ☐ Backdune
☐ Hummocky dunes ☐ Other:_______________

H. Human Impacts: **Unmanaged Trails**

1. Are unmanaged trails present?
☐ No (*if no skip to next section*)
☐ Yes

2. Location of trails (check all that apply)

☐ Beach	☐ Blowout(s)
☐ Foredune	☐ Parabolic dune
☐ Windward	☐ Windward
☐ Crest	☐ Crest
☐ Leeward	☐ Slipface
☐ Dune ridge	☐ Arms
☐ Windward	☐ Bottom of slipface
☐ Crest	☐ Perched dune
☐ Leeward	☐ Windward
☐ Dune and swale	☐ Leeward
☐ Ridge	☐ Interdunal wetland
☐ Trough	☐ Backdune
☐ Hummocky dunes	☐ Other:________________

3. Which of the above locations has the highest trail density?

4. Describe the intensity of the trail system
☐ Low- 1 or 2 trails on each dune
☐ Intermediate
☐ High- interconnected network of trails on dune

5. Vegetation on trails (check all that apply)
☐ No vegetation on trail
☐ Sparse vegetation on trail
☐ Trail overgrown with bare portions visible
☐ Trail completely vegetated

6. Are any trails incised greater than 5 cm?
☐ Yes ☐ No

7. Is litter present along the trails?
☐ No
☐ Scarce (e.g. 1 piece of litter approx every 50 m)
☐ Moderate amount (between scarce and common)
☐ Common (e.g. one piece of litter every 5 m)

8. Trail widths (Optional): ______________________

I. Management: Managed Trails

1. Are managed trails (excluding boardwalks) present?
☐ No (*if no skip to next section*)
☐ Yes

2. Location of trails (check all that apply)

☐ Beach	☐ Blowout(s)
☐ Foredune	☐ Parabolic dune
☐ Windward	☐ Windward
☐ Crest	☐ Crest
☐ Leeward	☐ Slipface
☐ Dune ridge	☐ Arms
☐ Windward	☐ Bottom of slipface
☐ Crest	☐ Perched dune
☐ Leeward	☐ Windward
☐ Dune and swale	☐ Leeward
☐ Ridge	☐ Interdunal wetland
☐ Trough	☐ Backdune
☐ Hummocky dunes	☐ Other:________________

3. Trail surface (check all that apply)

☐ Soil	☐ Sand
☐ Grass	☐ Gravel
☐ Wood chips	☐ Paved (concrete/asphalt)
☐ Paving stones	☐ Other: ____________

4. How are the trails indicated? (check all that apply)
☐ No indications
☐ Signs or markings along a trail
☐ Trail appears on a map
☐ Pamphlet at the start of trail
☐ Trail composition different than surrounding area

5. Vegetation on trails (check all that apply)
☐ No vegetation on trail
☐ Sparse vegetation on trail
☐ Trail overgrown with bare portions visible
☐ Trail completely vegetated

6. Does the trail have railings?
☐ Yes ☐ Some sections do ☐ No

7. Are any trails incised greater than 5 cm?
☐ Yes ☐ No

8. Is litter present along the trails?
☐ No
☐ Scarce (e.g. 1 piece of litter approx every 50 m)
☐ Moderate amount (between scarce and common)
☐ Common (e.g. one piece of litter every 5 m)

9. Trail widths (Optional) ____________

Appendix B: Weather data

Site weather data were collected at the beginning of each observation period, and compiled with averaged weekly wind data recorded at a foredune study site approximately 469 m (1,538 feet) south of site C. Weekly temperature and precipitation data were recorded at Muskegon County Airport (Weather Underground 2015), approximately 5 km (3 mi) northeast of P.J. Hoffmaster State Park.

	Weekly data	**Site data**
Week 1	**October 19-25**	**October 23**
Temperature (˚C)	9	14.3
Precipitation (mm)	0.1	Not collected
Average wind speed (m/s)	3.2	1.6
Wind direction	Variable*	SW (232˚)
Week 2	**October 26-November 1**	**October 30**
Temperature (˚C)	8.9	10.8
Precipitation (mm)	1.3	Not collected
Average wind speed (m/s)	4.5	2.2
Wind direction	Variable**	WSW (244˚)
Week 3	**November 2-8**	**November 6**
Temperature (˚C)	7.2	5.5
Precipitation (mm)	1.5	Not collected
Average wind speed (m/s)	5.8	5.7
Wind direction	Variable***	NNE (18˚)

*

Date	**Direction**
October 19	SSE (169˚)
October 20	WNW (288˚)
October 21	N (357˚)
October 22	NE (37˚)
October 23	ESE (116˚)
October 24	SW (226˚)
October 25	W (274˚)

**

Date	**Direction**
October 26	NNW (340˚)
October 27	SE (140˚)
October 28	WSW (250˚)
October 29	NW (317˚)
October 30	WSW (257˚)
October 31	NNW (346˚)
November 1	N (0˚)

***

Date	**Direction**
November 2	SE (139˚)
November 3	SSW (194˚)
November 4	SW (229˚)
November 5	W (264˚)
November 6	NNW (344˚)
November 7	E (95˚)
November 8	SW (278˚)