First-Year Research in Earth Sciences: Dunes

Oak Wilt and Dune Stability in North Ottawa Dunes

by Rebecca L. King, Edward R. Lambert, Benjamin W. Steenwyk, Jaimie E. Van De Burg, Jonathan D. Walt, Matt Wierenga, Elizabeth Wiley

FYRES: Dunes Research Report #26
June 2017

Department of Geology, Geography and Environmental Studies
Calvin College
Grand Rapids, Michigan

Abstract

Slope stability in coastal dune environments is threatened when surface stabilizers are removed. In North Ottawa Dunes, located in western Michigan, an infectious fungal disease requires the removal of hundreds of oak trees, which have extensive root systems used to maintain slopes. Our study investigated the vulnerability of the slope in areas marked for treatment. Using Trimble GPS devices, we mapped tree cover in two areas marked for tree removal and imported the data into ArcGIS to create a map showing the impact removal will have on these two areas. We analyzed DEM data to predict future slope instabilities based on slope angles, dune environment, and tree density. Surprisingly, a flat area may be more vulnerable to erosion following treatment as compared to a steeply sloped area where there are lower concentrations of oak trees. Our analysis also shows that new methods of mitigation are able to decrease tree mortality significantly, minimizing the impact of removal.

Introduction

Ceratocystis fagacearum is a fungus that infects oak trees and causes the disease oak wilt (Figure 1). This disease has spread throughout many states in the Midwest, including Michigan. The managers of the North Ottawa Dunes county park have recently discovered oak wilt has begun to infect a few red oak trees, requiring quick treatment to stop the spread of the disease. At the request of Ottawa County, this study aims to discover the spatial characteristics of oak trees in North Ottawa Dunes and to predict the impact of removing these trees on the stability of the dunes. Our study had three main objectives:

- To determine oak tree density and spatial patterns in the study areas with the infected trees.
- To create an impact map that displays mitigation areas where trees will be removed and calculate approximate number of trees saved.
- To predict future dune stabilities after the decomposition of oak tree roots.

Figure 1: Oak tree infected with oak wilt in North Ottawa Dunes, Michigan

Background

Oak trees play diverse roles in a dune environment. Trees can be critical in stability, centers for biodiversity, and barriers that trap sand and build the dune. Most notably, the extensive root systems of oak trees allow them to contribute to soil cohesion, making them key stabilizers of slopes (Ji *et al.* 2012). Due to their role in providing stability, removal of even one tree can have erosional impacts and can cause slope instability (Ali *et al.* 2012). While the impact of removing a large number of oak trees on a dune is still not well known, any removal of these trees is likely to cause an impact on the dune environment.

C. fagacearum, commonly known as oak wilt, first appeared in the United States in 1944 and has spread throughout much of the Midwest (Haight *et al.* 2011). It is considered to be the most dangerous disease threatening oak trees in North America and potentially the most destructive forest pathogen due to the rapid speed at which it can kill the tree hosts (Wilson and Lester 2002). Although it can impact any species of oak, red oak trees (*Quercus rubra*) are highly susceptible to infection (Saito *et al.* 2016). The infection period can vary depending on the species of oak; however, infected trees usually die within a year (Wilson 2001). Oak wilt is able to spread through two main methods: beetle transport and subterraneous root grafting.

The first method of spreading involves the transport and spread of spores via oak sap beetles (*Nitidulidae*) and bark beetles (*Scolytidae*) (Wilson 2001). A severe infection of oak wilt leads to a fungal mat being produced beneath the bark of the oak tree, which is exposed as the bark begins to fall from the tree. This mat releases an odor that attracts the beetles, which then involuntarily pick up spores (Saito *et al.* 2016). Beetles then feed on other trees, perpetuating the spread of oak wilt. While beetles can be a vector in spreading the disease in the United States, they are widely considered to be inefficient transmitters and therefore root grafting is much more relevant in the Midwest (Wilson 2001).

The second method through which oak wilt is transported occurs subterraneously and involves the tree's root system. Well-forested areas contain vast networks of interconnected root systems called grafts, which the fungus can use to travel from one oak tree to another (Wilson and Lester 2002). These grafts can occur at distances of almost 30 meters (100 feet) from one tree causing the need for large treatment areas to stop the spread of the disease. Furthermore, sandy soils, such as those found on wooded dunes, encourage greater spread of root systems and can expand the distance at which the infection can spread (O'Brien *et al.* 2011).

In soft, sandy soils with extensive root networks, the only way to protect an area is through the removal and destruction of infected trees. This process stops the spread of the fungus and can be done in several ways; however, each treatment has a lasting impact on the dune environment (Pollen-Bankhead *et al.* 2009). Standard treatment practices for areas infected with oak wilt involve severing underground root systems by trenching to a depth of 1.5 meters, followed by destroying all the above-ground material with spore-producing potential (Frei 2015.) In some cases, trench inserts are added to prevent the continued spread from root grafts that commonly grow through the trench and further the spread (Wilson and Lester 2002). In cases where inserts are not used, removal is often followed by chemical treatment with fungicides as a preventive measure for trees across the trench. These treatments are destructive and expensive as they involve large equipment that can have lasting impacts on the delicate dune environment (Haight *et al.* 2011).

An experimental treatment, which has been used in parks in the Midwest, seeks to reduce destruction and limit the amount of trees killed. This experimental treatment involves identifying an oak tree that has been infected with oak wilt and creating an infection zone circle with a radius of 50 meters, with the infected oak at its center. Every oak tree within the circle, whether infected or healthy, is killed and the trunks removed (Manion 2016). Ideally, this treatment will reduce the total number of trees killed, and it does not involve as much heavy equipment as the standard treatment.

In a well-established dune system, the loss of tree cover can be devastating, both for sediment stability and biodiversity (Pollen-Bankhead *et al.* 2009). While necessary, the removal of trees may cause remobilization of sediments, which alter the dynamics of the system leading to stress on other vegetation in the area and even on residential properties (Schwarz *et al.* 2010). In studies involving the removal of established tree root systems, erosion has been shown to increase up to 300% of its original level, while removal of grasses has been shown to increase erosion by at least 30% (Eamer *et al.* 2011).

On dunes that have steeper slopes, tree removal can lead to the possibility of mass movements and slope failure. In studies testing soil-root interactions and their effects on slope stability, trees increased the factor of safety on slopes by as much as 8%, especially if they were placed at the toe of the slope (Ali *et al.* 2012). Furthermore, the removal of one species of tree, such as oaks, can put stresses on other trees in the area and lead to tree root failure due to increase stress (Schwarz *et al.* 2010). Additionally, the possibility of perpetuating and creating blowouts, both on slopes and flat land, should be considered when removing vegetation, as vegetation is a stabilizer (Forman *et al.* 2008). In light of these impacts, vegetation removal due to oak wilt has the possibility of transforming and destabilizing a dune environment (Forman *et al.* 2008).

Study Areas

The study was conducted in North Ottawa Dunes, a county park located in Ottawa County, Michigan (Figure 2). The area of the park is 593 acres of forested dunes, with terrain that varies from flat to steep (Ottawa County 2017). The park contains a well-established dune system bordered by Lake Michigan to the west and residential properties and a road cutting off the dunes to the east. Vegetation consists mainly of established trees with ferns and grasses filling in the open areas.

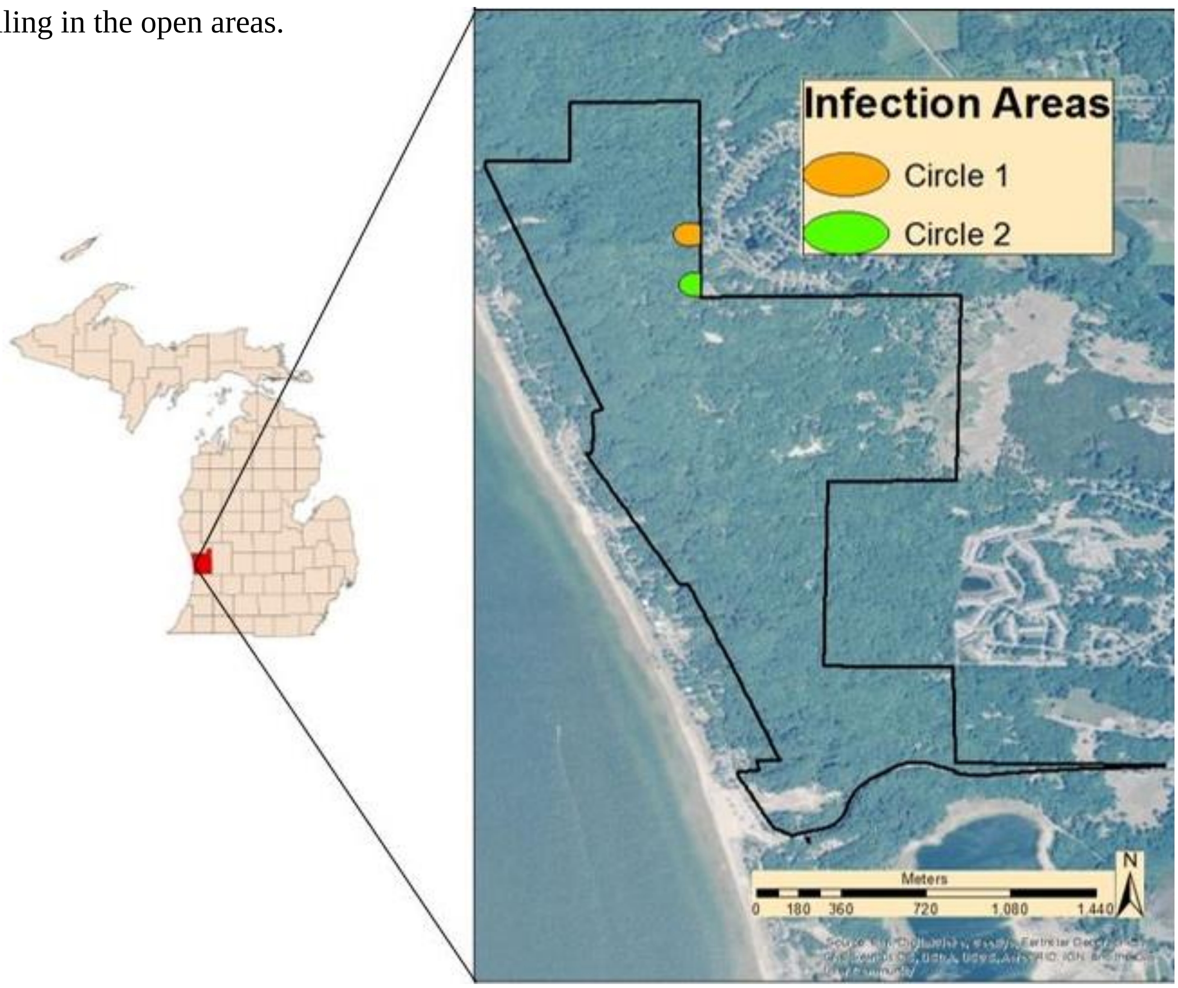

Figure 2: Map of North Ottawa Dunes with study area locations indicated.

In 2016, dune managers discovered an oak wilt infestation within the park boundaries, which prompted concerns about the stability of the dunes post-treatment. The oak wilt infestation has manifested on the northeastern half of the park bordering P.J. Hoffmaster State Park and the residential properties. Our study focused on two areas where infection had been found. The infestation areas consisted of two partial circles pre-determined by park managers to be future treatment areas. Both of these circles are located on the eastern edge of the park (see figure 2), bordering private property where the oak wilt is believed to have originated and penetrated park boundaries. The two study areas are located 213 meters from each other and each has a deceased red oak tree in the center. These two areas each have a radius of 50 meters (150 feet), but are cut off by the park boundaries to the east.

Methods

Data Collection

From October 27 through November 10, 2016, we set up our study areas and collected tree data and dune environment data. Our first step was to identify the infected oak tree at each study area, which became the center of the circle at both of the study areas (Figure 3). After identification, 50 meters of twine were measured out in four directions and fixed to posts placed in the ground, creating the boundaries for a circle with a radius of 50 meters. Using Trimble GPS devices, each tree inside the circle was recorded, including red oaks, white oaks, and other trees.

Figure 3: The oak used for the center of Circle 2. Twine extends from the tree in four directions, outlining the study areas.

The GPS and species data was entered in ESRI's ArcGIS software. Spatial density tools in ArcGIS were used to calculate the density of oak trees and other trees in the area. The calculated data was then used to create a map that illustrates the spatial characteristics of the two infected areas, such as tree density, location of trees on slope, elevation and slope angle, and the presence of blowouts.

Using ArcGIS, spatial analysis of the study areas yielded a map displaying the spatial characteristics of the infection area. We obtained digital elevation model (DEM) data from Ottawa County and used the data to show the slope and elevation of each area. Slopes and elevations were combined with oak tree density data and mapped erosion areas in order to determine the stability of the dune environment. The result was a map outlining the locations most likely to see erosional impacts after the removal of trees. Additional analysis using oak tree density extrapolated for the entire park and the density of the two circles allowed for the estimation of number of trees saved using the new mitigation method.

Creating an Impact Map

In ArcGIS, we imported oak tree GPS data and projected it in order to determine the spatial patterns and calculate density. Density was calculated using the sum of the oak trees located in each circle divided by the area. This provided us with the true density of each of our sample sites. After discovering the true density, we used information given to us by park managers to approximate a 1-mile long trench, which would have been the mitigation area for standard treatment. We drew this approximate trench location in ESRI ArcGIS in order to compare it to our study site, which is the mitigation area for the experimental treatment.

In order to represent a comparative view of tree casualities, we used ArcGIS tools and previously projected maps of Ottawa County. We used a map created by Wierenga *et al.* (2017), which defined the park into separate environments and extrapolated the approximate tree densities in each of those environments. Using ArcGIS, we determined how many trees existed in the approximate location the traditional trench would have been placed. Each dune environment that existed inside the trench boundaries were clipped and the tree density of those areas were added. This allowed us to determine the total number of trees that would have been killed using the traditional trenching method. The tree casualties from these two different mitigation techniques, the circles in our study area and the trench, were then compared.

Predicting Dune Instabilities after the Decomposition of Roots

The impact of root decomposition on dune slopes was predicted using the pre-existing digital elevation model (DEM) from Ottawa County. The DEM was used to determine the slope angles and elevation of the two affected areas. Other variables, such as previous evidence of erosion or human impacts, were also analyzed in ArcGIS and were used to predict future dune instabilities.

The elevation was classified into three categories using natural breaks: high elevation, medium elevation, and low elevation. Classification was first completed for Circle 1, and then the natural breaks had to be adjusted for Circle 2 because the dune areas had different elevation ranges (Table 1). In Circle 1, the lowest elevation category was 592-613 feet[1]; however, Circle 2 does not have any elevation points below 611 feet. Furthermore, the highest elevation category for Circle 1 was 681-738 feet; however, Circle 2 had no elevation points above 653 feet.

Elevation	Circle 1	Circle 2
Low	592-613 feet	611-622 feet
Medium	613-681 feet	623-637 feet
High	681-783 feet	638-653 feet

Table 1: Criteria used for classifying elevation using natural breaks in ArcGIS.

The sloped areas were classified into two categories: flat areas with slope angles less than 10° and sloped areas with angles greater than 10°. Slope and elevation classifications were combined to create three slope environments: toe of slope, medium slope, and crest of slope (Table 2). We further analyzed the study circles for critical areas of high slopes, which we defined as areas over the angle of repose (33°), which are in danger of exhibiting slope failure after the decomposition of the roots.

Slope Environment	Elevation	Slope
Toe of Slope	Low to medium	Flat
Medium Slope	Low, medium, or high	Sloped
Crest of Slope	High	Flat

Table 2: Criteria used for classifying slope environments.

[1] Feet instead of meters was used for this analysis because of the units in the DEM.

Results

Characteristics of Study Areas

Despite their proximity to each other, each study area has a different dune environment. The first infection area, Circle 1, is located on a steeply sloped dune with some slope angles reaching above 33°. Minor cases of slope failure are seen throughout the circle in steeper areas where the root networks failed to support the sand (Figure 4). A park path cuts through this circle and therefore vegetation has already been removed along the trail. The second infection area, Circle 2, is located on relatively horizontal ground far away from paths leading into the park. This area is much closer to the residential properties and numerous blowouts already exist, with some evidence of human impacts (Figure 5).

▲Figure 4. Localized slope failure in Circle 1. Soil horizons and tree roots are exposed. For scale, the yellow abney level is 12.5 cm long.

◄Figure 5. One of many blowouts in Circle 2. This blowout is cluttered with tree debris.

The tree cover of each of the study areas also varied (Table 3). Circle 1 had a higher tree concentration, with 701 total trees, 110 of which are oaks. Circle 2 had a lower tree concentration, with 383 total trees, but it had a higher number of oak trees (235 in total).

Tree Position	Circle 1	Circle 1	Circle 2	Circle 2
	Oak Trees	Other Trees	Oak Trees	Other Trees
Toe of Slope	20	114	61	27
Middle Slope	90	472	138	118
Crest of Slope	0	5	8	3
Blowout Edge	0	0	28	14

Table 3: Trees present in each study area.

Calculation of Approximate Number of Trees Saved

Although experimental treatment areas covered a much larger space (12,465.3 m^2) compared to the standard treatment trenching area (3,463.2 m^2), the new experimental mitigation effort reduces tree mortality overall. When comparing tree cover, the experimental treatment areas contained more oak trees (326) and more total trees (1,071) compared to the trenching area, which had 215 oak trees and 600 total trees (Figure 6). Since the experimental method kills only oak trees while standard treatment kills all trees in the trenched area, a total of 274 trees are saved using the experimental method.

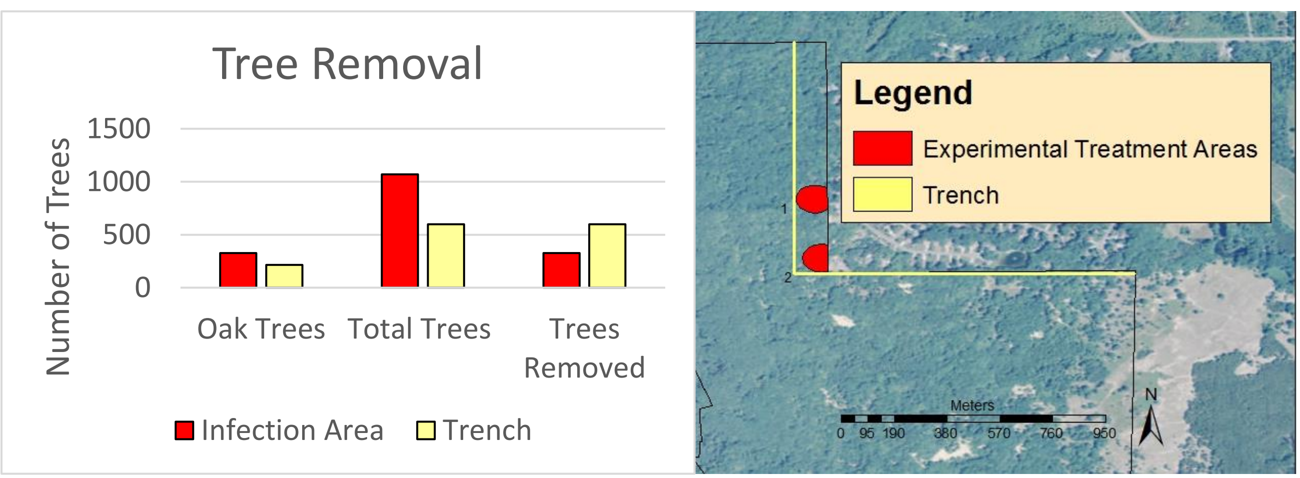

Figure 6: Comparison of experimental and standard treatment areas. Graph shows number of trees and expected removal for each area. Map shows locations and relative sizes of areas.

The two areas in the experimental treatment zone exist in two different environments and therefore the variables affecting stability will differ after tree removal. In Circle 1, the ratio of oak trees to other species is much smaller than Circle 2 (Figure 7). After treatment, 16% of trees will be removed from Circle 1 compared to 58% of trees from Circle 2. Additionally, a greater portion of Circle 2 has areas defined as the toe of slope compared to Circle 1, and Circle 2 has blowout areas that are non-existent in Circle 1 (Figure 8).

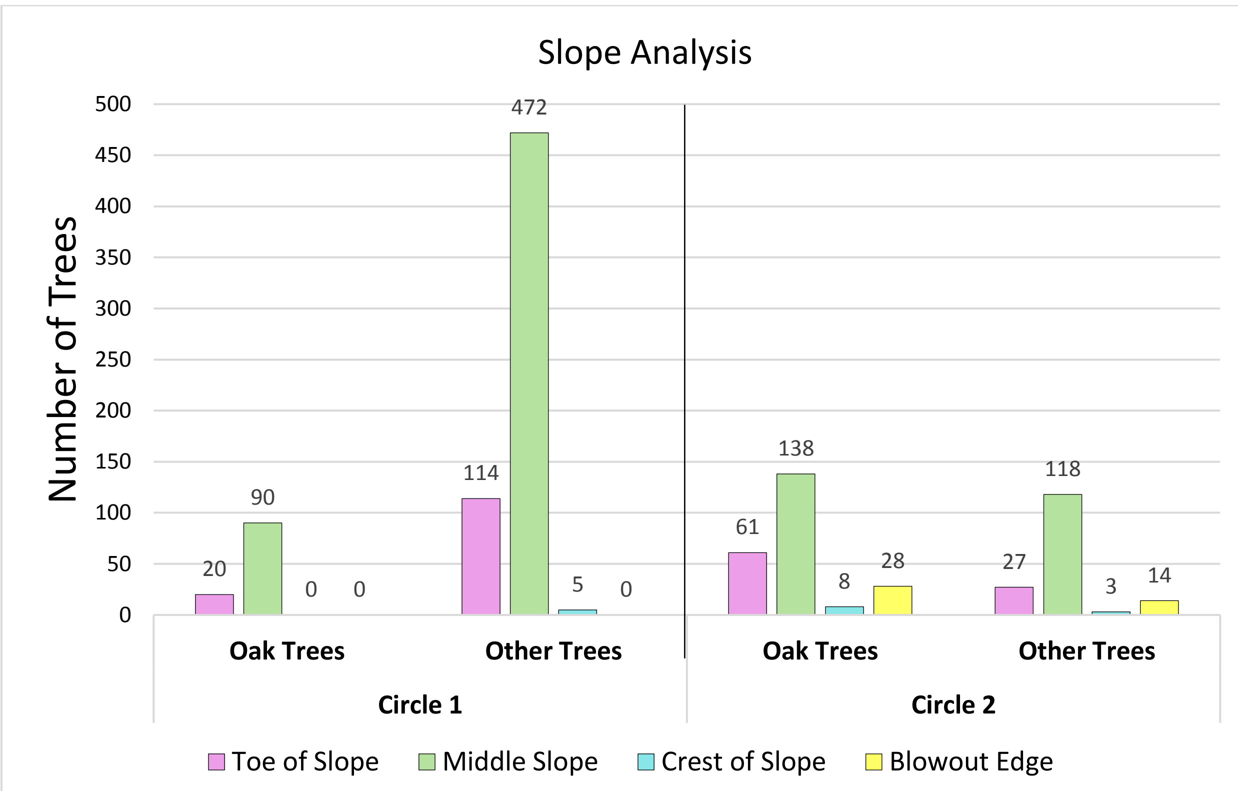

Figure 7: Number of trees in each dune environment in Circles 1 and 2.

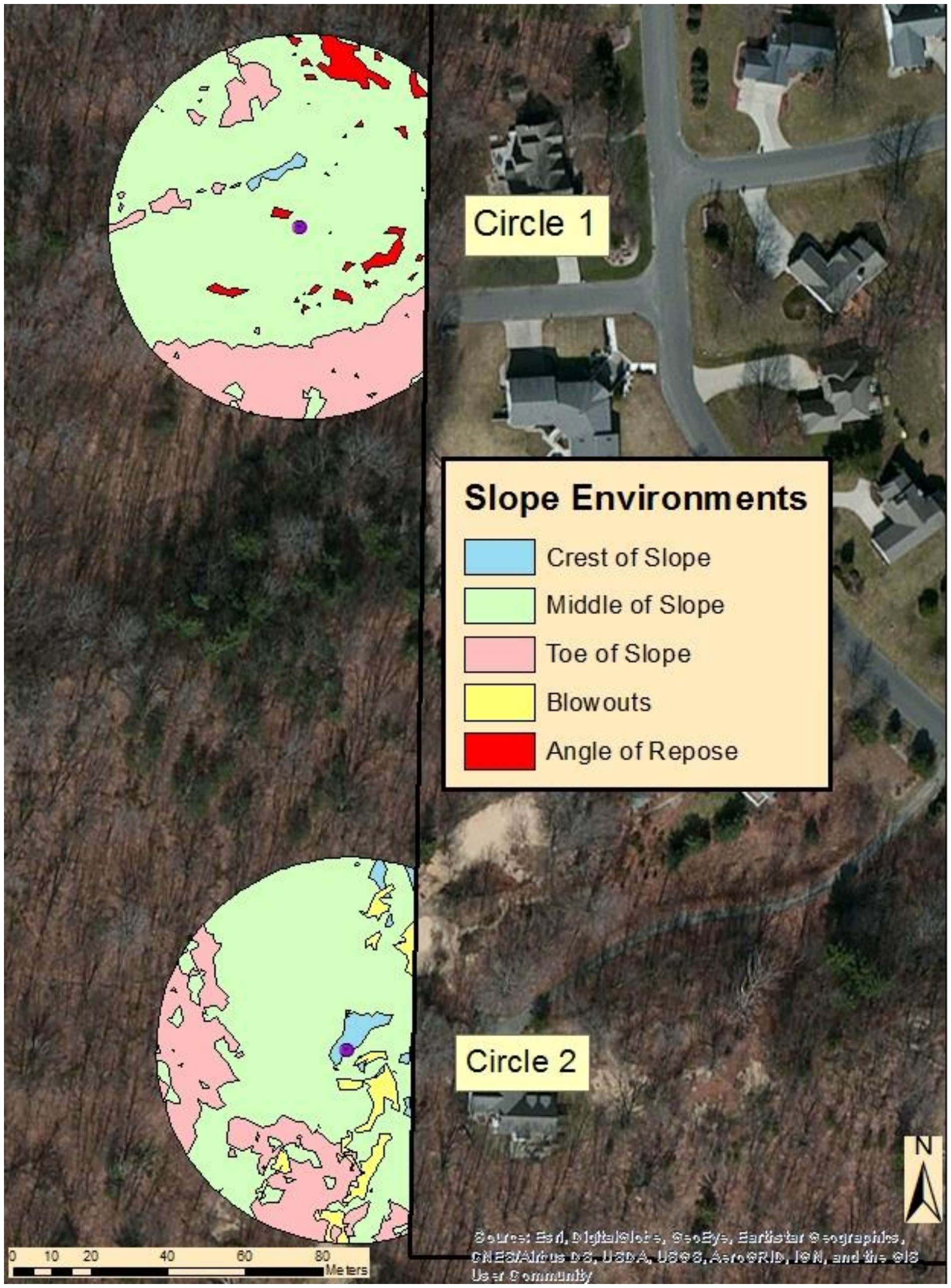

Figure 8: Spatial patterns of dune environments in Circles 1 and 2.

Discussion

Results indicate that the experimental treatment saves trees overall, even when the mitigation areas are larger. The reduction of tree mortality is due to the standard treatment method requiring all trees to be killed within the trench, whereas the new mitigation method only kills oak trees within the specified radius from infected trees.

The property line created an interesting challenge for our work because the circles are on only part of the Ottawa County park property and the remainder of the infection was on private property. Since mitigation is only occurring in the park and not on private property, we did not account for those trees in the tree mortality count. Some of the trees along the property line may have been included in our numbers, despite them being located on private property. We corrected this possible mistake in ArcGIS by clipping out the individual trees that were located outside of the property line.

Our slope stability predictions are adapted from the work of Ali *et al.* (2012), who determined the slope stability of the toe of slope, middle of slope, and crest of slope with or without the presence of a tree. We divided our study areas into environments based on those criteria, although we did not plug our variables into their categories to calculate numeric values for dune instability. Quantifying the analysis may be an interesting direction for future research. Using Ali *et al.* (2012), we predicted that the toe of the slope is the most critical location for tree removal and is most likely to become destabilized. The crest of the slope is less critical and removal may actually be beneficial to slope stability. Trees at the top of the slope can add weight, which can be problematic when disturbances happen downslope. This analysis is based on the factor of safety, which is calculated as the ratio of the resisting forces or available shear strength to the disturbing forces or shear force. The factor of safety takes into account factors such as gravity and soil root interaction to calculate the most critical location of the slope during a tree removal event.

Results suggest that Circle 2 is more likely to experience dune instability, including erosional impacts, than Circle 1. Since the ratio of oak trees to other tree species is much higher in Circle 2 compared to Circle 1, a greater percentage of the overall vegetation will be removed. The removal might increase the size of blowouts already in existence in the area. This is especially true for the trees being removed from the toe of slope, which is the most vulnerable area (Ali *et al.* 2012). Circle 1, despite being located on a very steep hill, has a lower ratio of oak trees to other trees which will continue to help stabilize the dune after mitigation.

Due to our analysis, we recommend that dune managers monitor Circle 2 further after the tree mitigation event. This monitoring will enable park managers to identify areas experiencing erosional impacts and focus more recovery attention where needed. Dune managers should use best known practices to stabilize the dune. This attention could include such activities as targeted planting of native grasses or trees. By planting native grasses and trees before the decomposition of roots, the dune managers may be able to stop the blowouts in this area from increasing in size.

Conclusion

Ceratocystis fagacearum, the fungus that causes oak wilt, has spread to North Ottawa Dunes, mandating the need to mitigate the impacts of oak wilt by removing oak trees. Using data collected in the field and ArcGIS, we were able to analyze the spatial distribution of oak trees in two future treatment areas and determine the likely repercussions of oak tree removal on slope stability. We determined that Circle 2, the southern-most study area, is the most likely to see erosional impacts after the removal due to the high concentration of oak trees and the already existing blowouts. Future monitoring in this area after mitigation will indicate whether management techniques, such as planting trees will be needed to stabilize the location.

We were also able to estimate the number of trees that will be saved by switching to an experimental treatment method as opposed to a traditional trench mitigation method. The new experimental method only kills 274 trees, whereas the traditional trenching method kills roughly 600 trees. This leads to the conclusion that the experimental treatment will decrease the tree mortality in the area by approximately 274 trees.

Acknowledgments

We would like to give special thanks to the following:

- Dr. Deanna van Dijk, for her support and guidance throughout our study.
- North Ottawa County GIS Department for sending us the North Ottawa Dune DEM data.
- Ottawa County Parks and Recreation for allowing us access to their park.
- Melanie Manion for providing the information about the treatment areas and asking us to conduct this study.
- Calvin College for providing us with the resources we needed to complete this study.
- The Michigan Space Grant Consortium (NASA) for the financial support that made this study possible.

Works Cited

Ali, N., I. Farshchi, M. A. Mu'azu, and S. W. Rees. 2012. "Soil-root interaction and effects on slope stability analysis." *Electronic Journal of Geotechnical Engineering* 17 (Bund. C): 319-328.

Eamer, J. B., I. B. Darke, and I. J. Walker. 2013. "Geomorphic and sediment volume responses of a coastal dune complex following invasive vegetation removal." *Earth Surface Processes and Landforms* 38 (10): 1148-1159.

Forman, S. L., Z. Sagintayev, M. Sultan, S. Smith, R. Becker, M. Kendall, and L. Marin. 2008. "The twentieth-century migration of parabolic dunes and wetland formation at Cape Cod National Sea Shore, Massachusetts, USA: Landscape response to a legacy of environmental disturbance." *The Holocene* 18 (5): 765-774.

Frei, H. 2015. "Beyond the usual suspects in invasive species control: Detection and control of oak wilt, *Ceratocystis fagacearum*, in Michigan State Parks." Stewardship Network Conference 2015. www.stewardshipnetwork.org/topics/2015-conference. 1-37.

Haight, G. R., F. R. Homans, T. Horie, S. V. Mehta, D. J. Smith, and R. C. Venette. 2011. "Assessing the cost of an invasive forest pathogen: A case study with oak wilt." *Environmental Management* 47: 506-517.

Ji, J., N. Kokutse, M. Genet, T. Fourcaud, and Z. Zhang. 2012. "Effect of spatial variation of tree root characteristics on slope stability. A case study on Black Locust (*Robinia pseudoacacia*) and Arborvitae (*Platycladus orientalis*) stands on the Loess Plateau, China." *Catena* 92: 139-154.

Manion, M. 2016. Personal communication in a telephone conversation with Deanna van Dijk on October 26, 2016.

Ottawa County. 2017. "North Ottawa Dunes." *Ottawa County Parks and Recreation Commission.* Accessed May 17, 2017. http://www.miottawa.org/Parks/dunes.htm

O'Brien, J. G., M. E. Mielke, D. Starkey, and J. Juzwik. 2011. "How to identify, prevent, and control oak wilt." United States Department of Agriculture and Forest Service NA-FR-01-11 (www.na.fs.fed.us): 1-38.

Pollen-Bankhead, N., A. Simon, K. Jaeger, and E. Wohl. 2009. "Destabilization of streambanks by removal of invasive species in Canyon de Chelly National Monument, Arizona." *Geomorphology* 103 (3): 363-374.

Saito, S., K. Hiroshi, A. Takahashi, M. Okada, and H. Miguchi. 2016. "Reducing damage caused by oak wilt disease transmitted by the ambrosia beetle *Platypus quercivorus* (Coleoptera: Platypodidae) using oak log pile traps." *Applied Entomology and Zoology* 51 (2): 267-274.

Schwarz, M., P. Lehmann, and D. Or. 2010. "Quantifying lateral root reinforcement in steep slopes: from a bundle of roots to tree stands." *Earth Surface Processes and Landforms* 35 (3): 354-367.

Wierenga, M., C. E. Boraby, C. S. Doan, T. J. R. Huizenga, and H. Pham. 2017. "Distribution of oak trees on North Ottawa Dunes." Calvin College. FYRES: Dunes Research Report #28: 10p.

Wilson, A.D. 2001. "Oak wilt: A potential threat to southern and western Oak Forests." *Journal of Forestry*. 99 (5): 4-12.

Wilson, A.D., and D. G. Lester 2002. "Trench inserts as long-term barriers to root transmission for control of oak wilt." *Plant Disease* 86 (10): 1067-1074.