Species diversity across the dune swales of Lake Michigan at Sturgeon Bay

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Abstract

The dune system of Lake Michigan at Sturgeon Bay leads back thousands of years into the surrounding forest and intermittently form small pools in the swales of the dunes. Maintained by rainwater and including a unique composition of species and chemistry, the pools of the dunes and the surrounding terrestrial life show a pattern of diversity unique to dune swales. Percent cover of species at four different swales of the dune system at Sturgeon Bay were effective in showing the differences in diversity, evenness, and species richness patterns across swales and within the dunes, separating the terrestrial and lentic elements to also discover differences between the two substrates. Diversity between aquatic and terrestrial areas was found to differ greatly, with terrestrial species following the pattern of increasing diversity as age increased. The aquatic species pattern did not follow this, and instead the diversity decreased from swales 1 to 3, and then increased in swale 4. Evenness across dune swales initially increased from the first to the second swale, and then dropped considerably from the second to the fourth swale. Richness followed the same pattern of evenness, and decreased from the second swale to the fourth. This data concluded that species diversity across swales cannot be lumped together with aquatic and terrestrial elements, and instead both elements must be considered separately, as they have different successional patterns. While terrestrial succession matches that of older research, the lentic patterns were very different.

Introduction

Dune formation provides a chronosequence of primary succession which displays the habitual pattern of species interactions and diversity. The formation of dunes provides a sound study for soil development, species colonization and interaction, and ecosystem changes, as the newly formed dunes must be first colonized and develop from there (Albert 2006). This primary succession provides a study firstly for chronosequence and succession of these dune systems, and secondly of how species interact and change over older dune swales through nonlinear development. Forest expansion as a result of dune formation is a normal result of the formation of both shore-parallel and parabolic dunes, providing diverse ecosystems to be studied in their own right (Lichter 1998). The colonization of grass species is the first species to stabilize the dunes, allowing for further colonization (Hemminga & Duarte 2000), which leads to the creation of a forest. The resulting land physiography in conjunction with the growing forest creates an interesting ability of the ecosystems to form swamp-like pools far back in the lake-surrounding forests in the swales of the older dunes, each colonized by different species and aged centuries apart (Albert 2003).

As the dune systems continuously grow with the addition of more dunes and the forest continues to expand, the colonizing species and successful species begin to change. Initially, seeds of colonizing species are brought in from dispersal from older to younger dunes, as in from the direction of the forest to the direction of the shoreline (Lichter 1998). The shoreline of Lake Michigan has little effect on the actual species compositions of the swales, instead being credited for both dune formation and possible swale formation depending on proximity of the swale to the shoreline (Albert 2003, Lichter 1995). Swales are established by water from the lake, but are maintained by the addition of rainwater. Because of this, the chemical balance of the lake has no gravity on that of the swales, though the soil development of the forests on the dune physiography can affect the chemical aspects of the swale and therefore the species of the swales. Climatic disturbances can also skew dune succession, as a study suggests that plant communities in foredune, interdune, and backdune habitats tend towards succession to a particular species composition (Miller et al 2010).

The purpose of this research is to determine species diversity in the swales of the dunes and the terrestrial life surrounding them at Wilderness State Park, MI off the shore of Lake Michigan. The species diversity, displayed through the Shannon Wiener Diversity Index, can further show the type of ecosystem the swale exists in. The factors determining the diversity can be hypothesized, as age of the dunes, climate, light tolerance, and soil or chemical development, are all variable factors between dunes. Past research has focused on the succession of plants alone dune ridges, only sampling the tops and sides of the ridge. It was found that diversity generally increases from the shore (Lichter 1998). This research focuses on which dune swales contain the most diversity, not the cause. The hypothesis is the older dune swales will contain the greatest plant species diversity and the greatest species evenness.

Methods

I. Vegetation analysis

A quarter-meter^2 PVC pipe quadrant was thrown randomly ten times within the dunes swale and was dropped five times on either side of the dune swale. The quadrants on either side of the swale were established with one edge of the quadrant right on the edge of the pool, so it contained the species in the transition zone between water and dry land. The percent cover of plant species present were recorded, with bare soil being counted if there was no vegetation on top of the water or in that space in the water. A meter stick was used to measure the average depth of the dune swale. The depth was measured every two steps and was repeated lengthwise twice per swale. New species at each swale were collected and kept in a herbarium for further identification. The swales were found going chronologically from the shoreline of Lake Michigan, so later swales were established earlier and were therefore older.

II. Statistical analysis

The Shannon Wiener Index (H) was used to analyze the diversity of the swales studied. The Shannon Wiener Index characterizes for species diversity in communities, taking into account both species evenness and species abundance. The index indicates which communities show higher diversity and higher evenness than others, with species evenness computing on a range from zero to one, with one meaning complete species evenness. Evenness between swales was compared, as well as was the H-values of the swales to indicate which swale is more diverse. A kruskal-wallis test and subsequent multiple comparison tests of both species richness and diversity were done. Boxplots were subsequently created, also comparing species richness and diversity (H) within swales and producing p-values.

Results

There was a difference in diversity of aquatic species between the first and third, first and fourth, second and third, and second and fourth swales. At 95% confidence (p-value=0.05), there was not a significant difference between the first and second, and third and fourth swales (Figure 4). Inversely, the terrestrial species had significant differences between the first and second, first and third, second and fourth, and third and fourth swales, whereas there was no difference in swales 1-4 or 2-3 (Figure 5). Testing these two in conjunction, as in lumping the lentic and terrestrial species together, showed significant difference of H between swales 2 and 4, and no difference in the other five swale combinations. The H-values of these swales was highest in swale 2 followed by swale 3, with swale 4 having the smallest H-value and swale 1 having the second smallest H-value (1= 1.08, 2=1.24, 3=1.10, 4=0.86)(Table 2)(Figure 3). Statistical tests of richness also showed significant difference with 95% confidence. Richness of the lentic species had differences in the first and third, first and fourth, second and third, and second and fourth swales (Figure 6). The richness of terrestrial species of the swales showed statistical difference in swales 1-2, 2-4, and 3-4 (Figure 7). The overall species richness between swales of both lentic and terrestrial species showed significant difference in swales 1-4, 2-4, and 3-4. There was no statistical difference of the overall richness between the first and second, first and third, and second and third swales. Evenness across dune swales initially increased from the first to the second swale, and then dropped considerably from the second to the fourth swale, (1= 0.35, 2=0.40, 3= 0.37, 4= 0.34)(Figure 1).

Taking into account both the water species and the terrestrial species, the fourth swale had the lowest evenness, lowest species richness, and the lowest diversity value (0.8602), though had the deepest pool of water. The second swale had the highest evenness, highest species richness, and the highest H (1.235). This swale also had the second deepest pool. Within the swales, the H-value of the ground was higher than the H of the water in the second, third, and fourth swales, and the two values were almost equal in the first swale. This showed that the terrestrial ecosystems were almost always more established and had more diversity than those of the aquatic. Woody debris increased smoothly from swale 1 to swale 4 (1= 0.09%, 1= 0.23%, 3= 0.28%, 4= 0.5%)(Figure 8), which showed the increasing succession and domination of terrestrial species. This negatively correlated with terrestrial richness, which decreased from swale 3 to 4 as woody species became more abundant.

Discussion

In the swale chronosequence we studied, evenness, species richness, and species diversity were looked at in comparison to the age of the swales from an estimation of percent cover of species at each swale (Table 1)(Chadde 2002, Peattie 1930). We approximated that the swales we studied were between 300-400 years old, found from comparing to Lichter's 1998 age descriptions to our observations at Sturgeon Bay. Evenness, which measures the distribution of species, was found to increase from the first to the second swale, and then decrease continuously from the second to the fourth swale (Figure 1). This measured the distribution of the entirety of the swale, so included both lentic and terrestrial evenness. The increase from swale 1 to swale 2 can be attributed to the establishment and youngness of the first swale. It was located on the shore of Lake Michigan after a small, half formed dune, and so was a relatively new formation. This would cause it to have very unestablished species that were vying for space and nutrients to increase their abundance. The instability of this swale could be the cause of the low evenness at this site. The species colonizing there were simply trying to succeed and take as much space as possible, which would lead to an uneven distribution, especially since none of the plants are especially established there. The jump to swale 2, which had the highest evenness and thereful the most equal distribution, could be caused by the medium-level of establishment. Swale 2 has maintained just enough species richness that comes along from the initial colonization and juggling for establishment while also maintaining more stability than swale 1, which leads to the more equal distribution. This swale also had the second deepest pool, which could change the species composition from that of swale 1 and change the diversity parameters. This mixture of stability and species diversity accounts for the evenness. Swales 3 and 4 both show a decrease in evenness. This can be caused by the domination of certain species that have been established and successful there. As the species eventually out-compete each other for space and nutrients at the swales, those that are more successful can become more and more dominant at the site. Swale 3 is an intermediate site with evenness starting to lower as diversity lowers and successful species become more distributed than less successful species. This is more exaggerated in swale 4, which has the lowest evenness and lowest H-value.

The species richness tells the overall number of species in the swales, in both the pools and on the land on the border of the pools (Figure 2). The pools of swale 1 and 2 have equal species richness, a fact that can be attributed to the initial colonization of species which leads to a high species number. Swale 4's pool had the lowest species richness, followed by swale 3. This pattern almost exactly follows that of evenness, which initially increased from swales 1 to 2, and then decreased thereafter. The richness, however, remains at the same number for the first two swales and then decreases incrementally after that. This pattern can help confirm the theory of why species evenness changed for the overall evenness of lentic and terrestrial swales. There is a high number of species in the beginning because species are beginning to colonize and nothing has out-competed other species in the unstable environment. As the swale gets older and more stable, species begin to establish themselves and have dominance of the swale, seen through percent cover in this study. While some species carry on between the transition zone of terrestrial and lentic habitats (Van der Valk & Davis 1978), separating the water and terrestrial species in this research gave a different pattern of richness. There was significant difference for swales 1 and 3, 1 and 4, 2 and 3, and 2-4 in richness of water species (Figure 6). This pattern, where the first swale had the highest richness and the other three swales having the same, lower richness value, is semi-reminiscent of the overall richness. The trend of decreasing is similar, though the water species of swale 2 were not as numerous as the overall. The species richness of the terrestrial quadrants shows a different pattern (Figure 7). There was significant difference between swales 1 and 2, 2 and 4, and 3 and 4. The terrestrial richness increased from swale 1 to 2, and then steadily decreased from swale 2 to 4. However, the values of terrestrial and lentic richness also showed a large disparity. While the values of water richness never went about 12 species (swale 1) and lowered to 7 species (swales 2, 3, and 4), the terrestrial richness ranged from 18 (swale 2) to 11 (swale 4). The terrestrial edge of the pools in the swales housed many more species than seen in the pools, which could account for the pattern in the overall species richness.

The Shannon Wiener Diversity Index values were also tested with the kruskal-wallis test. The water in the pool alone showed significant difference between swales 1 and 3, 1 and 4, 2 and 3, and 2 and 4 (Figure 4). These four differences are enough evidence to know that diversity is thoroughly changing throughout the swales as they age. However, the terrestrial diversity on the edges of the pool had significant difference between swales 1 and 2, 1 and 3, 2 and 4, and 3 and 4 (Figure 5). This terrestrial ecology seems to follow what Lichter had found with his studies, which was the gradual increase in diversity of species as dunes aged (Lichter 1998). Here, looking at only the ground surrounding the pools, the terrestrial values seem to agree with Lichter. The water does not, and instead H decreased from swales 1 to 3, and then increased in swale 4. The differences in H here show that we cannot predict the same sort of diversity chronosequence to lentic communities of the swales as the terrestrial communities. The overall diversity index, the H-value of both the water and ground together, showed significant difference only between the second and fourth swales (Figure 3). This supports the hypothesis that diversity differs between all of the swales studied, but does not support the hypothesis that diversity increases as the swales get older. Looking both individually at lentic and terrestrial H values and at each swale as a whole, the terrestrial species are the only communities that follow the hypothesis of increasing diversity with age. By applying the theories of terrestrial succession to that of wetland succession, we were able to disprove how the swale succession worked.

While some results of this study are consistent with those of other studies, like Lichter and Albert, this research shows a general disagreement of diversity findings. Diversity and evenness tends to rapidly increase for around 1000 years, and then plateau (Morrison & Yarranton 1973) in terrestrial dunes. The inner-pool swale findings are highly subjective and different from that of the outer-pool ground swale findings. This lends to a need for further research of inner-pool diversity and the causes of the sudden change between terrestrial and lentic in diversity patterns. Research suggests that dune formation usually undergoes succession toward a particular composition of species, which are later affected by climatic disturbances which can change the end result (Miller et al 2010). Other research has found that lake levels of the Great Lakes can affect the tree species dominant at these swamp-like habitats (Tepley, Cohen, & Albert 2004). Future predictions based on this research should include a heavy study on the climatic differences between locations, as the colonizations of plant species also depends on success in certain climates and soils. This research can only be said for the swales at Sturgeon Bay on Lake Michigan, and other dune systems may find differences in swale communities based on these climatic and successional differences.

Our results demonstrate that diversity between swales of dune systems differs across swales and between swales. Terrestrial and lentic species and patterns were not identical. Terrestrial diversity follows a pattern of positive correlation of age and diversity in a linear chronological progression. Lentic communities do not follow this pattern and are instead more inconclusive. Further experimentation would be necessary to reason out the cause of these disparities between lentic and terrestrial patterns.

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Tables and Figures

Table 1: Percent cover of species across four dune swales

Species	**Swale 1 (%)**	**Swale 2 (%)**	**Swale 3 (%)**	**Swale 4 (%)**
Bryophyta gn. Sp. 1	0.75	0	0	0
Carex unknown #1	0.05	0	0	0
Carex viridula	0.15	0	0	0
Cladium mariscoides	0.4	7.65	1.05	0
Cornus sericea	0.1	0.35	0.25	0.05
Dasiphora fruticosa	0.05	3.6	2.7	1
Deschampsia cespitosa	10.5	0	0	0
Dulichium arundinaceum	1.1	0	0	15.95
Equisetum arvense	0.1	0	0	0
Equisetum laevigatum	1.1	0.1	0	0
Eupatorium perfoliatum	0.2	0	0	0
Euthamia graminifolia	0.05	0	0	0
Juncus balticus	13.6	0	0	0
Lobelia kalmii	0.05	0.05	0	0
Potentilla anserina	0.35	0	0	0
Rhynchospora capillacea	0.05	0	0	0

Salix Unknown 7	0.15	0	0	0
Solidago uliginosa	1.05	0	0	0
Unknown 3	0.1	0	0	0
Unknown 6	0.1	0	0	0
Utricularia intermedia	0.35	0.85	0	0
Utricularia sp.	11.45	3.7	0.3	0
Bryophyte gn. Sp. 2	7.25	0	0	0
Carex aquatilis	0	8.95	4.5	4.45
Comandra umbellata	0	0.05	0	0
Hypericum kalmianum	0	0.6	0.1	0
Myrica gale	0	0.2	6.4	10.25
Parnassia glauca	0	0.2	0	0
Poaceae gn. Sp.	0	0.1	0.25	0
Potamogeton gramineus	0	2.05	0	0.15
Potentilla anserina	0	0.05	0	0
Rhynchospera alba	0	0.05	0.4	0
Schoenoplectus pungens	0	0.8	0.6	0
Solidago ohioensis	0	1.75	0.9	0
Spiranthes cernua	0	0.05	0.35	0
Thuja occidentalis	0	1.1	2	1
Triantha glutinosa	0	0.05	0	0
Bryphyte gn. Sp. 3	0	0	10.825	0
Drosera rotundifolia	0	0	0.75	0
Juncus canadensus	0	0	0.1	0
Juncus nodosus	0	0	1.45	0
Triadenum fraseri	0	0	0.5	0.05
Triglochin maritima	0	0	0.4	0
Calamagrostis canadensis	0	0	0	0.25
Lysimachia terrestris	0	0	0	0.15
Salex bebbiana	0	0	0	0.35
Salix candida	0	0	0	0.25
Unknown 4	0	0	0	0.5

Table 2: Overall evenness and diversity values (H) across swales

	H value	Evenness value	Average depth
Swale 1	1.08	0.35	9.69
Swale 2	1.24	0.40	14.71
Swale 3	1.10	0.37	10.47

Swale 4	0.86	0.34	15.69

Figure 1: Evenness across dune swales

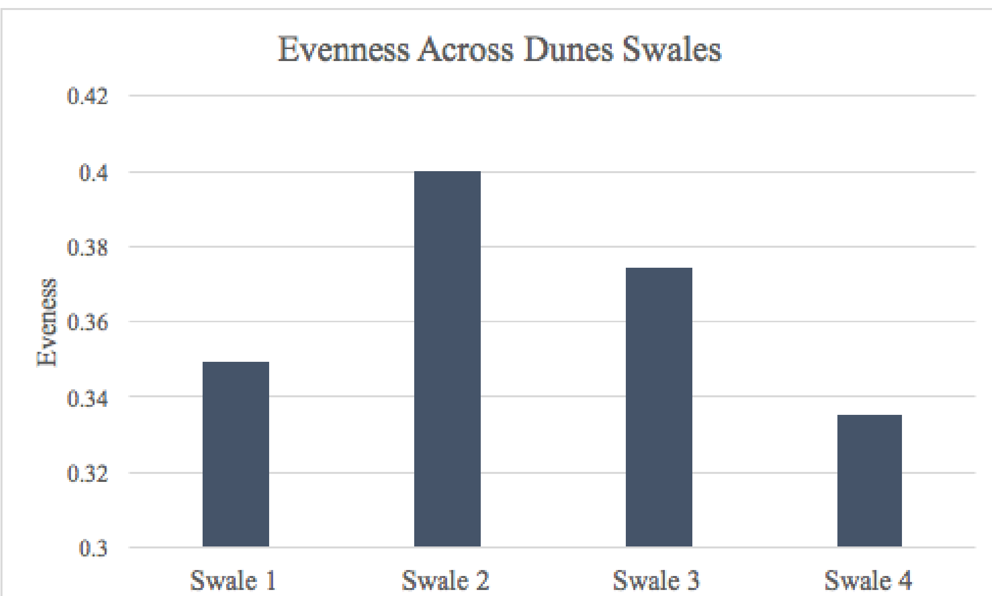


Figure 2: Species richness across dune swales, combining both aquatic and terrestrial elements

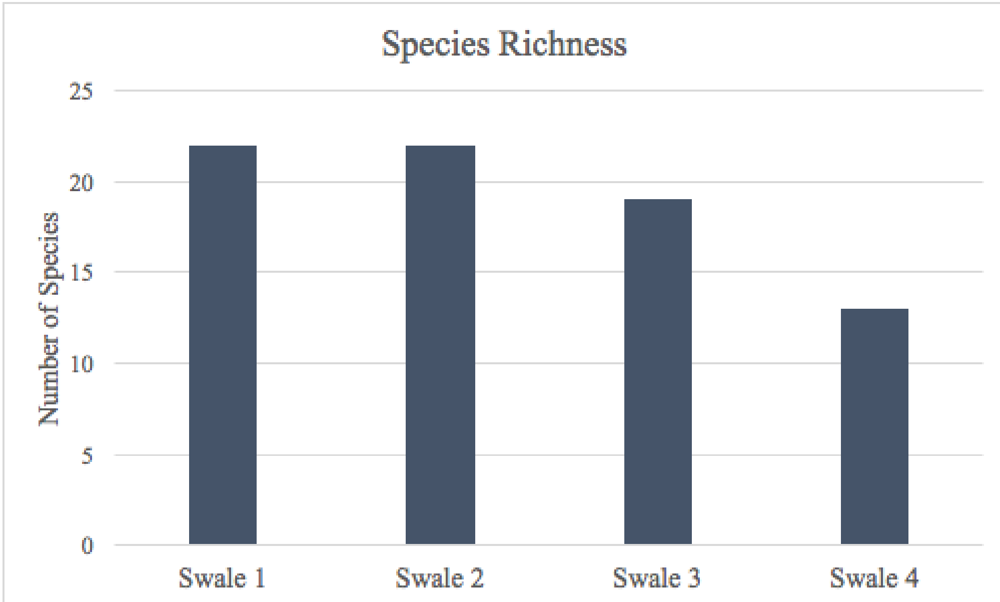
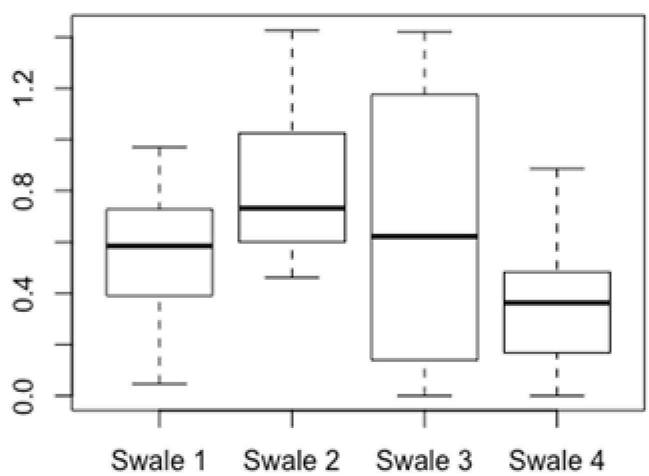


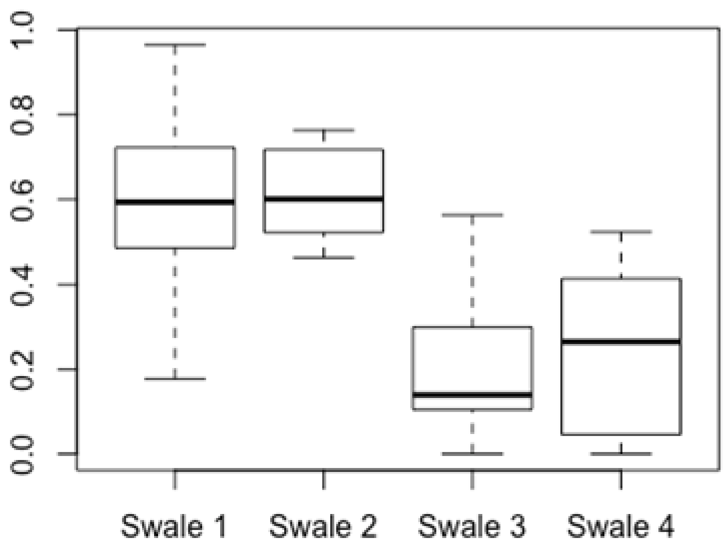
Figure 3: Boxplot comparing Shannon-Wiener Index of combined aquatic and terrestrial species



to swale number

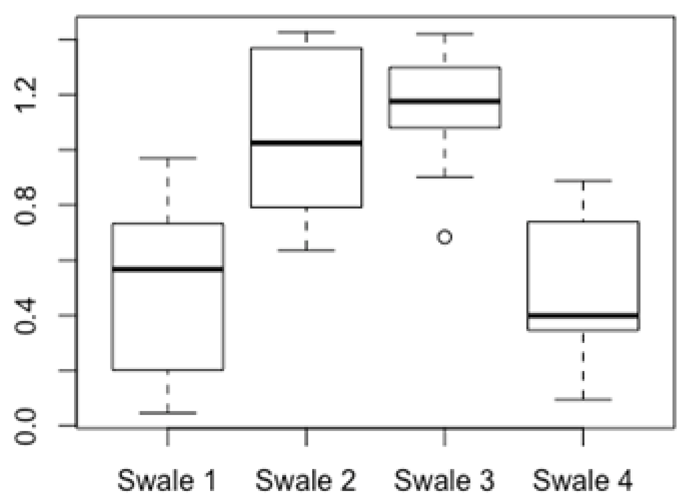
Swale

Figure 4: Boxplot comparing Shannon-Wiener Index of aquatic species to swale number



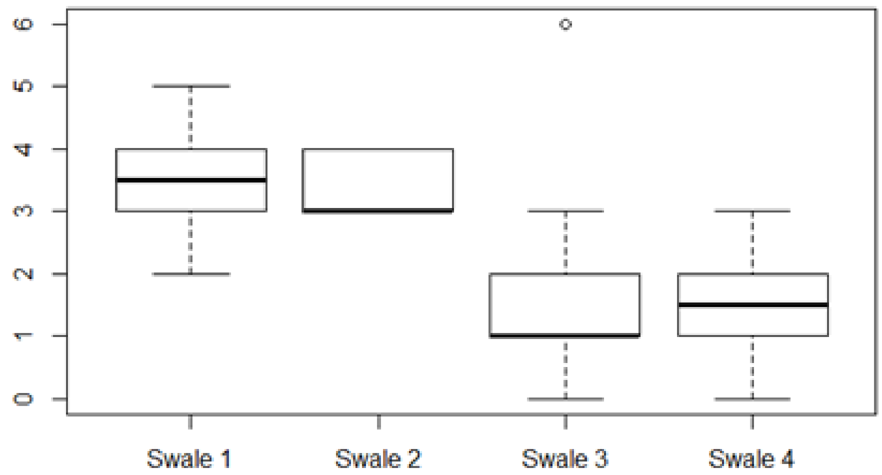
Swale

Figure 5: Boxplot comparing Shannon-Wiener Index of terrestrial species to swale number



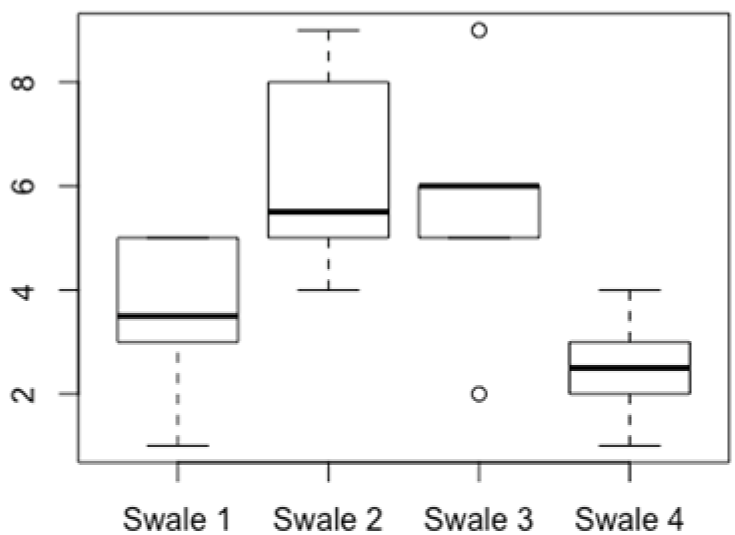
Swale

Figure 6: Boxplot comparing aquatic richness to swale number



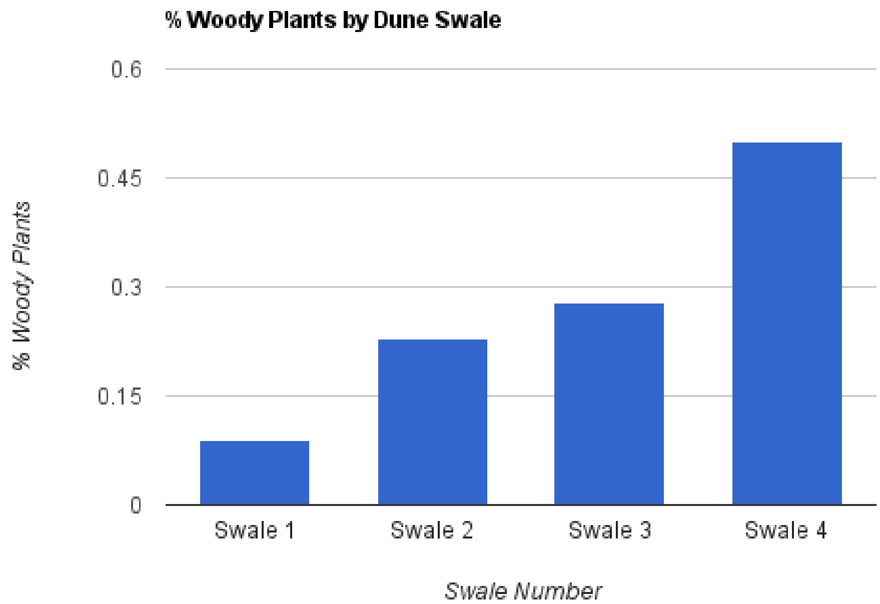
Swale

Figure 7: Boxplot comparing terrestrial richness to swale number



Swale

Figure 8: Percent woody debris in each swale



References

Albert, D. A. 2003. Between Land and Lake: Michigan's Great Lakes Coastal Wetlands. East Lansing, MI: Michigan State University.

Albert, D. A. 2006. Borne of the Wind. Ann Arbor, MI: The University of Michigan Press.

Chadde SW. 2002. A Great Lakes Wetland Flora. 2nd ed. Laurium: PocketFlora Press.

Hemminga, M. A., and C. M. Duarte. 2000. Seagrass ecology. Cambridge: Cambridge University Press.

Lichter, J. 1995. Lake Michigan Beach-Ridge and Dune Development, Lake Level, and Variability in Regional Water Balance. Quaternary Journal 44. 2: 181-189.

Lichter, J. 1998. Primary succession and forest development on coastal Lake Michigan sand dunes. Ecol. Monogr. 68: 487-510.

Miller, T.E., Gornish, E.S. & Buckley, H.L.(2010) Climate and coastal dune vegetation: disturbance, recovery, and succession. Plant Ecol 206: 97-104.

Morrison, R. G., Yarranton, G. A. 1973. Diversity, richness, and evenness during a primary sand dune succession at Grand Bend, Ontario. Toronto, Ontario: Canadian Journal of Botany. 2: 2401-2411.

Peattie, D. C. 1930. Flora of the Indiana dunes, a handbook of the flowering plants and ferns of the Lake Michigan coast of Indiana and of the Calumet district. Chicago, IL: Field Museum of Natural History. Retrieved from ArticlesPlus.

Tepley, A. J., Cohen, J. G., Albert, D. A., & Inventory, M. N. F. 2004. Ecological classification and analysis of swamp forests along the Lake Michigan and Lake Huron shorelines. Michigan Natural Features Inventory Report *12*: 31-35.

Van der Valk, A.G., Davis, C.B. 1978. The role of seed banks in the vegetation dynamics of prairie glacial marshes. Ecology 59: 322-335.