

**STABLE REGIMES IN AN UNSTABLE SYSTEM: FLORAL
COMMUNITY AND DIVERSITY IN THE GRAND SABLE DUNES**

by

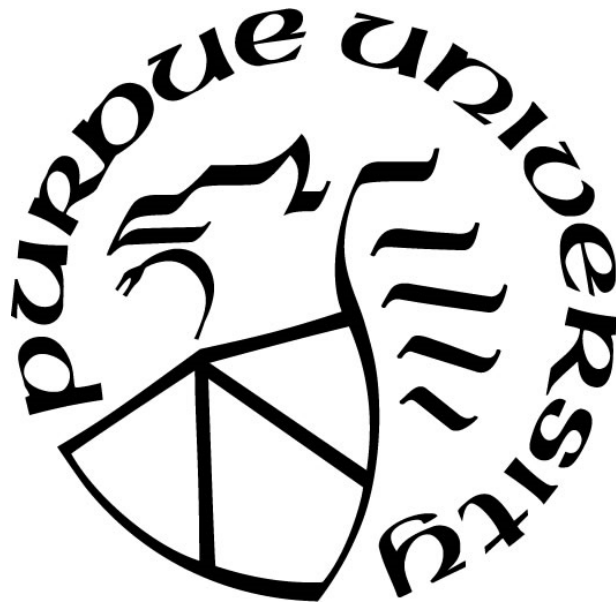
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This is dedicated to the family that has always had my back. When the going gets tough, the tough never quit.

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ABSTRACT

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Title: Stable Regimes in an Unstable System: Floral Community and Diversity in the Grand Sable Dunes

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Grand Sable Dunes, as a perched dune field on the shore of Lake Superior, is a sensitive ecosystem subject to continual disturbance. Repeated natural disturbances necessitate specialized plant communities to develop. There were two objectives of my research in this system that are treated in separate chapters. They include: 1) the quantification of successional changes in the plant community over time, and the identification of population demography changes for rare species within the dunes and 2) the evaluation of evaluate in pollinator species for two plants *Hieracium caespitosum* (Yellow Hawkweed) and *Lithospermum caroliniense* (Carolina Puccoon).

For the first objective, target plant community composition and structures (i.e. richness, diversity) were quantified in 2011 and 2018 across Grand Sable Dunes in 1 m² quadrats. Additionally, two relatively rare plant species (*Cirsium pitcheri* and *Tanacetum bipinnatum*) were selected to quantify demographic (i.e. flowering, non-flowering) patterns and changes over time. Samples for *C. pitcheri* and *T. bipinnatum* were acquired via circle-plots 2.5 m in diameter. Population comparisons between 2011 and 2018 illustrate minimal change in community structure (richness and diversity). Composition increased slightly with eight species occurring in 2018, but not 2011. Additionally, community similarity was high (~78%) between the two years. *C. pitcheri* occurrence was inversely related to presence of other species. Plant community composition in eastern and western survey zones within the dunes appear to be diverging. Minor changes in the plant community composition and structures indicate successional changes have occurred, but without major disturbance. This divergence in community composition may be related to weather related incidents associated with Lake Superior disturbance potential.

The secondary objective concerns pollinator species on two similar plant species found in the Grand Sable Dunes. Individuals of *H. caespitosum* and *L. caroliniense* were observed and all floral visitors were identified to family. The majority of arthropod families were observed

visiting both *H. caespitosum* and *L. caroliniense*, with an absence of typically important families (e.g. Apidae, Bombiliidae). Halictidae, Muscidae and Syrphidae were the most common visitors, with *L. caroliniense* attracting far more Muscidae than their *H. caespitosum* competitors. Overlap in visitors for both species was observed, which may lead to decreased reproduction in *L. caroliniense*.

COMMUNITY PATTERNS AND DISTRIBUTION OF RARE SPECIES IN GRAND SABLE DUNES, PICTURED ROCKS NATIONAL LAKESHORE

Introduction

Dune Formation

Dunes are known to be physiographic formations dominated by sandy parent material guided by a variety of factors, ranging from meteorological to tidal action. Desert dunes are formed almost purely from aeolian interaction, when sand encounters an obstacle and begins to collect. Barchan, transverse, linear and star dune formations may be found across the globe, but may be further broken down into two categories, based on the environmental controls of wind direction and sand supply (Wiggs 2001). Linear dunes occur in regions of much wind but poor sediment supply, while barchan and transverse dunes exist where sand is plentiful and wind is not. Star dunes have been identified as being in places with much wind and sand, refined by multi-directional winds, located in the interior of land masses (Wiggs 2001). By contrast, dunes located on or near ocean-based beaches are created with the assistance of glacial and tidal interaction, with the accompanying aeolian influences (Aagaard et al. 2006). Nearshore sand bars may, under the influence of wind and tide, migrate inland to become sources for sand dune formation. Lacustrine dune systems occupy 3.4% of the Great Lakes shoreline possess regular natural disturbances (Marsh 1990). Specialized vegetative communities dwelling in these areas require adaptations in order to exist here. This unique ecology is in a state of permanent change, the substrate in a state of constant renewal by Lake Superior (Marsh 1990, Anderton and Loope 1995). Various species are capable of dwelling in this region but their required parameters are, by nature of location, in need of flexibility (Maun 1998, van Dijk and Vink 2005).

Knowledge of dune topographical terms aids comprehension in multiple avenues, from conservation efforts to life history studies and invasive species management. A concise selection of relevant terms includes *scarp*, *ridge*, *blowout*, *slack*, and *surface creep*. The first, *scarp*, can be defined as the sheer, steep face of a dune caused by the removal of material by waves or other influences (Maun 2009). A *ridge* is the high point seen at the top of dunes, especially those of linear nature (Maun 2009). *Blowout* then is the result of the ridge collapsing at a stressed point, caused by a loss of vegetation, constant impact of animals or humans, including the influence of wind and waves (Maun 2009). *Slack* indicates the hollow regions between *ridges*, where the dune slowly collapses beneath the overall structure (Maun 2009). Finally, *surface creep* refers to a dune's progress across the terrain (Maun 2009). Vegetation growth on the *scarp* is difficult, considering the lack of stable growth points, but stabilization along the *ridge* and *slack* portions of the dunes promotes growth of both the dune itself and further vegetation (Maun 2009, Marsh and Marsh 1987). As plants accrue, there is more capacity for the dune to avoid erosion on the lee side of the dune, and a capacity for supporting further growth. Continued stabilization promotes growth, which in turn adds to the stabilization until either a blowout occurs, or full stability is achieved (Marsh and Marsh 1987).

Among these multiple forms of sand dunes, perched dunes are a unique structure. As a definition, Perched dunes exist at the top of high points, therefore 'perched' atop their position (Marsh and Marsh 1987). Their relationship in the four categories may be deduced as a linear style, with barchan influences; their existence combines a sediment supply capacity less than that of the linear dune structure, but more than the barchan designation while sharing a wind resource comparable to both. One example of these can be found in the Grand Sable Dunes, Pictured Rocks National Lakeshore, Michigan. Their linear structure rests atop a high bluff, and can be

seen parallel to Lake Superior shoreline (Marsh and Marsh 1987, Maun 2009). Sandstone foundations provide ample building material, eroded by the lake and wind, returned to the heights through wind and snow (Marsh and Marsh 1987, Wiggs 2001). The bottom of Lake Superior is made of sand, providing yet another source of construction material for the dunes (Marsh 1990), but not as accessible as what could be expected from a linear dune found in the Sahara Desert region (Wiggs 2001). Dead or hibernating vegetation grows little during the winter, incapable of reacting to the sand influx (Bach 1978, Marsh 1990, Maun 1998). Of the total sand dune ecosystems present in the Great Lakes region, a fraction of that small number consists of the Perched Dune structure (Figure 1).

Dune Ecosystems

Grand Sable Dunes is an active, and reactive ecosystem. As plants grow on its surface, cohesion is obtained, reducing erosion. Conversely, as the plants gain footholds, more sand is deposited upon the vegetation (Maun and Perumal 1999, Marsh and Marsh 1987). Grand Sable Dunes is believed to have formed due to multiple factors: (1) a high point devoid of vegetation, and composed of sandy materials independent of wind action, (2) an erosion-rich region traversing the upper length of the bluff, and (3) a dune field beyond the deflation zone (Marsh and Marsh 1987). Such dunes are understood to be fed from sand derived from the deflation zone located near the bluff's apex, and grows as time progresses. As the lake and winds continue to alternately remove and add to the location, the sand dunes have maintained their integrity since the last ice age (Rapson n.d.). Barren slopes yield the most in sand accumulation, aggregating 0.97 m^3 per meter on 90 m bluffs and 0.43 m^3 on 35 m slopes. Fine sand movement is estimated to extend 50 m inland, with the bulk of material deposited within 15 m of the dune's foot (Marsh and Marsh 1987). The general shape of Lake Superior, composition of the sandstone beneath the

Grand Sable Dunes, and strong winds combine to encourage further sand buildup, eroding the most in winter months (Marsh and Marsh 1987). While providing a reliable timescale opportunity, this also provides an unstable substrate environment; inhospitable for a large variety of vegetation. Areas within the Grand Sable Dunes exist with variations of active dune movement, and at various stages of stabilization (Bach 1978, Marshall et al. 2008). A majority of the dunes face the frequent northwestern winds, with trailing leeward edges angled southeast (Marshall 2014). Lacustrine dune systems occupying 3.4% of the Great Lakes shoreline possess regular natural disturbances (Marsh 1990). Specialized vegetative communities dwelling in these areas require adaptations in order to exist here. This unique ecology is in a state of permanent change, the substrate in a state of constant renewal by the adjacent lake (Marsh 1990, Anderton and Loope 1995). Various species are capable of dwelling in this region but their required parameters are, by nature of location, in need of flexibility (Maun 1998, van Dijk and Vink 2005).

Plants Focus

While the entire plant community is of importance and concern, there is added interest in understanding the distribution and flowering patterns of rare species (Figure 2). Three such species were selected for a more detailed survey within the plant community: *Cirsium pitcheri* (Torr. ex Eaton) Torr. & A. Gray (Pitcher's thistle, Asteraceae), *Stellaria longpipes* Goldie (longstalk starwort, Caryophyllaceae) and *Tanacetum bipinnatum* (L.) Sch. Bip. ssp. *huronense* (Nutt.) Breitung (Lake Huron tansy, Asteraceae). *C. pitcheri* is federally and state listed threatened, and has inflorescence stages from mid-June to late September (Higman and Penskar 1999, Chen and Maun 1998, Maun et al. 1996, USFW n.d.). *S. longpipes* is a Holarctic species that is a species of special concern in Michigan with inflorescence stages from early June to early

September (Penskar 2009). *T. bipinnatum* is listed as a threatened species in Michigan, (Choberka et al. 2001) with its inflorescence stage from mid-June to the end of August (Figure 2). Grand Sable Dunes in Pictured Rocks National Lakeshore provides habitat suitable for all three species. Evaluating the location and populations of all observed vegetative species allows a snapshot of community composition, showing growth and movement as the study area changes over time (Bach 1978). Concentrating a second survey on tracking the growth of the three plants (*C. pitcheri*, *S. longipes*, *T. huronense*) gives a greater knowledge of these critical species (Slaughter et al. 2014, Marshall 2014).

Objectives

The objectives of this study were to 1) quantify community composition and structure in Grand Sable Dunes, Pictured Rocks National Lakeshore, Michigan; 2) categorize demographic stages for *Cirsium pitcheri*, *Stellaria longipes*, and *Tanacetium bipinnatum*; 3) compare demographic and community measures between 2011 and 2018; and 4) test the hypothesis that shifts in community composition and structure will alter the proportions of flowering:non-flowering individuals for important dune species.

Methods

Grand Sable Dunes, Pictured Rocks National Lakeshore, Michigan ecosystem comprises of 900 hectares along the northern edge of Michigan's Upper Peninsula (46° 39' 27.5" N, 86° 19' 56.3" W). The 2018 growing season (May-September) had an average high/low temperature of 21.1°/8.9° F, and accumulated 37.57 cm precipitation (NOAA).

A previous survey in 2011 by Marshall (2014) surveyed 72 sites within the dunes, allowing evaluation of species presence and location shifts over a 7 year period. *Toxicodendron*

radicans (poison ivy) was exempted from survey evaluation due its potential health risk to observers. I surveyed plants at 57 plot locations during 2018, selected from 72 original plots chosen from a 100 m spaced grid. All eight plots from the central region of the dunes were omitted due to time and accessibility constraints. Three plots were omitted from zone three due to time constraints, and four plots were omitted from zone one due to time constraints and excessive poison ivy presence. A 1 m² quadrat was centered at each plot location. Whenever possible, all individuals within each quadrat were identified to species. Individuals were counted and percent cover estimated for each species. Species richness (count) and diversity (Shannon's measure of entropy; Shannon and Weaver 1963) were calculated per 1 m² quadrat in each year. Voucher specimens were collected and deposited in the Purdue University Fort Wayne Department of Biology herbarium, excluding those species listed as of concern, threatened, or endangered. Species were identified using Voss (1972, 1985, 1996) and acceptability of names using USDA (2019). In addition, circle plots (2.5 m diameter) were centered on each plot location. Within the circle plot, Pitcher's thistle (*Cirsium pitcheri*), Lake Huron tansy (*Tanacetum bipinnatum* ssp. *huronense*), and longstalk starwort (*Stellaria longipes*) were counted and noted as either flowering or non-flowering stages.

Paired t-tests were employed to compare all 57 plots to test for differences in richness, diversity and total percent cover. Sorensen similarity index was calculated at site level. Pearson's correlation was used to test relationships between percent flowering individuals for Pitcher's thistle, Lake Huron tansy, and longstalk starwort, and richness and diversity measures. Nonmetric multidimensional scaling (NMDS) was used to visualize compositional patterns using methods described by Mather (1976) and Kruskal (1964a,b) using the default settings of metaMDS function in the vegan package within R. Within the NMDS analysis, dissimilarities in

species individual counts were characterized using Bray-Curtis dissimilarity. All statistical tests were run in R (version 3.5.2).

Results

Observations from the 2011 and 2018 floral surveys showed 26 and 30 species, respectively, from a total of 19 families. Of those identified species, 22 were shared between both survey years. Four species were observed only in the 2011 survey and eight were observed only in the 2018 survey (Table 2). Sorensen similarity index between 2011 and 2018 surveys was relatively high at 0.79. The four species observed only in 2011 were all herbaceous in growth form (Table 2). Three were native (*Elymus trachycaulus* ssp. *trachycaulus*, *Oenothera biennis*, *Solidago simplex*) and one was considered non-native (*Leucanthemum vulgare*). Half of the species that were observed only in 2018 were woody in growth form. *Trifolium pretense*, an herbaceous species, is considered non-native. While not identified to species, several very common *Plantago* spp. are non-native. Overall, there were seven introduced species identified and 27 native (including one naturalized) species present.

There was no significant difference between 2011 and 2018 species richness ($t_{(2),56} = -1.65$, $p = 0.104$; Figure 3A). Similarly, Shannon's diversity index was not different between the two years ($t_{(2),56} = -0.28$, $p = 0.783$; Figure 3B). Overall pooled richness was 3.82 (SD \pm 2.81) and pooled diversity was 0.82 (SD \pm 0.55). Of the 57 plots surveyed, only two bare plots (void of vegetative cover) in 2011 remained bare in 2018. The remaining five plots found bare in 2011 had been colonized by the 2018 survey (richness range: 1-8 species). The mean richness for these colonized plots was 4.6 species, comparable to the overall mean richness at the site. Additionally, two plots that were bare in 2018 did contain vegetation in 2011. The two plots now bare in 2018 each had 1 and 4 species present in 2011. Evenness (displayed as relative rank

abundance) was similar between the two years, with mid-portions of the 2018 plot illustrating a increase in evenness between species (Figure 4).

The focused study of *C. pitcheri* and *T. bipinnatum* resulted in population changes, but these were not statistically different (Table 3, 4). For *C. pitcher*, while there was a major reduction in the mean number of flowering individuals, this was no difference overall (Table 3). Additionally, non-flowering counts for *C. pitcheri* were very similar between years. For *T. bipinnatum*, there was a slight increase in the mean number of flowering individuals (Table 4) but like *C. pitcheri*, this difference was not statistically supported. Whereas the non-flowering number of *T. bipinnatum* did decrease between years, again, this was not statistically different between years. *S. longipes* was included in the demographic counts in 2018, but was not in 2011. While the two years cannot be compared as performed with *C. pitcheri* and *T. bipinnatum*, there was an 80% population increase for *S. longipes* in the quadrat data. Approximately 58% of *S. longipes* individuals were flowering in 2018. The total number of *T. bipinnatum* decreased from 2435 to 1664 individuals observed, and *C. pitcheri* decreased from 111 to 50 observed specimens. There was no significant correlation between any of the three target species and the measures of richness or diversity.

Patterns can be seen in the relation of these three species to total cover (Figure 5). Both 2011 and 2018 quadrat data show *C. pitcheri* with their greatest numbers in low-cover situations (Figure 5A, D), and *S. longipes* has a medium population at the mid-level richness (Figure 5B, E). *T. bipinnatum* is somewhat of an outlier in comparison to their NMDS plotting (Figure 6), but this can be resolved with the realization that *A. breviligulata* exists in high-concentrated populations, and the samplings were taken at random (Figure 5C, F). Both species thrive in low-

density populations and medium-level disturbed terrain, and *A. breviligulata* exists in number-rich colonies.

The nonmetric multidimensional scaling (NMDS) ordination plot of the 2018 species occurrences illustrates a separation of *C. pitcheri* from the rest of the community (Figure 6). *T. bipinnatum* clustered with a few species, including several woody species (*Amelanchier arborea*, *Prunus pumila*, and *Salix interior*), as well as the very common *Ammophila breviligulata* (Figure 5). *S. longipes* clustered almost centrally in the community. NMDS ordination at the plot level comparing 2011 and 2018 illustrated an apparent divergence between Zones 1 (eastern side of Grand Sable Dunes) and 3 (western side) (Figure 7). There was overlap in the ordination between zones and years, however, the mean values for the two zones (east and west) were nearly identical in 2011. By 2018, the mean plot values had diverged.

The first survey in 2011 showed 38 individuals in 5 plots, while 58 individuals were encountered in 8 plots in the 2018 survey. In 2011 *C. stoebe* held a mean cover of 5.6% per plot, while the 2018 mean cover rose to 6.1%. Proportional content of overall richness increased as well, from a 1.4% to 1.9%.

Discussion

Perched lacustrine dune ecosystems cover 3.4% of the Great Lakes shoreline, possessing regular, natural disturbances (Marsh 1990). These dynamic structural changes guide floral colonization, frequently reverting entire swaths of terrain to earlier succession stages (Kennedy et al. 2002). Reversion to earlier stages eliminates or reduces community divergence, limiting growth to plants capable of existing in a frequent-burial, limited resource region (Maun 1998, Perumal 1999, Bach 2001). Constant disturbance may provide opportunities for invasion (Dekker 2005). In this manner, given a high turnover rate made possible by unstable conditions

eradicating local communities, newcomers have a greater potential for gaining footholds and establishing populations. However that same disturbance quantity and intensity renders the invading species equally susceptible to removal and replacement. For plants in continual disturbance regions, durability must be combined with a certain flexibility. This can result in varying impact effects on plant communities, which in turn affects the stability of both their environment and each other (Dale et al 2001, Dekker 2005, Denoth and Myers 2007, Rand et al. 2015).

It has been noted that perched dune structures help *C. pitcheri* in early development (Rand et al. 2015). Adding the presence of an invasive species such as *Centaurea stoebe* (spotted knapweed) complicates survival capacity, as it has also been observed that *C. pitcheri* survival in the presence of *C. stoebe* decreases, depending on the life stages and habitat conditions involved (Rand et al. 2015). Less disturbance-dependent plants such as *S. longipes* and *T. bipinnatum* were observed in my study to at least tolerate the presence of other plants, including *C. stoebe*. This is a sign of stabilization; nutritional value is minimal on sand substrates, and while drainage is good, there comes a point when *good* becomes *too good*. Excessive drainage eliminates plant growth by creating a hostile environment. When plant communities accrue richness and diversity, stability of its growth substrate is believed to occur (Tilman and Downing 1994).

Community Survey

The growing season in Michigan's Upper Peninsula progresses from May-September, the optimal growth conditions for vegetation. Prior to this the temperature remains in reach of freezing leaving only five months for plants to obtain the greatest possible quantity of sunshine and liquid water. Considering the different habitat conditions available in the Grand Sable Dunes, this growing season permits notable biodiversity.

Four species observed in 2011 were lost in the intervening seven years to 2018, but eight new species arrived as well. Of the four lost species, three were native, and one (*Leucanthemum vulgare*) was introduced while among the eight new species, seven were native to the region, and one (*Trifolium pretense*) was a naturalized import (NRCS 2019). Such turnover may be a natural process in perched dune ecosystems (Marsh 1990, Morrison and Yarranton 1973). The net gain of three native species, and a naturalized species, suggests a healthy environment; an unhealthy locale would see consistent loss of species. Many of the eight 2018 native newcomers prefer dune system habitats (USDA 2019). Dune structures are unstable at the best of times, discouraging long-term growth which allows these plants an advantage over plants less amenable to disturbance. Blowouts, collapses along slack regions, and loss of material, all contribute to unfavorable growing conditions (Smith 1983).

Through the paired t-tests and Sorensen Index analysis, floral stability is present throughout the Grand Sable Dunes. However, while the paired t-tests on diversity and richness do not give statistical significance to either, this is not to say there is a lack of significance altogether. Biologically, there are interesting trends in the dataset. Minor fluctuations in species community preferences observed through NMDS testing are possible indicators of a potential shift in habitat changes. The shoreline present along the Grand Sable Dunes changes dramatically from an east-west configuration to an almost north-south direction. Directional shifts of this nature alter currents of both wind and water, which in turn could potentially deter strong storms from the western half of the park leading to a significant impact on growth conditions.

Returning to the Sorensen index, the likelihood of finding one species between both 2011 and 2018 surveys is high (approximately 80% overlap between years). A greater richness, even if

statistically non-significant, is appreciable as well. The eight new plants appearing in 2018 increased the richness by a little over 4%, nearly the same quantity as the total number of Introduced species discovered in both surveys. Woody plants were observed in greater abundance in 2018, signs of greater stabilization as well (Bryant et al. 2017), which in turn will continue to build diversity and richness.

A strong factor in the diversity similarity is in how typical taxa diversity are governed by multiple factors, both biotic and abiotic. As time progresses, the slopes of species/time relationships frequently decline during the ecosystem's average species richness accretion. Abiotic models dictate species turnover by environment heterogeneity and species range of tolerance, while biotic models suggest a more flexible interaction of species survival due to inherent traits (Shurin 2007). Rephrased, abiotic models adapt the landscape to suit the organism, while biotic demands suitable life forms adapt, immigrate, or otherwise make their way to the location under study. Combining the two models provides an interesting challenge to headache medications, but must be considered for comprehending diversity turnover, or the lack thereof. Given the minimal nature of the observed changes, I would recommend waiting until 2025 for the next survey before committing to the idea of an in-progress major change.

Nineteen plant families were found, and thirty-four species identified. There were several grasses observed, but lacked the inflorescences necessary for identification. Seven bare plots in 2011 were reduced to four in 2018, two of which were formerly observed as having cover in 2011. As the mean diversity of the two 2011 plots was in keeping with the overall mean, no statistical significance was assigned. However, the change to fewer bare patches, in conjunction with a greater woody plant population and increased richness is indicative of increased stabilization (Tilman and Downing 1994). Each plot, when compared for abundance and

diversity, shares a similar position but in 2018 those differences become less obvious. This is even more important when considering how rare perched dunes are, 3.4% of lacustrine dune.

Demographic Stages and Comparison of Potential Community Shifts

Grand Sable Dunes, as a perched sand dune ecosystem, is an inherently disturbed ecosystem. *C. pitcheri* demonstrates a clear preference for as little competition as possible, an existence made possible by constant disturbance (Rand 2015, Keddy and Keddy 1984). Observations in this project and on parallel projects have placed almost no specimens in thoroughly stabilized areas, although there are samples in semi-stabilized locales (i.e. Marshall et al. 2008, Marshall 2014). The three focus plants have their own traits adapted to thriving in the Grand Sable Dunes: *C. pitcheri* is a monocarpic perennial with a 5-7 year juvenile stage, *T. bipinnatum* is a biennial, and *S. longipes* is a perennial (USDA 2019).

Given the *C. pitcheri*'s 5-7 year juvenile stage and observed habitat preference, there appears to be a distinct fitness advantage for slow growth in an unstable region. An ability to survive 15 cm burial is useful for plants living on unstable sand (Rand 2015, Marshall 2014). Sand accretion increases *C. pitcheri* germination rates, and discourages competition. In the full species accounting performed in this project, *C. pitcheri* is one of the very few endemic to the Great Lakes Region. Its population during the 2011-2018 survey time gap suggested a slight decline. Continued observations on the species are needed to further ascertain if this population decrease is of concern.

As observed in this study, *T. bipinnatum* exists in habitats already occupied in part by multiple other vegetative species. Due to the inability of most vegetation to survive highly disturbed conditions, the presence of other plants can infer greater stability. Plants such as *Ammophila breviligulata* and *Amelanchier arborea* aligned neighboring *T. bipinnatum* in the

ordination, the latter of which is a perennial shrub, requiring a fairly stable environment. However, the *T. bipinnatum* shares a long-term strategy with *C. pitcheri* in its biennial nature. By giving itself a full year to gather resources before committing to seed making, *T. bipinnatum* is prioritizes growth in its first year and prior producing the most viable seeds possible in its second. Its population in the last seven year period has decreased, with a bare quarter of its representative members flowering as of this study. Due to the biennial nature, this could be a standard population flux, but it is also possible that biotic traits inherent to *T. bipinnatum* are rendering it less suitable for the slow stabilization of the Grand Sable Dunes. Additionally, *T. bipinnatum* may have adaptations to germinate early in light (unburied) or overwinter if buried, facilitating successful establishment depending on dune stability (Marshall 2011).

S. longipes had the greatest increase in population with a tripling in the 2011-2018 time period. Taking into consideration its preference for diverse-rich communities, this is again evidence for increasing stability in the Grand Sable Dunes. Its Holarctic range is extensive, spreading across the entirety of Canada to Arizona. A flexible perennial, it has a variable morphology which makes it able to grow either as upright stems or mats (Dang and Chinnappa 2007). Rhizomatic tendencies and a lack of capacity to survive burial make its requirements for greater stability understandable. If it were to dwell on the unstable dune regions alongside *C. pitcheri*, it would be very likely to either be uprooted by shifting substrate or strong winds. If buried, *S. longipes* would expire. Unlike the monocarpic *C. pitcheri*, its perennial aspect means it will attempt to gain inflorescence in its germination time, no matter when that germination occurs. *S. longipes* does not possess the same monocarpic traits as *C. pitcheri*; even if disturbed through burial or uprooting, *S. longipes* will attempt to gain inflorescence in its germination

period. This drive to flower pushes *S. longipes* to expend all of its energy rather than reserve it for compensating tactics in disturbed locations.

Conclusion

Diversity in the Grand Sable Dunes has achieved a more stable condition in the past seven years, as observed in the diversity, richness and Sorensen Index analysis. Reduced bare plots, additional plant species appearing, and an increase in woody plant populations combine with a lower population in plants adapted to disturbed growth conditions.

One of the three plants focused upon in this study, *C. pitcheri*, is only able to exist on active dune regions. Non-metric multidimensional scaling (NMDS) ordination performed on both surveys demonstrated a strong predilection for solitary growing patterns, not to mention previous research indicating the same. When this unstable dune requirement is combined with the shared cover intolerance, available growth conditions become even more restricted. *T. bipinnatum* demonstrated a tolerance, if not preference, for additional cover nearby, and *S. longipes* thrived in the most competitive-rich environments. Observing these changes in population, and comparing them with the lack of change in the overall community diversity and richness, I conclude that there are few, if any, influential factors of the Grand Sable Dunes floral community on the populations of the three selected focus species.

Table 1. Identified plant family and species observed in Grand Sable Dunes, Pictured Rocks National Lakeshore, Michigan, with number of plots species occurred (n = 57) and mean counts of individuals per plot in which they occurred. Code is USDA (2018) species symbol.

Family	Species	Code	2011		2018	
			Plots	Mean per plot	Plots	Mean per plot
Sapindaceae	<i>Acer rubrum</i>	ACRU			2	3
Asteraceae	<i>Achillea millefolium</i>	ACMI2	1	4	1	1
Roseaceae	<i>Amelanchier arborea</i>	AMAR3			2	4.5
Poaceae	<i>Ammophila breviligulata</i>	AMBR	38	17.1	46	14.4
Brassicaceae	<i>Arabis lytra</i>	ARLY2			2	1.5
Ericaceae	<i>Arctostaphylos uva-ursi</i>	ARUV	1	16	4	27.3
Asteraceae	<i>Artemisia campestris</i>	ARCA12	26	4.3	20	4.3
Apocynaceae	<i>Asclepias syriaca</i>	ASSY	1	4	2	1
Cyperaceae	<i>Carex eburnea</i>	CAEB2	12	18	11	13.6
Cyperaceae	<i>Carex umbellata</i>	CAUM4	16	51.2	27	41.2
Asteraceae	<i>Centaurea stoebe</i>	CEST8	5	10.9	8	7.3

Table 1. Continued.

Family	Species	Code	2011		2018	
			Plots	Mean per plot	Plots	Mean per plot
Asteraceae	<i>Cirsium pitcheri</i>	CIPI	3	1.3	3	2
Poaceae	<i>Elymus trachycaulus</i> ssp. <i>trachycaulus</i>	ELTRT	1	2		
Equisetaceae	<i>Equisetum xferrissii</i>	EQFE	2	8	1	6
Rosaceae	<i>Fragaria virginiana</i>	FRVI	9	10.4	17	5.7
Asteraceae	<i>Hieracium caespitosum</i>	HICA10	13	3.6	24	7.2
Cistaceae	<i>Hudsonia tomentosa</i>	HUTO	3		1	3
Fabaceae	<i>Lathyrus japonicus</i>	LAJA	13	13.8	12	4.2
Asteraceae	<i>Leucanthemum vulgare</i>	LEVU	2	2		
Boraginaceae	<i>Lithospermum canescens</i>	LICA12	2	1.5	2	2
Asparagaceae	<i>Maianthemum stellatum</i>	MAST4	5	13.8	8	6.75
Onagraceae	<i>Oenothera biennis</i>	OEBI	2	2.5		
Pinaceae	<i>Pinus banksiana</i>	PIBA2			5	1.8
Plantaginaceae	<i>Plantago</i> spp.	PLANT			2	1.6

Table 1. Continued.

Family	Species	Code	2011		2018	
			Plots	Mean per plot	Plots	Mean per plot
Poaceae	<i>Poa compressa</i>	POCO	5	13.4	2	33
Rosaceae	<i>Prunus pumila</i>	PRPU3	5	16.25	6	8.8
Rosaceae	<i>Rosa blanda</i>	ROBL	1	1	1	4
Polygonaceae	<i>Rumex acetosella</i>	RUAC3	4	6	3	4
Salicaceae	<i>Salix cordata</i>	SACO3	1	1	1	1
Salicaceae	<i>Salix interior</i>	SAIN3			3	26.7
Asteraceae	<i>Solidago simplex</i>	SOSI3	6	2.5		
Caryophyllaceae	<i>Stellaria longipes</i>	STLO2	4	4.5	12	14.8
Asteraceae	<i>Tanacetum bipinnatum</i>	TABI	16	13.8	10	10
Fabaceae	<i>Trifolium pratense</i>	TRPR2			1	1

Table 2. Species observed during only one survey year.

2011 Only	2018 Only
<i>Elymus trachycaulus</i> ssp. <i>trachycaulus</i>	<i>Acer rubrum</i>
<i>Leucanthemum vulgare</i>	<i>Amelanchier arborea</i>
<i>Oenothera biennis</i>	<i>Arabis lyrata</i>
<i>Solidago simplex</i>	<i>Hudsonia tomentosa</i>
	<i>Pinus banksiana</i>
	<i>Plantago</i> spp.
	<i>Salix interior</i>
	<i>Trifolium pratense</i>

Table 3. *Cirsium pitcheri* flowering, non-flowering, and total counts (SE) in Grand Sable Dunes, Pictured Rocks National Lakeshore, between survey years. Plots represent frequency of occurrence. T-test includes plots with zero occurrence.

	Plots	Flowering	Non-Flowering	All
2011	10	0.22 (0.12)	0.84 (0.37)	1.07 (0.45)
2018	12	0.05 (0.04)	0.81 (0.33)	0.86 (0.37)
t-value		1.39	0.07	0.36
p-value		0.168	0.945	0.721

Table 4. *Tanacetum bipinnatum* ssp. *huronense* flowering, non-flowering, and total counts (SE) in Grand Sable Dunes, Pictured Rocks National Lakeshore, between survey years. Plots represent frequency of occurrence. T-test includes plots with zero occurrence.

	Plots	Flowering	Non-Flowering	All
2011	28	2.05 (0.91)	39.93 (13.30)	41.98 (14.01)
2018	24	6.78 (4.40)	21.91 (9.47)	28.69 (11.11)
t-value		-1.05	1.1	0.74
p-value		0.295	0.272	0.459

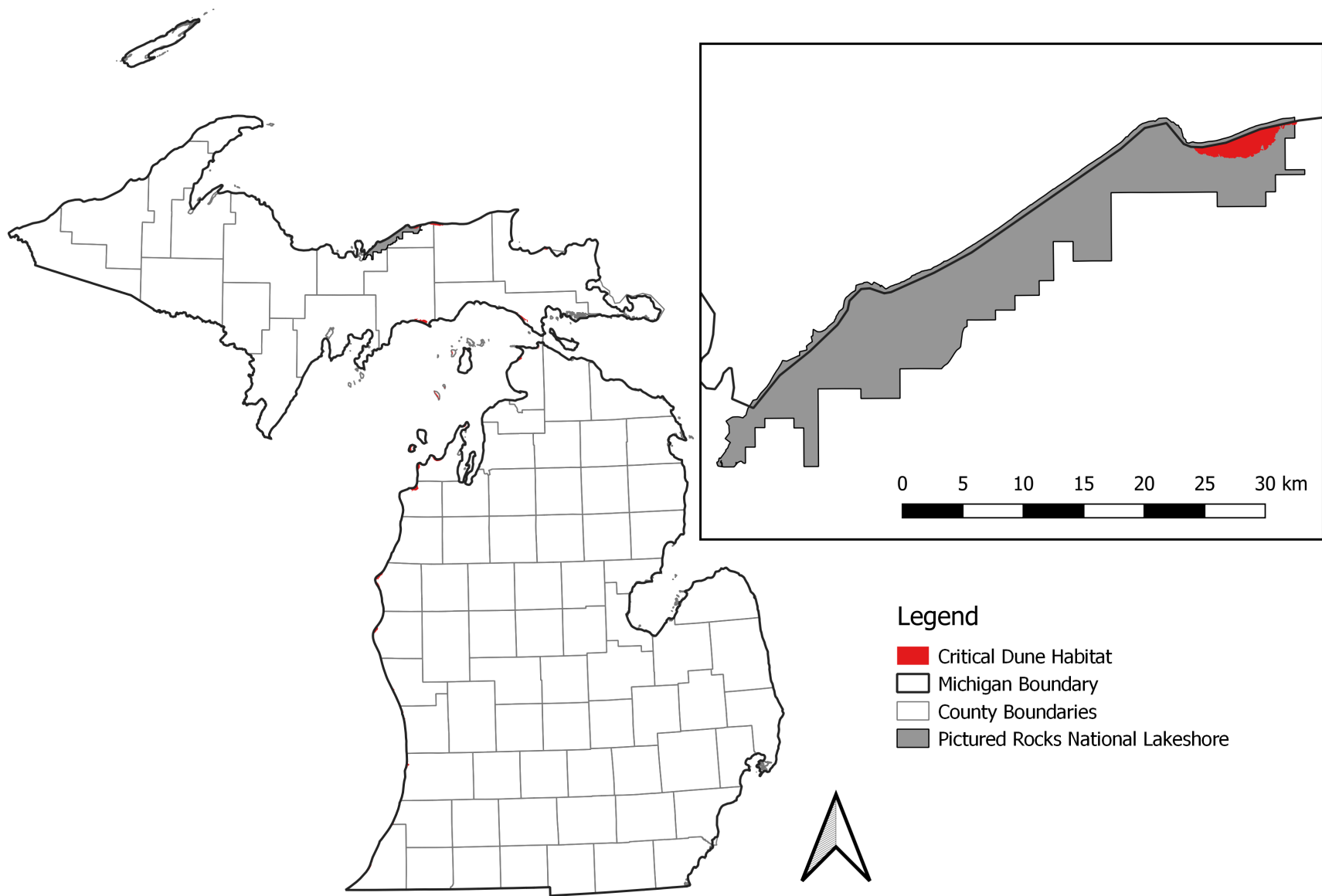


Figure 1. Distribution of critical dune habitat in Michigan and Pictured Rocks National Lakeshore.

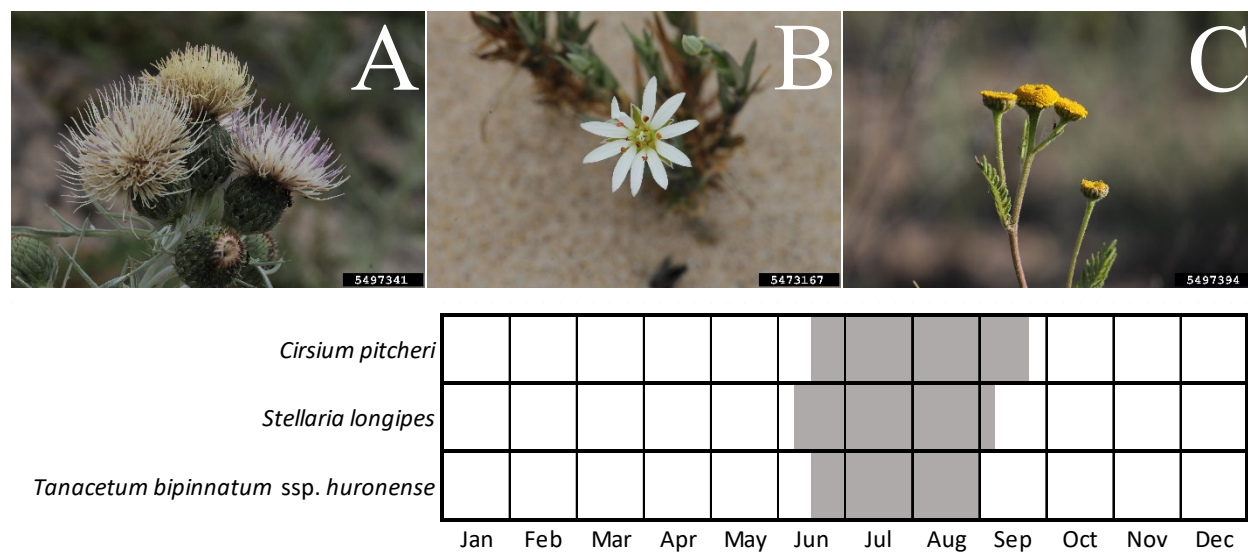


Figure 2. Examples of *Cirsium pitcheri* (A, Routledge 2013a), *Stellaria longipes* (B, Routledge 2013b), and *Tanacetum bipinnatum* ssp. *huronense* (C, Routledge 2013c) flowers and their flowering phenologies in Michigan (Choberka et al. 2001, Higman and Penskar 1999, Penskar 2009).

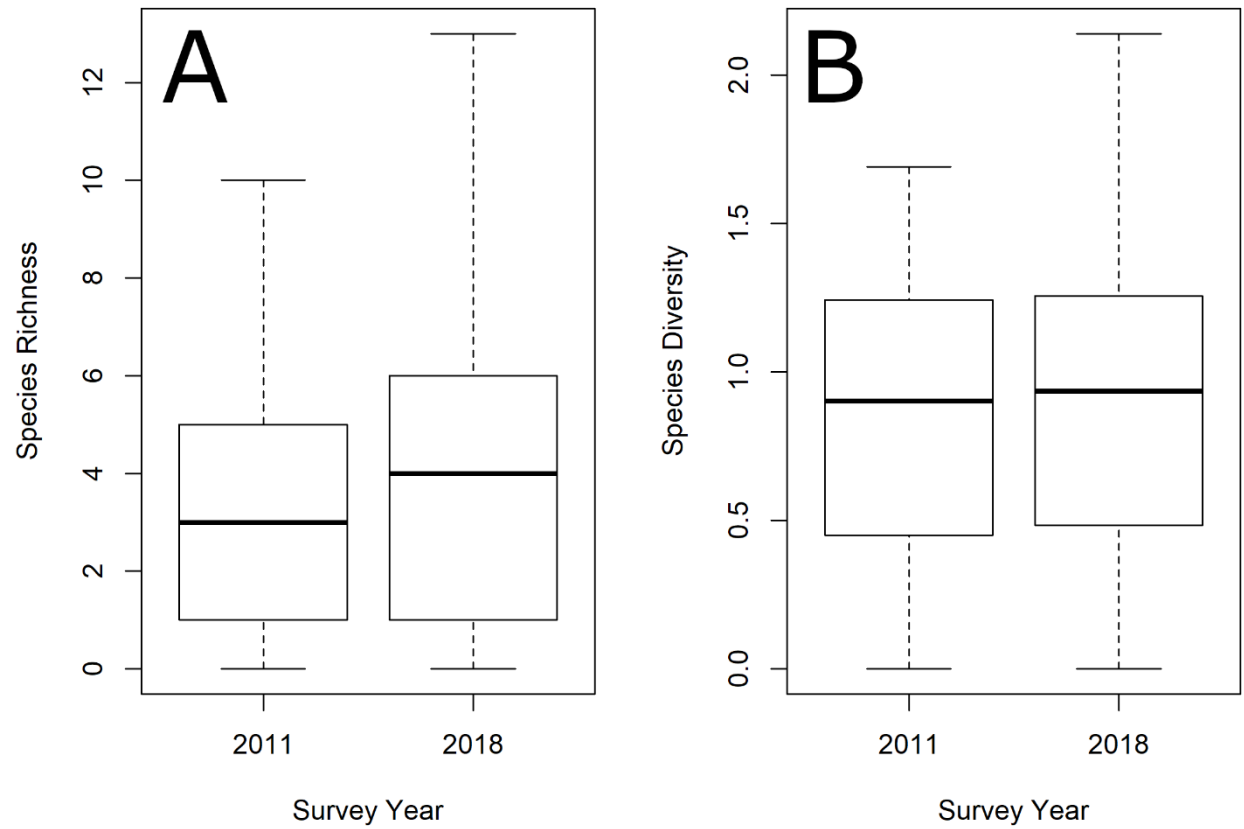


Figure 3. Mean species richness (counts; A) and species diversity (Shannon's diversity index; B) for 2011 and 2018 in Grand Sable Dunes, Pictured Rocks National Lakeshore.

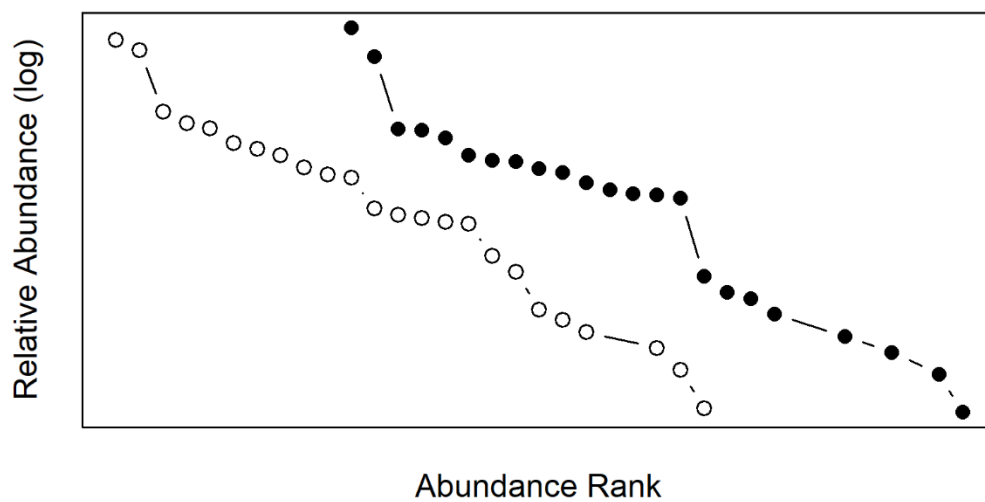


Figure 4. Log relative abundance for species organized by rank in 2011 (open circles) and 2018 (closed circles) in Grand Sable Dunes, Pictured Rocks National Lakeshore. 2018 points were shifted right to display both years without overlap

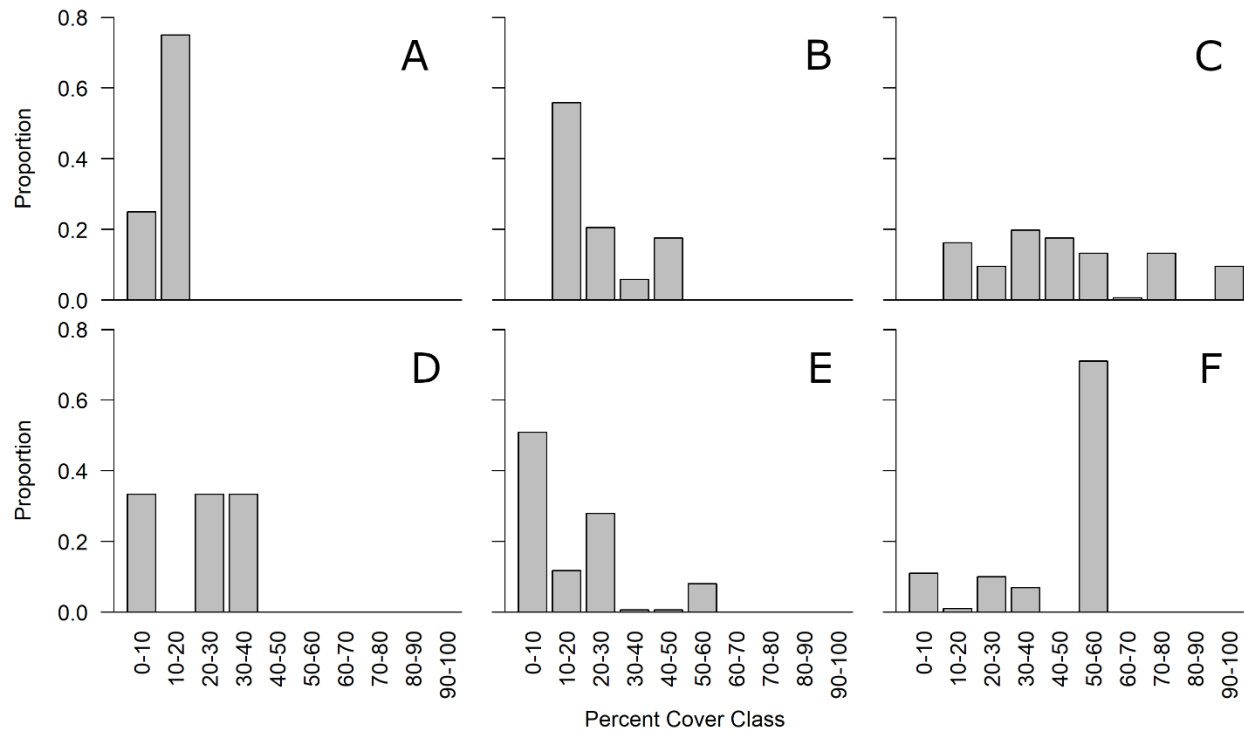


Figure 5. Proportion of *Cirsium pitcheri* (A,D), *Stellaria longipes* (B,E), and *Tanacetum bipinnatum* (C,F) individuals occurring in percent plant cover classes during 2011 (A-C) and 2018 (D-F).

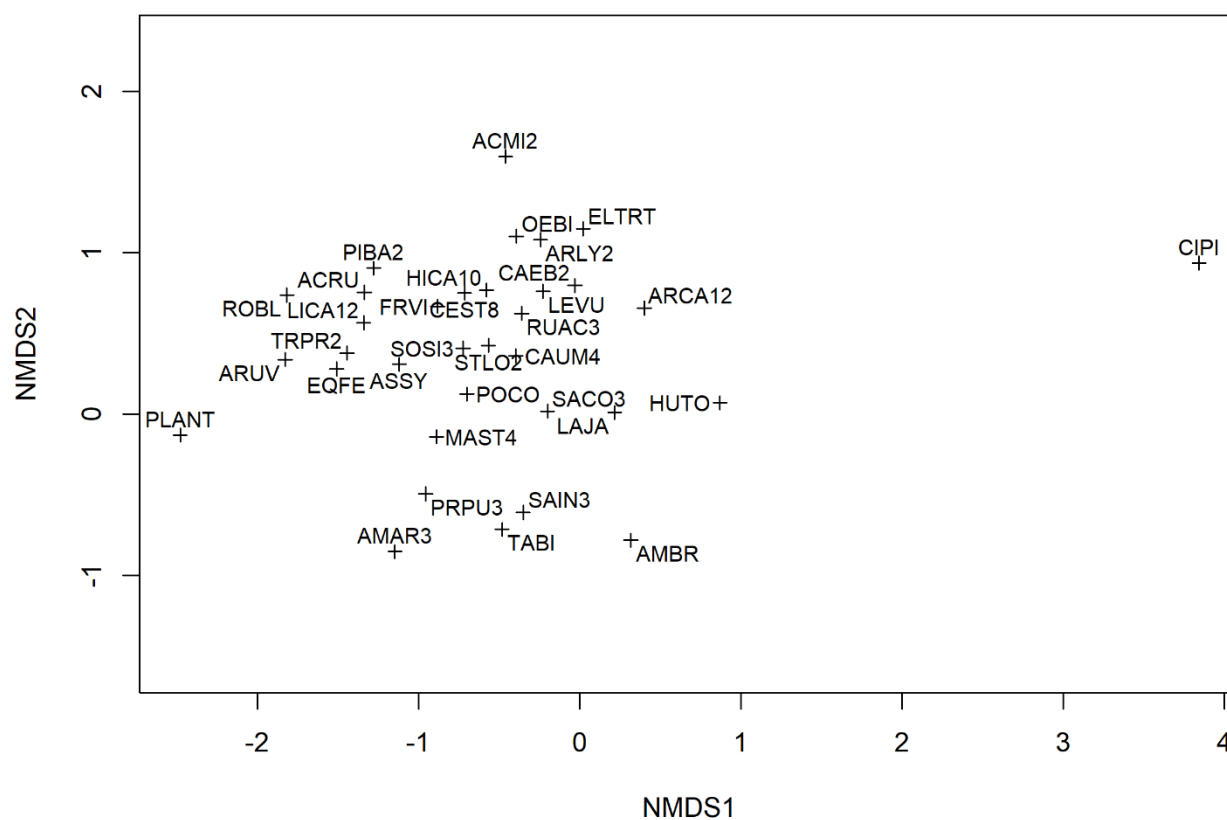


Figure 6. Nonmetric multidimensional scaling (NMDS) ordination of species occurrence in Grand Sable Dunes, Pictured Rocks National Lakeshore. Distances calculated as Bray-Curtis dissimilarity based on counts per plot. Species represented by USDA (2018) symbols defined in Table 1.

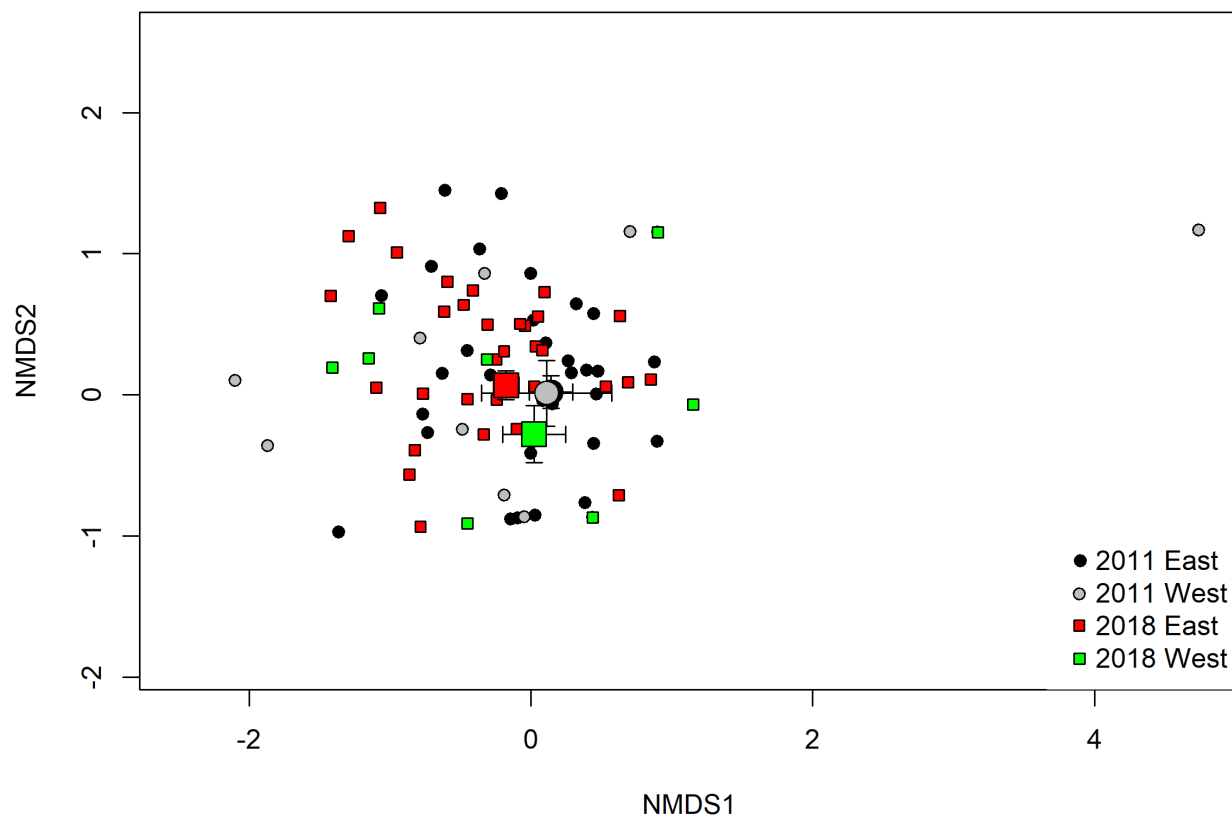


Figure 7. Nonmetric multidimensional scaling (NMDS) ordination of plots located in eastern and western extremes of Grand Sable Dunes, Pictured Rocks National Lakeshore. Distances calculated as Bray-Curtis dissimilarity. Large symbols represent mean values with standard error.

COMPARISON OF POLLINATOR VISITORS BETWEEN *HIERACIUM CAESPITOSUM* AND *LITHOSPERMUM CAROLINIENSE* IN PICTURED ROCKS NATIONAL LAKESHORE

Introduction

Open sand dune ecosystems are ranked as vulnerable on both a global and state level (Albert 1999). In the Great Lakes region, these dune systems exist along the shores of Lakes Huron, Michigan, and Superior, and account for 3.4% of the shoreline (Marsh 1990). Grand Sable Dunes is defined as a perched dune field in Pictured Rocks National Lakeshore on Lake Superior, which is situated atop a bluff with sand replenishment coming from the associated lake (Marsh 1990, Anderton and Loope 1995). Sand movement results in continuous, repeated disturbance, leading to a rather temporary habitat compared to other ecosystems (van Dijk and Vink 2005). Specialized plant communities form to survive this repeated disturbance and exploit limited resources (e.g. Maun 1998).

Hieracium caespitosum Dumort. (Asteraceae; yellow hawkweed) is a non-native species introduced from Europe as an ornamental (Prather et al. 2015). First collected in Michigan in 1936 (University of Michigan Herbarium catalog number 1254593), it has become a common species in Grand Sable Dunes (Marshall et al. 2008). *H. caespitosum* ranges from southeast Canada and northeast United States, west to Manitoba and south to South Carolina, as well as several northwestern states and British Columbia (USDA NRCS 2019). Often, *H. caespitosum* is rhizomatus and occasionally produces stolons (Gleason and Cronquist 1991). However, it also reproduces sexually with achenes as the result of insect pollination. A penchant for disturbed areas and shade tolerance capacity gives it an advantage in colonizing a wide range of habitats, in fields, along roadsides, and in dry woods (Gleason and Cronquist 1991).

Lithospermum caroliniense (Water ex J.F. Gmel.) MacMill. (Boraginaceae; Carolina puccoon) is a species native to North America. Within the United States, *L. caroliniense* ranges from the northeast coast, west to South Dakota and south to Texas (USDA NRCS 2019). It is considered endangered in Pennsylvania, and threatened in Ohio, but common in much of the remainder of its range (Ohio DNR 2016, PNHP 2018). Nutlets are produced as a result of insect pollination. Inflorescence takes the form of cymes with short-stalked or sessile flowers in clusters attached to the tips of clustered stems (Gleason and Cronquist 1991). *L. caroliniense* is found in sand dunes, along shores, and in oak and pine forests (Voss 1996).

While not considered an invasive species, *H. caespitosum* has become common within the Grand Sable Dunes in Pictured Rocks National Lakeshore (Marshall et al. 2008). *L. caroliniense* is common in specific areas and not as widespread in these dunes (Marshall et al. 2008). As these two species occupy similar habitats, are found in in close proximity to each other, have similar floral color, and have similar flowering times, the objectives of this study were to 1) identify the insect communities visiting each species and 2) quantify similarities in arthropod families visiting *H. caespitosum* and *L. caroliniense*.

Methods

Established populations of *H. caespitosum* and *L. caroliniense* were selected within the Grand Sable Dunes, Pictured Rocks National Lakeshore (46° 39' 27.5" N, 86° 1' 56.3" W). Ten individuals of each species were randomly selected on 20 June 2018 within 25 m of each other. Each individual was observed for 10 minutes during a 2 hour time bracket centered on solar noon. A second set of 10 individuals in each species was randomly selected and observed on 21 June 2018 within 25 m of each other. Locations for the two survey dates were approximately 100 m apart. All floral arthropod visitors were identified to family and counted. Family richness (S)

was calculated as the total number of families visiting each species pooled for the two survey dates. Family diversity was calculated for each species pooled for the two survey dates as Shannon's index $H' = -\sum p_i \ln p_i$, where p_i is the proportion of the i th family. Sørensen similarity was calculated as $(2 * (A \cap B)) / (A + B)$, where A is the number of families visiting *L. caroliniense* and B is the number of families visiting *H. caespitosum*.

Results

Overall, I observed 20 families visiting the flowers. On 20 June, two individuals of both species had zero visitors. However, on 21 June, all individuals of *H. caespitosum* received visitors, while two individuals of *L. caroliniense* had zero. There was a definite decrease in visitors for both species (Table 5). Both family richness and diversity were marginally greater for *L. caroliniense* compared to *H. caespitosum* (Table 5). However, family similarity was relatively high (Sørensen = 0.75), with 12 of the 20 families visiting both species. HesperIIDae was the single family that only visited *H. caespitosum*, with a single individual (Figure 8). The majority of families that only visited *L. caroliniense* included only one or two individuals (Figure 8). The top-3 families based on abundance were shared between the two species (Halictidae, Muscidae, and Syrphidae).

Discussion

In this survey, the majority of families were observed visiting both *H. caespitosum* and *L. caroliniense*. Families typically considered of importance due to visible pollen loads (e.g. Apidae, Bombyliidae) were relatively uncommon. Additionally, Halictidae individuals were counted as visitors to both the non-native *H. caespitosum* and the native *L. caroliniense*. Apidae and Halictidae were two insect families of great importance in another Great Lakes dune

pollinator survey for *Cirsium pitcheri* (Torr. ex Eaton) Torr. & A. Gray, an endemic and threatened species also found in Grand Sable Dunes (Marshall 2017). Halictidae was observed at a much higher abundance on *H. caespitosum* than on *L. caroliniense*, even though it was in the shared top-3 families.

The other two most common families on both species were Muscidae and Syrphidae visitors. *L. caroliniense* attracted far more Muscidae than their *H. caespitosum* competitors. Syrphidae visitors were more similar between the two species, with the family being the second ranked most abundant on both species. While neither of these two families are considered important to pollination (Brunet and Sweet 2006), their relatively high abundance at *H. caespitosum* and *L. caroliniense* demonstrate some importance in attraction. Syrphidae is a common visitor to a broad range of plant species and may have importance as a non-bee family to the success of pollination and fertilization (Rader et al. 2016). Formicidae was one arthropod family that is common in these areas of Grand Sable Dunes, especially with dune stabilization (Marshall et al. 2008), but was not observed. Often omitted from pollinator surveys, Formicidae can have negative impact on pollinator efficacy (Beattie et al. 1984, Baskett et al. 2011). In this study, Formicidae individuals were observed around plants and on stems, but they were never observed on flowers. Specimens from Aphididae were observed on *H. caespitosum* during the 2-hour period, but not on the specific plants being observed during the 10 minute periods.

Neither of these plant species have any label of concern, *H. caespitosum* is not invasive and *L. caroliniense* is not widely rare, although it may be rare locally. They are both fairly common in Michigan. However, this survey does demonstrate overlap in floral visitors between the two species. Such overlap could lead to reductions in reproductive success in *L. caroliniense*. Expanding this study into more dune ecosystems could provide further information regarding the

scale of the overlap in pollinators. Additionally, quantifying seed set could be helpful. State threatened species *Tanacetum bipinnatum* (L.) Sch. Bip. (Asteraceae) does occur in the Grand Sable Dunes in close proximity to both *H. caespitosum* and *L. caroliniense*. Flowering time for *T. bipinnatum* is later into the summer than the observation dates for this study. However, *H. caespitosum* continues to flower for much of the summer in the Grand Sable Dunes and overlapping pollinators could have important influence on successful reproduction of *T. bipinnatum*.

Table 5. Count of insect visitors on two survey days (20 and 21 June 2018) and family richness and diversity pooled for two survey days for *Hieracium caespitosum* and *Lithospermum caroliniense* populations in Grand Sable Dunes, Pictured Rocks National Lakehore.

Species	20 June	21 June	Richness	Diversity
<i>Hieracium caespitosum</i>	40	19	13	2.18
<i>Lithospermum caroliniense</i>	51	22	19	2.49

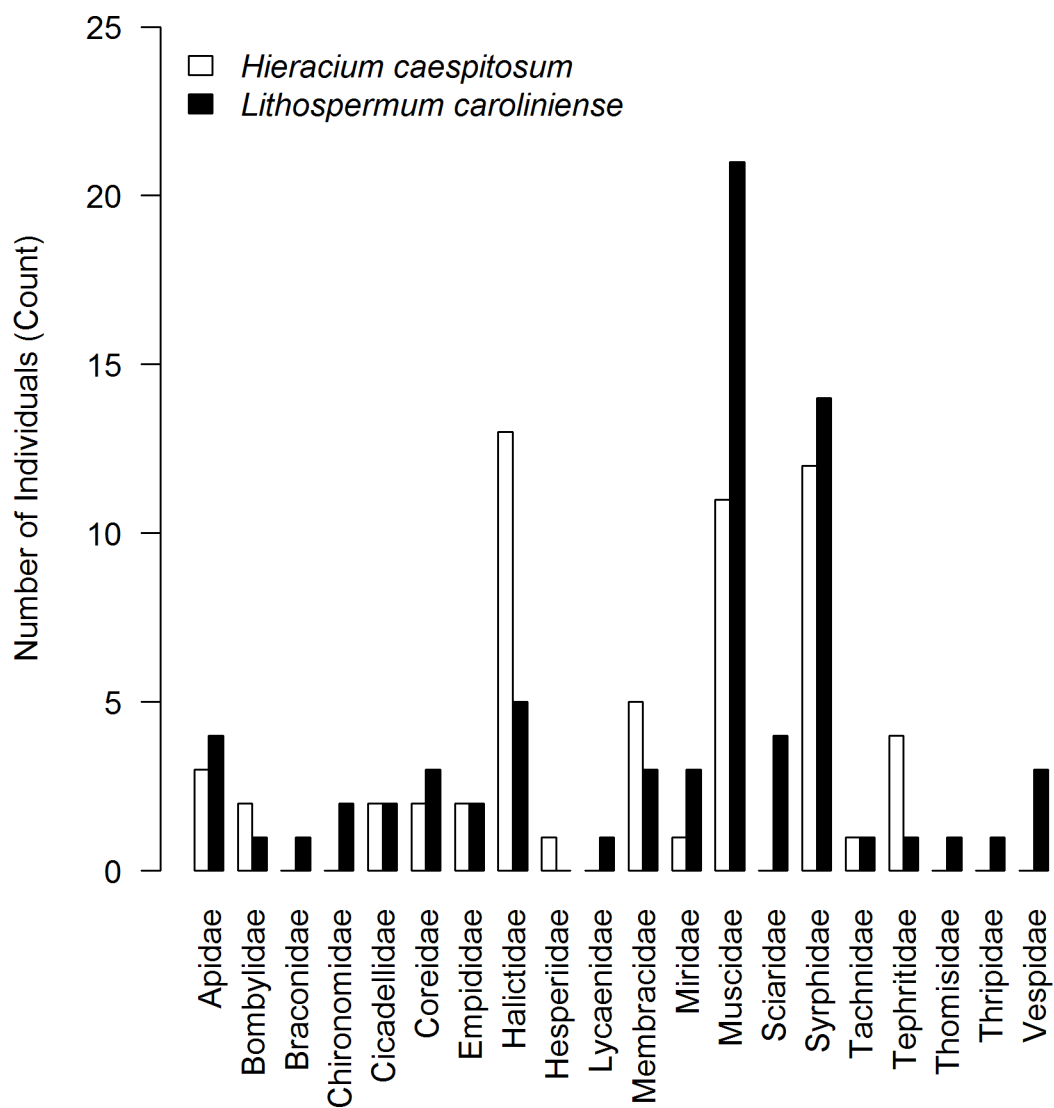


Figure 8. Number of individuals (count) of arthropod families visiting *Hieracium caespitosum* and *Lithospermum caroliniense* populations in Grand Sable Dunes, Pictured Rocks National Lakeshore.

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