Measuring the potential success of glade/alvar plant species in the DePauw Nature Park quarry bottom

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Abstract: The quarry bottom in the DePauw University Nature Park is an abandoned aggregate property. After it became inactive in 1977, the quarry bottom has not been managed and has turned into a novel ecosystem. The quarry bottom contains soil and environmental conditions that are similar to limestone glades and alvars. This study aimed at determining the germination, survival and growth success of glade and alvar plant species in the quarry bottom. The study showed that there is a substantial possibility of success with introducing glade and alvar plant species into the quarry bottom. Germination on petri plates and transplantation into the soil are the most likely successful methods of plant introduction.

Introduction:

The quarry in the DePauw University Nature Park was once an active limestone quarry. It was mined for limestone between the years of 1917 and 1977. After the quarry became inactive, it was effectively abandoned in terms of active human management and maintenance. As such, the nature park's quarry bottom can be referred to as an abandoned aggregate property, meaning it was formed in response to a certain event, in this case, limestone mining.

Since the quarry became inactive, it has developed into a novel ecosystem. A novel ecosystem has the following characteristics: (1) it must contain new (novel) combinations of species and (2) it must be created as a product of deliberate human agency (Hobbs et al. 2006). Since both of these characteristics are present in the quarry bottom, it can be classified as novel. It is worth noting, though, that a novel ecosystem is not one that is maintained by human activity; only that it is the result of human action (Hobbs et al. 2006).

The novel ecosystem in the quarry bottom of the Nature Park is currently home to a variety of invasive plant species thriving in the harsh rocky soil due to their superior survival skills and dispersal techniques, including rhizomes and wind dispersal. As these invasive species to grow and proliferate, the task of rehabilitating the ecosystem in the quarry bottom also grows in magnitude. While the novel ecosystem is interesting in its own light, there are compelling reasons to intervene in an effort to make the quarry bottom more similar local to ecosystems. Two ecosystems that are similar to the one found in the quarry bottom are **alvars** and **limestone glades**. These ecosystems contain plant species that are specifically adapted to thrive in soil similar to the soil found in the quarry bottom (Kost et al. 2007).

Limestone glades are composed of thin soil with a limestone or dolomite bedrock and scattered shrubs and trees (Kost et al. 2007). Alvars are similar to limestone glades in that the same types of vegetation grow, the sun exposure is similar, and the soil types are comparable. The shallow soil in the quarry bottom, glades, and alvars results in poor drainage and a dominance of herbaceous vegetation. These shrubs and other vegetation tend to spread across the rocky surfaces of these ecosystems (Kost et al. 2007). The quarry bottom is a comparable environment due to its thin rocky soil and sun exposure. As such, the quarry bottom could possibly support species that thrive in glades and alvars.

Rehabilitating the quarry bottom ecosystem to look similar to glades and alvars would have two major benefits. First, it would increase the educational value of the Nature Park. By making the quarry bottom more similar to glades and alvars in Indiana and the Midwest, the Nature Park could provide a more comprehensive view of different types of ecosystems, specifically ecosystems that host rare endemic species. Second, introducing plant species that are adapted specifically to environments like the quarry bottom may help curtail the presence and expansion of invasive species. Plant species that are well adapted to survive in the quarry bottom's soil could provide formidable competition for the invasive species due to their high fitness in rocky dry environments.

While there are benefits to introducing glade and alvar plant species to the quarry bottom, it is important to recognize that the quarry bottom is *not* a glade or alvar. While it is similar to these ecosystems, the introduction of native species would not assuredly be a success. Before beginning to rehabilitate the quarry, it is important to first determine the potential success of our efforts. If the species found in glades and alvars cannot germinate and grow in the quarry bottom's soil, the efforts to introduce them to in the quarry would be futile.

A project with a similar goal is currently being explored in Ontario, Canada. The Management of Abandoned Aggregate Properties project, or MAPP, dedicates itself to rehabilitating abandoned pits and quarries (Campeau 2010). This project indicates that rehabilitating a limestone quarry is possible but costly. Throughout the time period of 1990-2011, this project spent more than six million dollars rehabilitating 540 hectares of land. Undertaking a similar project with respect to the Nature Park would be costly and time consuming.

The goal of this project is to determine the feasibility of rehabilitating the quarry bottom with plant species native to glades and alvars. Specifically, we studied the germination rates and overall survival and fitness of several native plant species in soil collected from the quarry bottom to determine if a glade-like environment can be created in the quarry.

Methods:

Area of Study:

The soil used in the germination and fitness tests was collected in the DePauw Nature Park's quarry bottom. The soil was collected from the southeast corner of the quarry bottom in an area that lacked leaf litter but with vegetation.

Selection of Species:

We compiled a list of plant species that are native to glades and alvars in the Midwest. We selected ten plant species based on their appearance and their potential for successful growth in the quarry bottom. All ten plant species grow in similar environments with respect to soil type, according to the literature. (Matheson 2007). It was said of each species that they could grow where only rocky and sandy soil is found.

We initially selected nine plant species based on reading literature about glades and alvars. We selected one additional plant species based on a suggestion from John Eskew, the DePauw University greenhouse manager and Dana Dudle, Professor of Biology. We obtained seeds for each plant species from Prairie Moon Nursery, a native plant nursery in Winona, MN.

The ten selected plant species were:

- *Allium stellatum*, prairie onion
- *Dalea purpurea*, purple prairie clover

- *Echinacea pallida*, pale purple coneflower
- *Echinacea simulata*, pale purple coneflower
- *Oenothera macrocarpa*, Missouri evening primrose
- *Physostegia virginiana*, obedient plant
- *Rudbeckia fulgida*, orange coneflower
- *Ruellia humilis*, fringeleaf wild petunia
- *Silphium integrifolium*, prairie rosinweed
- *Sorghastrum nutans*, Indian grass

We selected two plant species for initial comparison: *Dalea purpurea* (purple prairie clover) and *Sorghastrum nutans* (Indian grass). These two species were selected because they do not require a vernalization period. The two species chosen are shown in Photo 1.

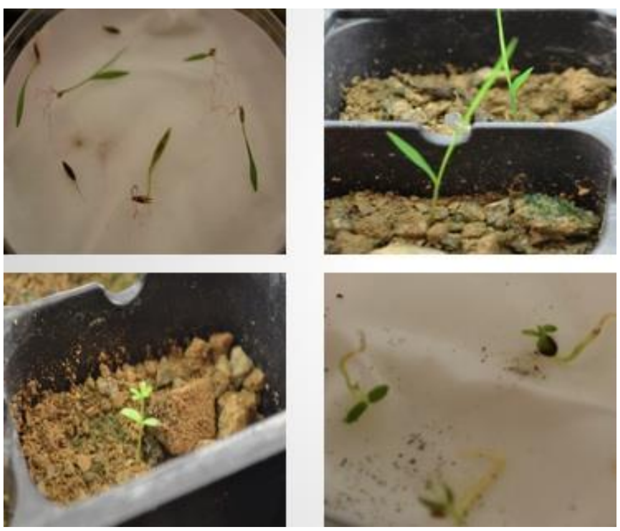

Figure 1: The germinated plants in petri plates and quarry soil: (Top: *Sorghastrum nutans,* Indian grass and Bottom: *Dalea purpurea*, purple prairie clover)

Germination Methods:
We conducted germination trials for two weeks. The germination protocol was adapted from protocols found in the literature (Keinsley 2011, Kramer 2011, Sanford 2013) as well as advice from John Eskew and Professor Dana Dudle. We placed seeds on moist petri plates of filter paper and cheesecloth or in soil collected from the quarry bottom. Eight seeds were placed on each petri plate or planted in quarry soil. We replicated these conditions 20 times for each species and treatment condition. The *Dalea purpurea* samples were sprinkled with *Rhizobium* as the seed packages dictated in both treatment conditions. Each day for two weeks, we recorded the number of germinated seeds and checked the samples to ensure that they remained adequately moist.

Transplant Methods:
After two weeks of germination trials, we transplanted 20 germinated seeds of each plant species from the petri plates to soil collected from the quarry bottom. To determine which seeds were to be transplanted, we randomly selected petri plates. All germinated seeds within each selected petri plate were transplanted. We used this method to avoid arbitrarily (or inadvertently) selecting the most-fit looking plants for transplantation. We used the same soil from the quarry bottom that we used for the germination trials. As before, *Rhizobium* was sprinkled on the transplanted *Dalea purpurea* samples.

Care of plants:
Every day the plants were checked to ensure adequate water supply and were watered with deionized water. For the first four weeks of study, the plants were kept in a growth chamber set to 72 degrees with 50% humidity and 12 hours of daylight. During the next four weeks, the plants were moved to the greenhouse. All plants received exactly the same care.

Winterized seeds:
In order to replicate winter, seeds that required a vernalization period were placed in ziploc bags filled with cup of moist vermiculite. After 4 weeks of refrigeration, we selected two additional plant species for the same germination experiment described above.
The two species selected for this experiment were *Allium stellatum* and *Physostegia*

virginiana. These two species were selected because they had the shortest vernalization time (60 days) and were the easiest to remove from the vermiculite due to their size and color. We used the same protocol for the germination trials except there were only 10 replicates for each treatment condition instead of 20 replicates. Due to time constraints, the analysis of the winterized plants was not completed.

Data Analysis:
We compared germination rate, survival rate, and overall fitness of *Dalea purpurea* and *Sorghastrum nutans*.

Germination Comparison: We recorded the total number of germinated seeds for sample for each plant species and treatment condition. We marked seeds that had not germinated to avoid confusion between non-germinated seeds and germinated seeds that had died. We analyzed the germination data using an ANOVA.

Survival Comparison: We recorded the number of germinated seeds that died four weeks after transplantation. We analyzed the data using an ANOVA. The sample sizes differed between plant species and treatment conditions. In order to simplify the data analysis, we randomly chose 20 germinated seeds from each treatment condition for comparison.

Fitness Comparison: We counted and recorded the number of leaves after 6 weeks of growth (4 weeks after transplant) as a representation of overall fitness. We analyzed the data using an ANOVA.

Winterized Seeds: The winterized seed comparisons have not been evaluated at this time since the experiment is continuing. After the two week germination period, the total number of germinated seeds will be compared to the germination rates of the non-winterized seeds.

Results:

Germination: Figure 2 shows the number of germinated seeds on each day of the 14-day trial, out of a total of 160 possible seeds, for each species in each treatment condition. There was a significant effect of species (F = 254.2, $p < 0.001$) and treatment condition (F = 269.6, $p < 0.001$) on germination success. Both *Dalea purpurea* and *Sorghastrum nutans* seeds germinated more quickly and more successfully in the petri plates than in the quarry bottom soil.

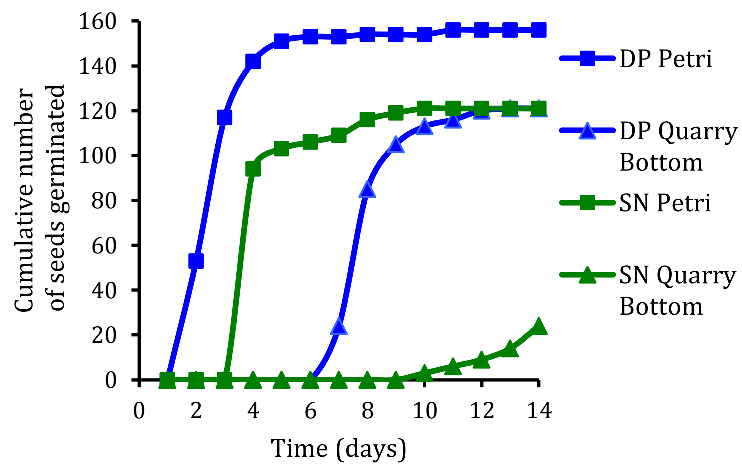

Figure 2: Cumulative number of seeds (out of 160 total) germinated on each day of the two-week germination trial. DP = *Dalea purpurea*, SN = *Sorghastrum nutans*.

Survival:
Table 1 shows the survival of germinated seeds and the number of leaves per plant four weeks after transplantation. There was a significant effect of species (F = 13.7, $p < 0.001$) and treatment condition (F = 6.1, $p < 0.001$) on survival. Survival of both *Dalea purpurea* and *Sorghastrum nutans* was higher for seeds germinated in petri plates than seeds germinated in soil. Survival rates were higher for *Sorghastrum nutans* than *Dalea purpurea*.

Table 1. Survival and number of leaves for two plant species.

Species	Treatment	Survival rate	Number of leaves
Dalea purpurea	Soil	50%	2.2
	Petri	80%	3.6
Sorghastrum nutans	Soil	88%	2.3
	Petri	100%	3.0

Number of leaves

There was a significant interaction effect of species and treatment (F = 2.4, $p < 0.001$) on the number of leaves per plant. Both plant species produced a similar number of leaves when seeds were germinated in soil. *Dalea purpurea* produced significantly more leaves than *Sorghastrum nutans* when seeds were germinated in petri plates.

Discussion:

Our results indicate that the soil from the quarry bottom was a less favorable environment for germination of seeds and survival of plants than the petri plates. However, our data also show that germination in the quarry soil is possible despite being less successful than petri plate germination. This possibility is contingent on adequate conditions such as sunlight and enough water, but shows that planting these species in the quarry bottom soil is likely to result in some germinated seeds of each species.

The time it took for the seeds to germinate, as shown in Figure 1, could indicate that the seeds appeared to germinate more slowly they were covered with a thin layer of the soil. It was easier to see the seed germination in the petri plates. In order to account for this potential disparity, we continued the germination trials for two weeks. This ensured that the germinated seeds grew enough to be seen in the soil.

Suggestions for Future Study:

Continuing this research and applying the findings to the quarry bottom would be an excellent future project. The species that were not selected that went through the winterization process were not analyzed in this study due to the limited time. Assessing the germination of these plants compared to the species that did not require a winterization period would be a worthwhile expansion of our current project. Further, within the winterized species, the three comparisons (germination, survival and fitness) could be studied to determine how successful the species would be if they were introduced into the quarry bottom soil.

A study longer than six weeks would also be a helpful. Measuring survival over a longer time would give a more accurate assessment of the potential success of these plant species in the quarry bottom.

One aspect of the study that could distort the results was the environmental conditions in which the seeds were germinated and grown. Since the seeds were germinated and grown in constant temperature growth chambers with 12 hours of daylight and plenty of water, the conditions that are present in the quarry soil during germination would likely not be as ideal as these conditions were. Indiana tends to have fluctuating temperatures, which could impact the germination, survival, and fitness of these species. Additionally, the water availability could impact the success of the plants. Further studies that assessed the effect of the environmental fluctuation on the species would also give us insight into the potential success of introducing the species.

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