THE ROLE OF REMNANT NATIVE VEGETATION AND MANAGEMENT STRATEGIES IN THE RECLAMATION OF NATIVE PRAIRIE PLANT COMMUNITIES

by

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Abstract

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Native prairie ecosystems along with their ecosystem services are diminishing in Texas. In order to restore the native prairie ecosystems and their services as a whole, the native prairie plant communities on which they are based must be reclaimed. Effects on native plant community establishment of past land use, seed dispersal from nearby remnant plant communities, and various management strategies were studied to better understand the reclamation process and formulate recommendations for native prairie reclamation. [add sentence or two here describing the land use you studied: previously agricultural and recent quarries] Establishment of desired native prairie plant communities was negatively affected by more recent disturbance, but positivity affected by the proximity of disturbed areas to remnant native vegetation. Management practices recommended as most successful at establishing desired native plant communities include increasing available native propagules, adding soil amendments whose nutrient levels are similar to native surface soils, and reducing any further disturbance of existing plant

communities. Although use of these management strategies may allow for the reclamation of native prairie plant communities in general, or simply speed up and steer the natural reclamation process, reclamation to the native Little Bluestem dominant prairie community may be more difficult and take more time.

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Chapter 1

Introduction

1.1 Diminishing Prairie Ecosystems

A large portion of the center of North America was once covered by grasslands ranging from shortgrass, to mixed grass, to tallgrass, with only sparse tree cover. These prairies once covered over 250 million acres of North America from Texas to Canada, but they have now been reduced to approximately 1 million acres (Sims, et al. 1978), making them one of the most endangered ecosystems on the continent (Samson, et al. 2004). A comparison of these grasslands over just 30 years from the 1940's to the 1970's revealed that plant communities degraded 85% during that time (Sims, et al. 1978).

This reduction in prairie extent is linked to human population patterns. Urban populations in the United States have been growing for over 100 years and are still continuing to grow (US Census Bureau 2012). It is because of this population growth that settlements are expanding, destroying native prairie ecosystems at such a fast rate. Alteration of the native plant communities on which these entire prairie ecosystems are based often happens through agricultural practices including cultivation and overgrazing by cattle, because the treeless and fertile nature of grasslands supports these practices (Sims, et al. 1978). Prairie ecosystems have also been historically altered by invasion of non-native plant species, often deliberately, for the purpose of farming or grazing (Lindenmayer, et al. 2008). Settlement and the expansion of cities have also destroyed native prairie by completely removing all plant matter and top soil for building purposes, or by fragmenting prairie into small patches that cannot survive (Lindenmayer, et al. 2008).

The Dallas-Fort Worth metropolitan area (DFW) in Texas is the fourth largest metropolitan area in the United States by population, according to 2010 Census data (US Census Bureau 2012). It sits on a convergence between several different ecoregions (Bureau of Economic Geography 2010), which all have prairie components and have many of the same plant species as main constituents (Shaw 2012, Dyksterhuis 1948, Dyksterhuis 1946). Here I have chosen to focus on the junction between the Grand Prairie and Western Cross Timbers ecoregions, which sits almost directly on Fort Worth, the western part of DFW (Bureau of Economic Geography 2010, Dyksterhuis 1948). The Grand Prairie ecoregion is composed of mainly tallgrass prairie that extends from central Texas, up through Oklahoma (Bureau of Economic Geography 2010, Dyksterhuis 1946). It is flanked by the Western and Eastern Cross Timbers ecoregions, which consist of forested areas with patches of prairie throughout (Dyksterhuis 1948). The Northern portion of the Grand Prairie ecoregion, which blankets the city of Fort Worth, has been named the Fort Worth Prairie (Dyksterhuis 1946).

The native prairies that once completely covered much of North Texas have suffered the same fate as grasslands across North America, and have now been mostly destroyed and fragmented (Texas Parks and Wildlife, 2015), especially in and around large cities or metropolitan areas such as DFW. This destruction of prairie in North Texas begun as far back as 1850, when the prairie began to change due to influence of Native

Americans and their driving of the large buffalo herds southward (Dyksterhuis 1946). By the late 1800's, the population of the area increased and so did cattle grazing, further altering and damaging the entire ecosystem (Dyksterhuis 1946). Since 1900, widespread farming and overgrazing of most of the prairie land that had not yet been built upon, and complete removal of a large portion of the native prairie cover by urbanization, has continued to degrade the few native portions that remain (Texas Parks and Wildlife 2015, Dyksterhuis 1946). In North Texas, where agriculture is a common land use, often the only native prairie fragments that have remained over the years were those that had surface soil too shallow for cultivation (Texas Parks and Wildlife 2015). This overall destruction of the native prairie regions of Texas has been predicted to have long-lasting effects on wildlife and habitat resources in these regions (Texas Parks and Wildlife 2015).

Although it is mainly the actions of humans and the growth of settlements that have been at fault for the destruction of native prairies in the North Texas region, it is the resources that these native ecosystems sustained that originally brought people to settle in the region (Dyksterhuis 1946). As expected, the resources and services that this vast prairie ecosystem once supported have begun to dwindle along with native prairie cover (Shaw 2012, Isenburg 2000). In North Texas, precipitation is relatively low and seasonal; therefore drought is often a concern (Texas Parks and Wildlife 2015, Godfrey, et al. 1977). The native prairie ecosystem is comprised of plant species that not only thrive in these low water conditions, but also have mechanisms that aid in water retention (Isenburg 2000). Thus, the widespread use of non-native plant species for landscaping has increased the amount of water needed to keep these landscapes alive, while simultaneously decreasing the presence of plant species that help replenish water resources. Certain native animal species, such as prairie dogs and bison, also aid in replenishing the water table (Isenburg 2000). Both of these species, that were once abundant and supported by the prairie, are now virtually non-existent in the wild (Texas Parks and Wildlife 2015, Isenburg 2000). Native prairies are also habitats for a variety of other North Texas wildlife, however with the destruction of the prairie has come the decrease in populations of animal species, including many game animals (Texas Parks and Wildlife 2015). Native prairie plants are resources for native pollinators, like bees and birds, which are valuable to the agricultural industry for pollination of food crops (Texas Parks and Wildlife 2015, Isenburg 2000). When managed properly, ensuring that native processes are preserved and allowed to recover, prairie can be used as rangeland for livestock and farmland for row crops (Texas Parks and Wildlife 2015, Dyksterhuis 1946). The tallgrass and deep rooted nature of the Fort Worth Prairie also allows it to sequester more carbon than invasive plant communities common to the area and impermeable landscape, a feature that is known to be an effective way to mitigate climate change (Texas Parks and Wildlife 2015, Natura 2015, Condon 2010, Dyksterhuis 1946).

In addition to these practical solutions the prairie ecosystems provides for the difficulties of living in the area, it is also worth mentioning its great aesthetic value. The prairie is treasured for its vast expanses, unobstructed sunsets, numerous and vibrant wildflowers, and diverse wildlife, offering countless outdoor recreational opportunities (Texas Parks and Wildlife 2015). The destruction of this once vast prairie ecosystem has allowed for the degradation of the many resources and services that the prairies once provided to the inhabitants of this region (Texas Parks and Wildlife 2015, Isenburg 2000).

Although the original extent of the prairie has been greatly reduced, in North Texas there are also several green spaces within the city, such as city parks, as well as native remnants and undeveloped land, where native plant populations have persisted. These areas contain differing degrees of native habitat, but can offer a way to allow the native ecosystem persist (Doody, et al. 2010). In recent years, increased public awareness of conservation and sustainability, due at least in part to dwindling resources like water, has resulted in more consideration of native prairie preservation and reclamation (Condon 2010, Derner, et al. 2004). Although the changes made to the prairie components of these native ecoregions may be long-lasting (Texas Parks and Wildlife 2015), if restoration efforts are made, native remnants could expand and the negative impacts on the ecosystem as whole could be reduced.

1.2 Little Bluestem as a Native Prairie Indicator

The entire ecosystem, as well as the ecosystem services offered by it, is based on the native plant community assemblage, which consists mainly of abundant native tall grasses and native forbs. In the prairies of the Western Crosstimbers, the Grand Prairie, and even the neighboring Blackland prairies, the native Little Bluestem grass (LBS), *Schizachyrium scoparium*, is the dominant species (Dyksterhuis 1948, 1946). In the Fort Worth Prairie, when a plant community is at its climax native condition, LBS covers an average of more than 60% of the plant community and occupies 100% of native prairies (Dyksterhuis 1946). LBS is so dominant that it is often used as an indicator species for native prairies of these ecoregions in North Texas, where they are often deemed as “Little Bluestem grasslands” (Griffith, et al, 2004) and the dominant plant community series has been named the LittleBluestem-IndianGrass series (US Department of Agriculture 1996). LBS is a tall bunchgrass that forms dense clumps, has blueish-green stems in the spring, and has bright red stems and cottony seeds in the fall (LBJ Wildflower Center 2014, Dyksterhuis 1946). Many of LBS’s qualities have been discovered to be ecologically important for other native species. For instance, quail, a bird species that has seen population losses over the years and is being actively managed by the state of Texas, prefers LBS dominated prairie because of the mosaic terrain its clumping nature provides (US Department of Agriculture, 1996). LBS seeds are also valuable to many different native bird species including larger species like turkey, and smaller songbirds (LBJ Wildflower Center 2014, US Department of Agriculture 1996). Due to the dominant nature of LBS and its importance to the ecosystem, prairie reclamation efforts often focus on its establishment (Derner 2004).

1.3 Overall Objective

Increasing the extent of native prairie that once existed in North Texas will require land to be converted from varying states of damage. For this to be achieved, first well-studied and concise reclamation practices must be compiled. However, this can be difficult when each individual site may be reclaimed from different levels of past disturbance. Historically, the prairie has been maintained by disturbances such as lightening fire and grazing by ungulates (Dyksterhuis 1946). The prairie has evolved alongside these disturbances, and the native plants have mechanisms to rebound (Dyksterhuis 1946). Disturbances by humans can vary widely and as such, the ability of the native prairie communities to regenerate themselves is highly variable. Due to this variability, strategies employed for reclamation can also vary widely.

To facilitate reclamation of disturbed areas, better understanding of the role of the regional species pool is required, as well as a better understand of how those populations might be dispersing. While manually reseeding or replanting native plants can be effective, there can be many problems associated with it, particularly the high cost and the fact that the species are picked and the areas they are planted are chosen, resulting in an unnatural prairie that may not have all the same complexity and benefits as a natural one (Palmer, et al. 1997). The drawbacks of this method are enough to warrant the exploration of more minimal and natural methods of reestablishment. Although native prairie remnants may be few and far between, and potential reclamation sites may be at a great distance from sources of native plant propagules, one study performed in previously mined grassland and forest areas showed that plant populations up to 17 km away could play an important role in passive reclamation (Kirmer, et al. 2008). Furthermore, passively reclaimed sites have been shown to have a greater native plant species richness than and be favored by native arthropod species more than actively reclaimed sites (Tropek, 2010).

While passive reclamation using existing native populations may be optimal in many cases, there may be instances when this reclamation method is impossible or is not optimal due to a variety of reasons. For this reason, a thorough understanding of the effectiveness of various reclamation strategies needs to be determined. If an effective amount of prairie restoration is to take place, which is what would probably be required to restore many of the ecosystem services the prairie ecosystem provides, more needs to be understood about the dynamics of native prairie restoration. Specifically, the effect of past land use on reclaimed prairie plant communities, how existing native plant communities can affect reclamation efforts, and how different management approaches can affect reclamation outcome need to be investigated.

1.4 Prior Land Use Affects Reclaimed Prairie Plant Community

Past disturbance to plant communities can affect reestablished plant communities in a variety of ways. Depending on the degree and nature of the disturbance, plant communities may be affected differently. Land use prior to reclamation could fall under a variety of categories including grazed by livestock, farmed for crops, invasive-covered suburban lawn, quarried, or covered with a concrete structure, such as a building or a road. Plant communities could be completely removed along with any native soil, which might happen with construction. Plant communities could be completely removed, but enough soil left to allow for a seed or bud bank to remain to possibly foster reestablishment of native species. Plant communities could also just be altered by introduction of non-native species for the purpose of grazing or landscaping. This vast spectrum of possible native prairie disturbances and levels of disturbance warrants a further investigation of the effects these difference may have on the reclamation process. Based on prior knowledge, I hypothesize that:

H1: Plant communities differ in previously disturbed and undisturbed native prairies.

H1.1: Proportions of LBS and of total native plant cover will be greater in prairies that were historically unworked than those that were previously farmed and grazed.

H1.2: The proportion of invasive plant cover will be greater in prairies that were previously farmed and grazed than in those that were historically unworked.

1.5 Native Plant Populations are Spreading from Remnant Native Communities

Movement between fragments can be especially challenging to plants since they are sessile organisms and many plants rely on clonal growth as a means of reproduction, which is very likely inhibited almost completely by many types of barriers. Because of this, seed dispersal of plants from a native population is an important method of reproduction to consider in a fragmented habitat (O'Connell, et al. 2013). The production of new individuals by seed, rather than clonally, can allow individuals to disperse further and can increase genetic variation in a plant population (Gurevitch, et al. 2006). However, there are still many challenges faced by seeds on their journey to establishment in new areas. For instance, barriers such as buildings or trees could prevent seed movement. The conditions normally needed for dispersal could be absent, such as an animal that usually disperses a seed (Cordeiro, et al. 2009), high wind speeds, or water.

The dispersal abilities of native plants are important to maintaining a healthy native ecosystem because diversity in plant communities are thought to support maximum diversity of other native organisms that depend on the habitat to live (Harmon-Threatt and Hendrx 2015, Tews, et al. 2004, Siemann, et al. 1998) and declining biodiversity can negatively affect ecosystem performance (Naeem, et al. 1994). In order to go beyond adult community composition in remnant native prairies, to see what species are being dispersed and could reach disturbed land on their own to facilitate passive reclamation, a better understanding of native seed dispersal patterns in needed. Focusing on the dispersal of native wind dispersed seeds, and mainly LBS seeds because LBS is the primary native prairie indicator, my hypotheses are as follows:

H2: Native plant species are dispersing from remnant native prairie plant communities

H2.1: A greater abundance of native seeds will be dispersed to areas that are closer to significantly large LBS dominated native prairie plant populations than to areas that are further away.

H2.2: A greater abundance of LBS seeds will be dispersed to areas that are closer to significantly large LBS dominated native prairie plant populations than to areas that are further away.

H2.3: A greater abundance of LBS seeds will be dispersed to areas that are closer to an individual LBS plant than to areas that are further away.

H2.4: A greater abundance of native seeds will be dispersed to areas that are in the direction of average prevailing winds from a source than in those areas that are not in the direction of prevailing wind patterns from a source.

H2.5: A greater abundance of LBS seeds will be dispersed to areas that are in the direction of average prevailing winds from a source than in those areas that are not in the direction of prevailing wind patterns from a source.

1.6 Management Strategies Affect Reclaimed Plant Communities

The focus of my study was on reclamation to prairie vegetation of quarry areas. A quarry, or an open-pit mine, is an area where reserves like rocks, minerals, gravel, or sand are pulled from below the surface, to be used as resources (Vulcan Materials Company, 2013). This removal of vast amounts of material leaves deep pits in the ground, and the use of heavy machinery needed to get the resources out often destroys the surface of surrounding land, even if it is not being quarried. These quarry processes completely remove the native prairie plant community and native surface soil within the actual quarry and damage surrounding plant communities to different degrees.

In order to reclaim a once native prairie area that was quarried, soil may be added to refill the pit, surface soil may be added on top of that, and the surface soil can then prepared in a variety of ways. Success of reclamation management techniques may be variable based on the combination of management techniques used and the persistence of native prairie plant communities within a proximity that could possibly foster natural, passive reclamation. In order to form a more comprehensive set of management techniques for quarry and overall native prairie reclamation, the effects of these management strategies on established plant communities needs to be further investigated. Focusing on the plant community that results from variable reclamation strategies performed on quarried prairies, my hypotheses are as follows:

H3: Effectiveness differs among different native prairie reclamation strategies.

H3.1: Quarry filling will decrease native plant communities and increase chances of invasive establishment.

H3.2: Seeding and planting for native species will increase native plant community cover.

H3.3: Clearing existing plant matter will increase likelihood of establishment of seeded plant species.

H3.4: Time elapsed since disturbance will affect native plant community structure.

H3.5: Surface soil characteristics will differ in prairies with different land histories and affect vegetation.

Chapter 2

Methods

2.1 Study Site

This study was conducted at the Fort Worth Nature Center and Refuge (FWNCR) in Fort Worth, Texas, USA (32^{0} 50’ 14.09” N, 97^{0} 28’ 48.29” W) (Figure 2.1). The climate is humid-subtropical with hot summers and seasonal rainfall (National Weather Service, 2009). It sits near the transition between the Western Cross Timbers and Grand Prairie ecoregions of Texas (Texas Bureau of Economic Geology, 2010), and is characterized by a mosaic of prairies and forests (Fort Worth Nature Center, 2015). This site was chosen because its mosaic nature allows for scattered, various sized patches of prairie, and because of the varied land use histories amongst those prairies.

The FWNCR is part of land that was acquired by the city of Fort Worth in 1913 in order to make a lake. Prior to this acquisition, many portions of the land that is now FWNCR was used for agricultural purposes, including farming and livestock grazing. Between then and 1950, Lake Worth, the lake that directly borders the FWNCR, and Eagle Mountain Lake, built in conjunction with Lake Worth, were both filled with water. During this time, portions of the area were still being farmed and grazed, while other portions of the area were quarried by the city, to build the city of Fort Worth’s infrastructure. In 1970, the land was designated as park by the city of Fort Worth and made in to the FWNCR and all of these land use activities stopped. In the years since 1970, land management practices aimed at reclamation of native North Texas ecosystems have been employed in some areas, while other areas have been left to natural processes (R. Denkhaus, Personal Communication, October, 2013 – January, 2015).

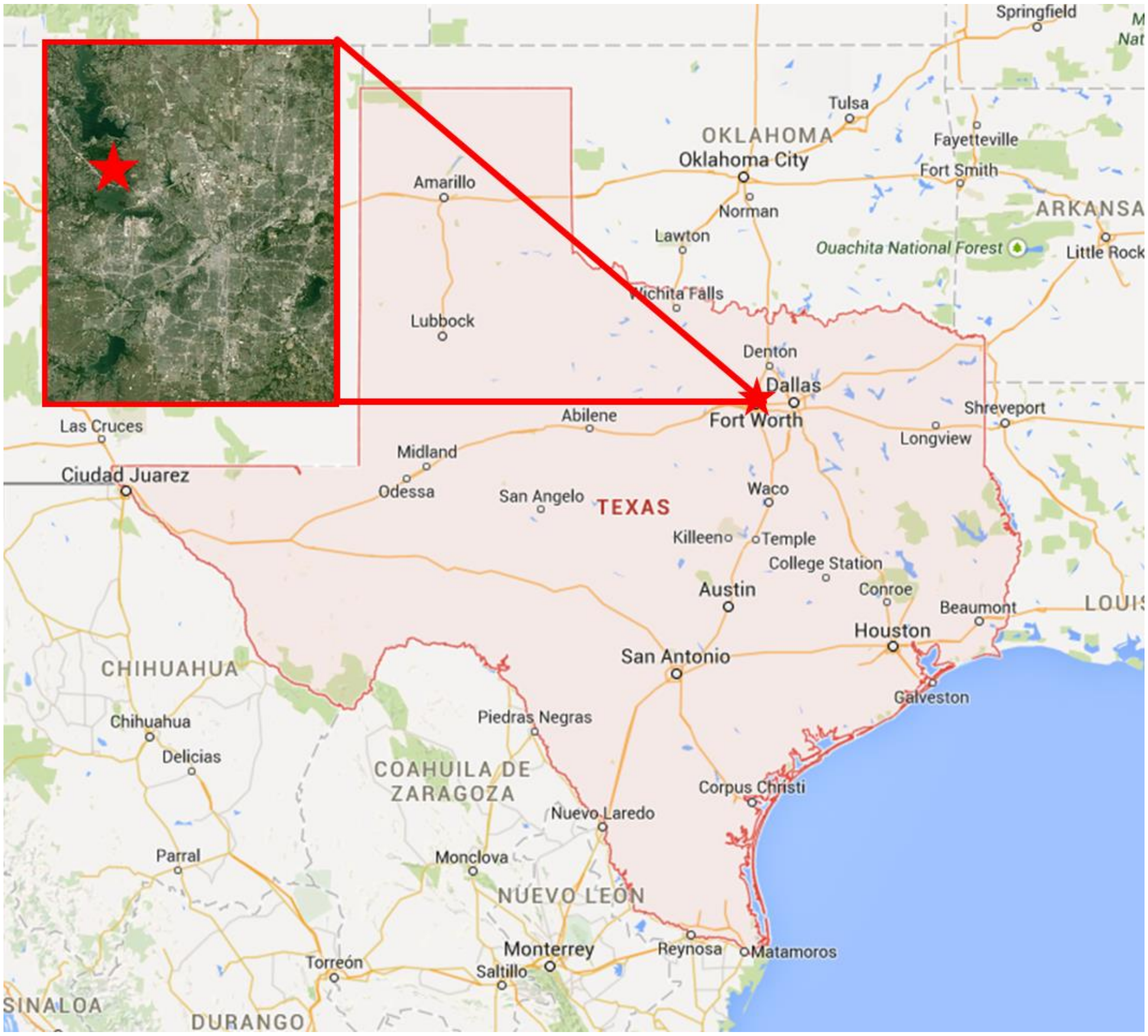

Figure 2.1 Map showing study location (Google, Inc., 2014)

In the FWNCR, 20 sites were chosen for this study based on their land use histories, management histories, and geographic proximity to one another. All chosen sites were fragments of prairie with little to no woody growth, surrounded by a woodland matrix. In one area of the park that was used primarily for agriculture, four sites designated as “Prairie Sites” were chosen, along with six sites designated as “Seed Rain Sites”. Two Prairie Sites were previously farmed and overgrazed up until the 1970’s, and have had little to no management in the 45 years since (P2 and P3). The other two Prairie Sites were left mostly untouched prior to 1970 and have had little to no management since (P1 and P4) (Table 2.1, Figure 2.2) (R. Denkhaus, Personal Communication, October, 2013 – January, 2015). The six Seed Rain Sites (A1-A3 and B1-B3) were placed at various distances and directions from these Prairie Sites (Figure 2.2). Prairie sites P1 and P2, also known as Little Farview Prairie (LFVP) and Farview Prairie (FVP) respectively, have been deemed by the FWNCR as model native prairies due in part to the overwhelming dominance of LBS and lack of invasive species in the plant community (R. Denkhaus, Personal Communication, October, 2013 – January, 2015). As such, the condition of these two prairies is regarded here as the “target” for native prairie reclamation success.

In the area of the park that was previously used primarily for quarrying, ten sites designated as “Quarry Sites” were chosen. Of these Quarry Sites; two were prairie fragments that had never been quarried but were within immediate proximity to quarried fragments (Q7and Q8). These two served as the “controls” for the other quarry sites. Two were fragments that were quarried and left unmanaged for the 45 years since (Q5 and Q6); two were quarried and had soil amendments, including bison manure and commercial fertilizer, applied haphazardly in the 1980’s, approximately 35 years previous to this study (Q9 and Q10); two were quarried and filled with a sequence of soils, starting in 2003 and ending in 2009 with grading of the surface, 9 years previous to this study (Q1 and Q2); and two sites were quarried and filled with a sequence of soils ending in 2011, 3 years prior to this study, then topped off, graded, and seeded with native plant species during this study (Q3 and Q4).

The quarried areas that were filled were first prepared by scraping any native surface soil that remained, which was kept in piles to be placed back on the surface after filling. After scraping and grading, deep fill dirt was brought in from multiple unknown sources throughout the city and placed in the bottom of the quarry pits. In the uppermost portion of the filled pits and surrounding area, the previously saved native surface soil was added, but depending on the volume needed, "top soil" from unknown origins was also added. Also depending on site and soil availability, this surface layer varied in depth from approximately 0.5 m to 1 m. Of the two sites that were filled 9 years prior to this study, half of Q1 was seeded with a collection of native prairie seed species when it was filled, and part of the seeded area was planted with native plants between 2010 and 2014. Q2 had no further management after it was filled and graded in 2005 (Table 2.1, Figure 2.2). Filled quarry sites that were seeded (Q1, Q3 and Q4) were seeded with a combination of native prairie seed mixes using a Truax seed drill (R. Denkhaus, Personal Communication, October, 2013 – January, 2015).

Table 2.1 Summary of all sites and their land use histories.

	Land Use Abbreviation	Disturbance	Filled	Seeded	Planted	Soil Amendments	Duration Since Disturbance	Survey Season
Site								
P1	NP	None					Never	Spring, Fall
P2	AG-45	Agriculture					45	Spring, Fall
P3	AG-45	Agriculture					45	Spring, Fall
P4	NP	None					Never	Spring, Fall
Q1	Q-9-FSP	Quarried	X	X	X		9	Spring, Fall
Q2	Q-9-F	Quarried	X				9	Spring, Fall
Q3	Q-3-F	Quarried	X				3	Spring
Q4	Q-3-F	Quarried	X				3	Spring
Q3	Q-<1-FS	Quarried	X	X			<1	Fall
Q4	Q-<1-FS	Quarried	X	X			<1	Fall
Q5	Q-45	Quarried					45	Fall
Q6	Q-45	Quarried					45	Fall
Q7	NP	None					Never	Fall
Q8	NP	None					Never	Fall
Q9	Q-35-SA	Quarried				X	35	Spring, Fall
Q10	Q-35-SA	Quarried				X	35	Spring, Fall

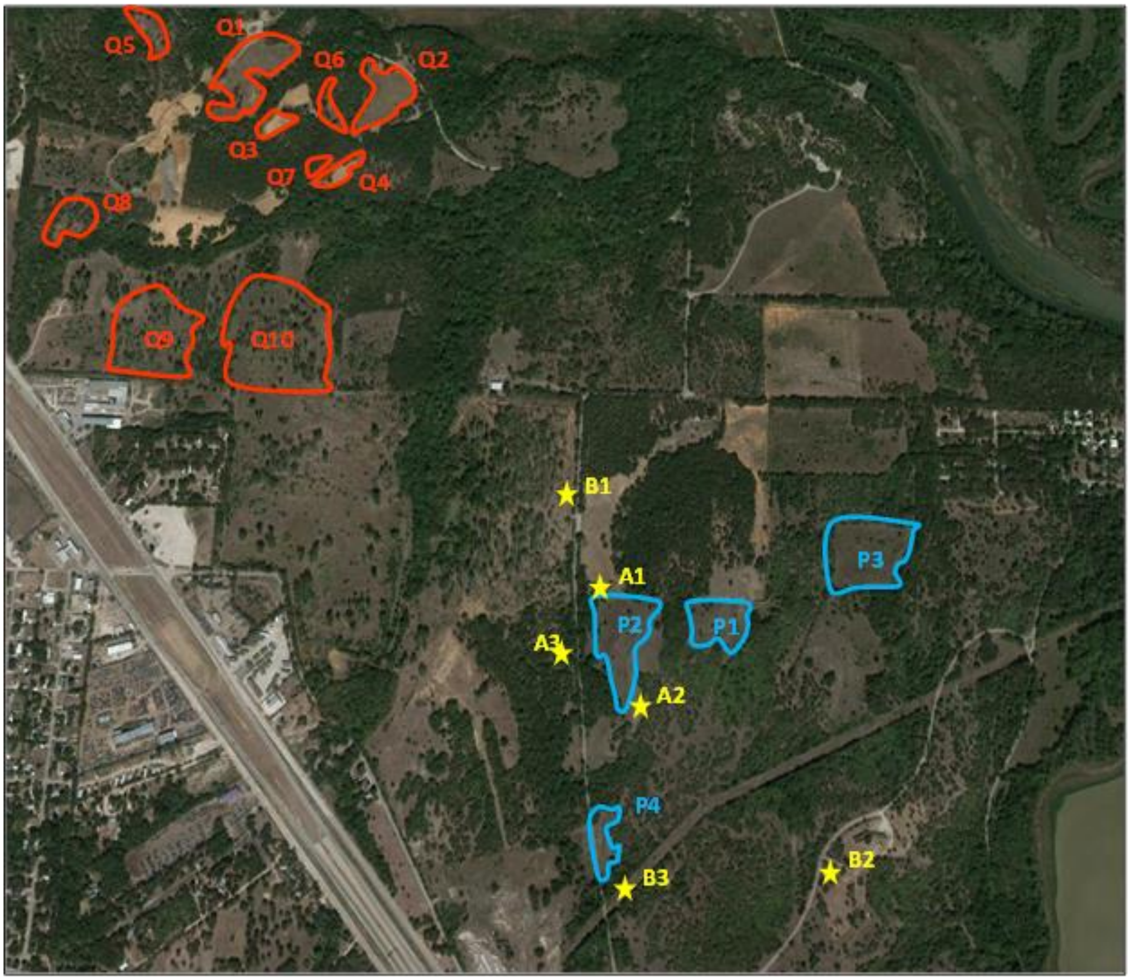

Figure 2.2 Aerial view of study area with sites highlighted and labelled.

2.2 Plant Community Surveys

Plant community surveys were performed at every site by visual estimation of ground cover proportions of individual plant species, bare ground and other cover components. The cover category “other” consisted of all ground cover that was not a vascular plant or bare ground, such as plant litter, standing dead plant matter, bio soil crust, trash, and animal feces. In each site, 3 10m long transects, each with 5 quadrats

(1m x 1m) 1m apart were surveyed. Transects were started 3m in from the edge of the prairie, on the side closest to the nearest road or trail. In seed rain sites, transects were surveyed directly adjacent to seed rain plots. Surveys were done in the spring between May 20 and June 8, 2014 in all prairie sites and in Q1-Q4. Fall surveys were performed in all sites between October 28 and November 12, 2014.

More extensive plant community surveys were conducted on filled quarry sites Q1 and Q2 in the fall. Each site had 4 transects radiating from a single point out in different directions. Quadrats (1m x 1m) were 5m apart and continued to the tree line. Transects in Q1 spanned planted and seeded areas, areas only seeded, and unseeded areas adjacent to seeded ones. The 4 transects in Q2 only spanned unseeded land. Cover proportions were assessed in the same way as in the general surveys.

In each quarry site, seedling counts were also done during the fall plant community surveys. For each quadrat, seedlings were counted in three adjacent squares totaling $0.12m^2$. Seedlings were deemed as small plants with at least one visible cotyledon and no more than 1 true leaf.

2.3 Seed Rain

At each of the 6 seed rain sites, 4 0.5m x 0.5m mats made of Astroturf were placed 0.5m apart from each other in a square pattern and staked to the ground. Mats were left out to collect seeds in two different time periods. Mats were placed out in May of 2014 and brought in at the end of August 2014 for the spring sampling. For the fall, new mats were put out at the end of August 2014 and left until January 2015. Mats were sealed in to bags and brought back to a laboratory at the University of Texas at Arlington for processing. All debris was removed from mats and sorted for seeds. Seeds were identified using references gathered from plants throughout the year and the USDA Plants website (United States Department of Agriculture, 2015) and counted.

Distances from each seed rain site to the nearest LBS plant and to the nearest significant LBS dominated native prairie community were measured on the ground with a measuring tape for distances under 100m or with the measurement tool on Google Earth (Google, Inc., 2014) for distances over 100m. Significant LBS dominated native prairie communities were defined as plant communities larger than 15m x 15m ($225m^2$) comprised of more than 30% LBS. Prevailing wind directions were calculated from wind rose averages from the Texas Commission on Environmental Quality (2014) for the DFW metropolitan area. Percentages of time the wind was blowing in each direction were averaged over the same months that the mats were out for each season.

2.4 Manipulation

To further test aspects of H3, a manipulation experiment was conducted in addition to the community surveys and seed rain study described above. In quarry sites Q1-Q4, one manipulation plot was set up in each site. Each plot included a $1m^2$ area seeded with two native species and cleared of all above ground plant matter (SC), a $1m^2$ area seeded with two native species with all ground cover left intact (SNC), a $1m^2$ area not seeded but cleared of all above ground plant matter (NSC), and a $1m^2$ area not seeded and left intact (NSNC, control). The plots were established on May 9, 2014 and were surveyed for seedling abundance every week until January 15, 2015. In the areas that were cleared, above ground plant matter that had encroached from the sides or grown back from rhizomes was hand clipped at the surface every week. A 0.25m buffer zone was left around each treatment and either cleared or left intact according to the treatment. Seeded areas were seeded with Purple Coneflower (*Echinacea purpurea*), a native forb, and Little Bluestem (*Schizachyrium scoparium*), a native grass, at the levels recommended by the company they were acquired from (Native American Seed, 2014). Seedlings were not removed and each seedling was monitored throughout. In late August of 2014, the plots in Q3 and Q4 were cleared and grated in preparation for seeding and only Q1 and Q2 were surveyed past then. As a result, manipulation data is divided between spring and fall by this date.

2.5 Soil Surveys

To determine if soil quality differed among sites (H3.5), soil was collected and analyzed from a subset of the sites described above. Surface soil surveys were conducted in quarry sites Q1-Q8, in prairie sites P1 (LFVP) and P2 (FVP), and in two piles of soil to be used as deep quarry fill (F1 and F2). Q-<1-FS sites were deemed as recently filled because the soil surveys were performed after the plant community surveys, and by that time the sites had been filled for a longer amount of time, although still less than 1 year. Quarry sites Q-9-F and Q-9-FSP are in the same category here (quarries filled for 9 years), even though Q-9-FSP was partially seeded and planted, because the same soil was presumably used to fill them.

A soil coring device was used to gather soil from the surface to 0.15 m deep in random locations in all sites. In each site, 4 samples were taken consisting of 10 subsamples each. The 10 subsamples for each sample were homogenized and all rocks were removed. Sample volumes and associated rock volumes were measured, and percent of sample volume consisting of rock was calculated. Random soil core spots were generated by dividing each site in a grid pattern with 1m x 1m squares, numbering each square, and then using a random number generator to generate numbers associated with squares to collect subsamples. Before homogenization, each subsample was left out to dry in the laboratory at room temperature. After homogenization, samples were packaged in plastic bags and sent to the Texas A&M Agrilife Soil, Water and Forage Testing Laboratory to be analyzed for nitrate concentration (NO_3-N), conductivity, phosphorus concentration (P), potassium concentration (K), calcium concentration (Ca), magnesium concentration (Mg), sodium concentration (Na), sulfur concentration (S), and proportions of textural elements (sand, silt, and clay).

2.6 Statistical Analysis

All plant cover proportions were normalized to 100% for each quadrat, and then averaged for each plot and land use history to determine relative cover for each category. To determine differences between plant communities, proportions of native and invasive plant cover, proportions of LBS cover, proportions of bare ground cover, and species richness were compared. From here on, these will be referred to as standard community parameters.

To determine how land use, reclamation strategy, and time since quarrying affected the plant community, separate analyses were conducted on the standard community parameters by multiple ANOVA using each cover category as a dependent variable and LBS cover was compared by ANOVA.

To determine the effectiveness of seeding and planting native plant species within a mid-term time frame (1-10 years) in filled quarries, standard community parameters were compared for community surveys in areas in Q-9-FSP that were seeded and planted with native plants, only seeded with native plants, and unseeded but directly adjacent to seeded areas. These areas were compared to Q-9-F which was unseeded but not directly adjacent to any seeded areas. A comparison of species present in these filled quarries and species that were sowed and planted was also made. Fall seedling counts from plant community surveys were also compared between the same four management variationsStandard community parameters were compared by Multiple ANOVA and pair-wise Tukey tests. LBS cover and seedling abundance was compared by ANOVA. A regression was performed to determine if there was a correlation between seedling abundance and bare ground cover.

All seed rain plot seed species abundances for each mat were averaged across the four mats in each plot. Regression was used to determine if abundance of native seeds was affected by distance of seed rain plot from significant LBS dominated native plant communities, referred to from here on as sources. Comparisons based on native seed abundance were performed for spring and fall separately, however LBS abundance comparisons were only done using fall data.

To determine if prevailing wind direction had an effect on the abundance of seeds dispersed to an area, a regression was performed with average abundance of native seeds and average wind percentages based on the direction from each seed rain site to the nearest source community. Comparisons based on native seed abundance were performed for spring and fall separately, however LBS abundance comparisons were only done based on fall data.

To determine the short-term (<1 year) effectiveness of seeding and clearing, maximum seedling abundances were calculated for each plot based on the most seedlings that were recorded in each plot across the entire study. Maximum seedling abundance is defined here as the greatest abundance of seedlings in each plot and treatment, that were counted during one survey time, throughout the whole season. Seedling survival rate was calculated for each treatment in each plot by dividing the number of seedlings left after each season by the maximum seedling abundance for that treatment and plot, in that season. Abundances and survival rates were calculated separately for each seasonand were analyzed using a two-way ANOVA with seeding and clearing as the main effects. To determine what time of year seed sprouting and survival was the greatest, seedling abundances and survival were compared between the two seasons they were surveyed. In all comparisons, special attention was paid to abundances and survival of seedlings that could be identified as species of seeds that I planted.

Each soil variable was compared among land use histories and among sites to highlight any differences between soils in sites that have had the same land use history. To determine if LBS cover or seedling abundance was correlated with surface soil conditions, regressions were performed. A PCA was done using all soil variables for each land use history, in order to better understand which soil variables were associated with the variation in surface soil between different management histories. A similar PCA was performed using all soil variables for each site, in order to parse out any differences between soils in sites with the same management history. The PCAs were used to narrow the matrix of variables into a dominant pattern, in order to more clearly gauge associations between them (Wold, et al., 1987, Sokal and Rohlf, 2012) and were both done using R (R Development Core Team, 2008) and R Studio (RStudio, 2012). To determine if the LBS populations were correlated with soil characteristics, averages for each soil variable were compared to average proportion of LBS plant cover in each site. To determine if soil characteristics affected the sprouting and survival of seeds, averages for each soil variable were compared to average seedling abundance in all quarry sites that were surveyed for soil, and average seedling survival in quarry sites with manipulation plots. Regressions were performed for average LBS cover and each soil parameter, as well as for seedling abundances and each soil parameter. To determine the differences between soil used as deep fill in filled quarries and soil used as surface soil in filled quarries, and the potential for deep fill soil to affect surface prairie plant communities, averages for soil variables in deep fill soil were compared to averages among surface soil in filled quarries.

All statistical analysis was conducted using Microsoft Excel (Microsoft, 2010), unless otherwise stated.

Chapter 3

Results

3.1 Prairie Community Structure

Prior disturbance significantly altered plant community structure overall compared to undisturbed prairies in the spring ($F_{4,55}$=12.66; P=<0.0001). However, farming and grazing 45 years ago (AG-45) did not change native plant cover or “other” cover relative to undisturbed prairies (NP; Figure 3.1). In the spring, invasive plant cover was significantly greater ($F_{1,58}$=12.78; P=0.0007), and the proportion of bare ground was significantly less in disturbed sites ($F_{1,58}$=26.89; P<0.0001).In the fall, prior disturbance also significantly altered plant community structure compared to undisturbed prairies ($F_{4,55}$=9.87; P=<0.0001). In contrast to spring, disturbed prairies had significantly greater native plant cover ($F_{1,58}$=34.46; P=<0.0001), less bare ground ($F_{1,58}$=17.35; P=0.0001), and lower cover in the other category ($F_{1,58}$=7.82; P=0.007) than undisturbed prairies (Figure 3.2).

There was not a significant difference in LBS cover between disturbed and undisturbed sites in either season although mean LBS cover was a bit higher in undisturbed plots in the spring (Figure 3.3). The insignificant result and the high error value on the proportion of LBS cover in the disturbed sites were caused by very high LBS cover in just one of the disturbed sites. Species richness was not very different between disturbed and undisturbed sites (Table 3.1).

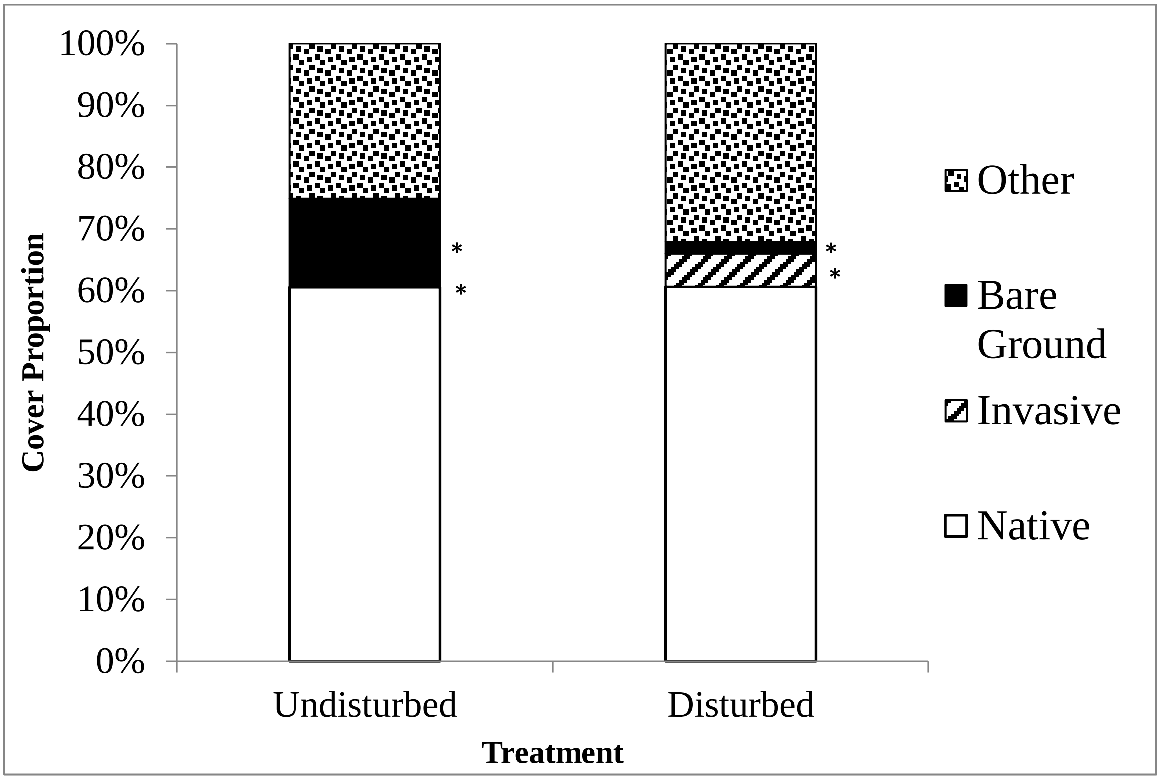

Figure 3.1 Average spring 2014 plant community coverage proportions in undisturbed (NP) and disturbed (AG-45) sites, normalized to 100%. Asterisks represent significant between site differences within each cover category at P<0.05.

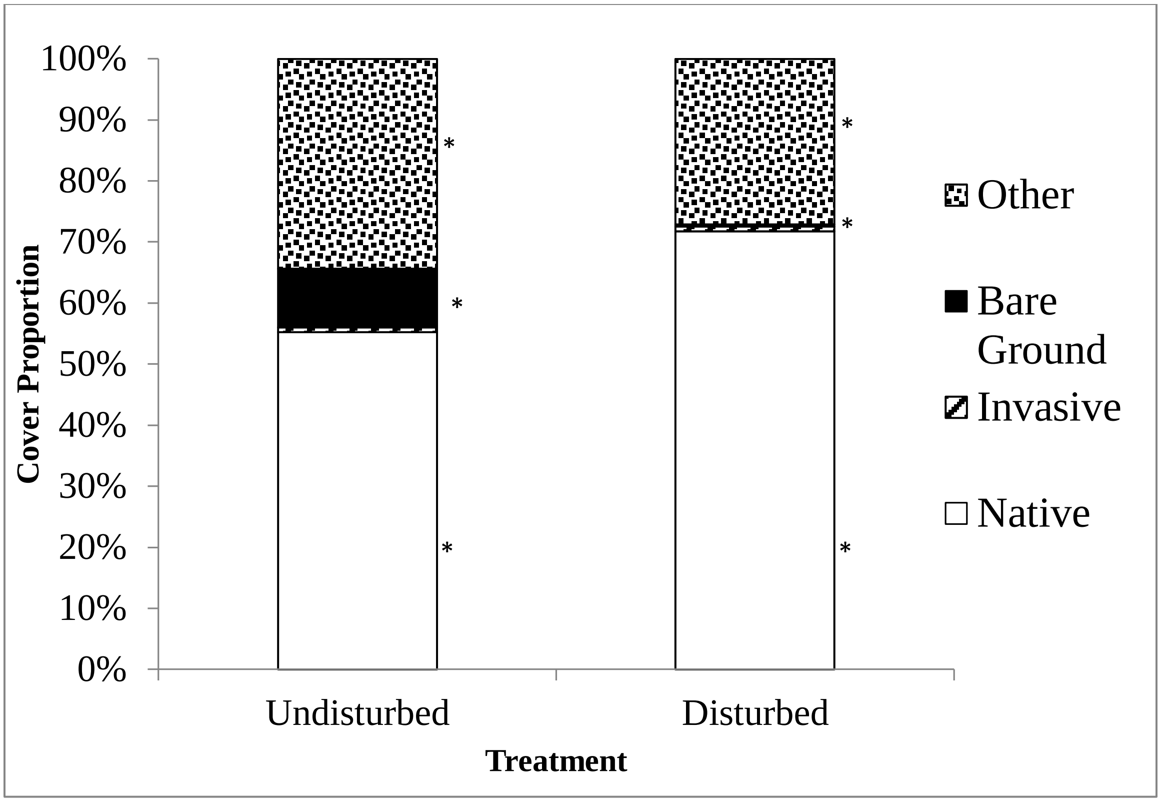

Figure 3.2 Average fall 2014 plant community coverage proportions in undisturbed (NP) and disturbed (AG-45) sites, normalized to 100%. Asterisks represent significant between site differences within each cover category at P<0.05.

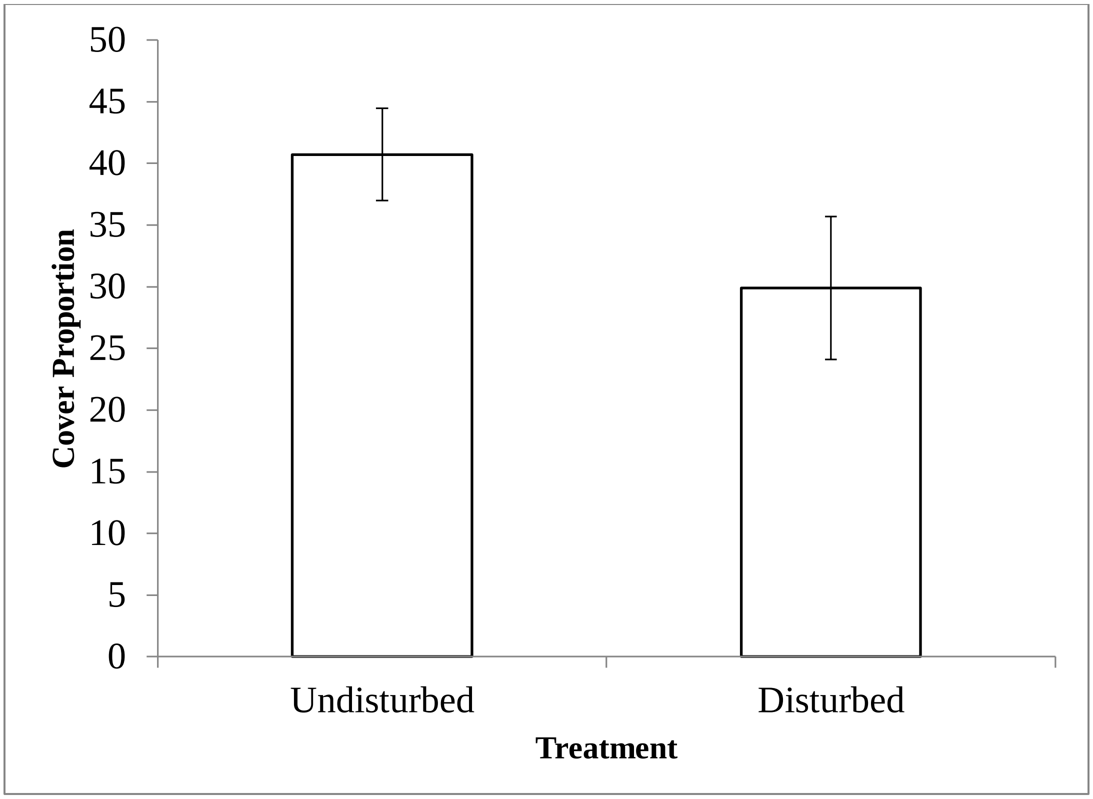

Figure 3.3 Average proportion spring LBS cover (±SE) in undisturbed (NP) and disturbed (AG-45) sites.

Table 3.1 Species richness for each site in the spring and fall.

Site	Land Use Abbreviation	Spring	Fall
P1	NP	19	14
P2	AG-45	13	14
P3	AG-45	16	14
P4	NP	12	5
Q1	Q-9-FSP	13	11
Q2	Q-9-F	8	5
Q3	Q-3-F	11	n/a
Q4	Q-3-F	10	n/a
Q3	Q-<1-FS	n/a	7
Q4	Q-<1-FS	n/a	4
Q5	Q-45	n/a	12
Q6	Q-45	n/a	17
Q7	NP	n/a	11
Q8	NP	n/a	13
Q9	Q-35-SA	8	6
Q10	Q-35-SA	12	11

3.2 Seed Rain

A total of 13,346 seeds were captured on 24 mats over a period of 9 months. Of those, 11,972 (90%) were identified, and of those identified, 7,890 were native. The majority of seeds captured were wind dispersed, which is to be expected for this capture method. One exception was some Prickly Pear Cactus (*Opuntia* sp.) seeds that were found intact inside rabbit feces on one mat. Overall, more seeds were collected in the fall, between the months of September and January, than in the spring, between the months of May and August. In the fall and beginning of winter, total seeds summed across all mats averaged 1,166 per month, while in the spring and summer, an average of 671 seeds were captured per month. In the spring the species with the greatest abundances of seeds captured overall were *Gaillardia pulchella* (17%), *Elymus* sp. (13%), *Euphorbia dentate* (9%), *Lolium arundinaceum* (9%), and *Phyla nodiflora* (7%). In the fall the species with the greatest abundances of seeds captured overall were *Amphiachyris dracunculoides* (36%), *Bothriochloa ishchaemum* (34%), unknown (11%), *Sporobolus* spp. (11%), and *Gaillardia pulchella* (2%). LBS seeds were captured in the fall only; abundances of LBS seeds were too low for statistical comparisons. For example, in seed rain site A1 there were only 4 LBS seeds captured in a 1m^2 area throughout the entire study, even though the site is less than 8m from a large LBS population.

For both seasons, native seed abundance was not significantly correlated with distance from the nearest source prairie plant community (Figure 3.4).

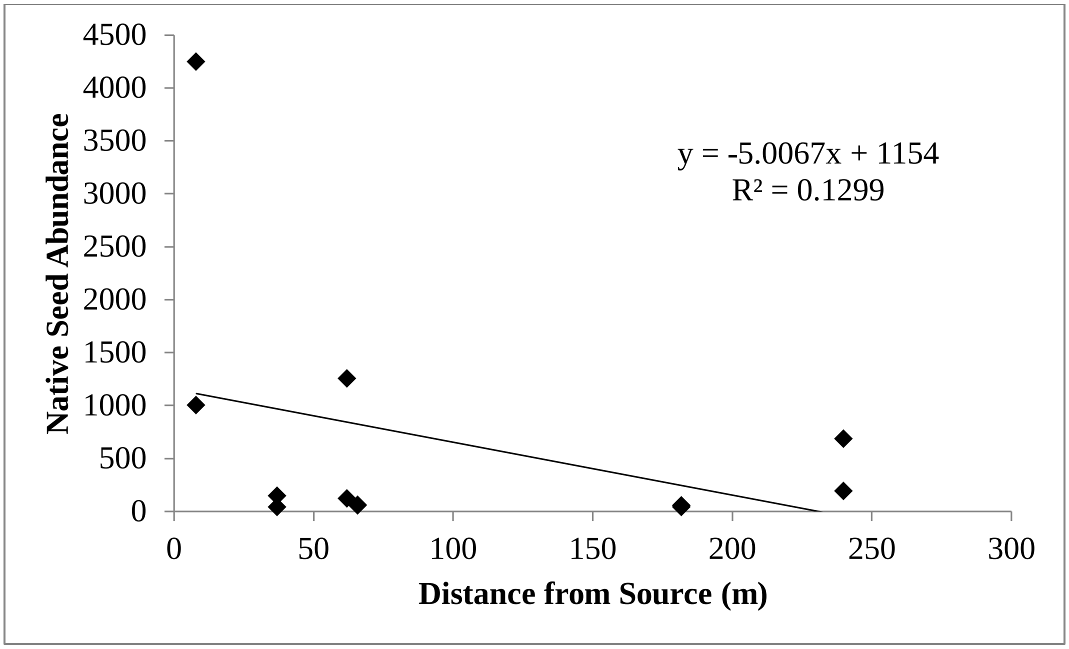

Figure 3.4 Spring and fall native seed abundance captured in seed rain plots at various distances from the source native plant community, with a best fit line, along with its associated equation and R^2 value.

Average native seed abundance was not correlated with average prevailing wind directions during each season (Figure 3.5). In both fall and spring there was a greater abundance of native seeds being dispersed to the North, even though it was not the most prevalent wind direction.

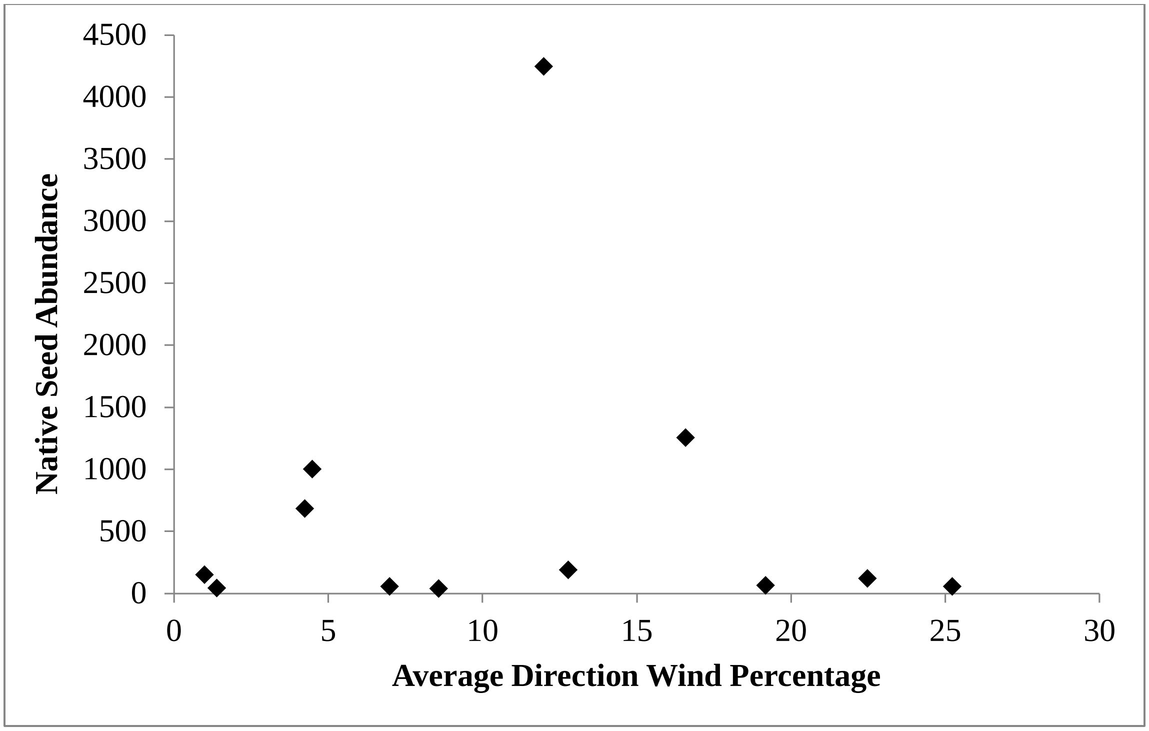

Figure 3.5 Spring and fall native seed abundance captured in seed rain plots, compared to the average percent of time the wind blows in the direction of the plots from the nearest source, during each season.

3.3 Quarry Plant Community Structure

3.3.1 Quarry Filling Effectiveness

Plant community structure was significantly different among quarries reclaimed using different strategies ($F_{24,692}$=16.92; P=<0.0001). Quarries that were never filled but with added soil amendments (Q-35-SA) had the greatest proportion of native plant cover (Figure 3.6), while quarries that had been filled for less than a year (Q-<1-FS) had the lowest proportion of native plant cover. All other land use histories had an average of around 30% native cover, with the exception in quarries filled 9 years ago without reclamation seeding (Q-9-F), which had lower average native cover.

Although native plant cover differed between each individual land use history, invasive plant cover had less variation, dividing the land use histories in to only two groups. Quarries that were filled (Q-3-F, Q-9-F, and Q-9-FSP) had greater invasive plant cover than those that were never quarried (NP) or never filled after quarrying (Q-45 and Q-35-SA). One exception to this was the recently filled sites (Q-<1-FS), which had a low proportion of plant cover overall, including a lower proportion of invasive cover. The invasive species present also differed between filled quarries and others. Invasive species present in sites where fill soil was not brought in from other areas (NP, Q-45, and Q-35-SA) include King Ranch Bluestem (*Bothriochloa ischaemum*) and Tall Fescue (*Lolium arundinacea*). In sites that were quarried and filled with outside soil (Q-<1-FS, Q-3-F, Q-9-F, and Q-9-FSP), invasive species include the same two that are in non-filled sites, along with Bermuda Grass (*Cynodon dactylon*) and Johnson Grass (*Sorghum halepense*).

Bare ground cover was greatest in quarries that had been filled and seeded 2-3 months prior (Q-<1-FS) and occupied the majority of the ground. The small amount of plant cover that did exist was mainly invasive and was growing from rhizomes beneath the surface, rather than sprouting from seeds. Quarries that were never filled (Q-45) had a greater proportion of bare ground than prairies that were never quarried (NP), Q-35-SA sites, and all sites that were filled 9 years prior. Quarried areas that were filled 9 years ago (Q-9-F and Q-9-FSP) had similar bare ground proportions, regardless of whether they were seeded and planted or not.

The proportion of other cover generally increased with the amount of time elapsed since disturbance. When a regression was performed, proportion of the other category was significantly positively correlated to time elapsed since disturbance ($F_{1,178}$=93.55; $P<0.0001$).

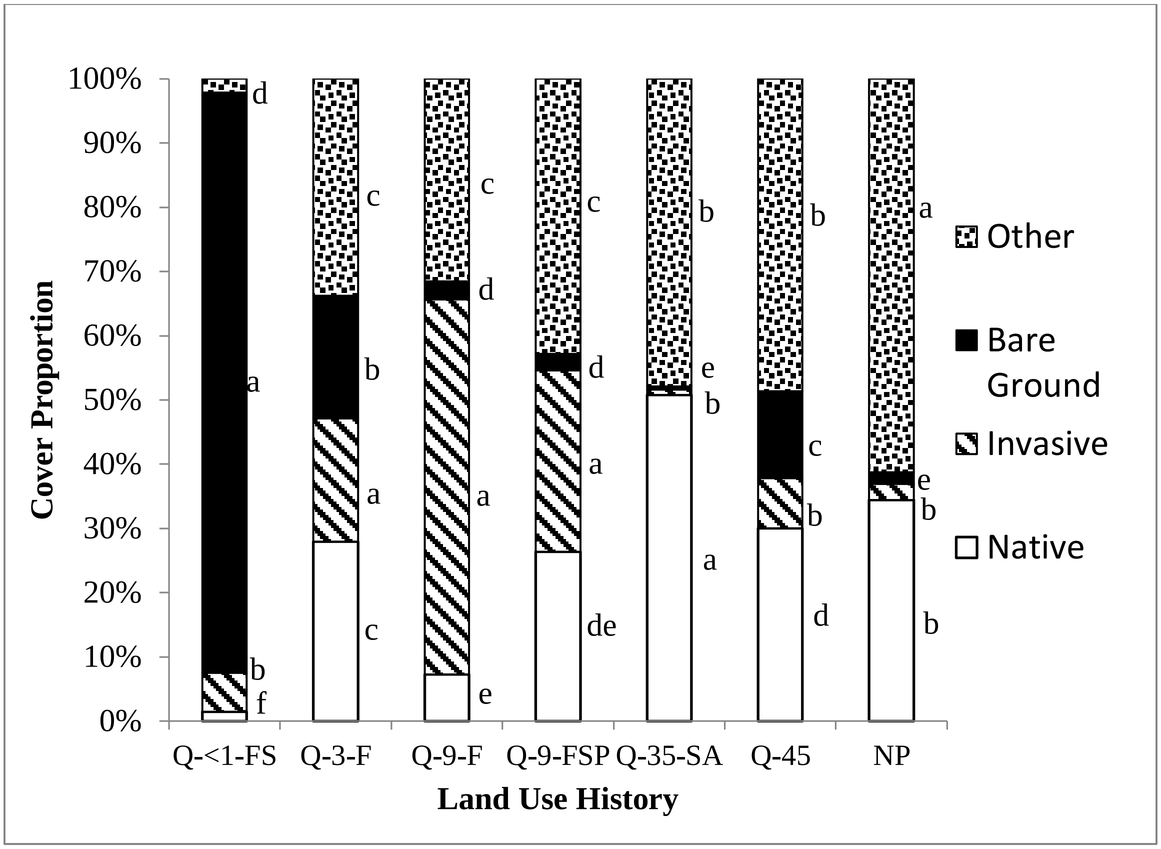

Figure 3.6 Average proportions of plant community structure components by quarry site land use history, normalized to 100%. Land use history abbreviations as in Table 2.1. The same letters represent groups that are not statistically different within each cover category.

Remnant native prairie plant communities within the quarry area (NP) were more similar to target prairie plant communities than all quarry sites (Table 3.2). Of all the sites that were quarried, sites that were unfilled and have had no management (Q-45) had plant communities most similar to target communities. Q-9-FSP had a plant community that was most similar to target communities.

Table 3.2 Jaccard similarities between each quarry site and target native prairie plant communities (P1 and P2). For reference, similarity between target sites was 0.47.

Site	Land Use Abbreviation	Jaccard Similarity
Q1	Q-9-FSP	0.15
Q2	Q-9-F	0.09
Q3	Q-3-F	0.07
Q4	Q-3-F	0.07
Q3	Q-<1-FS	0.04
Q4	Q-<1-FS	0.04
Q5	Q-45	0.10
Q6	Q-45	0.19
Q7	NP	0.19
Q8	NP	0.22
Q9	Q-35-SA	0.08
Q10	Q-35-SA	0.07

Proportions of LBS cover were significantly different in prairies reclaimed using different strategies ($F_{6,173}$=11.40; P<0.0001). Although there was no difference between Q-9-FSP and Q-45 sites in overall native plant cover, the Q-45 sites had a significantly greater average LBS cover (Figure 3.7). Remnant native prairie fragments that were never quarried but were adjacent to quarried areas (NP) had the greatest proportion of LBS cover. The greatest proportion of LBS in areas that were quarried was in Q-45 sites, although there was no difference in LBS cover between unfilled quarries with and without added soil amendments (Q-45 and Q-35-SA). Q-9-FSP had a very small amount of LBS cover, even though LBS seeds were part of the mixture sowed there. In all filled quarries (Q-9-F, Q-9-FSP, Q-3-F, and Q-<1-FS) LBS cover was not significantly different than zero. LBS cover was significantly positively correlated with time elapsed since disturbance ($F_{1,178}$=68.02; P<0.0001), while general native plant cover was not.

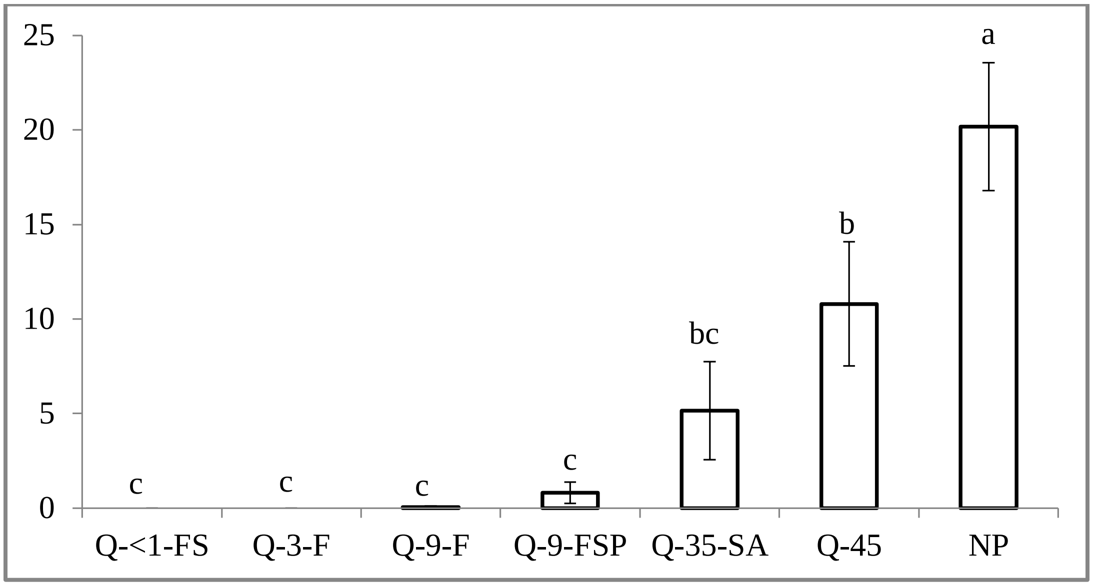

Figure 3.7 Average LBS plant cover (±1 SE) by quarry site land use history (see Table 2.1 for abbreviations), normalized to 100%. Letters represent groups that are not statistically different.

3.3.2 Mid-term Seeding and Planting Effectiveness

Overall, on the basis of the entire site (Figure 3.7), areas filled 9 years prior with reclamation seeding and planting (Q-9-FSP) did not have a significantly different proportion of native plant cover than quarries that were filled at the same time but not seeded or planted (Q-9-F). Q-9-FSP was also grouped with sites that were quarried but never filled (Q-45). The quarries filled and unseeded for 3 years (Q-3-F) had a significantly greater proportion of native plant cover than Q-9-FSP, despite the addition of native propagules and longer time elapsed for native plant establishment. However, the native plant species present in the areas of Q-9-FSP that were seeded were different and generally more desirable for reclamation of a native prairie community, than the native species present in the Q-3-F sites, which consisted mainly of Ragweed (*Ambrosia psilostchya*), a less desirable native species. For example, in Q-3-F sites there was only one native grass species found, Texas Winter Grass (*Nassella leucotricha*), while in Q-9-FSP there were 8 native grass species observed. Species richness was also consistently greater in Q-9-FSP than in Q-3-F (Table 3.1). The plant community in Q-9-FSP was more similar to target communities than Q-9-F and Q-3-F (Table 3.2).

Among sites that were quarried and filled 9 years prior to this study, seeded areas had more native species and significantly greater native species cover than unseeded areas (Figure 3.8). Invasive plant cover was significantly greater in all unseeded areas than in all seeded areas. Proximity to seeded areas did not affect native plant cover for areas that were not seeded, but was correlated with reduced invasive cover. There was not a significant enough amount of LBS present to gauge the effects of seeding on LBS, however although both seeded and unseeded areas had a small amount of LBS cover, the distribution was different reflecting the different manners of propagule deposition.

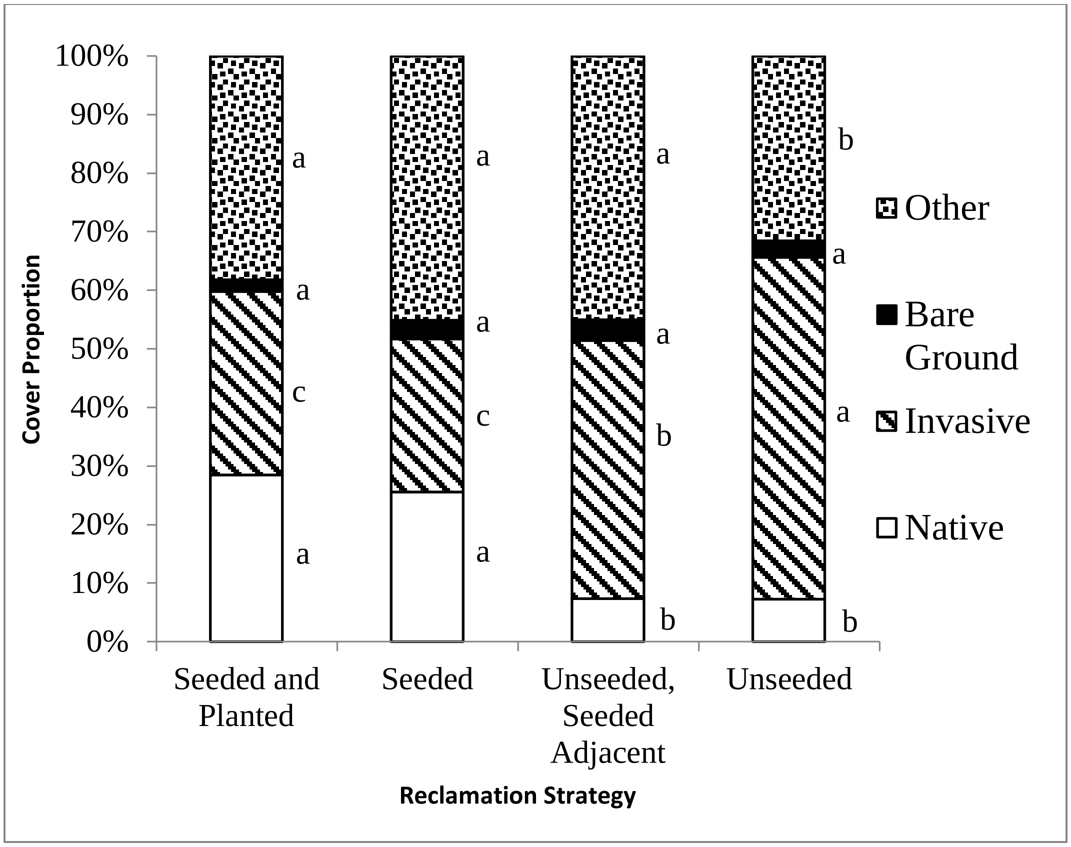

Figure 3.8 Average proportions of plant community structure components during the fall in quarried and filled areas with various management strategies (Q-9-F and Q-9-FSP), normalized to 100%. Letters represent groups that are not statistically differentwithin each cover category.

Planting of species seemed to aid in colonization more than seeding. Many species that were seeded for were not found at all. Some species that were planted were found beyond the area they were planted in. Three species that were planted for were present beyond the planted and seeded boundary (Table 3.3), in the areas that were unseeded but adjacent to seeded areas, however these three species seem to be common in surrounding areas and may have established from other sources.

Table 3.3 Presence of species chosen for reclamation planting and/or seeding in the fall.

Species Only Planted	**Present in Planted and Seeded Areas**	**Present in Seeded Only Areas**	**Present in Unseeded Areas**
Artemesia ludoviciana			
Cirsium texana			
Desmanthus illinoiensis			
Engelmannia peristenia			
Eupatorium serotinum			
Gaillardia pulchella			
Glandularia bipinnatifida			
Helanthus maximilliani			
Heterotheca subaxillaris	X	X	X
Ipomopsis rubra			
Liatris mucronata	X	X	X
Monarda citriodora	X	X	X
Monarda punctata			
Neptunia lutea			
Oligoneuron nitidum			
Rudbeckia hirta			
Senna roemeriana			
Verbena halei	X		
Vernonia baldwinii			
Andropogon ternarius	X		
Bothriochloa laguroides		X	
Sporobolus compositus			
Opuntia phaeacantha	X		
Yucca pallida		X	

Table 3.3 – *Continued*

Species Only Seeded	**Present in Planted and Seeded Areas**	**Present in Seeded Only Areas**	**Present in Unseeded Areas**
Argemone albiflora			
Chamaecrista fasiculata			
Dalea purpura			
Leptochloa dubia			
Bouteloua gracilis	X		
Buchloe dactyloides		X	
Eragrostis trichoides	X		
Sporobolus cryptandrus			
Species Planted and Seeded			
Andropogon gerardii			
Bouteloua curtipendula	X	X	
Elymus canadensis			
Panicum virgatum			
Schizachyrium scoparium		X	
Sorghastrum nutans		X	
Tridens flavus			
Tripsacum dactyloides			

In the fall, seeded and planted areas filled 9 years prior (Q-9-FSP) had significantly greater seedling abundance ($F_{1,88}$=12.41; P=0.0007) than those filled at the same time with no reclamation seeding (Q-9-F) (Figure 3.9). In Q-9-FSP and Q-9-F, seeding and proximity to seeding significantly positively correlated with seedling abundance (Figure 3.10. However, planting did not significantly affect seedling abundance.   In both sites that were quarried and filled 9 years prior (Q-9-F and Q-9-FSP), seedling abundance was positively correlated with proportion bare ground, but with a low explanation of variance ($F_{1,109}$=20.43; P<0.0001) (Figure 3.11).

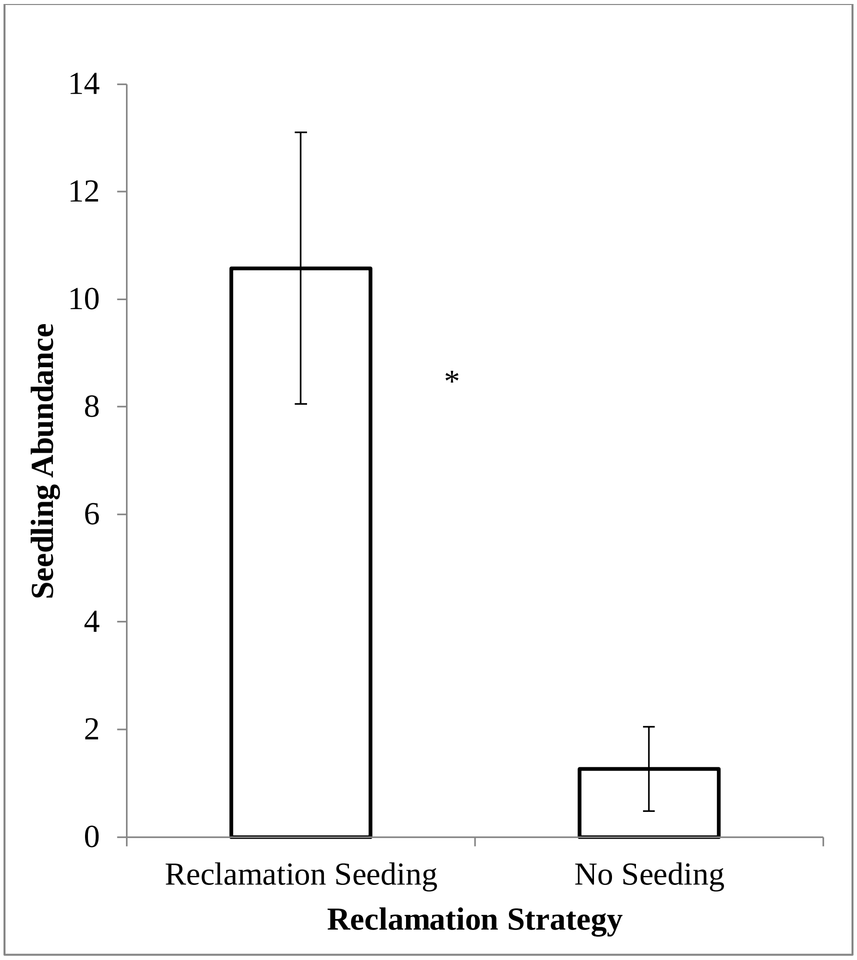

Figure 3.9 Average seedling abundance per $0.04m^2$ (±SE) in quarry sites with previous reclamation seeding after filling and in quarry sites that had no reclamation seeding. The asterisk represents a significant difference at $P<0.05$.

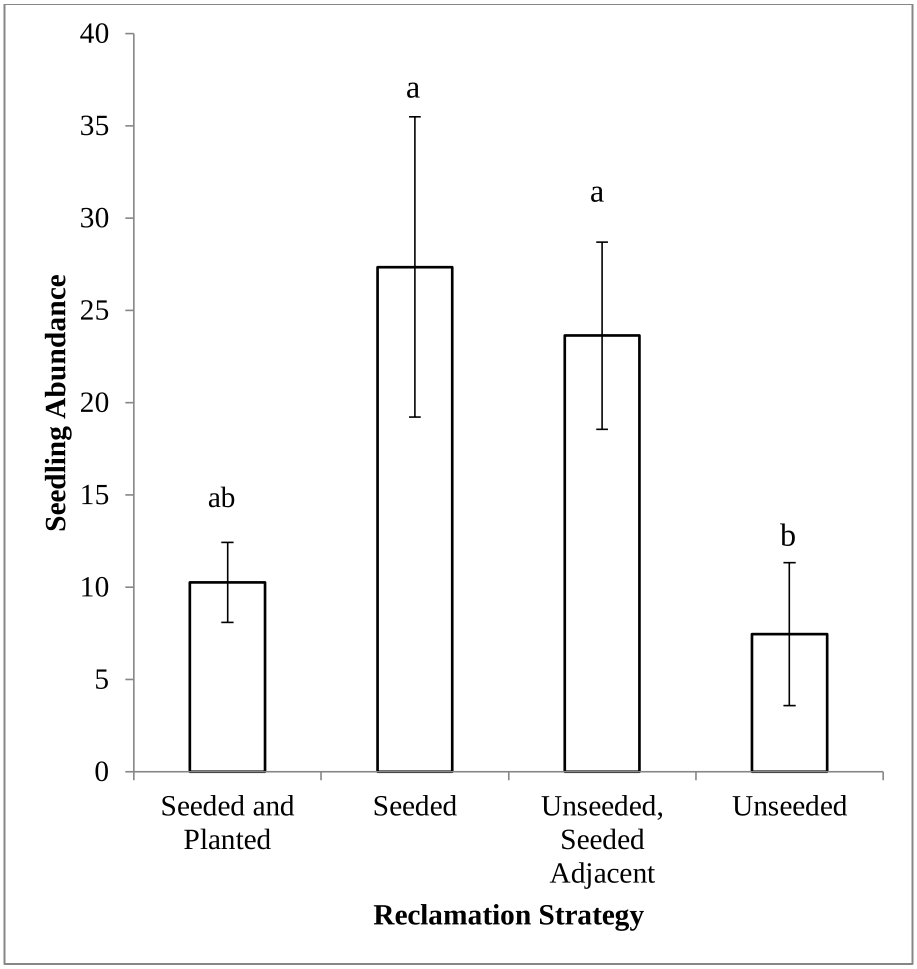

Figure 3.10 Average seedling abundance per $0.04 m^2$ (±SE) in areas quarried and filled 9 years prior with variable management strategies. Letters represent groups that are not statistically different.

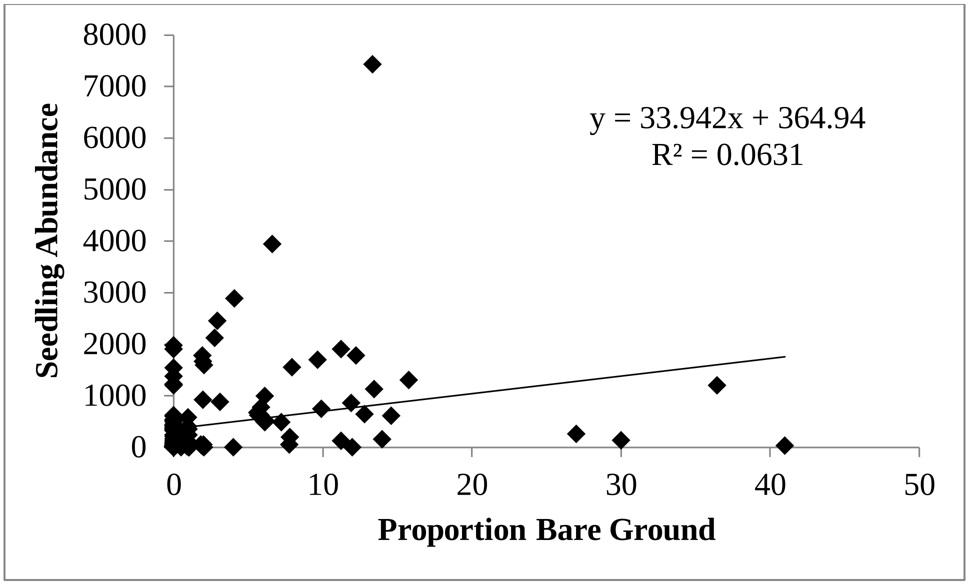

Figure 3.11 Total fall seedling abundance compared to the proportion of bare ground present in $1m^2$, with a best fit line, along with its associated equaltion and R^2 value.

3.4 Short-term Seeding and Clearing Effectiveness

Overall, abundances of seedlings of species I sowed were very low after monitoring them for a little less than a year. Most of the seedlings instead established from the seed bank or dispersal from nearby communities and were identified as the native One-Seeded Croton (*Croton monanthogynus*) and the invasive, mat-forming Bur Clover (*Medicago polymorpha*) in the spring, and mainly Bur Clover in the fall. Out of the 1000+ total seedlings counted, <10 were grasses. More seedlings were observed in the fall than in the spring, with the greatest amount of seedlings in any plot in the fall being more than 10 times the greatest amount of seedlings in any treatment in the spring (Figures 3.12, 3.13).

In both the spring and fall, there were no significant differences among treatments. The greatest average maximum abundance of seedlings that sprouted in the spring was in seeded but non-cleared areas (SNC), (Figure 3.12), while in the fall, the greatest abundance of seedlings was in seeded but cleared areas (SC; Figure 3.14). Error was high and results were not significant in both seasons because there was as much variation between the different sites as between the treatments within each site. Average seedling survival rate was not different between seasons. When seedling abundance is looked at on the basis of each site, Q2, which was filled 9 years prior and has received no further management, is consistently the lowest. Q2 also had the most treatment areas that contained no seedlings for the longest time.

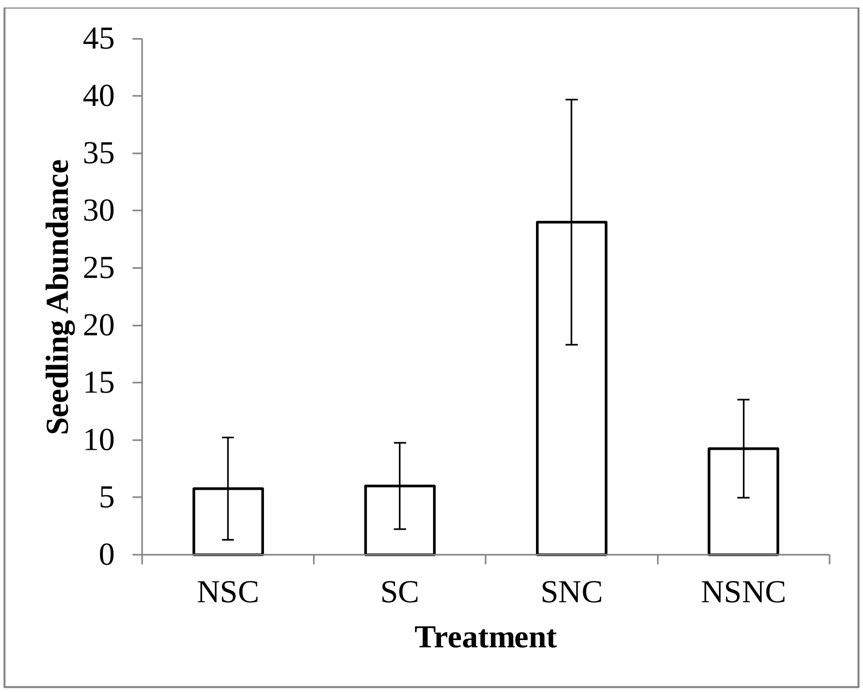

Figure 3.12 Average spring maximum seedling abundance (±SE) amongst the treatments in manipulation plots.

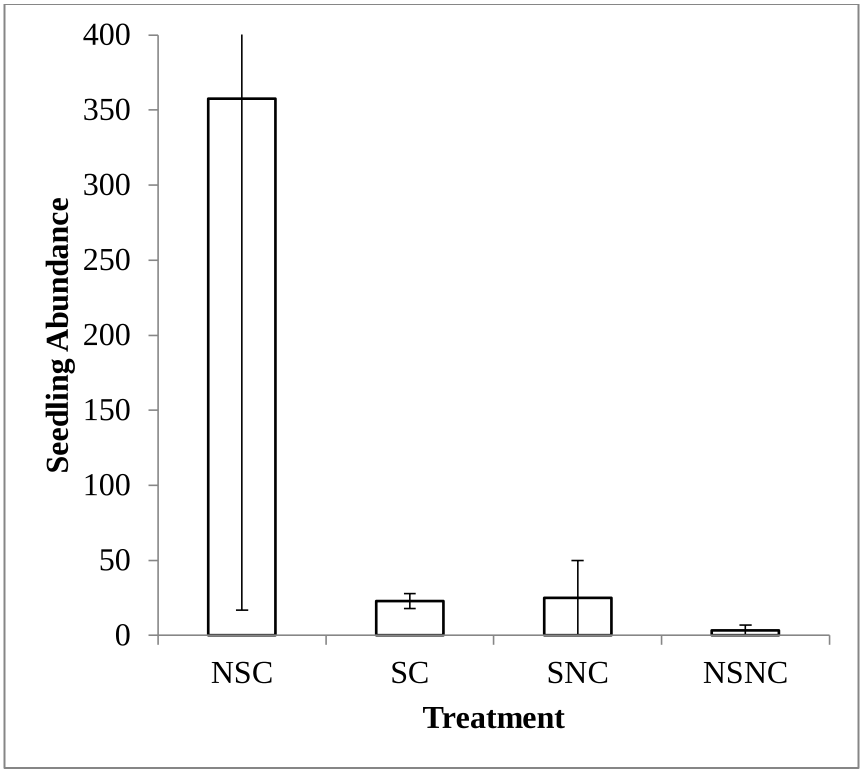

Figure 3.13 Average fall maximum seedling abundance (±SE) amongst the treatments in manipulation plots.

3.5 Soil Surveys

3.5.1 General Analysis

The majority of soil variables tested differed across different quarry reclamation strategies. Overall, the pH did not differ among samples (Table 3.4). Conductivity was not strongly correlated with any particular site or use history; however it was strongly tied to clay content, which is to be expected considering the properties of clay. NO3-N was lowest in both LBS dominated target prairies and the greatest in F1. F1 and quarries filled for 9 years had greater levels of P than all other sites, which had similar P levels.

Native LBS prairie had greater Ca levels than all other land uses. Unfilled quarries had similar Ca levels to all other quarried sites, even though they had LBS populations. Deep fill soil and soil from recently filled quarries had greater Mg concentrations than all the other land use histories. Deep fill soil had greater Mg levels than soil from recently filled quarries. S levels were highest in deep fill soil, intermediate in the LBS native prairie soil, and lowest among the rest of the land use histories. Na concentrations were greatest in deep fill soil, intermediate in the soil from recently filled quarries, and lowest among the rest of the land use histories. K levels were not different between different land use histories. Texture proportion was not different between different land use histories, except in the soil from quarries that were filled 9 years ago, which had a greater proportion of sand and a lower proportion of silt and clay than all the others.

Table 3.4 Soil variable averages by site. Conductivity values are reported in micromhos/cm. Sand, silt and clay values are reported by proportion. All other variable concentrations, besides pH, are reported in ppm.

Site	Status	pH (SE)	Conductivity (SE)	Sand (SE)	Silt (SE)	Clay (SE)	NO3N (SE)	P (SE)	K (SE)	Ca (SE)	Mg (SE)	S (SE)	Na (SE)
P1 LFVP	Native	7.8 (0)	243.8 (2.3)	56.0 (1.2)	24.5 (1.3)	19.5 (1.0)	0.3 (0.1)	4.3 (0.4)	149.2 (2.8)	18973.0 (1183.0)	106.9 (5.3)	18.5 (0.9)	13.6 (0.7)
P2 FVP	Native	7.8 (0)	215.8 (4.1)	59.5 (1.5)	23.5 (1.0)	17 (0.8)	0.4 (0.2)	5.5 (0.8)	160.9 (12.2)	10652.9 (2204.5)	76.3 (3.6)	11.7 (1.4)	8.4 (0.7)
Q1	9 Year Fill	8.1 (0)	135.0 (2.7)	92.8 (1.0)	1.3 (0.8)	6.0 (0.6)	1.0 (0.6)	12.8 (1.2)	136.3 (14.0)	8845.7 (865.9)	67.6 (3.9)	10.0 (1.0)	8.3 (1.0)
Q2	9 Year Fill	8.0 (0)	173.8 (19.9)	85.5 (1.3)	5.0 (0.6)	9.5 (0.9)	0.5 (0.2)	15.4 (1.1)	182.0 (2.1)	5244.9 (256.3)	88.7 (2.8)	6.6 (0.5)	8.2 (0.7)
Q3	Recent Fill	8.1 (0)	194.5 (23.3)	65.5 (1.7)	14 (1.6)	20.5 (1.3)	0.4 (0.1)	7.9 (0.3)	158.8 (3.1)	5627.2 (61.1)	184.6 (12.9)	6.0 (0.5)	56.8 (4.2)
Q4	Recent Fill	7.9 (0)	211.3 (5.3)	62.5 (1.7)	16.5 (1.5)	21.0 (0.8)	0.6 (0.1)	2.9 (0.3)	159.8 (4.9)	5652.9 (32.9)	138.9 (3.6)	7.0 (0.7)	15.9 (1.0)
Q5	Unfilled	7.7 (0)	169.0 (3.9)	83.5 (1.6)	6.5 (1.0)	10.0 (0.6)	0.9 (0.5)	7.1 (0.3)	90.8 (4.9)	4123.2 (162.5)	46.5 (4.5)	6.4 (0.8)	2.5 (0.8)
Q6	Unfilled	7.9 (0)	260.0 (1.4)	49.0 (2.4)	24 (1.7)	27.0 (0.8)	0.5 (0.1)	4.5 (0.6)	211.2 (3.0)	7599.7 (300.5)	84.8 (1.8)	7.6 (0.7)	2.9 (0.3)
F1	Deep Fill	8.2 (0)	295.0 (9.9)	57.8 (1.7)	14.8 (2.0)	27.5 (1.9)	1.5 (0.8)	17.7 (1.8)	146.6 (2.3)	9435.6 (633.9)	171.4 (8.3)	57.3 (2.9).	58.7 (9.1)
F2	Deep Fill	8.2 (0)	263.5 (16.3)	65.5 (2.9)	14.0 (1.4)	20.5 (1.7)	0.9 (0.1)	6.7 (1.3)	154.1 (12.3)	5932.9 (287.3)	235.9 (30.6)	9.3 (1.6)	157.5 (14.7)

Only a few vegetation variables were correlated with soil characteristics. LBS cover was significantly positively correlated with Ca ($F_{1,6}$=12.05; P=0.01), S ($F_{1,6}$=12.12; P=0.01), and silt ($F_{1,6}$=8.80; P=0.02) levels in soil. A significant negative correlation was found between K concentration and seedling abundance ($F_{1,4}$=14.45; P=0.02). No other significant correlation between fall seedling abundance and soil chemistry or texture was found.

3.5.2 Soil PCAs

Surface soils differed between target prairies and reclaimed quarries, as well as among quarries with different reclamation histories. Deep fill soil also differed from all surface soil. Regarding the soil PCA, PC1 accounted for 36.9% of variation, while PC2 accounted for 23.7% of the variation (Figure 3.14). PC1 is associated mainly with variation in texture, specifically between sand and clay proportions. PC2 is mainly associated with variations in nutrient levels, with Ca and K at one end, and all other nutrients tested for on the opposite end.

In general, quarries that were not filled grouped with native prairie remnants and deep fill soil grouped together, while grouping of filled quarries varied depending on time of fill. Most sites in the same category grouped closely together, except for unfilled quarry sites. Samples from native prairie sites dominated by LBS cover are grouped most closely and are associated with greater amounts of Ca and silt, and to a lesser extent, K. Samples from sites that were quarried but never filled had the greatest variation between the two sites that were sampled. All of the soil samples from quarries that were never filled were associated with the upper, positive portion of PC2; however Q6 was more tightly associated with the positive portion of PC1, while Q5 was associated with the negative portion of PC1. These differences in placement between unfilled quarries Q5 and Q6 indicate that while the nutrient content of the soils were moderately similar, Q5 was associated with a sandier texture than Q6. Q6 was the site with the closest placement to the native prairie soil grouping, and also the site with the greatest LBS cover among quarried sites.

Sites that were filled 9 years ago were tightly associated with the far negative side of PC1, and a sandy texture. Soil in both quarries that were filled 9 years ago had soil samples that were closely grouped. Soil used as deep fill in quarries was associated with chemical properties, including Mg, S, Na, P, and NO_3-N, and a greater pH. The soil samples tested were grouped tighter for deep fill pile F1, than for deep fill pile F2. F1 was also more closely associated with Mg, S, and Na. F1 had the highest NO_3-N, P, and S concentrations of all soil sampled, and had the greatest volume of rock. Soil from quarries that were recently filled fell in the midrange between all other samples. Q3 and Q4 were grouped in the same general middle area, although Q3 was closer to the deep fill grouping, and Q4 was closer to the grouping of native prairies and Q6.

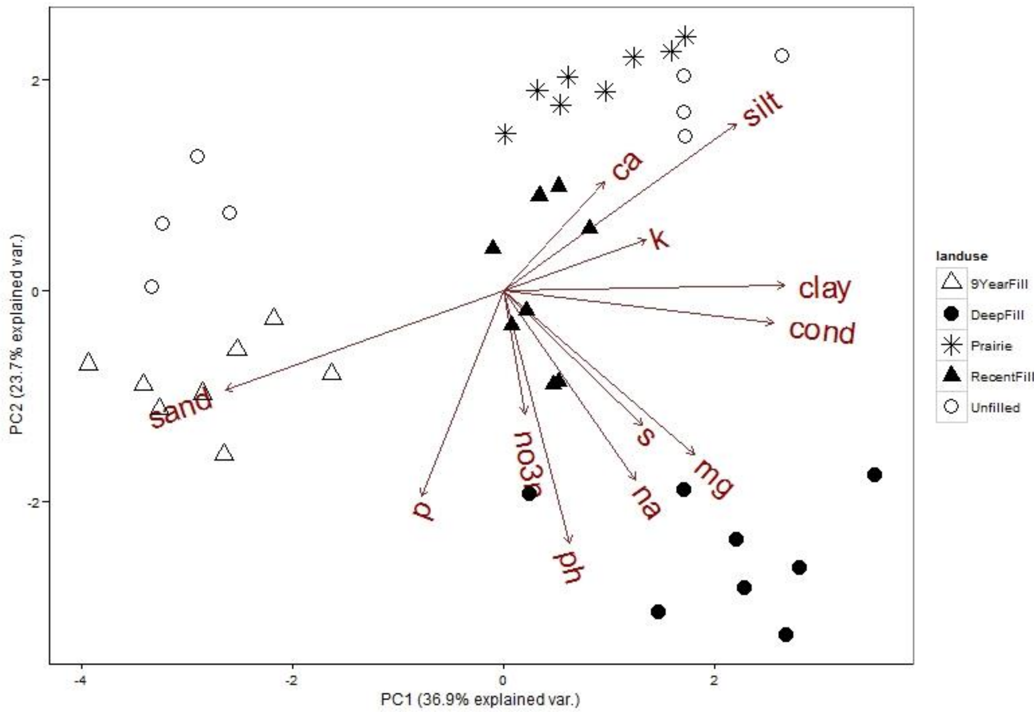

Figure 3.14 PCA of soil variables grouped by land use histories.

Chapter 4

Discussion

4.1 Prior Land Use Affects Reclaimed Prairie Plant Community

Plant community composition was different in prairies that were disturbed by past agricultural practices compared with native prairie remnants that had little disturbance, and this pattern was sometimes affected by the season in which the community was assessed. In both seasons, undisturbed native prairie remnants had greater proportion of bare ground cover, indicating that their plant communities may consist of more clumping type grasses, which is characteristic of many native C_4 grasses that allow for the presence of bare ground and are important to various wildlife species (US Department of Agriculture, 1996). plant cover in disturbed and undisturbed prairies was not greater in undisturbed prairies, suggesting that after 45 years of little to no management, native populations have been able to naturally recolonize disturbed prairies from nearby remnant sources. 45 years also appears to be enough time for LBS, a late successional species (Dyksterhuis 1946), to become established enough to regain its status as a dominant species. Although one of the sites disturbed by agricultural practices was able to establish a LBS dominant plant community after 45 years, another disturbed site did not, indicating that factors other than time are affecting colonization. Disturbed prairies had a greater amount of invasive plant cover, indicating that even if native communities are able to disperse back in to a disturbed area naturally, they may not completely push out any invasive species that may have been allowed to establish due to the disturbance.

4.2 Native Plant Populations are Spreading from Remnant Native Communities

As documented in the seed rain data and seedling abundance data, LBS and other native seeds are being dispersed from native plant populations within the FWNCR. The majority of all species of seed captured were native so at least in the FWNCR, native communities are dispersing more propagules than invasive plant species. Even though only a small portion of seeds perform long distance dispersal (Nathan 2005, Nathan, et al. 2002, Cain, et al. 2000), the small amount of seeds could add up to a significant amount at the final resting site because there are so many potential long distance sources. The fact that disturbed prairies within the proximity of known native sources, with no further land management performed after the disturbance stopped, are able to rebuild a native plant community, and that native seeds are being captured outside of sources, proves that native plant communities are dispersing and that the dispersal can aid in the passive reclamation of native plant communities in the FWNCR. However, invasive seeds are also dispersing within the FWNCR, indicating the opportunity for invasive species to colonize if conditions are favorable.

Significantly more native seeds were not dispersed to areas closer to native sources, suggesting that within the spatial scale of the FWNCR, seed movement is not correlated with distance from a source. There was a weak trend toward a negative relationship between native seed dispersal and distance from a source, but other factors such as barriers to wind dispersal or differences in elevation are also probably affecting dispersal.

A greater abundance of LBS seeds were not dispersed to areas that are closer to native sources than to areas further away. Because so few LBS seeds were captured a solid conclusions could not be made, my results suggest that although LBS plants appear to be producing many seeds within the FWNCR, their dispersal is being restricted. These results may partially explain why LBS has not recovered to reference abundance levels in some sites that have been disturbed. The lack of LBS seeds could also be because the seeds are eaten by animals after they are dispersed, and only a small portion of them are allowed to remain on the ground for possible germination, since LBS seeds are a known source of food for many wildlife species (LBJ Wildflower Center, 2014; US Department of Agriculture, 1996).

Native seed dispersal was not related to direction from a source, regarding average prevailing wind directions. Although North was not the most prevailing wind direction in either season, a greater amount of native seeds were dispersed to mats to the North. This could be because North is lower in elevation at the FWNCR. However the differences in native seed abundance by direction from source could have also been due to a difference in barriers, or the difference in distance from source, since the plot due North with the greatest abundance of native seeds is the closest with the least invasive barrier in between.

A greater abundance of LBS seeds were not dispersed to areas that are in the direction of average prevailing winds from a source than in those areas that are not in the direction of prevailing wind patterns from a source. LBS seeds are likely to follow the direction of prevailing winds, however so few LBS seeds were found, this cannot be confirmed. Overall, LBS seed dispersal will likely follow the same patterns as other wind dispersed native species.

4.3 Management Strategies Affect Reclaimed Plant Communities

4.3.1 Quarry filling does not promote native plant establishment

Plant communities that reestablish in a disturbed prairie can vastly differ depending on the management strategy used for reclamation. Filling did not necessarily decrease native plant cover relative to unfilled quarries and native prairie remnants. However, filling did increase the likelihood of invasive establishment, Many invasive species are quick colonizers from seed, and although this could account for the reason that the small amount of plant matter that did establish in very recently filled quarries was almost exclusively invasive, the plants that were present were not newly colonized. The almost exclusively Bermuda (*Cynodon dactylon*) and Johnson (*Sorghum halepense*) invasive grass growth was breaking through the surface layer of soil from previously established colonies underneath. When these sites were surveyed in the spring, after they had been filled 3 years prior, but before the final surface fill and grading when fall surveys were done, invasive grasses colonized much of the filled areas.

Although the original colonization of invasive species (mainly Bermuda and Johnson grasses) of the quarries when they had been filled for 3 years could have been from incoming seed rain from existing invasive species populations, they likely were not. When the two quarries were surveyed in the spring 3 years after filling, one was dominated almost solely by Bermuda and Johnson, while the other was dominated by Ragweed (*Ambrosia* sp.) and Bermuda. Edges of both of these quarry fragments were remnant native prairie, indicating there was a source from which native populations could recolonize. Prior to the beginning of filling, there was no significant source of Bermuda or Johnson grass in the area, suggesting the source of these two invasive species must have been in the fill soil. These two grasses grow from both seeds and rhizomes, thus either or both propagule type could be contained in the fill soil. With this conclusion in mind, the degree in which filling of quarried land effects plant community structures is likely variable depending on fill soil quality.

Quarries that were never filled but had added soil amendments approximately 35 years ago had the greatest native plant cover, but only the third greatest LBS cover among all the quarry reclamation strategies. This indicates that although they have been successfully reclaimed to native prairies, they are not yet reaching the target LBS dominated community composition. The lack of LBS could be due to the lack of significant LBS sources in the immediate area, since the areas that had added soil amendments are further from LBS dominant remnants and separated from the other quarried areas by a creek, but it could also be that these sites are in a mid-successional stage of passive reclamation and on track to becoming a LBS dominated climax community (Dyksterhuis 1946).

Although quarries filled 3 years ago had a marginally greater proportion of native cover than quarry areas filled and seeded 9 years ago, which is more desirable to native prairie reclamation, the native cover in the 3 year quarries consists of less native plant species and is less similar to designated target communities, while the native cover in the 9 year seeded quarry areas contains more species and is more similar to the target. For instance, the 9 year seeded areas contain LBS and other common native prairie grasses, while the 3 year areas do not.

The fact that there was no significant difference between proportion of native plant cover in quarry areas filled and seeded 9 years ago and in quarry areas that were never filled shows seeding and planting desired species may be able to mitigate the negative effects of filling. Reclamation from quarry back to a partially native prairie is possible in 10 years or less. Seeding and planting in these filled quarries was clearly the defining factor to adding native plants, because unseeded areas filled at the same time had far less native plant cover.

4.3.2 LBS establishment is correlated with time elapsed since disturbance

Time elapsed since disturbance does affect native plant community structure. Time elapsed since disturbance was positively correlated with LBS and “other” cover, but no other community category. It makes sense that there would be a significant gradient of cover in the “other” category that increases with time elapsed since disturbance, because the other category consists mainly of standing dead and litter. Both of these are dead plant matter, which generally does build up over time.

The significant positive correlation between LBS cover and time elapsed since disturbance despite the similarity in overall native cover indicates that the recolonization of LBS may take more time than other native plants, or that it has a more difficult time colonizing from seed than other natives. Research has suggested that dominant LBS populations are characteristic of a climax community that has had time to recover from disturbance (Dyksterhuis 1946).

4.3.3 Seeding and planting for native species increased native plant cover

Seeding and planting increased the chances that native species are established. Plant species that were planted could have been more visible in surveys because of their probable larger size, due to the amount of time they have had to grow, or because they were more likely to be established, due to adult plants greater resilience than seedlings. Many species that were seeded for were probably not found because the conditions were not right for all species' seeds to germinate and survive. Another possibility is that my survey did not detect them, because every square meter of the site was not examined. The presence of planted species past the area that they were planted in indicates that either seeds from these species were naturally dispersed in to the area, propagules of these species were in the fill dirt, or the species that were planted are now acting as sources native propagules.   Of all the filled quarries, the site seeded and planted with native species had the greatest similarity to target plant communities, indicating that adding chosen propagules can be an effective way to facilitate reclamation of native prairie plant communities.

The possible reasons for the greater average total seedling abundance in the quarry that was previously seeded than in those that were not previously seeded are that

1) there were more seeds in seed bank left over from previous reclamation seeding, 2) conditions were more conducive to sprouting due to the plant community present as a result of previous reclamation seeding, 3) previous reclamation seeding enabled establishment of a plant community that produces more viable seeds, or 4) soil conditions are more conducive to sprouting, because the plant community that was seeded for and established as a result affected soil conditions after filling. The most likely reason is because of increased seed availability, whether they are left in the seed bank from previous reclamation seeding, or produced by plants established after reclamation seeding. Areas directly adjacent to seeded areas also had a greater abundance of seedlings, even when not directly seeded, suggesting that species purposefully reintroduced were spreading beyond the area in which they were seeded and planted. The existence of a difference in seedling abundance nearly ten years after seeding suggests that the effects of seeding are still a factor in the shaping of the plant community.

LBS cover was similarly low in both quarries filled 9 months prior, regardless of seeding or planting status. However, LBS cover in unseeded quarries was clumped at one edge, spreading clonally from adjacent LBS populations, while LBS cover in seeded and planted areas is scattered and likely not from natural dispersal of remnant populations.

4.3.4 Clearing existing plant matter did not increase likelihood of establishment of seeded plant species

Seeding did not consistently guarantee that there would be a greater abundance of seedlings of species that I seeded for in the short-term (<1 year).In the fall, when more seedlings of sowed species were detected, the seeds had been there for a longer period of time than when surveyed in spring, the weather was more conducive to seed sprouting, and more seeds overall sprouted. Seeding might have proved to be more successful if the experiment lasted longer. Overall, seedling abundances were not significantly different among treatments. This was because seedling abundances differed among sites and treatments. The variation among sites was probably due to the differences in site soil characteristics and management histories.

Clearing existing above ground plant matter did not increase the likelihood of seeded species sprouting. The probable reason why in the spring maximum seedling abundance was generally greater in non-cleared areas, but in the fall it was generally greater in cleared treatments, is because in the spring and summer, when the climate is hot and dry in North Texas, many seedlings cannot handle the stress of being out in the open and need the shelter of other plants. In the fall, when temperatures are lower and there is more moisture in the soil at the surface, seedlings do not have as much of a chance of drying out, and do not need protection by neighboring plants. Without the restriction of the need for a neighbor to germinate and survive, more seedlings sprouted in areas with more open space.

Some seedlings of species that I seeded for were found in areas that were not seeded. This could be either because they are being naturally dispersed to the area, or because the seeds that I placed migrated from their original location. Abundances of seedlings of sowed species were too low to make any conclusions about the treatments.

The low abundances indicate that within a short term time frame, germination rates for Purple Coneflower are low and germination rates for LBS are very low. Another study on prairie reclamation by seeding concluded that results from seeding are often not seen until the second year (citation?); Most of the seedlings that did sprout were invasive species. LBS most likely uses vegetative propagation more frequently than colonization from seed (Derner 2004)

Seedling abundance was likely consistently lowest in Q2 because of its plant community and the resulting lack of bare ground. A large portion of Q2, including the area that the manipulation plot was in, is colonized by Bermuda grass, which has formed a dense mat. Even after the above ground plant matter was cleared, the soil immediately below the surface was visibly packed with Bermuda grass rhizomes, and plant matter grew back quickly. These conditions produced a ground surface where there was likely no room for many seeds to germinate.

4.3.5 Surface soil differs in prairies with different land histories

Most of the soil characteristics examined differed between surface soil in native prairies, surface soil in quarries with different management histories, and soil used as deep fill in quarry reclamation. Sites with substantial LBS cover had similar soil characteristics. Target sites with dominant LBS cover had relatively low nitrate (NO_3-N) concentrations and high calcium, sulfur, and silt concentrations. Although LBS is known to inhabit calcified soils (Dyksterhuis 1946), its dominating presence in the Blackland Prairie ecoregion indicates that high calcium levels are not a growth requirement. Here, LBS was present in all of the sites surveyed with the greatest soil calcium levels, as well as two sites with moderate calcium levels. These observations support the assumption that LBS colonization is not specific to a narrow soil type, and thus can be achieved in a range of soil environments. However, in the two native prairies that were not quarried and had LBS populations that dominated more than 50% of overall ground cover, calcium levels averaged over 10,000 ppm, indicating that for a LBS dominated native prairie, high calcium levels may be important. An aerial satellite view of both LBS dominated native prairies at FWNCR shows a clear banding pattern in the plant community, with bands of dense LBS growth located next to and parallel with exposed limestone.

Soil in both quarries that were filled 9 years ago had similar surface soil characteristics, although Q1 was seeded and planted with native species while Q2 was not, resulting in different plant communities. Since the native soil that was left at quarried sites after they were quarried was collected, saved, and used as surface fill, the surface soil that was left after quarrying was probably originally similar in these sites. Their current soil similarity shows that within the 9 year time frame, the different plant communities resulting from seeding and planting have not significantly changed soil nutrient levels.

Deep fill soil was different from all surface soil, and all deep fill had relatively similar soil characteristics. Deep fill pile F2 may have had less tightly associated soil samples than F1 due to it being made of soils hauled from different source areas, while

F2 was from one source. Visually, F1 was a large homogeneous mound of dark soil with various sized chunks of asphalt concrete and trash, while F2 was a large mound with a mosaic of different shades of tan colored soil. The presence of asphalt in the deep fill dirt from pile F1 probably also explains why F1 had such high levels of certain elements. Therefore, the soil being used to fill these quarries is of varying chemistry and texture, and overall has very high nutrient levels. If nutrient levels are too high, it can be a detriment to plant growth. The level at which the use of this type of deep fill soil can affect plant communities at the surface depends on depth of surface soil layer and concentrations of nutrients available for uptake. Even at a surface soil depth of 2 m, some native plant species' roots would be able to reach (Natura, 2015).

4.4 General Conclusions and Recommendations

Overall, reclamation of prairies from a disturbed state back to a state where native plant communities are dominant may not be that difficult, especially if remnant native communities are still within a close enough proximity to disperse propagules to disturbed areas. Over a time frame of 3-35 years, native species were able to establish in disturbed prairies through passive reclamation, when native sources were proximal. Within the FWNCR, native seeds are being dispersed and establishment of native plant communities is happening with no management. However, reclamation to a target state where not only is native plant cover dominant, but where LBS is the most dominant species, could take longer to achieve.

Disturbed prairies that had intact top soil and were within close proximity to remnant native plant populations were able to be reclaimed to a state similar to target plant communities with a dominant LBS population within 45 years, with little to no management. Therefore, passive reclamation to climax LBS dominated native prairie plant communities is possible within a 50 year time frame, as long as colonization conditions are optimal. Prairies disturbed around 45 years ago but in other locations did not have plant communities as similar to LBS dominated target communities. Therefore, by the time 45 years has elapsed, the presence of large, nearby LBS dominant native plant sources are probably more influential on the reclamation of LBS cover in disturbed prairies, than time elapsed since disturbance.

Prairies subjected to disturbances that removed the top layer of soil, were within close proximity to remnant native plant populations, and had little to no management were not able to be reclaimed to be as similar to target plant communities within 45 years. This indicates that passive reclamation from more disturbed conditions to LBS dominated communities may take longer than 50 years. Overall, LBS took a longer time to naturally colonize than other native plant species, reflecting its role as a late successional species in tall grass prairie (Dyksterhuis 1946). Although this could result from differences in soil conditions at each site or because of differences in the source populations providing propagules for establishment. The results of the seed rain portion of the experiment also showed that even right next to large LBS populations, very few LBS seeds are received for possible germination, indicating that a combination of low dispersal success and low seedling germination rates could be the underlying cause for LBS's slow establishment.

Based on results and conclusions here, in fragments like these that are still within close enough proximity to native populations that can act as a source for colonization in disturbed areas, time elapsed since disturbance may be the most important factor in determining the plant community composition with passive reclamation. If the disturbed prairie is near native remnant sources and the goal is to achieve a reclaimed prairie with a plant community dominated by native prairie plants with no specific composition in mind, passive reclamation is likely sufficient. Or, if the reclamation goal is to have a plant community similar to remnant sources nearby and time is not a factor, passive reclamation is likely sufficient.

Active reclamation can allow for more control over reclamation outcomes, but also takes more money and effort. Solely in terms of reclamation of previously quarried prairies, filling did not increase the likelihood of establishment of target plant communities. Since filling did not prove to be an effective reclamation tool and takes effort, filling of quarried land should only be done if a more even topography is desired, or if the acceleration of topsoil formation is desired.

If quarry filling is desired, the following recommendations could ensure native prairie reclamation is successful. First, timing of the grading and filling of quarries should be conducive to native plant community establishment. To allow maximum time for establishment of native propagules, quarries should be filled as soon as possible after use is discontinued. If the quarried area is allowed to rest for long enough after use but before reclamation filling, native plants may begin to establish from passive processes. If native communities have already been allowed to establish before grading and filling, it might be best to try and leave as much of them intact as possible throughout the filling process. For instance, if native plant communities have established in the areas that surround the quarry pit, do not grade the areas surrounding the pit along with the filled pit, and only place fill soil in to the actual pit, being mindful not to disturb the edges of the prairie patch. If surface soil that already houses native plants is scraped from the surface to be kept for later deposition, like is currently done at the FWNCR, ensure that the quarry is filled and the native soil is replaced within a short time frame, to avoid loss of functionality for any beneficial microbes or native propagules in the soil. Ideally, if soil needs to be brought in as fill for prairie reclamation purposes in cases such as reclamation of quarried land, the deep fill dirt would be similar to surface fill. If not, the depth of the surface fill should be greater than the greatest depth of root growth for the desired set of species. According to just the small set of common North Texas prairie species presented in a graphic depicting common prairie plant root depths (Natura 2015), surface soil depth would need to be around 5 m to achieve this goal. Considering LBS alone, the surface soil might need to be at least 2 m thick.

Since much of the invasive cover that established in filled quarries likely came from invasive species propagules within fill soil that was used, fill soil should not be used if it contains propagules of invasive or undesired plant species. If lower quality fill soil is used deep in quarry pits that does contain invasive propagules, ensure that the deep fill soil is not allowed to sit uncovered for a long enough time to allow invasive propagules to establish, and/or place top soil at a thick enough depth so that any growth from beneath is inhibited. If invasive species have been allowed time to establish it is likely best to till the surface of the soil to break up any rhizomes that could possibly recolonize the surface, before the layer of top soil is added. Top soil should defiantly not contain any invasive propagules and should be of the greatest quality possible. In the case of the FWNCR and any other natural recreation areas that are owned by the city or have access to city resources, top soil harvested from the development of native land would likely be optimal for the establishment of native plant communities. After quarries are filled, passive reclamation induced by native prairie plant propagules can be allowed to take course, or further management can be performed.

If a specific plant community composition is desired, or if time is a factor in the desired reclamation trajectory, establishment of native plant species can be enhanced by seeding and planting of native plants, although these are costly in terms of time, labor and money. Seeding and planting maybe necessary if there are not any sources of native propagules nearby or if the local species pool is lacking. More seedlings sprouted in the fall and more seeds were dispersed in the fall, indicating that if seeding is performed, it should be done just before or during the fall. Since seeds dispersed by several common native prairie grass species were either not found or found in low abundances and grass seedling abundances were lower than forb seedling abundances, if a traditionally grass-dominated native prairie plant community is what is desired for reclamation, it may be more effective to increase seeding and planting intensity for native grasses. If a dominant LBS population is desired, intense seeding for LBS is likely to accelerate establishment and dominance. As an alternative to seeding and planting native species, addition of green hay from a native source has been shown to be more effective than seeding (Tischew, et al. 2014). This method could benefit natural recreation areas like the FWNCR in a number of ways. If the FWNCR used green hay from their prairies they have deemed as targets for reclamation of quarried areas it could provide a more effective source of native propagules for reclamation of quarried areas, allow money to be saved because commercial seed mixes do not need to be purchased, ensure that the propagules being deposited on the reclaimed areas resemble the target community composition, and provide a regular low-intensity disturbance that is needed to maintain native prairies.

Variation in soil condition did not seem to play as important of a role as reclamation strategy, since native populations were able to establish in filled quarries with different soil conditions than native surface soil. However, soil conditions could be a factor in LBS colonization. Though the presence of more LBS propagules will generally aid in greater and quicker colonization, soil conditions could dampen or increase colonization effectiveness and time. LBS cover was not only found to be positively correlated with calcium, but also with sulfur and silt in soils. It was also dominant in sites that had lower nitrate concentrations. In other studies, reduction of nitrate in soils promotes establishment of native C4 grasses including LBS (Priest and Epstein 2011), which seems to be supported by the findings here. These results indicate that a reclamation strategy at FWNCR aimed at establishment of LBS dominant populations could benefit from the addition of calcium, sulfur, and silt to reclaimed soils, along with the reduction of nitrate,

Overall, general native plant cover was correlated more with reclamation strategy; while LBS cover was correlated more closely with time elapsed since disturbance. Therefore, native plant cover can be influenced more heavily by reclamation strategies than LBS cover alone, and to achieve a specific plant community composition within a certain time frame, active reclamation techniques are warranted.

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Biographical Information

Heather L. Bass was born in Fort Worth, Texas on March 24, 1988 to James and Angela Bass. She received her Bachelor’s Degree in Biology in 2013 from The University of Texas at Arlington. Between 2011 and 2015 she worked as a research assistant and a field assistant on a project in the Alaskan Arctic studying climate change and its effects on Arctic ecosystems. Based on that work she was awarded the Student Employee of the Year Award for the 2012-2013 academic year from The University of Texas at Arlington. As a part of this large system of funded Arctic studies, she conducted an undergraduate research project on the effects of nutrient addition on vegetation composition and seed production in the tundra that was published in *Arctic, Antarctic, and Alpine Research* in early 2015. In 2013, she was awarded a two-year scholarship from the NSF funded AUGMENTS Program to attend The University of Texas at Arlington for a Master’s Degree in Earth and Environmental Sciences. Her Master’s project was dedicated to the restoration of native Texas prairies, a cause she is passionate about. Heather plans to pursue a career in ecological conservation or environmental restoration.