Strip Mining Impacts On Plant Diversity

Kelley Ann Hays
University Undergraduate Research Fellow, 1994-95
Texas A&M University
Department of Rangeland Ecology and Mangement

Approved
Undergraduate Advisor ____________
Exec. Dir., Honors Program ____________

Abstract

Differences in species richness, index of diversity, and indices of similarity were assessed for three study sites located at the Jewett Mine operated by the Northwestern Resources, Company near Jewett, Texas. Sites were also evaluated for differences in herbaceous cover, density, and production. The study sites consisted of an area of reclaimed mine land, an area of unmined land dominated by woody vegetation, and an area of unmined land dominated by grasses. Significant differences were found in cover, density, and production levels between the various study sites. Species richness did not differ between sites, although richness fluctuated with time. Diversity values were high to moderately high on the Reclaimed and Woody Dominated sites. Similarity indices indicated little overlap between species. Maintaining diversity is generally agreed to be important, but no definitive measures of diversity have been established. Motyka and others' version of Sorensen's similarity index is a favorable measure of diversity and can directly compare two different plant communities.

Introduction

Federal laws require reclamation of surface mined areas. Primary reclamation goals are to provide for plant growth, to use vegetation for the reduction of soil erosion, and to restore productivity to a site (Skousen et al. 1990). Restoration of the land's sustainable productivity is important because large portions of minable land in the United States are used for pasture and rangeland. Successful revegetation of strip mined lands is crucial in controlling erosion and in maintaining a sustainable and productive system.

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 requires the establishment of "a diverse, effective, and permanent vegetative cover . . . at least equal in extent of cover to the natural vegetation of the area" (Stark and Redente 1985). Strip mined lands in Montana, Wyoming, and Colorado must meet plant diversity standards in combination with plant production requirements to determine revegetation success. In Texas, however, strip mines are only required to meet plant production and cover requirements when determining revegetation success.

Biological diversity is a measure of variety and abundance. Diversity includes species, processes, functions, structure, and various scales (Ratliff 1993). Chambers (1983) describes the two components of diversity as species richness and evenness. Species richness refers to the number of species present in an area, while evenness refers to the "proportionate distribution of individuals among species" (Chambers and Brown 1983). Diversity can also be broken down into categories: alpha diversity, beta diversity, and gamma diversity. Alpha diversity refers to intracommunity diversity, beta diversity refers to diversity between communities, and gamma diversity refers to diversity across a landscape (Ratliff 1993).

The issue of diversity on reclaimed land is important to assessing the land's productivity and stability. Humans are dependent on plant and animal diversity for food, clothing, fuel, raw materials, and medicines (Noss and Cooperrider 1992). Diversity is related to ecological processes and is considered a characteristic of natural communities (McIntosh 1967). Plant diversity can also provide increased ecological stability, greater niche differentiation, mutualistic or symbolic interspecies benefits, greater sustained seasonal forage production, and beneficial effects of mixed diet to herbivores (Whisenant 1993).

Previous studies in Texas addressing reclamation of surface mines have addressed the establishment and development of plants rather than vegetative diversity. Many mines in Texas are planted in monoculture Coastal bermudagrass. No studies addressing plant diversity on strip mines have been done in Texas. Diversity studies in other states have explored the relationships between soil properties and plant diversity (Stark and Redente 1985), the effects of manipulative disturbance on species richness (Armesto and Pickett 1985), and the development of a test for comparing diversities of two plant communities (Pielou 1986).

The objective of this study was to evaluate the destruction of plant communities and the related plant diversity by strip mining. The study compared a strip mined area several years after reclamation to areas of undisturbed land supporting native vegetation. Study hypotheses were:

1) There are no differences in herbaceous production, cover, and density between the study sites.
2) There are no differences in species richness (number of species) between the study sites.

Methods

Study Sites

Research was conducted on the Jewett Mine, a strip mine operated by the Northwestern Resources Company. The strip mine is located near Jewett, Texas in Leon and Freestone counties, approximately ninety miles north of College Station, Texas. The Jewett

Mine is found in the Post Oak Savanna vegetative region of Texas. Grassland with scattered oak mottes was the area's pristine climax plant community. Historical land uses included long-term cotton farming, which depleted soil resources, and heavy grazing. These land uses with suppression of fire have contributed to the current plant community's domination by woody vegetation with occasional grass areas.

Research involved three study sites on the strip mine: an area of reclaimed mine land, an area of unmined land dominated by woody vegetation, and an area of unmined land dominated by grasses. The study sites were chosen based on accessibility, slope, size, homogeneous terrain, and number of years under reclamation. The area of reclaimed mine land had been strip mined, leveled, and then seeded back to native herbaceous vegetation. At the time that the study began, the site had been under reclamation for about five years. This area will be referred to as the reclaimed (RC) site. The areas of unmined land have not been disturbed by strip mining and support native vegetation to this area. The areas will be referred to as the woody dominated (WD) site and the native grass (NG) site.

On the RC and WD sites, three areas approximately 100 m x 100 m were marked off. Three transect lines ten meters apart and thirty meters long were laid out in each section. Within each section, ten permanent plots the size of a 0.25 m^2 square quadrat were marked off along the transect lines (Fig. 1). We were unable to find an undisturbed area with grassland vegetation that could accommodate the same sample size as the other two study sites. Plots on the NG site consisted of eight randomly located sample plots.

Soil Sampling

Samples of the surface soil were taken from all three study sites. Samples were collected in November 1993 and March 1994 for the reclaimed and woody dominated sites. Samples were collected from the native grass site in April 1994. Using a shovel, the surface 5 cm of soil was removed adjacent to each permanent plot. Samples were consolidated into one sample for each section. Two samples were taken from the native grass site. Each sample was dried and thoroughly mixed. A subsample was taken from each sample and sent to the Texas Agricultural Extension Service Soil Testing Laboratory at Texas A&M University. The lab analyzed the soil samples for texture, pH, organic matter, and nutrients cations. An average of soil results across sections was used in the analysis of soil sample data to give one set of numbers for each study site.

Vegetation Sampling

Herbaceous vegetation on each study site was measured for cover, density, and production using a 0.25 m^2 square quadrat. Samples were taken at three different times in order to capture seasonal variations in production and species present (cool season, warm season, annuals, etc.) over the fall, spring, and summer. Cover and density measurements were conducted on the RC and WD sites on three dates: 1, 15-16 October 1993; 11, 26 May 1994; and 9-10 July 1994. Sampling dates for cover and density on the NG site were 25 March 1994 and 9 July 1994. Production samples were taken on 16 and 22 October and 25 March on the WD, RC, and NG sites respectively. A second production sample was taken on each site on 9 July 1994.

Data from the March collecting date on the NG site was considered with the data from the October collection dates on the RC and WD sites during data analysis. March data was considered with the October data because the vegetation present on the NG site in March reflected the vegetation that would have been present in October to a higher degree than vegetation that was present in May. This was a result of the dry conditions during the fall which did not stimulate decomposition of material or early spring growth.

Percent cover by species, was visually estimated for each plot. Density counts were conducted on each plot by species. Production of the herbaceous vegetation was assessed using the double sampling technique (Pechanec and Pickford 1937). In order to avoid damaging the plots, an area of similar vegetation adjacent to the plot was clipped. The clipped vegetation samples were dried at 60°C and weighed. The results were used to estimate production on the plot. Percent cover of woody vegetation was measured using the line intercept method along transects.

Data Analysis

Analysis of variance was used to determine site differences for cover, density, and production data using the General Linear Model in SAS. The Duncan Multiple Range Test was used to separate differences in means when there was a significant difference. Species richness was determined as the number of species per unit area. The Shannon's diversity index (Chambers and Brown 1983), Sorensen's similarity index (Southwood 1966) and Motyka and other's version of Sorensen's similarity index (Chambers and Brown 1983) were used as measures of diversity.

Results and Discussion

Soil

Soil texture is the size distribution of inorganic primary particles in the soil. Differences in soil texture affect soil cation exchange capacity (CEC), infiltration rate, plasticity, and porosity. Texture differences between the study sites had a large influence on associated soil properties. The WD and the NG sites both had sandy loam soils (Table 1). The NG site had a higher percentage sand than the WD site.

The RC site had a clay soil. The soil on this site represents the mixed overburden that was leveled when reclamation began on the site. Overburden is the material present above the lignite. During mining, overburden is removed and placed in large piles in order to access the lignite. When these piles are leveled, the structure and arrangement of the original soil profile is lost. The soil on the RC site is a mix of soil layers that have not had the time to undergo extensive weathering and development. The other two study sites have older, more highly leached and developed soils.

Bulk density is a measure of the pore space in a soil and is defined as the dry weight of the soil divided by the volume. The higher the bulk density, the less pore space available for air and water movement. Bulk density is negatively correlated with percent porosity and water infiltration rate (Pluhar et al. 1987). The bulk density was higher on the RC site because of the lack of soil development.

Soil organic matter is an important soil component because it increases soil aggregate stability, increases infiltration rate thereby decreasing runoff and soil erosion potential, decreases bulk density and increases soil porosity, and improves soil structure. Soil organic matter is also an important source of nutrients. On the RC site, soil organic matter was greater in the fall than in the spring. The drop in percentage of organic matter from 2.90% to 1.57% (Table 1) on the RC area is explained by the removal of litter and plant cover on the site by a prescribed burn during February 1994 and by decay and leaching.

Acidity of a soil is measured by its pH level. As a soil property, pH affects biological activity and cation exchange capacity in the soil. The optimum pH range for biological activity is between 6 and 7. The Railroad Commission of Texas regulates pH levels on reclaimed land and requires adjustments, such as liming, if soil acidity is too high. Older soils tend to have lower pH values due to leaching effects. Sandy texture sites with high organic matter tend to have low pH levels. The WD site had the lowest pH values and the RC site had the highest. The RC site was initially limed when reclamation began.

Important soil macronutrients include nitrogen, phosphorus, and potassium. The levels of these macronutrients in the soil are influenced by plant and animal residues, fertilizers, organic matter removal, and leaching. Nitrogen levels were greatest on the RC site in the fall because of soil texture and fertilization. The remaining nitrogen levels reported are all equal to 1 ppm since this is the lowest level that the Soils Testing Laboratory is able to detect. Nitrogen levels on the RC site decreased between sampling dates due to the removal of organic matter by the prescribed burn. The sandy loam texture of the WD and NG sites are subject to greater loss of nutrients by leaching than the clay texture found on the RC area.

High potassium levels on the RC site are due to the weathering of overburden materials and soil texture. Phosphorus is subject to leaching on sandy soils and fixation into unavailable forms by iron and aluminum. The WD site had lower phosphorus levels than the RC site because of higher iron levels and sandier soil. The RC site had the highest levels of phosphorus because of the exposure of new material to weathering, the clay textured soil, and fertilization.

Micronutrients important in soils and regulated by the Railroad Commission of Texas include iron and manganese. High iron levels are associated with low pH levels. This association was apparent with the sample results. Manganese can be deficient on highly leached, acid sandy soils. Manganese levels were similar between the RC and WD sites, but the NG site had a lower level.

Herbaceous Vegetation

Cover

No significant differences were found between dates for total herbaceous cover, but significance differences were apparent between study sites (Table 2). The NG site had the greatest total cover, 82%, and the WD site had the least, 21%. Herbaceous vegetation on the WD site was a measure of only the understory vegetation. The understory was influenced by the heavy overstory cover of woody vegetation which ranged from 65 to 98%. Forb and grass cover also had no significant differences by date, but were different between sites (Tables 3 & 4). The WD site had the greatest forb cover, but differed significantly only from the NG site. The WD site had the lowest grass cover at 5% caused by shading effects from overstory vegetation and competition for nutrients. The NG site had a higher grass cover than the RC site, 74% compared to 61%.

The WD site had the highest percentage of bare ground between study sites (Table 5) from lack of ground cover and soil disturbances by feral hogs. The NG site had the lowest percentage of bare ground, although it differed significantly only with the WD site. Bare ground cover also differed significantly by date. The October sampling date had the lowest levels of bare ground, while the May and June levels did not differ significantly. None of the bare ground percentages were high enough to cause concern about excessive erosion. Litter cover also differed significantly by date and study site (Table 6). Litter cover in July was the lowest for the three sampling dates, which was the date with the highest total herbaceous cover (Table 2). Mean litter cover on the WD site, 71%, was the highest between sites. Means between RC and NG sites did not differ significantly.

Density

Analysis of variance for density showed an interaction effect between site and date. Therefore, differences were only analyzed by site across dates, or by date across sites. Total herbaceous density (Table 7) was significantly lower in October than in May and July on the RC site. October density was 500 m^{-2} versus density values over 1200 m^{-2} for May and July. The differences on the RC site are explained by the annual species that sprouted in the spring following the February burn. The majority of the high density values in May and July on the RC site was attributable to the sheer numbers of annual grasses present on the plots. The dominant annual grasses were six-weeks fescue (*Vulpia octoflora*) and ryegrass (*Lolium perenne*). Appendix A contains a complete list of species present on each date for the study sites. The WD and NG sites did not have significant differences between dates. The RC site had significantly more herbaceous density than the other sites for all dates. The herbaceous vegetation did not significantly differ between the WD and NG sites for all dates.

Forb density (Table 8) was significantly lower than both the RC and NG sites for all dates. The RC and NG sites did not differ significantly in forb density for all dates. The RC site differed significantly with the WD site in May, but not for either October or July. Forb density on the RC site was highest in May, and differed significantly for both October and July. The NG site did not differ significantly across dates. The WD site had the greatest density in forbs during May. This differed significantly from October but not from July. July did not differ significantly from October results.

Grass density (Table 9) was significantly higher on the RC site for all dates than on the WD or NG sites, which did not differ significantly for all dates. The RC site had significantly less grass density in October than for the other sampling dates. Grass density on the WD and NG sites did not differ have significant differences between dates.

Production

Total herbaceous production did not differ significantly between dates (Table 10). Herbaceous production was greater in July on the RC site because of the large amount of annuals present. The abundant annual vegetation on the RC site may be attributable to stimulation by the February burn and the adequate moisture conditions that existed in the spring. Annuals did not dominate the NG site because of the competition with well established perennial bunchgrasses. The WD site had significantly less herbaceous vegetative production than the two grass dominated sites. This was an anticipated result due to the nature of the tree dominated plant community present on the WD site.

Although forb cover (Table 3) had significant differences between study sites, forb production (Table 11) showed no significant differences between sites or dates. This aberration can be explained by forb size. The majority of the forbs were small annuals that contributed to cover because of density and some had broad, thin leaves. The leaves were large enough to influence cover, but not enough to significantly contribute to production.

Grass production (Table 12) showed no significant difference by date. While a decrease in grass production on the RC site may have been expected after the prescribed burn, the opposite occurred. Production samples were not clipped until after it was estimated that vegetation had reached peak growth for the spring-summer growing season. Grass production on the RC site had adequate time to recover from the burn. Production greater than October's can be attributed to the positive effects of the burn and the dry conditions in the fall. Prescribed burns are conducted to stimulate vegetation growth and promote nutrient cycling. The NG site had less grass production in July than in October. Grass production was significantly less on the WD site as expected by the nature of the woody dominated plant community. Grass production did not differ significantly between the RC and NG sites, although the NG site had a higher mean value.

Diversity Measures

Results of species richness, the number of different species present on the study sites, is summarized by date in Table 13. The WD site had the largest number of species present on two of the three sampling dates and the same number as the RC site in May. Each site showed fluctuations in the number of species present across time. Differences in species richness between dates is a function of the different growth periods (cool season versus warm season), growing conditions (adequate moisture, desirable temperatures, etc.), and management practices (fertilizing, prescribed burning, etc.).

High species richness values occurred on the May sampling date had a high species richness value compared to the October and July sampling dates, because of the presence of cool season annuals. The large number of annuals, present on the RC plots, was possibly due to the growth stimulation caused by the prescribed burn in February. Old growth and litter that would inhibit the growth of annuals was removed by the fire, leaving a partially bare soil surface. An open canopy and a large crop of annual vegetation on one of the areas of the WD site caused the high richness value in May.

The Shannon diversity index measures both species richness and species evenness. The formula for the H' index is:

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

where p_i is the percentage importance (Peet 1974). For this report, average cover of each of the study sites was used as the importance value. The Shannon diversity index is based on "the assumption that the more species there are and the more even the distribution of individuals among species, the greater the diversity" (Chambers and Brown 1983). The index ranges in value from 0 to 1, with a value of 1 having the highest diversity. While diversity indices are not directly comparable across communities, looking at individual index values for a community can give an idea of the relative diversity of an area.

The RC site had diversity values of 0.61, 0.86, and 0.75 for October, May, and July respectively (Table 14). These numbers are all moderately high index values. This indicates that the site has a large number of species with fairly even distribution. High diversity values for the WD site occurred on all three dates. Relatively similar cover values for all the species present in the understory vegetation contributed to the high diversity values. The NG site had low diversity values for October and July. The low diversity value reflects the unevenness of species on the site, which is dominated by little bluestem (*Schizachyrium scoparium*).

Direct comparison of two plant communities is possible using similarity indices. For comparison, similarity data consisted of two indices, Sorensen's quotient of similarity (Southwood 1966) and Motyka and others' version of Sorensen's similarity index (Chambers and Brown 1983). Sorensen's similarity index or quotient of similarity is:

$$QS = \frac{2j}{a + b}$$

where j is the number of species in both communities, a is the number of species in community A, and b is the number of species in community B. This index of similarity is measured in terms of species composition, that is the number of species present. It does not take into account the difference in abundance between species. Rare species may be overvalued relative to dominate species in the communities (Southwood 1966).

Motyka and other's version of Sorensen's similarity index include importance values when assessing similarity. For this report, cover was used as the importance value. The formula for Motyka and others' index is:

$$IS_{MO} = \frac{2\ MW}{MA + MB}$$

where

MW = sum of the smaller importance values of the species common to both sites

MA = sum of the importance values of all species in community A

MB = sum of the importance values of all species in community B.

The values for Motyka's index ranges from 0 to 1, with a value of 1 indicating complete similarity. An index value of 0.8 or larger is considered a high similarity value. (Chambers and Brown 1983).

Calculation of similarity between all sites, two sites at a time, indicated that none of the study sites were very similar (Table 15). The highest similarity value was 0.38 using Sorensen's index between the WD site and the NG site. Although species richness was similar between sites (Table 13), overlap of species between sites was minimal. The differences in how similarity is calculated between the two indices is apparent in Table 15. Motyka and other's index reflects not only the presence of similar species, but also the differences in importance values for similar species. A similarity index value decreases as the number of common species decreases and the difference in importance values between the common species increases (Chamber and Brown 1983).

Conclusions

As my research for this paper progressed, the issue of diversity became less and less clearly defined. Numerous diversity measures exist, but there is little agreement on which measure should be used when. The Surface Mining Control and Reclamation Act (SMCRA) of 1977 calls for a diverse vegetative cover on reclaimed sites, but does not specify how the diversity should be measured, or how the diversity should relate to the natural vegetation of the area.

The diversity of revegetated mined land is often assessed in comparison to a premining community or a reference area (Chambers and Brown 1983). Green (1979) suggests that for comparative purposes, species richness is a biologically meaningful measure of diversity. Comparison of species richness between study sites show that species richness was very similar between sites, except for July on the NG site (Table 13). Based on these results, it can be concluded the hypothesis that there are no differences in species richness between study sites should be accepted.

Diversity indices are the most often used method to evaluate diversity. This study measured diversity using Shannon's diversity index because of its wide use. However, there is some question as to the usefulness of diversity indices to compare sites (Chambers and Brown 1983, Green 1979). Green (1979) discourages the use of diversity indices because of the lack of connection between diversity values and environmental quality values, and the absence of relationships with community structure and stability. Pielou (1986) argues that it may be more desirable to have the revegetated area resemble the reference area than to have the same level of diversity on the two sites.

If the quality of the vegetation is an important consideration for revegetation success, then weedy plant species should not be included when comparing sites. Calculation of the total importance value should include the weedy species on that site, but these species should be neglected when determining the diversity index (Chambers and Brown 1983). For the purposes of this study, all plant species present on the plots were considered equally.

Chambers (1983) identified limitations for diversity indices. The first limitation of a diversity index is the assumption that all individuals are equal to one another despite differences in life forms. Also, index values are not directly comparable between different communities, and diversity indices fail to identify the species or the proportion of individuals among species. Shannon's diversity index meets all of Chambers' limitations, so it does not qualify as a useful measure of diversity.

Similarity indices are considered useful measures of diversity because direct comparison between different plant communities can be made (Chambers 1983, Chambers and Brown 1983, Southwood 1966). The modification of Sorensen's similarity index by Motyka and others includes both species richness and evenness. Sorensen's similarity index uses presence-absence data while Motyka and others' similarity index uses importance values. Chambers and Brown (1983) consider Motyka and others' the better index since this similarity index is sensitive to changes in importance values, one of their important criteria for determining a good measure of diversity when comparing revegetated sites.

Assessing revegetation success based on cover, density, and production has widely accepted standards and generalized values that can be agreed upon, unlike diversity. Again, however, the difference in type of vegetation between the revegetated site and the reference site must be considered. Determination of success must also be evaluated in terms of future use of the site. Based on the analysis of variance tests preformed on the cover, density, and production data, it can be concluded that there are differences in herbaceous cover, density, and production between sites and my hypothesis should be rejected.

Acknowledgements

I am grateful to my advisor, Dr. Robert W. Knight, for his advice, encouragement, and invaluable assistance that made this study possible. We would like to thank the Northwestern Resources, Company for allowing us access to the Jewett Mine to conduct the study and especially Joel Trouart and Glenn Stewart for their assistance in coordinating the project. Computer assistance from Ray Hinnant is greatly appreciated. Thank you to Dr. Debbie Miller for her suggestions on diversity measures and to Dr. Mort Kothmann for his help in modeling. We thank the Honors Department, the Department of Rangeland Ecology and Management, and the Graduate Research Minigrant Fund at Texas A&M University for their support.

Literature Cited

Armesto, J.J., and S.T.A. Pickett. 1985. Experiments on disturbance in old-field plant communities: Impact on species richness and abundance. Ecol. 66:230-240.

Chambers, J.C. 1983. Measuring species diversity on revegetated surface mines: An evaluation of techniques. U.S.D.A. For. Serv. Res. Pap. INT-322.

Chambers, J.C., and R.W. Brown. 1983. Methods for vegetation sampling and analysis on revegetated mined lands. U.S.D.A. For. Serv. Gen. Tech. Rep. INT-151.

Cuba, T.R. 1981. Diversity: A two-level approach. Ecology 62:278-279.

Green, R.H. 1979. Sampling designs and statistical methods for environmental biologists. Wiley-Interscience, N.Y.

McIntosh, R.P. 1967. An index of diversity and the relation of certain concepts to diversity. Ecol. 48:392-403.

Noss, R.F., and A.Y. Copperrider. 1994. Savings nature's legacy: Protecting and restoring biodiversity. Island Press, Washington, D.C.

Pechanec, J.F., and G.D. Pickford. 1937. A weight estimate method for the determination of range or pasture production. J. Amer. Soc. Agron. 29:894-904.

Peet, R.K. 1974. The measurement of species diversity. Ann. Rev. Ecol. Syst. 5:285-307.

Pielou, E.C. 1986. Assessing the diversity and composition of restored vegetation. Can. J. Bot. 64:1344-1348.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theor. Biol. 13:131-141.

Pluhar, J.J., R.W. Knight, and R.K. Heitschmidt. 1983. Inflitration and sediment production as influenced by grazing systems in the Texas Rolling Plains. J. Range Mange. 40:240-243.

Railroad Commission of Texas. 1984. Texas surface coal mining and reclamation act. Surface Mining and Reclamation Division, Austin.

Ratliff, R.D. 1993. Sierra Nevada meadows: Species alpha diversity. U.S.D.A. For. Serv. Res. Note PSW-RN-415.

Skousen, J.G., C.A. Call, and R.W. Knight. 1990. Natural revegetation of an unreclaimed lignite surface mine in east-central Texas. Southw. Nat. 35:434-440.

Southwood, T.R.E. 1966. Ecological methods. Chapman and Hall, N.Y.

Stark, J.M., and E.F. Redente. 1985. Soil-plant diversity relationships on a disturbed site in northwestern Colorado. Soil Sci. Soc. Amer. J. 49:1028-1034.

Whisenant, S.G. 1993. Landscape restoration: Design and implementation of sustainable, wildland landscapes. Unpublished class notes for RLEM 320-Landscape Restoration, Texas A&M University.

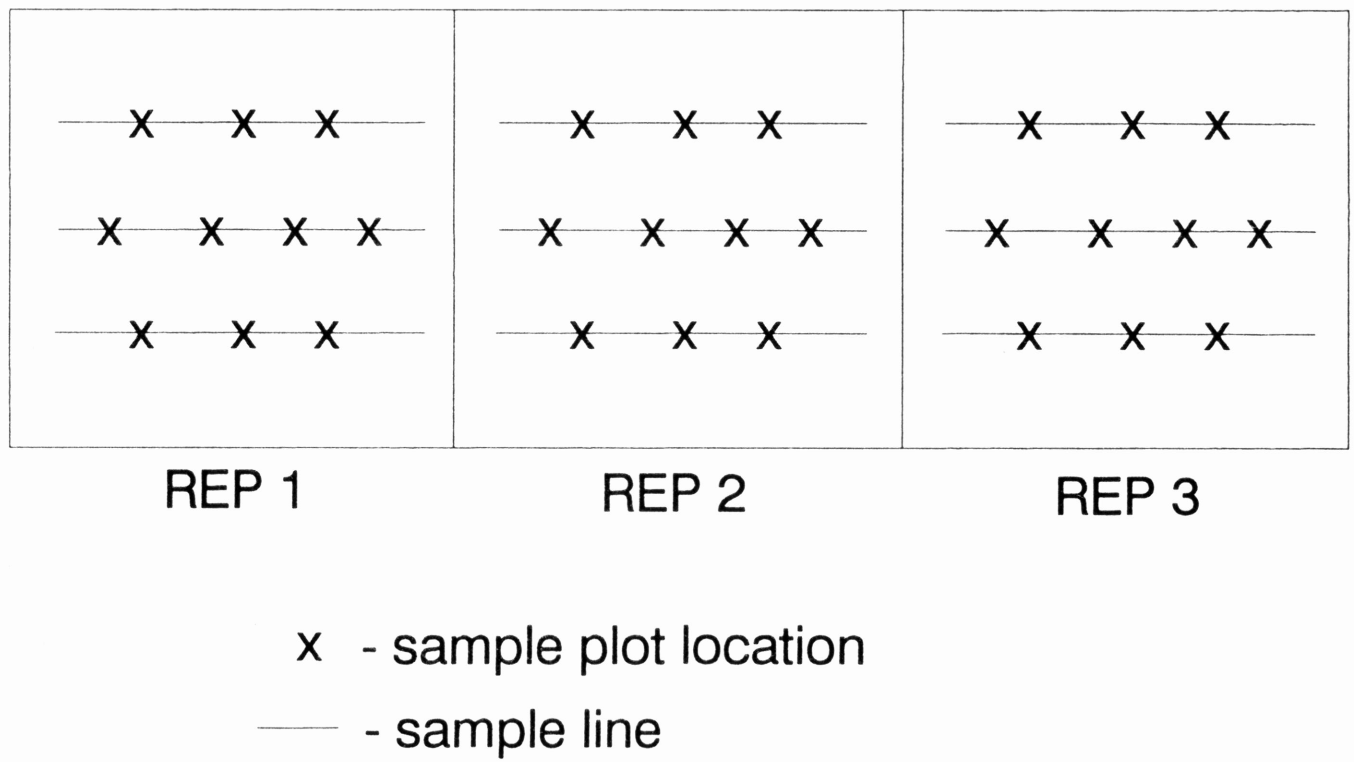

Fig. 1. Map of plot layout on Reclaimed and Woody Dominated sites at Jewett Mine in Texas.

Table 1. Soil analysis results of samples from the Jewett Mine study sites in Texas.

	FALL 1993		SPRING 1994		
	Reclaimed	Woody Dominated	Reclaimed	Woody Dominated	Native Grass
Soil Texture Class	Clay	Sandy Loam	Clay	Sandy Loam	Sandy Loam
Bulk Density (g/cm^3)	1.37	1.21	-	-	-
Organic Matter (%)	2.90	2.53	1.57	2.17	2.05
pH	6.73	5.40	6.77	5.47	6.50
Nitrogen (ppm)	2.67	1.00	1.00	1.00	1.00
Phosphorus (ppm)	21.67	6.00	18.33	6.33	3.50
Potassium (ppm)	258.00	49.00	262.33	59.33	97.00
Iron (ppm)	25.89	51.14	26.31	48.28	15.99
Manganese (ppm)	6.73	7.06	7.04	6.52	4.93

Table 2. Herbaceous cover (%) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	68	20	85	49a[1]
May 1994	71	24	-	48a
July 1994	76	18	79	51a
MEAN	71b	21c	82a	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 3. Forb cover (%) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	9	14	4	11a[1]
May 1994	14	19	-	17a
July 1994	10	14	8	12a
MEAN	11ab	16a	8b	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 4. Grass cover (%) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	59	6	79	38a[1]
May 1994	57	4	-	31a
July 1994	66	4	69	39a
MEAN	61b	5c	74a	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 5. Bare ground cover (%) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	3	3	1	3b[1]
May 1994	11	11	-	11a
July 1994	8	12	5	9a
MEAN	7ab	9a	3b	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 6. Litter cover (%) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	30	77	15	49a[1]
May 1994	19	66	-	43ab
July 1994	17	70	16	41b
MEAN	22b	71a	16b	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 7. Herbaceous density (plants m^{-2}) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	500aY[1]	76bX	104bX	264
May 1994	1460aX	56bX	-	756
July 1994	1228aX	36bX	108bX	572
MEAN	1063	56	106	

[1] Means in a row followed by the same lowercase letter and means in a coulmn followed by the same uppercase letter are not different ($P \leq 0.05$).

Table 8. Forb density (plants m^{-2}) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	48abY[1]	20bY	84aX	40
May 1994	136aX	40bX	-	88
July 1994	56abY	24bXY	92aX	48
MEAN	80	28	88	

[1] Means in a row followed by the same lowercase letter and means in a coulmn followed by the same uppercase letter are not different ($P \leq 0.05$).

Table 9. Grass density (plants m^{-2}) on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	452aY[1]	56bX	24bX	228
May 1994	1324aX	12bX	-	668
July 1994	1172aX	12bX	16bX	524
MEAN	983	27	20	

[1] Means in a row followed by the same lowercase letter and means in a coulmn followed by the same uppercase letter are not different ($P \leq 0.05$).

Table 10. Herbaceous production (kg ha^{-1}) on the Jewett Mine study sites in Texas for two sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	111	3	187	78a[1]
July 1994	147	2	105	72a
MEAN	129a	3b	146a	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 11. Forb production (kg ha^{-1}) on the Jewett Mine study sites in Texas for two sampling dates.

DATE	STUDY SITE			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	400	40	80	200a[1]
July 1994	560	40	560	200a
MEAN	480a	40a	320a	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 12. Grass production (kg ha^{-1}) on the Jewett Mine study sites in Texas for two sampling dates.

DATE	TREATMENTS			MEAN
	Reclaimed	Woody Dominated	Native Grass	
Oct. 1993	100	2	184	67a[1]
July 1994	132	2	98	71a
MEAN	117a	2b	141a	

[1] Means within a column or row followed by the same lowercase letter are not different ($P \leq 0.05$).

Table 13. Species richness (number of species) from sample plots on the Jewett Mine study sites in Texas for three sampling dates.

DATE	STUDY SITE		
	Reclaimed	Woody Dominated	Native Grass
October 1993	22	29	24
May 1994	41	41	-
July 1994	31	33	20

Table 14. Index of plant species diversity on the Jewett Mine study sites in Texas for three sampling dates.

	October 1993			May 1994		July 1994		
	Reclaimed	Woody Dominated	Native Grass	Reclaimed	Woody Dominated	Reclaimed	Woody Dominated	Native Grass
Shannon's	.61	.77	.15	.86	1.00	.75	.92	.31

Table 15. Number of species common between sites and two similarity indices for the Jewett Mine study sites in Texas for three sampling dates.

	October 1993				May 1994	July 1994			
	Reclaimed & Woody Dominated	Reclaimed & Native Grass	Woody Dominated & Native Grass	All	Reclaimed & Woody Dominated	Reclaimed & Woody Dominated	Reclaimed & Native Grass	Woody Dominated & Native Grass	All
Number of Common Species	5	5	3	1	6	4	8	10	3
Sorenson's	.20	.22	.11	-	.15	.13	.31	.38	-
Motyka's	.22	.34	.015	-	.34	.16	.27	.066	-

Appendix A

List of plant species present on the Jewett Mine study sites.

Appendix A1. Species present on the Reclaimed site.

Common Name	Scientific Name
Switchgrass	*Panicum virgatum* L.
Slim aster	*Aster subulatus* Michx.
Maximilian sunflower	*Helianthus maximiliani* Schrad.
Western ragweed	*Ambrosia psilostachya* DC.
Sixweeksgrass	*Vulpia octoflora* (Walt.) Rydb.
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Yellow Indiangrass	*Sorghastrum nutans* (L.) Nash
Horsetail conyza	*Conyza canadensis* (L.) Cronq.
Pitted bluestem	*Bothriochloa pertusa* (L.) A. Camus
Wooly croton	*Croton capitatus* Michx.
Plains lovegrass	*Eragrostis intermedia* A.S. Hitchc.
Dillens oxalis	*Oxalis dillenii* Jacq.
Mat euphorbia	*Euphorbia serpens* (Kunth in H.B.K.)
Seacoast sumpweed	*Iva annua* (L.)
Late eupatorium	*Eupatorium serotinium* Michx.
Rosettegrass	*Dichanthelium sp.*
Prairie agalinis	*Agalinis heterophylla* (Nutt.) Small *ex* Britt. & A. Br.
Bitter sneezeweed	*Helenium amarum* (Raf.) H. Rock
Cattail	*Typha sp.*
Sedge	*Carex sp.*

Common Name	Scientific Name
Heath aster	*Aster eriochoides* L.
Japanese brome	*Bromus japonicus* Thunb. *ex* Murray
Prionopis	*Prionopis ciliata* (Nutt.) Nutt.
Bottle-brush plantain	*Plantago aristata* Michx.
Ryegrass	*Lolium perenne* L.
Winter bentgrass	*Agrostis hyemalis* (Walt.) B.S.P.
Paleseed plantain	*Plantago virginica* L.
One-flower hawthorne	*Crategusa uniflora* Muench.
Prairie pepperweed	*Lepidium densiflorum* Schrad.
Butterweed	*Sencio glabellus* Poir.
Heart-wing sorrel	*Rumex hastulus* Baldw.
Black-eyed Susan	*Rudbeckia hirta* L.
Rescuegrass	*Bromus unioloides* Kunth in H.B.K.
Goldenrod	*Solidago sp.*
Small Venus looking-glass	*Triodanis biflora* (L.) Nieuw.
Prairie wedgescsale	*Sphenopholis obtusata*(michx.) Scribn.
Vetch	*Vicia sp.*
Illinois -bundleflower	*Desmanthus illinoensis* (Michx.) *ex* Robins & Fern.
Cudweed	*Gnaphalium purpureum*
Canarygras	*Phalaris sp.*
Southwestern carrot	*Daucus pusilus* Michx.

Common Name	Scientific Name
Mountain pink	*Heterotheca villosa* (Pursh) Shinners
Hairy goldaster	*Centarium beyrichii* (T, & G.) Robins.
6 unknown forbs	

Appendix A2. Species present on Woody Dominated site.

Common Name	Scientific Name
Broadleaf woodoats	*Chasmanthium sessiliflorum* (Michx.) Yates
Yaupon	*Ilex vomitoria* Soland. in Ait.
Saw greenbriar	*Smilax bona-nox* L.
Postoak	*Quercus stellata* Wang.
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash
American beautyberry	*Callicarpa americana* L.
Sedge	*Carex sp.*
Rosettegrass	*Dichanthelium sp.*
Narrowleaf pinweed	*Lechea tennuifolia* Michx.
Eastern red cedar	*Juniperus virginiana* L.
Texas flax	*Linum medium* (Planch.) Britt.
Beaked panicum	*Panicum anceps* Michx.
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch. V.
Broomsedge bluestem	*Andropogon virginicus* L.
Thin paspalum	*Paspalum setaceum* Michx.
Tall dropseed	*Sporobolus asper* (Michx.) Kunth
Silver croton	*Croton argyranthemus* Michx.
Violet woodsorrel	*Oxalis violacea* L.
Dillens oxalis	*Oxalis dillenii* Jacq.
Oldfield threeawn	*Aristida oligantha* Michx.
Wooly croton	*Croton capitatus* Michx.

Common Name	Scientific Name
Rosemary sunrose	*Heliantherum rosmarinifolium* Pursh
Texas snoutbean	*Rhynchosia texana* T. & G.
Black-eyed Susan	*Rudbeckia hirta* L.
Goldenmane coreopsis	*Coreopsis basalis* (Dietr.) Blake
Fall witchgrass	*Digitaria cognata* (Schult.) Pilger
Flattop woolywhite	*Hymenopappus scabiosaeus* L'Her.
Purpletop	*Tridens flavus* (L.) A.S. Hitchc.
Southwestern carrot	*Daucus pusilius* Michx.
Tephrosia	*Tephrosia potosina* Brandeg.
Black hickory	*Carya texana* Buckl.
Drummond skullcap	*Scutellaria drummondii* Benth.
Goldenrod	*Solidago sp.*
Plains lovegrass	*Eragrostis intermedia* A.S. Hitchc.
Forked scaleseed	*Spermolopis divaricata* (Walt.) Raf. *ex* Ser.
Rosettegrass	*Dichanthelium ravenelii* (Scribn.) Gould
St. Andrews Cross	*Ascyrum hypericoides* L.
Posion oak	*Toxicodendron radicans* (L.) O. Ktze.
Drummond St. Johns-Wort	*Hypericum drummondii* (Grev. & Hook.) T. & G.
Fuzzy goldaster	*Heterotheca villosa* (Pursh) Shinners
Seacoast sumpweed	*Iva annua* L.
Pririe Rose-Gentian	*Sabatia campestris* Nutt.
6 unknown forbs and 2 mushrooms	

Appendix A3. Species present on the Native Grass site.

Common Name	Scientific Name
Little bluestem	*Schizachyrim scoparium* (Michx.) Nash
Rosettegrass	*Dichanthelium sp.*
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Broomsedge bluestem	*Andropogon virginicus* L.
Balck-eyed Susan	*Rudbeckia hirta* L.
Paleseed plantain	*Plantago virginica* L.
Vetch	*Vicia sp.*
Dillens oxalis	*Oxalis dillenii* Jacq.
Basin fleabane	*Erigeron gieseri* Shinners
Forked scaleseed	*Spermolopis divaricata* (Walt.) Raf. *ex* Ser.
Common goldstar	*Hypoxis hirsuta* (L.) Cov.
Marsh milkwort	*Polygala cruciata* L.
Wooly croton	*Croton capitatus* Michx.
Butterfly milkweed	*Asclepias tuberosa* L.
Western ragweed	*Ambrosia psilostachya* DC.
Prairie spiderwort	*Tradescantia occidentalis* (Britt.) Smyth
Tephrosia	*Tephrosia potosina* Brandeg.
Stueve lespedeza	*Lespedeza stuevei* Nutt.
Texas snoutbean	*Rhynchosia texana* T. & G.
Skydrop aster	*Aster patens* Dryand in Ait.
Heath aster	*Aster eriochoides* L.
Sedge	*Carex sp.*

Common Name	Scientific Name
Partridge pea	*Chamaecrista fasciculata* (Michx.) Green
Dewberry	*Rubus sp.*
Seacoast sumpweed	*Iva annua* L.
Narrowleaf pinweed	*Lechea tenuiflora* Michx.
Texas flax	*Linum medium* (Planch.) Britt.
Anemone	*Anemone sp.*
9 unknown forbs	