2016

Vegetative Community Development over 30 Years within Mixed Pine-Hardwood Mine Reclamation sites in east Texas

Christy Christian

Brian P. Oswald
stephen f. austin, boswald@sfasu.edu

Hans M. Williams

Kenneth W. Farrish

Recommended Citation

Vegetative Community Development over 30 Years within Mixed Pine-Hardwood Mine Reclamation sites in east Texas

VEGETATIVE COMMUNITY DEVELOPMENT OVER 30 YEARS WITHIN MIXED PINE-HARDWOOD MINE RECLAMATION SITES IN EAST TEXAS

Christy L. Christian[1], Brian P. Oswald, Hans M. Williams, and Kenneth W. Farrish

Abstract. The practice of mine reclamation aims to balance the energy needs of society with proactive environmental restoration of degraded land, and long-term studies of vegetative community development on reclaimed mine land have been invaluable in developing effective reclamation practices. This study investigated vegetative community characteristics (composition, richness, species importance) over a 30-year time frame in planted mixed pine-hardwood areas on reclaimed surface coal mine land in East Texas, United States. Reclaimed sites were compared vegetatively to unmined reference forests. A chronological pattern was shown for reclaimed community development in both understory and overstory strata. Understory community development exhibited natural patterns, while the overstory community varied with different groups of planted species. The older reclaimed sites were most similar to unmined reference sites. Dissimilarities between mined and unmined communities were also apparent; for example, the woody vine community of reference sites was much more substantial in midstory and overstory strata as compared to reclaimed sites. Overall, this study provided baseline ecological information about these plant communities that may assist land managers and researchers in furthering their development of reclamation techniques and attainment of reclamation goals.

Additional Key Words: composition, importance, lignite coal, microtopography, richness, surface mining, succession, wildlife habitat

---

[1] Christy L. Christian is a Master of Science Degree Recipient in Environmental Science, Brian P. Oswald is a Professor, Hans M. Williams is a Professor, and Kenneth W. Farrish is a Professor, Division of Environmental Science, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962.

Journal American Society of Mining and Reclamation, 2016 Volume 5, Issue 2 pp 19-55

DOI: 10.21000/JASMR16020019

Introduction

Ecosystems are highly disturbed during surface mining for coal, a staple energy resource for the United States. Past post-mining experiences led to federal and state laws aiming to proactively mitigate environmental hazards and degradation left after mining. Reclamation of mined lands includes revegetation, which is accomplished with various land covers (commercial forest plantations, farmland, hay and pasture land, and mixed forest). Zipper et al. (2011) and Skousen and Zipper (2014) provide background information on surface coal mine reclamation, post-mining land uses and the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA).

Many studies have investigated soils, vegetation, water quality, and more on unreclaimed and reclaimed mine lands both pre- and post-SMCRA (see Zipper et al., 2011 and Skousen and Zipper, 2014, for examples). Over time, reclamation strategies have changed in order to effectively address environmental issues common on mined land (e.g., acid mine drainage, erosion, lack of natural revegetation) and to achieve more successful post-mining land uses; methods intended for specific geographic application are also being developed (e.g., the Forestry Reclamation Approach (FRA) for the eastern United States) (Zipper et al., 2011; Skousen and Zipper, 2014). Long-term studies of vegetative community development on reclaimed mine land have been invaluable in developing effective reclamation practices, and several have been conducted within the United States (e.g., Brenner et al., 1984; Holl and Cairns, 1994; Holl, 2002).

In Texas, current lignite coal mine permits cover nearly 132,000 ha of land (RCT, 2015). Although no long-term studies for East Texas (Pineywoods vegetation area) were discovered during literature review, a few were conducted in east-central Texas (Post Oak Savannah/Blackland Prairie vegetation area) (Skousen et al., 1990; Gorsira and Risenhoover, 1994; Westerman, 1997). Several short-term vegetation-related studies on reclaimed mine land have been conducted in East Texas; these included research on survival and growth of various native pine species in mine soil as well as effects of fertilization rates, cover crops, ectomycorrhizal inoculation, stock type, and seed source on seedlings and young trees planted on reclaimed mine land (Bryson, 1973; Mask, 1983; Kee, 1984; Wood, 1985; Shupe, 1986; Toups, 1986; Musgraves, 1995; McGuire, 1998). However, none of these studies addressed plant communities as a whole or over time.

The objectives of this study were to determine vegetative community characteristics (composition, richness, species importance) over a 30-year time frame (1980 to 2009) in planted mixed pine-hardwood areas on reclaimed surface coal mine land in East Texas, U.S.A. and to vegetatively compare reclaimed communities to unmined reference forests. These areas were planted with a mixture of *Pinus taeda* (loblolly pine) and various hardwood species. This study provided baseline ecological information about these plant communities that may assist land managers and researchers in furthering their development of reclamation techniques and attainment of reclamation goals.

Methods

Study Area

This study was conducted on Luminant Mining Company property at the Beckville mine in Panola County, Texas, United States (approximately lat 32°10′ N, long 94°20′ W). Post-SMCRA reclamation activities occurred within the study area over the past 30 years. The study area was characterized by irregular, gently rolling to hilly forestland; high precipitation, humidity and temperatures; acidic sand and sandy loam soils; mixed land use (includes timber, pasture, farm); and major overstory species consisting of pines, oaks, hickories, and maples (Pineywoods vegetation area) (Gould, 1962). The “subtropical” climate was characterized by annual rainfall of 42 to 46 inches (approximately 107 to 117 cm), mean annual temperature of 66°F (approximately 19°C), and mean frost free period of 230 to 245 days (Diggs et al., 2006).

Generally, pre-mine soil associations consisted of Sacul-Bowie, Fuquay-Troup, and Nahatche-Mantachie-Urbo, described as follows: Sacul-Bowie, “gently sloping to moderately steep, slightly acid to medium acid, loamy soils on uplands,” Fuquay-Troup, “gently sloping to moderately steep, slightly acid, sandy soils on uplands,” and Nahatche-Mantachie-Urbo, “nearly level, slightly acid to strongly acid, loamy to clayey soils on bottom lands” (Dolezel, 1975). A mixed overburden reclamation technique was used at this mine, whereby soil overlying coal resources was removed and set aside, coal was extracted, and the removed soil was used to re-fill excavated areas without any effort to restore pre-mining soil profile (i.e., generally, weathered surface soils became mixed with deeper, unweathered soils).

Study Sites

Site age since establishment was the main variable used to discern trends over time in vegetative community development. Thirty-one reclaimed sites planted in mixed pine-hardwood were sampled during the 2010 and 2011 growing seasons. Study sites were randomly selected to include sites reclaimed between 1980-2009 and were grouped into six categories (i.e., 1 to 5 years, 6 to 10 years, 11 to 15 years, 16 to 20 years, 21 to 25 years, 26 to 30 years). If available, five sites were randomly chosen within each age category (at least one per year as possible). Study sites were not chosen based on site management techniques (e.g., initial cover crop, seedling type, planting density, percentage of each planted species, thinning, etc.), and, given the length of time covered by this study and frequent changes in post-SMCRA reclamation techniques, management methods may have varied among sites and were not accounted for; time since site establishment was the focus of this study. For this study, a pseudo-chronosequence was constructed using available reclaimed sites of various ages to represent a 30-year timeline. The phrase "over time" throughout this manuscript should be viewed based on the above explanation. The terms "younger," "middle-aged," and "older" were applied to sites within the following age ranges, respectively: 1 to 10 years, 11 to 20 years, and 21 to 30 years. In order to compare vegetative communities of reclaimed sites and nearby unmined forest, three reference sites were established in unmined forested land within Beckville mine property and sampled in an identical manner to reclaimed sites. For this study, it was assumed reference sites had been undisturbed for at least 30 years (amount of time for which land was controlled by mining company), and, for analysis purposes, reference sites were assigned ages of greater than 30 years. Representative photographs of study sites are included as Appendix 2.

Vegetation

One plot was established in each study site using a modified-Whittaker plot design (20 x 50 m rectangular plot containing nested rectangular subplots of three sizes) (Fig. 1) (Stohlgren et al., 1995; NIISS, 2010). The 50-m side of the plot was situated parallel to the slope to ensure that vegetative samples captured as much heterogeneity as possible. Understory, midstory, and overstory strata were sampled for vegetation parameters and defined by vegetation height: understory (≤ 1 m), midstory (> 1 m to ≤ 6 m), and overstory (> 6 m) (Fig. 1). Vascular vegetation was identified to species, as possible, for all strata, following the USDA PLANTS

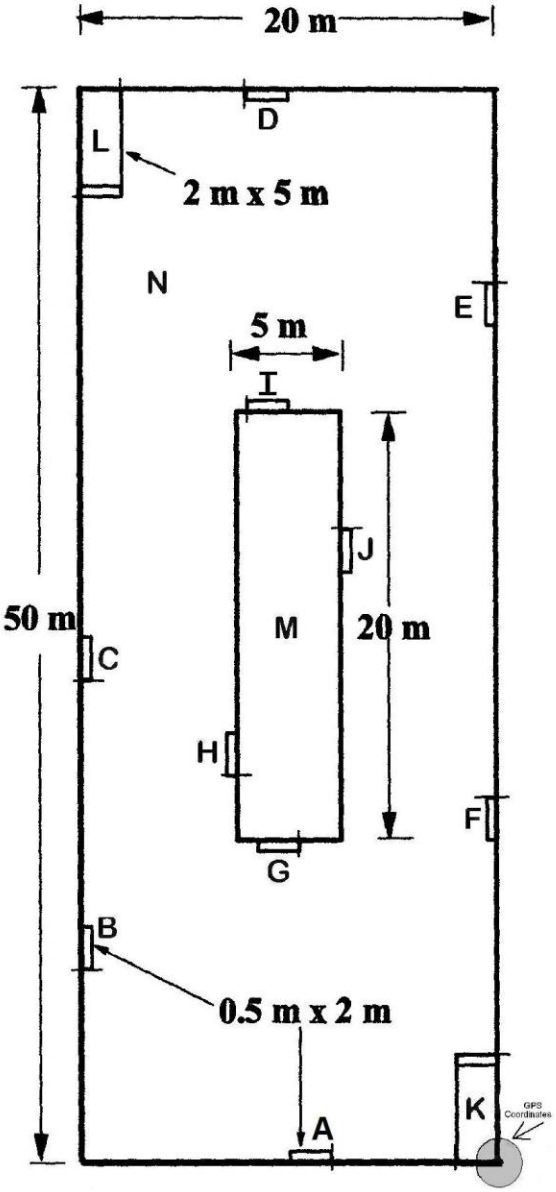

Figure 1. Layout of the modified-Whittaker plot design (Stohlgren et al., 1995). Alphabetical labels and location of GPS coordinates were added. Vegetation was sampled in subplots and strata based on vegetation height as follows: understory (≤1 m), "A" through "J," midstory (> 1 m to ≤ 6 m), "K" through "M," overstory (> 6 m), "M" and entire plot "N".

Database for scientific name and authority (USDA, 2013). Species planted on reclamation sites varied over time (Appendix 1, Table A-1); planting years listed for each species were considered approximate and should not be viewed as absolute for data analysis. Visual estimates of species cover (%) were recorded for understory and midstory strata, and overstory species cover was represented by basal area, which was calculated from diameter at breast height (dbh) using the formula $\pi*(dbh/2)^2$. Stem counts (density) were recorded for midstory and overstory strata and converted to stems/hectare. Overstory relative density was derived from ratio of absolute species density (stems/hectare) to total stem density of site.

Species composition (i.e., presence), species richness, and species importance values (IV) were obtained from field data. Species IV are unitless numbers that indicate the overall contribution of an individual species to a community relative to all other species in the community (Barbour et al., 1999). The original definition of IV is the sum of relative cover, relative density, and relative frequency (Curtis and MacIntosh, 1951; as cited by Barbour et al., 1999), and this definition was used for midstory and overstory. For understory, IV was calculated as the sum of relative cover and relative frequency. For each species, the total species IV was calculated as the sum of understory, midstory, and overstory IV.

Data analysis included nonmetric multidimensional scaling (NMS), an ordination statistical technique performed using PC-ORD 6 statistical software (McCune and Mefford, 2011). Species codes displayed on ordination graphs are defined in Appendix 1 (Table A-2). City-block distance measures were used for two reasons: 1) the sparsity of the matrices of the datasets and 2) zeros in the dataset did not necessarily mean the numerical zero. Both Sorensen and Jaccard city-block distance measures were used to ensure that solutions obtained were similar for the two measures. In order to determine the appropriate number of axes, Autopilot was run a minimum of three times using random seeds for each of the Sorensen and Jaccard distance measures. If solutions among the Sorensen and Jaccard distance measures were similar, then Sorensen was used in the manual and final analyses. Running several different analyses ensured that a qualitatively inconsistent solution was not chosen as the final solution. Randomization tests were included to assess the strength of the data pattern. Final stress values, randomization test p-values, scree plots, and plotted ordination solutions were examined for overall qualitative consistency among all solutions. Then, a minimum of three manual NMS analyses were run using the number of axes recommended by Autopilot using Sorensen distance measures. In situations where it appeared that a different number of axes from what Autopilot recommended might be more appropriate, three manual analyses were also run using this alternative axis number. For example, in many cases, two axes were recommended, but stress values and other information indicated that three axes might also be appropriate. Mantel tests were run to compare the two axis quantities in order to determine whether or not they conveyed similar information. If the two different axis quantities provided similar information, the least number of axes was used in the final solution in order to simplify interpretation of results.

Further statistical analyses beyond this were not incorporated into the design of this study as its main goal was to provide basic ecological information where none existed for this type of land reclamation in this region of Texas. This study is intended as a starting point for further research. As such, statements concerning results should not be viewed in a statistical sense.

Results

Species Composition

A strong chronological pattern was observed with distinct groups emerging for younger, middle-aged, and older sites along Axis 1 (axis represents sites age) (Fig. 2). Species associated with older sites were woody vines (e.g., *Toxicodendron radicans* (poison ivy), *Parthenocissus quinquefolia* (Virginia creeper)), woody shrubs (e.g., *Ilex vomitoria* (yaupon), and trees (e.g., *Juniperus virginiana* (eastern red cedar), *Fraxinus pennsylvanica* (green ash)) (species lines point toward older sites). Younger sites had strong association to many shade-intolerant herbaceous and grass species (e.g., *Trifolium vesiculosum* (arrowleaf clover), *Sorghum halepense* (Johnsongrass)) as well as certain oak species (e.g., *Quercus lyrata* (overcup oak), *Quercus shumardii* (Shumard's oak)) (species lines point toward younger sites). These patterns were echoed in separate analysis of understory species (Fig. 3). Ordination of overstory species indicated a chronological pattern as well (Fig. 4). Loblolly pine had strong association with older sites (species line points toward older sites), and a group of several oak species were associated with younger sites (species lines point toward younger sites) (Fig. 4). Other non-oak hardwoods were also associated with older and middle-aged sites (e.g., *Celtis laevigata* (sugarberry), *Liquidambar styraciflua* (sweetgum)) (see species lines). Anecdotally, sites reclaimed in the 1980s had an approximate planting ratio of eight or nine loblolly pine trees to each hardwood tree (Grimes, 2010, personal communication); field data verified that planted loblolly pine stem density decreased from older sites (established in 1980s, 21 to 30 years old) to younger and middle-aged sites (established after 1980s, 1 to 20 years old (Fig. 5)).

Species Richness

Generally, after 20 years, overstory richness declined while midstory richness showed some increase (Fig. 6). Understory richness was fairly variable from site to site over time (Fig. 6).

Between reclaimed and unmined sites, mean total site richness was similar for the understory while unmined sites had higher mean richness in both midstory and overstory strata (Table 1).

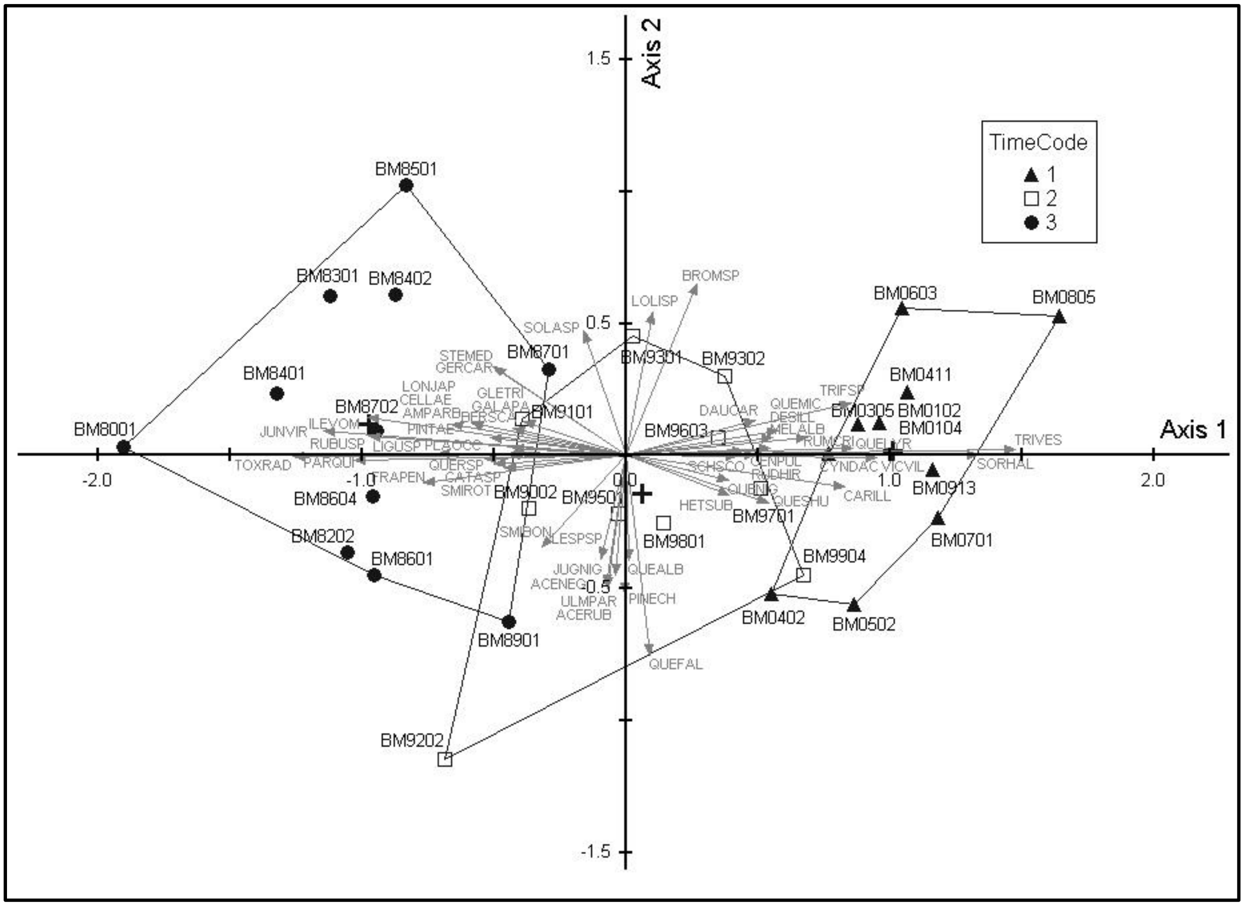

Figure 2. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values and including all vegetation strata (understory, midstory, overstory). Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years. Stand name: BM = Beckville mixed, first two numbers indicate year of site establishment, last two numbers indicate randomly assigned site number. Sites with similar vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

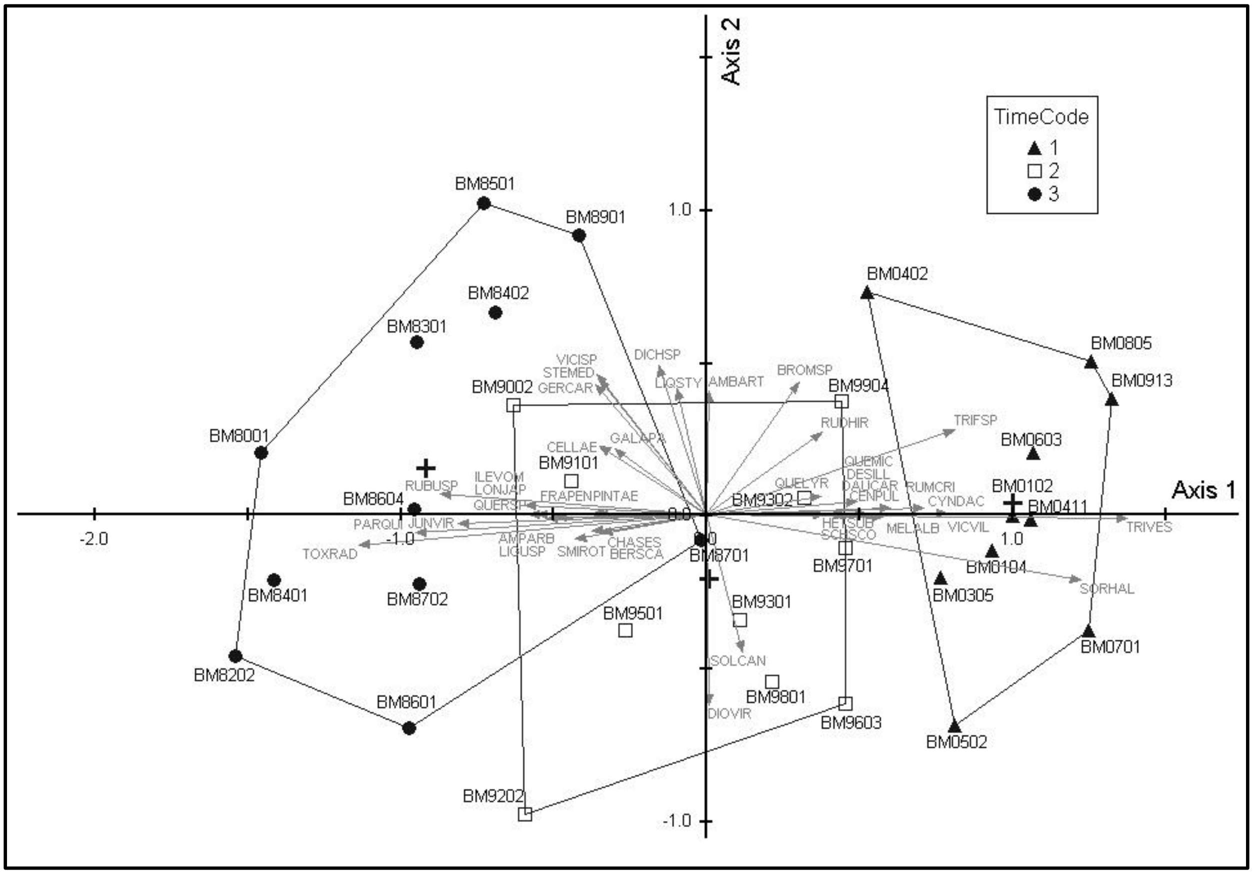

Figure 3. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values for all understory species. Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years. Stand name: BM = Beckville mixed, first two numbers indicate year of site establishment, last two numbers indicate randomly assigned site number. Sites with similar understory vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

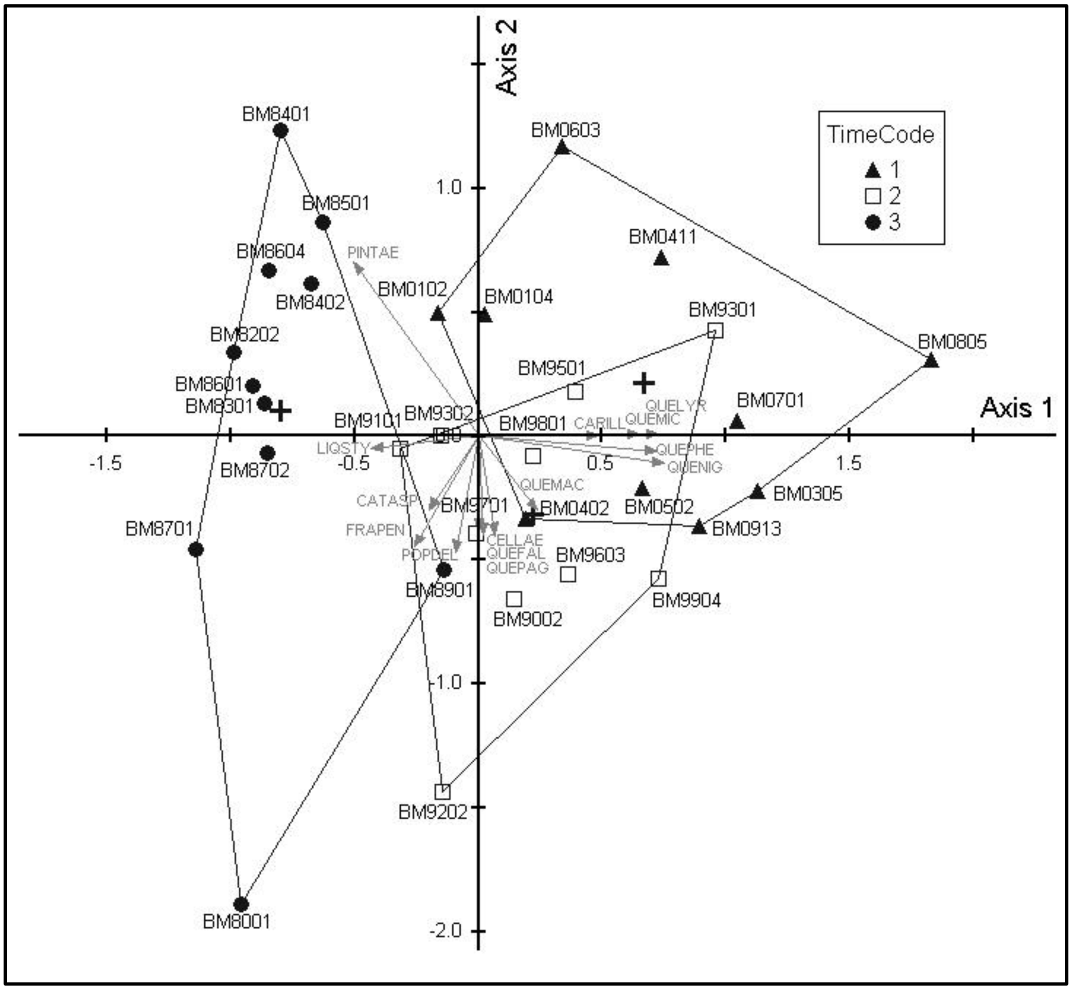

Figure 4. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values for all overstory species. Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years. Stand name: BM = Beckville mixed, first two numbers indicate year of site establishment, last two numbers indicate randomly assigned site number. Sites with similar overstory vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

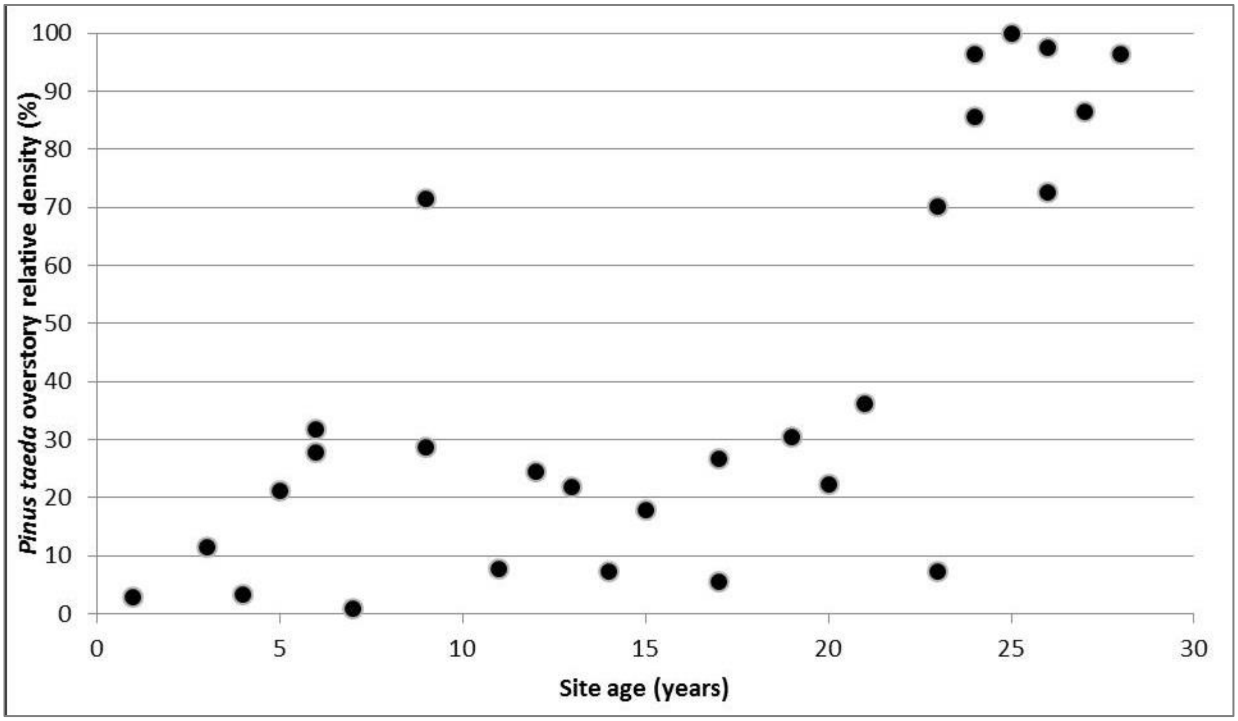

Figure 5. Overstory relative species density (%) for *Pinus taeda* (loblolly pine) on reclaimed sites aged 1 to 30 years (sites established from 1980 to 2009) at Beckville lignite coal surface mine, Panola County, Texas. Reclaimed sites were planted in mixed pine-hardwood.

Species Importance Value

The ubiquitous and dominant presence of loblolly pine in multiple strata of sites of multiple ages placed it clearly as the most important species in reclaimed sites (Table 2). Other species (*Baccharis halimifolia* (eastern baccharis), *Quercus nigra* (water oak), eastern redcedar, green ash) with similar presence patterns were also important overall, albeit to a lesser degree than loblolly pine. Several oak species were of notable importance in both midstory and overstory strata along with other various trees and shrubs (sweetgum, *Diospyros virginiana* (common persimmon), yaupon, *Morella cerifera* (wax myrtle). A mixture of herbaceous, grass and vine species were most important in the understory.

Table 1. Mean total site richness for reclaimed sites (planted in mixed pine-hardwood) and unmined forested reference sites on Beckville lignite coal surface mine in Panola County, Texas, (sampled in 2010 and 2011).

Site type	Understory stratum	Midstory stratum	Overstory stratum	All strata combined
Reclaimed (planted in mixed pine-hardwood) (31 sites, 1 to 30 years old)	23	9	6	28
Unmined forested reference (3 sites, > 30 years old)	20	21	14	32

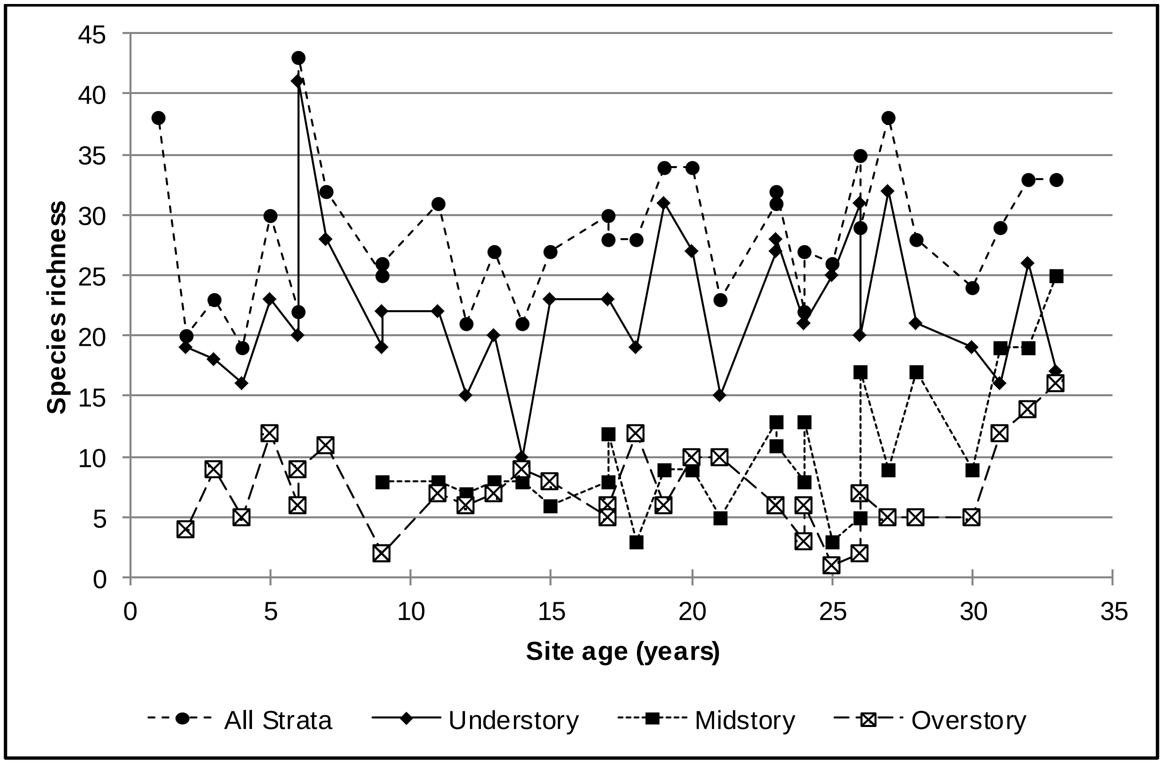

Figure 6. Species richness over time by vegetation stratum for 31 reclaimed sites aged 1 to 30 years (planted in mixed pine-hardwood) and three unmined forested reference sites at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011). Specific age of reference sites unknown and assumed to be undisturbed for at least 30 years; reference sites graphed at age 31, 32, and 33 years.

Table 2. Total species importance values for all sites combined for plant species observed on reclaimed sites aged 1 to 30 years (planted in mixed pine-hardwood) at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011). Site age codes: 1 = 1 to 10 years old; 2 = 11 to 20 years old; 3 = 21 to 30 years old. Species with total importance values of 200 or less were omitted.

Species name	**Site age codes where observed**	**No. of sites where observed**	**Total species importance value by stratum**			**Total species importance value**
			Understory	Midstory	Overstory	
Pinus taeda (Loblolly pine)	1, 2, 3	28	1,029	1,563	5,591	8,182
Baccharis halimifolia (Eastern baccharis)	1, 2, 3	23	1,908	2,266	750	4,924
Quercus nigra (Water oak)	1, 2, 3	22	1,200	763	2,709	4,672
Juniperus virginiana (Eastern redcedar)	2, 3	19	1,703	1,804	616	4,123
Fraxinus pennsylvanica (Green ash)	2, 3	16	700	1,319	1,315	3,334
Vicia villosa (Winter vetch)	1, 2, 3	23	2,929	0	0	2,929
Solidago canadensis (Canada goldenrod)	1, 2, 3	26	2,922	0	0	2,922
Quercus macrocarpa (Bur oak)	1, 2, 3	15	600	1,129	1,029	2,758
Quercus phellos (Willow oak)	1, 2, 3	16	921	444	1,263	2,628
Trifolium sp. (Clover)	1, 2, 3	24	2,590	0	0	2,590
Liquidambar styraciflua (Sweetgum)	2, 3	13	700	761	1,116	2,576
Quercus falcata (Southern red oak)	1, 2, 3	15	800	713	1,049	2,562
Quercus michauxii (Swamp chestnut oak)	1, 2	13	800	814	801	2,415
Diospyros virginiana (Common persimmon)	1, 2, 3	13	1,005	765	634	2,405
Ilex vomitoria (Yaupon)	2, 3	14	1,214	1,079	102	2,396
Quercus acutissima (Sawtooth oak)	2, 3	10	515	436	1,232	2,184
Toxicodendron radicans (Poison ivy)	2, 3	15	1,609	405	100	2,114
Morella cerifera (Wax myrtle)	2, 3	11	521	1,447	105	2,073
Rubus trivialis (Southern dewberry)	1, 2, 3	19	2,003	0	0	2,003
Sorghum halepense (Johnsongrass)	1, 2	17	1,981	0	0	1,981
Quercus pagoda (Cherrybark oak)	2, 3	10	400	817	719	1,936
Quercus alba (White oak)	1, 2, 3	12	500	500	864	1,864
Trifolium vesiculosum (Arrowleaf clover)	1, 2	17	1,841	0	0	1,841
Quercus shumardii (Shumard’s oak)	1, 2	12	500	245	1,039	1,784
Celtis laevigata (Sugarberry)	2, 3	11	601	674	386	1,661
Quercus lyrata (Overcup oak)	1	8	500	362	738	1,600
Rubus sp. (Blackberry)	2, 3	15	1,549	0	0	1,549
Bromus sp.(Brome)	1, 2, 3	14	1,470	0	0	1,470
Carya illinoinensis (Pecan)	1, 2	11	200	416	644	1,260
Daucus carota (Wild carrot)	1, 2	12	1,239	0	0	1,239

Table 2, continued.

Species name	Site age codes where observed	No. of sites where observed	Total species importance value by stratum			Total species importance value
			Understory	Midstory	Overstory	
Oxalis sp. (Woodsorrel)	1, 2, 3	12	1,223	0	0	1,223
Prunus angustifolia (Chickasaw plum)	1	5	600	310	203	1,113
Ampelopsis arborea (Peppervine)	2, 3	9	905	200	0	1,105
Catalpa sp. (Catalpa)	3	5	200	413	488	1,101
Lonicera japonica (Japanese honeysuckle)	2, 3	8	884	100	100	1,084
Chaerophyllum tainturieri (Hairyfruit chervil)	2, 3	10	1,036	0	0	1,036
Desmanthus illinoensis (Illinois bundleflower)	1, 2	10	1,027	0	0	1,027
Quercus sp. (Oak)	2, 3	10	1,016	0	0	1,016
Erigeron philadelphicus (Philadelphia fleabane)	1, 2	10	1,003	0	0	1,003
Callicarpa americana (American beautyberry)	2, 3	7	501	500	0	1,001
Cynodon dactylon (Coastal bermudagrass)	1	9	990	0	0	990
Vicia sp. (Vetch)	2, 3	9	971	0	0	971
Melilotus officinalis (Sweetclover)	1, 2	10	953	0	0	953
Panicum virgatum (Switchgrass)	1, 2	9	939	0	0	939
Schizachyrium scoparium (Little bluestem)	1	9	937	0	0	937
Parthenocissus quinquefolia (Virginia creeper)	2, 3	9	922	0	0	922
Ligustrum sp. (Privet)	2, 3	6	614	242	0	855
Quercus muehlenbergii (Chinkapin oak)	1	4	200	333	315	848
Dichanthelium sp. (Rosette grass)	2, 3	8	835	0	0	835
Rhus copallinum (Winged sumac)	3	5	501	200	125	826
Elymus sp. (Wildrye)	1, 3	8	813	0	0	813
Berchemia scandens (Alabama supplejack)	2, 3	6	601	200	0	801
Paspalum notatum (bahiagrass)	1, 3	6	793	0	0	793
Elaeagnus sp. (Oleaster)	2, 3	3	303	432	0	735
Platanus occidentalis (American sycamore)	3	5	100	300	314	714
Ambrosia artemisiifolia (Annual ragweed)	2, 3	9	703	0	0	703
Eupatorium serotinum (Lateflowering thoroughwort)	2, 3	7	702	0	0	702
Ulmus parvifolia (Chinese elm)	2, 3	4	141	300	223	664
Lespedeza cuneata (Sericea lespedeza)	3	6	664	0	0	664
Geranium carolinianum (Carolina geranium)	2, 3	6	625	0	0	625
Trifolium repens (White clover)	2, 3	6	624	0	0	624
Gleditsia triacanthos (Honeylocust)	3	4	400	200	0	600

Table 2, continued.

Species name	**Site age codes where observed**	**No. of sites where observed**	**Total species importance value by stratum**			**Total species importance value**
			Understory	Midstory	Overstory	
Quercus texana (Nuttall's oak)	2	2	0	200	360	560
Stellaria media (Common chickweed)	3	5	554	0	0	554
Trifolium incarnatum (Crimson clover)	1, 2, 3	5	503	0	0	503
Heterotheca subaxillaris (Camphorweed)	1	5	503	0	0	503
Acer rubrum (Red maple)	2, 3	2	100	300	102	502
Verbena brasiliensis (Brazilian vervain)	1, 2	5	501	0	0	501
Centaurium pulchellum (Branched centaury)	1	5	501	0	0	501
Rudbeckia hirta (Blackeyed Susan)	1	5	500	0	0	500
Smilax rotundifolia (Common greenbrier)	3	3	300	200	0	500
Ulmus sp. (Elm)	2, 3	4	427	0	0	427
Galium aparine (Catchweed bedstraw)	3	4	408	0	0	408
Ilex opaca (American holly)	2, 3	4	203	200	0	403
Lespedeza sp. (Lespedeza)	1, 2, 3	4	401	0	0	401
Salix nigra (Black willow)	3	3	0	141	205	347
Lolium perenne (Perennial ryegrass)	1, 3	3	334	0	0	334
Lolium sp. (Ryegrass)	1, 3	3	303	0	0	303
Andropogon glomeratus (Bushy bluestem)	1, 2	3	300	0	0	300
Asclepias viridis (Green milkweed)	2, 3	3	300	0	0	300
Cirsium sp. (Thistle)	1, 2	3	300	0	0	300
Pinus echinata (Shortleaf pine)	1, 2	2	0	0	246	246
Vitis rotundifolia (Muscadine)	3	2	208	0	0	208
Quercus virginiana (Live oak)	2	2	0	100	105	205
Ipomoea cordatotriloba (Cotton morningglory)	2	2	204	0	0	204
Zanthoxylum clava-herculis (Hercules' club)	3	1	0	100	104	204
Helianthus maximiliani (Maximilian sunflower)	1	1	203	0	0	203
Acer negundo (Boxelder)	2	1	100	0	103	203
Solanum sp. (Nightshade)	3	2	202	0	0	202
Paspalum sp. (Crowngrass)	1	2	201	0	0	201
Erigeron sp. (Fleabane)	3	2	201	0	0	201

Reference Sites

With regard to reclaimed sites, the unmined forested reference sites were most similar to older reclaimed sites, but, even so, dissimilarities between mined and unmined forest communities were quite apparent (Fig. 7 - 9). Several of the same woody vine species were important in the understory of reclaimed and reference sites, but vines in the midstory and overstory were rare in reclaimed sites and common in reference sites. Based on species importance in the overstory stratum, species differentiating reference from mined included tree species sugarberry, *Ulmus alata* (winged elm), *Ulmus americana* (American elm), and *Carya cordiformis* (bitternut hickory) and vine species *Lonicera japonica* (Japanese honeysuckle), *Berchemia scandens* (Alabama supplejack), Virginia creeper, and poison ivy (Tables 2 & 3). Several older reclaimed sites contained understory herbaceous species not observed in reference sites. Green ash was similarly important in older reclaimed and reference sites in the understory and midstory strata but not present in the overstory of reference sites; sweetgum was important in all strata of both reclaimed and reference communities. Winged elm was observed occasionally in reclaimed sites but was consistently important in midstory and overstory of reference sites.

At the site level, reference sites exhibited greater midstory and overstory richness than older reclaimed sites but similar understory and overall richness (Table 2, Fig. 7). Out of a combined richness of 155 species for reclaimed and reference sites, 15 species were exclusively observed in reference sites and 39 species were found in both reclaimed and reference sites (Table 3). Based on importance values, reference sites were forest communities with well-developed physical structure illustrated by several tree, vine, and shrub species contributing to all three strata (Table 3). Dominant species included the trees sweetgum, winged elm, water oak, and sugarberry and six different vines.

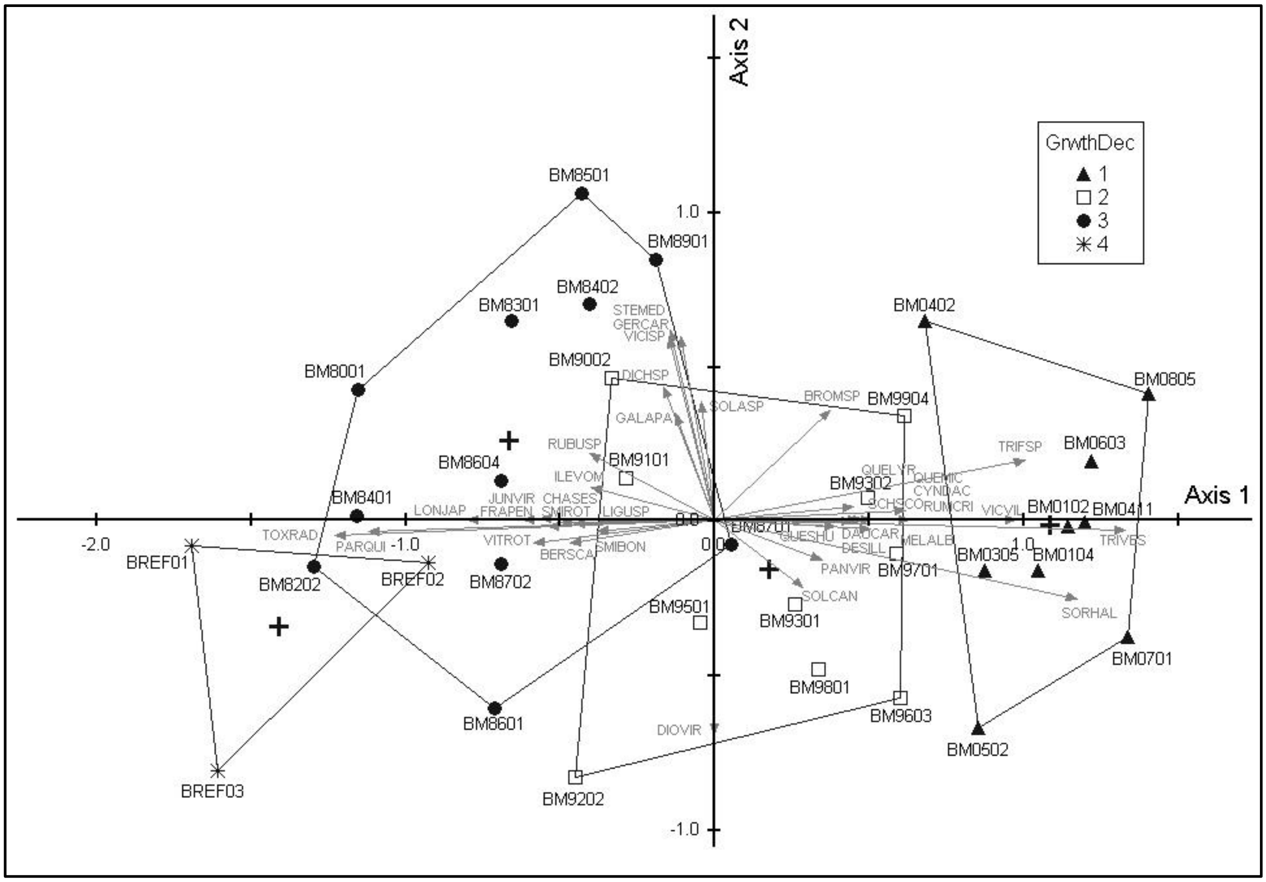

Figure 7. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood and unmined forested reference sites at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values for all understory species. Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years; 4 = reference sites. Stand name: BM = Beckville mixed, BREF = Beckville reference, first two numbers indicate year of site establishment; last two numbers indicate randomly assigned site number. Sites with similar understory vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

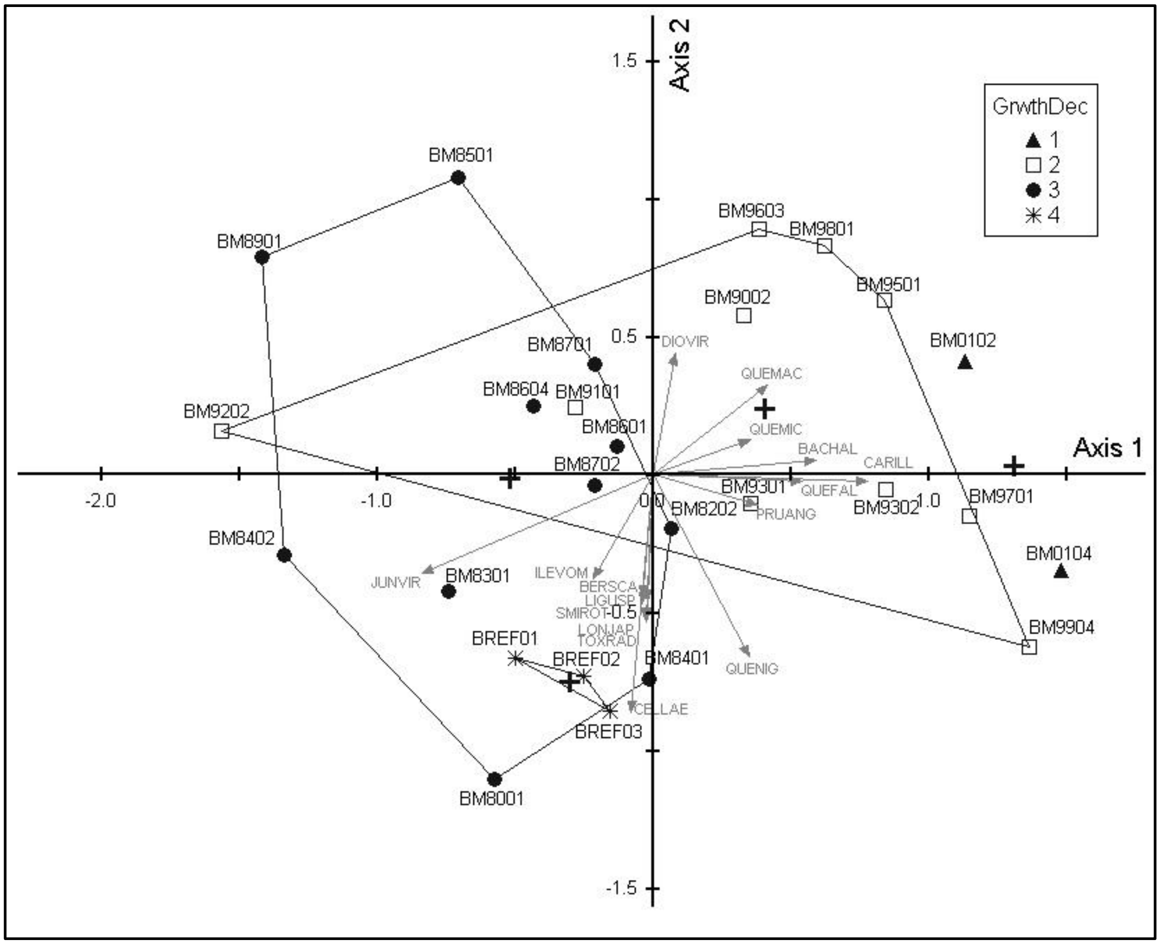

Figure 8. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood and unmined forested reference sites at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values for all midstory species. Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years; 4 = reference sites. Stand name: BM = Beckville mixed, BREF = Beckville reference, first two numbers indicate year of site establishment; last two numbers indicate randomly assigned site number. Sites with similar midstory vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

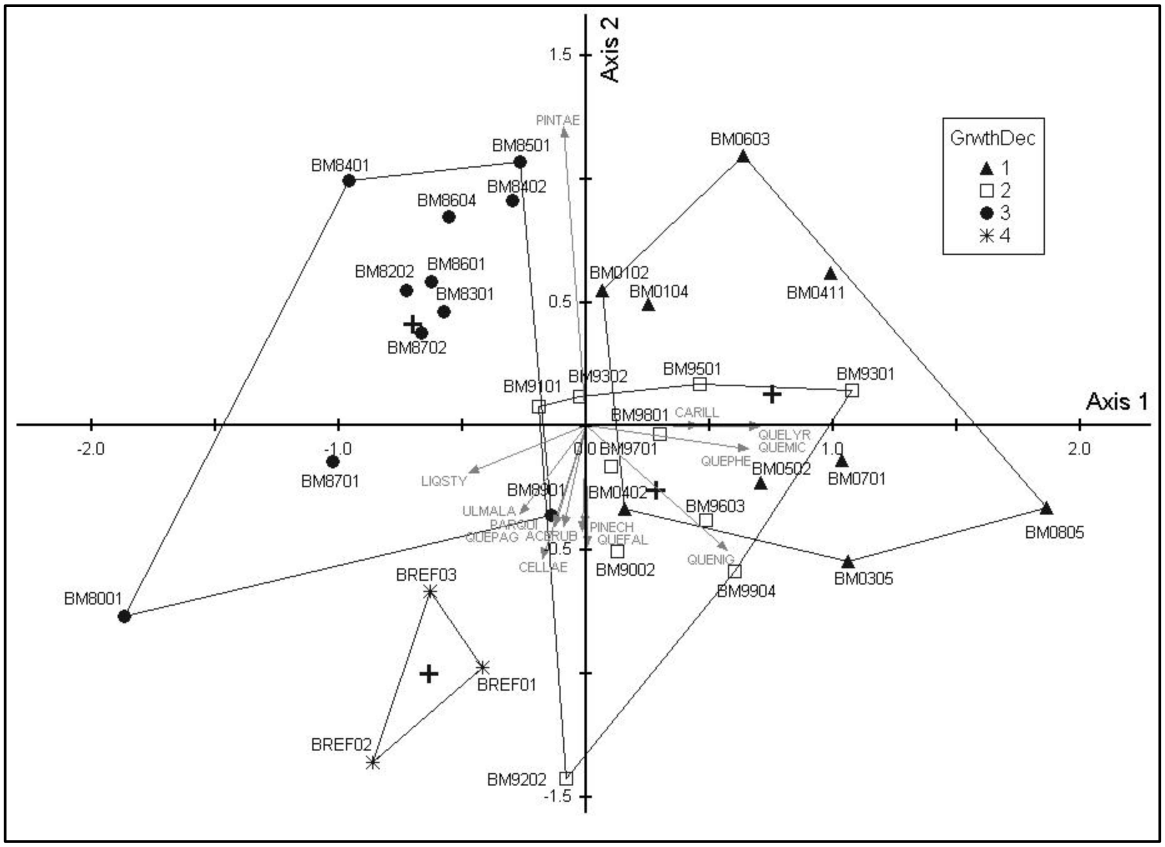

Figure 9. Nonmetric multidimensional scaling (NMS) ordination of reclaimed sites planted in mixed pine-hardwood and unmined forested reference sites at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011) based on species importance values for all overstory species. Site legend: 1 = sites aged 1 to 10 years; 2 = sites aged 11 to 20 years; 3 = sites aged 21 to 30 years; 4 = reference sites. Stand name: BM = Beckville mixed, BREF = Beckville reference, first two numbers indicate year of site establishment; last two numbers indicate randomly assigned site number. Sites with similar overstory vegetation communities plotted relatively close together and dissimilar sites plotted relatively far apart. Species represented by lines and species codes (first three letters each of generic name and specific epithet); species lines represent strength (direction and magnitude) of a species' association with an axis.

Table 3. Total species importance values for all sites combined for plant species observed on unmined forested reference sites (undisturbed for at least 30 years) at Beckville lignite coal surface mine (Panola County, Texas, sampled in 2010 and 2011). Species observed in both reclamation sites (planted in mixed pine-hardwood, age range 1 to 30 years) and reference sites are indicated.

Species name	**Observed in both reclaimed & reference sites**	**Total species importance value by stratum**			**Total species importance value**
		Understory	Midstory	Overstory	
Liquidambar styraciflua (Sweetgum)	•	300	308	448	1,056
Lonicera japonica (Japanese honeysuckle)	•	343	382	200	925
Ulmus alata (Winged elm)	•	101	453	327	881
Toxicodendron radicans (Poison ivy)	•	424	211	200	835
Quercus nigra (Water oak)	•	100	300	360	760
Parthenocissus quinquefolia (Virginia creeper)	•	332	200	200	732
Celtis laevigata (Sugarberry)	•	102	316	305	724
Juniperus virginiana (Eastern redcedar)	•	201	314	207	722
Fraxinus pennsylvanica (Green ash)	•	317	354	0	671
Berchemia scandens (Alabama supplejack)	•	222	200	200	622
Vitis rotundifolia (Muscadine)	•	300	200	100	600
Ilex vomitoria (Yaupon)	•	114	475	0	588
Quercus pagoda (Cherrybark oak)	•	0	211	238	449
Smilax bona-nox (Saw greenbrier)	•	310	112	0	422
Ulmus americana (American elm)	•	0	211	207	417
Carya cordiformis (Bitternut hickory)		0	200	209	409
Quercus alba (White oak)	•	100	200	102	402
Pinus taeda (Loblolly pine)	•	0	0	344	344
Ligustrum sp. (Privet)	•	200	132	0	332
Quercus falcata (Southern red oak)	•	0	100	222	322
Callicarpa americana (American beautyberry)	•	100	214	0	314
Sassafras albidum (Sassafras)		100	100	108	308
Chionanthus virginicus (White fringetree)		100	100	106	306
Ampelopsis arborea (Peppervine)	•	105	100	100	305
Smilax rotundifolia (Common greenbrier)	•	100	203	0	303
Diospyros virginiana (Common persimmon)	•	200	0	102	302
Chasmanthium sessiliflorum (Longleaf woodoats)	•	214	0	0	214
Acer rubrum (Red maple)	•	0	100	105	205
Prunus serotina (Black cherry)		0	100	105	205
Acer barbatum (Florida maple)		101	103	0	204
Dichanthelium sp. (Rosette grass)	•	201	0	0	201
Morella cerifera (Wax myrtle)	•	100	100	0	200
Morus rubra (Red mulberry)		100	100	0	200
Nandina domestica (Sacred bamboo)		100	100	0	200
Sideroxylon lanuginosum (Chittamwood)		100	100	0	200
Fraxinus americana (White ash)		0	0	198	198
Rubus trivialis (Southern dewberry)	•	109	0	0	109
Pinus echinata (Shortleaf pine)	•	0	0	108	108
Solidago canadensis (Canada goldenrod)	•	101	0	0	101

Table 3, continued.

Species name	Observed in both reclaimed & reference sites	Total species importance value by stratum			Total species importance value
		Understory	Midstory	Overstory	
Oxalis sp. (Woodsorrel)	•	101	0	0	101
Rubus sp.	•	100	0	0	100
Ambrosia artemisiifolia	•	100	0	0	100
Cornus florida		0	100	0	100
Hypericum hypericoides	•	100	0	0	100
Ilex opaca	•	0	100	0	100
Lespedeza cuneata	•	100	0	0	100
Paspalum sp.	•	100	0	0	100
Polystichum acrostichoides		100	0	0	100
Prunus caroliniana	•	100	0	0	100
Quercus stellata	•	0	100	0	100
Smilax glauca		0	100	0	100
Smilax laurifolia		100	0	0	100
Viburnum rufidulum		0	100	0	100
Vitis aestivalis		0	100	0	100

Discussion

A chronological pattern was shown for reclaimed community development overall, specifically echoed in both understory and overstory. However, the trends over time in understory and overstory were due to different reasons. Aside from planted tree species, understory species were observed to shift from shade-intolerant herbaceous and grass species in younger sites to more diverse groups of shade-tolerant herbaceous species, shrubs, and woody vines in older sites; this chronological trend was illustrative of a natural development of the community. Natural succession, which produces diversity and stability over time in disturbed ecosystems, is important in mine reclamation because volunteer colonization of native species will produce plant communities that will have long-term stability in a given locale's climate and be most beneficial to native wildlife in terms of food and cover (Brenner et al., 1984).

When considering the overstory, the main influence on chronological patterns was shown to be human design, i.e., a variety of oaks was planted in younger sites while an abundance of loblolly pine along with some nonoak hardwoods was planted in older sites. For this reason, comparison of reclaimed sites along a temporal continuum was confounded. Essentially, three age-associated overstory communities were revealed (Fig. 2). Older sites largely resembled loblolly pine plantations with a few other large hardwood tree individuals present. Middle-aged sites exhibited a diverse mixture of loblolly pine, oaks and a few other hardwoods with dominance shared by loblolly pine and several oaks. Younger sites were generally observed to contain several oaks and loblolly pine with a few other tree species. Several younger sites were even dominated by loblolly pine and water oak only. The shade-intolerant shrub eastern baccharis was also a substantial component of some younger sites. The overstory community of younger sites was altered from middle-aged by 1) absence or near-absence of *Quercus acutissima* (sawtooth oak), green ash, *Catalpa* sp. (catalpa), eastern red cedar, and sweetgum, 2) lessened abundance of *Quercus falcata* (southern red oak) and *Quercus pagoda* (cherrybark oak), and 3) the substantial addition of overcup oak and *Carya illinoinensis* (pecan). For these reasons, when reclaimed younger sites reach age 30, their overstory communities will likely not resemble the older or middle-aged sites of this study; however, in the understory and midstory, it is reasonable to expect that a succession from shade-intolerant herbaceous and grass species to a diverse mixture of shade-tolerant herbaceous species, shrubs and woody vines will occur, as demonstrated by understory composition patterns of younger and older reclaimed sites.

The notable presence of woody vines in reclaimed plant communities is encouraging. Of 39 species occurring in both reclaimed and reference sites, nine are woody vines; while found in all strata of reference sites, vines were generally only observed in the understory of reclaimed sites, which was likely due to lack of time for fuller development of the vine component. In the future, reclaimed communities will likely see movement of woody vines into the midstory and overstory. The presence of volunteer vine species is indicative of development of vertical structure in the community. An earlier study conducted on reclaimed woodland sites aged 3 to 11 years in east-central Texas (Gould's (1962) Post Oak Savannah) noted lack of vertical structure ("layering") in those sites and uncertainty about time requirements for vertical structure resembling that in native woodlands to form (Gorsira and Risenhoover, 1994). This study demonstrated that a middle (midstory) vegetation layer developed around age 10 and that vine species commonly contributing to vertical forest structure in East Texas were colonizing reclaimed sites during the second decade after establishment. Gorsira and Risenhoover (1994) also noted the importance of evergreen species as cover for wildlife species in winter. In this study, evergreen species such as yaupon, eastern red cedar, and *Smilax* spp. were observed to be both present and fairly important in understory and midstory strata of reclaimed sites.

Given that the forest communities of reference sites had developed without apparent disturbance for at least three decades, it was reasonable to observe the differences noted between reclaimed and reference. An earlier study by Holl (2002) concluded that, although the oldest reclaimed sites (35 years old) had some resemblance to unmined reference sites, the oldest and reference sites still differed substantially. Reference communities possessed species composition and physical structure representative of the East Texas forest ecosystem. The effects of human design were apparent in observations of greater midstory and overstory richness in reference sites than in older reclaimed sites, where loblolly pine was dominant due to planting procedures. However, four of the same tree species (water oak, green ash, sweetgum, eastern red cedar) were observed to have high importance in both reclaimed and reference sites. In time, loblolly pine dominance may lessen as the pines age and allow other large tree species to be greater contributors to the older reclaimed site communities.

None of the 15 species (10 trees, one shrub, three vines, and one fern) observed exclusively in reference sites were consistent residents across sites or strata, indicating that these are less common forest species (Table 3). However, their presence indicated that they fill certain environmental niches and contribute to greater community diversity. Several of the trees are smaller-stature species that would be expected to do well in the midstory and lower overstory strata (e.g., *Cornus florida* (flowering dogwood), *Morus rubra* (red mulberry)), and the vines were of some of the same genera found in reclaimed sites. Holl (2002) likewise observed that less common forest species were not colonizing reclaimed mine sites three decades after establishment although present in nearby unmined forested sites. The future presence of these less common forest species in reclaimed sites would indicate improving diversity.

Past concern with reclamation activities involved soil compaction and subsequent “arrested succession” that prevents return of mined land to forest. Creation of microtopography using the end-dump method within the reclaimed landscape is suggested as a remedy for arrested succession in reclaimed areas and to encourage increased vegetative diversity (Gilland and McCarthy, 2014). Soil compaction was empirically demonstrated to not be an issue on these sites, and “arrested succession” as described by Gilland and McCarthy (2014) was not observed; bulk density values ranged from 1.00 to 1.35 g/cm^3 for reclaimed and 1.04 to 1.10 g/cm^3 for reference, which are favorable values for root growth (Christian, 2013). However, incorporation of greater microtopography during establishment of reclamation sites may increase plant species diversity on younger reclaimed sites and form diverse forest plant communities in an even more expedient manner. Provision of a greater variety of topographic positions may, for example, encourage eventual colonization of some of the tree species observed exclusively in reference sites (e.g., bitternut hickory, *Sassafras albidum* (sassafras)). This method may also help control erosion in newly planted sites by encouraging plants to occupy more physical space using the greater abundance of unique topographic positions.

Overall, reclamation was effective in achieving diverse plant communities. Resampling of younger sites after another 10 and 20 years of growth will give insight to successional development. Incorporation of microtopography during reclamation site establishment may increase diversity of the early reclaimed community and expedite the formation of a diverse forest community. Direct assessment of how plant communities developed over time was not possible for this study due to variation in reclamation techniques over the past 40 years (e.g., tree species selection). As newer methods such as the Forestry Reclamation Approach (Skousen and Zipper, 2014) are more widely implemented and other reclamation techniques that have been successful thus far continue to be used, the sample size of sites that share identical reclamation methods will increase. Temporal comparisons can then be made for more accurate ascertainment of vegetation community development over time.

Acknowledgements

Funding was provided by the Luminant Environmental Research Program. The authors gratefully acknowledge Luminant Generation Company LLC and the Division of Environmental Science, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University for their support of this research and Melissa Bozarth and Brittany Compton for their assistance in the field. This manuscript was greatly improved by the invaluable comments of several anonymous reviewers.

Literature Cited

Barbour, M.G., J.H. Burk, W.D. Pitts, F.S. Gilliam, and M.W. Schwartz. 1999. *Terrestrial Plant Ecology*. 3rd ed. Benjamin/Cummings, Menlo Park. 649 p.

Brenner, F.J., M. Werner and J. Pike. 1984. Ecosystem development and natural succession in surface coal mine reclamation. Minerals and the Environment 6: 10-22. http://dx.doi.org/10.1007/BF02072661

Bryson, H.L., Jr. 1973. *Early survival and total height, and foliar analyses of eleven tree species grown on strip-mine spoils in Freestone County, Texas*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

Christian, C.L. 2013. Vegetative community development on reclaimed lignite coal mine land in east Texas. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

Diggs, G.M., Jr., B.L. Lipscomb, M.D. Reed, and R.J. O'Kennon. 2006. *Illustrated Flora of East Texas, Vol. 1: Introduction, Pteridophytes, Gymnosperms, and Monocotyledons*. Botanical Research Institute of Texas, Fort Worth.

Dolezel, R. 1975. *Soil Survey of Panola County, Texas*. United States Department of Agriculture, Soil Conservation Service, in cooperation with Texas Agricultural Experiment Station.

Gilland, K.E. and B.C. McCarthy. 2014. Microtopography influences early successional plant communities on experimental coal surface mine land reclamation. Restoration Ecology 22:232-239. http://dx.doi.org/10.1111/rec.12066

Grimes, P. 2010. Personal communication. Beckville Mine, Beckville, Texas. Luminant Mining Company.

Gorsira, B. and K.L. Risenhoover. 1994. An evaluation of woodland reclamation on strip-mined lands in east Texas. Environmental Management 18: 787-793. http://dx.doi.org/10.1007/BF02394641

Gould, F.W. 1962. *Texas plants, a checklist and ecological summary*. The Agricultural and Mechanical College of Texas, Texas Agricultural Experiment Station.

Holl, K.D. 2002. Long-term vegetation recovery on reclaimed coal surface mines in the eastern USA. Journal of Applied Ecology 39: 960-970. http://dx.doi.org/10.1046/j.1365-2664.2002.00767.x

Holl, K.D. and J. Cairns, Jr. 1994. Vegetational community development on reclaimed coal surface mines in Virginia. Bulletin of the Torrey Botanical Club 121: 327-337. http://dx.doi.org/10.2307/2997006

Kee, D.D. 1984. *The effect of cover crop and fertilizer rate on the growth and survival of loblolly pine in east Texas mine spoil*. MS thesis. Texas A&M University, College Station, Texas.

Mask, C.L. 1983. *Row seeding of forest tree species on lignite spoils in east Texas*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

McCune, B. and M.J. Mefford. 2011. *PC-ORD. Multivariate analysis of ecological data*. Version 6.0. MjM Software, Gleneden Beach, Oregon.

McGuire, M.A. 1998. *Effects of stock type, fall nursery fertilization and ectomycorrhizal inoculation on survival of longleaf pine (*Pinus palustris *Mill.) seedlings planted on lignite minespoil*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

Musgraves, J.R. 1995. *Survival of longleaf pine (*Pinus palustris *Mill.) on mine reclamation sites using different regeneration methods*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

NIISS (National Institute of Invasive Species Science). Updated May 25, 2010. *Modified Whittaker Plot*. Accessed June 4, 2010. http://www.niiss.org/cwis438/websites/niiss/FieldMethods/ModWhit.php?WebSiteID=1

RCT (Railroad Commission of Texas). 2015. *Annual coal production* (web page link to Excel file). Available online at http://www.rrc.state.tx.us/mining-exploration/programs/surface-coal-mining-exploration-program/; last accessed Nov. 6, 2015.

Shupe, M.A. 1986. *The effects of nitrogen and phosphorus fertilizer on a young loblolly pine plantation on lignite mine spoil in east Texas*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

Skousen, J.G., C.A. Call, and R.W. Knight. 1990. Natural revegetation of an unreclaimed lignite surface mine in east-central Texas. The Southwestern Naturalist 35: 434-440. http://dx.doi.org/10.2307/3672042

Skousen, J. and C.E. Zipper. 2014. Post-mining policies and practices in the Eastern USA coal region. International Journal of Coal Science & Technology 1: 135-151. http://dx.doi.org/10.1007/s40789-014-0021-6

Stohlgren, T.J., M.B. Falkner, and L.D. Schell. 1995. A modified-Whittaker nested vegetation sampling method. Vegetatio 117:113-121. http://dx.doi.org/10.1007/BF00045503

Toups, B.G. 1986. *Comparison of site quality for loblolly pine on selected mined and non-mined soils in Panola County, Texas*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

USDA (United States Department of Agriculture), Natural Resources Conservation Service. 2013. *The PLANTS Database* (http://plants.usda.gov, 4 March 2013). National Plant Data Team, Greensboro, North Carolina, United States.

Westerman, C.A. 1997. *Vegetation trends in reclaimed areas at Gibbons Creek Lignite Mine, Grimes County, Texas*. Proceedings American Society of Mining and Reclamation 1997. pp 77-81. http://dx.doi.org/10.21000/JASMR97010077

Wood, G.A. 1985. *Two-year survival and growth of loblolly pine seedlings from two Texas seed sources on lignite minesoils*. MS thesis. Stephen F. Austin State University, Nacogdoches, Texas.

Zipper, C.E., J.A. Burger, J.G. Skousen, P.N. Angel, C.D. Barton, V. Davis, and J.A. Franklin. 2011. Restoring forests and associated ecosystem services on Appalachian coal surface mines. Environmental Management 47: 751-765. http://dx.doi.org/10.1007/s00267-011-9670-z

Appendix 1.

Table A-1. Species planted on mixed pine-hardwood reclamation sites from 1980 to 2009 on Beckville lignite coal surface mine in Panola County, Texas.

Scientific name	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Acer rubrum						•																•	•	•						
Betula nigra			•	•	•	•		•	•		•				•							•		•	•	•	•	•		
Callicarpa americana																•						•				•	•		•	
Carya aquatica																•						•	•	•	•	•	•	•	•	•
Carya illinoinensis											•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Catalpa sp.	•		•				•	•	•	•		•	•	•	•															
Celtis laevigata									•			•										•				•	•	•		
Cercis canadensis																						•	•		•	•	•	•	•	
Diospyros virginiana						•	•	•	•			•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•
Elaeagnus sp.		•	•	•			•	•	•																					
Fraxinus pennsylvanica	•		•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•						•	•	•	•
Ilex vomitoria															•	•						•		•						
Juglans nigra						•																•	•	•	•	•	•	•	•	
Juniperus virginiana												•					•					•		•						
Lespedeza sp.						•	•		•						•	•	•	•		•	•									
Liquidambar styraciflua					•	•	•	•	•	•		•	•	•		•														
Morella cerifera																•		•	•		•		•	•	•	•		•	•	•
Morus spp.	•	•								•		•	•	•																
Pinus echinata													•																	
Pinus taeda	•	•	•	•	•	•	•	•	•	•	•	•			•		•	•	•	•	•	•	•	•	•	•	•	•	•	•
Platanus occidentalis			•	•	•	•	•	•	•	•																				
Populus deltoides	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•	•				
Prunus angustifolia																							•	•					•	•

Table A-1, continued.

Scientific name	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Prunus mexicana																										•	•	•	•	
Quercus acutissima					•			•	•			•	•	•	•	•	•	•	•	•										
Quercus alba					•		•	•		•	•	•	•	•		•	•	•	•	•	•	•	•		•	•	•	•	•	•
Quercus falcata									•					•	•	•	•	•	•		•	•	•	•		•	•	•	•	
Quercus lyrata											•	•			•	•	•	•	•	•		•	•	•	•	•	•	•	•	•
Quercus macrocarpa								•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Quercus michauxii							•	•	•	•	•	•	•	•	•		•	•	•	•		•	•	•	•	•	•	•	•	•
Quercus muehlenbergii												•		•													•	•	•	
Quercus nigra								•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Quercus pagoda	•										•	•	•	•	•	•	•	•	•	•	•						•	•	•	•
Quercus phellos											•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•
Quercus shumardii			•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Quercus stellata																									•		•	•		•
Quercus texana										•		•	•	•	•	•	•	•	•	•							•	•	•	•
Quercus virginiana		•								•		•	•	•	•															
Rhus glabra					•	•	•	•									•													
Sassafras albidum																•	•	•												
Taxodium distichum			•	•	•	•	•	•	•	•	•	•	•	•	•		•	•			•	•	•	•	•	•	•	•	•	•
Ulmus alata																						•								
Ulmus parvifolia										•			•																	

Table A-2. Species codes utilized in ordination graphs (Figs. 2, 3, 4, 7, 8, 9).

Species code	**Scientific name**	**Common name**
ACENEG	*Acer negundo* L.	Boxelder
ACERUB	*Acer rubrum* L.	Red maple
AMBART	*Ambrosia artemisiifolia* L.	Annual ragweed
AMPARB	*Ampelopsis arborea* (L.) Koehne	Peppervine
BACHAL	*Baccharis halimifolia* L.	Eastern baccharis
BERSCA	*Berchemia scandens* (Hill) K. Koch	Alabama supplejack
BROMSP	*Bromus* sp. L.	Brome
CARILL	*Carya illinoinensis* (Wangenh.) K. Koch	Pecan
CATASP	*Catalpa* sp. Scop.	Catalpa
CELLAE	*Celtis laevigata* Willd.	Sugarberry
CENPUL	*Centaurium pulchellum* (Sw.) Druce	Branched centaury
CHASES	*Chasmanthium sessiliflorum* (Poir.) Yates	Longleaf woodoats
CYNDAC	*Cynodon dactylon* (L.) Pers.	Coastal bermudagrass
DAUCAR	*Daucus carota* L.	Queen Anne's lace
DESILL	*Desmanthus illinoensis* (Michx.) MacMill. ex B.L. Rob & Fernald	Illinois bundleflower
DICHSP	*Dichanthelium* sp. (Hitchc. & Chase) Gould	Rosette grass
DIOVIR	*Diospyros virginiana* L.	Common persimmon
FRAPEN	*Fraxinus pennsylvanica* Marshall	Green ash
GALAPA	*Galium aparine* L.	Catchweed bedstraw
GAMOSP	*Gamochaeta* sp. Weddell	Everlasting
GERCAR	*Geranium carolinianum* L.	Carolina geranium
GLETRI	*Gleditsia triacanthos* L.	Honeylocust
HETSUB	*Heterotheca subaxillaris* (Lam.) Britton & Rusby	Camphorweed
ILEVOM	*Ilex vomitoria* Aiton	Yaupon
JUGNIG	*Juglans nigra* L.	Black walnut
JUNVIR	*Juniperus virginiana* L.	Eastern redcedar
LESPSP	*Lespedeza* sp. Michx.	Lespedeza
LIGUSP	*Ligustrum* sp. L.	Privet
LIQSTY	*Liquidambar styraciflua* L.	Sweetgum
LOLISP	*Lolium* sp. L.	Ryegrass
LONJAP	*Lonicera japonica* Thunb.	Japanese honeysuckle
MELALB	*Melilotus alba*	Sweetclover
PANVIR	*Panicum virgatum* L.	Switchgrass
PARQUI	*Parthenocissus quinquefolia* (L.) Planch.	Virginia creeper
PINECH	*Pinus echinata* Mill.	Shortleaf pine
PINTAE	*Pinus taeda* L.	Loblolly pine
PLAOCC	*Platanus occidentalis* L.	American sycamore
POPDEL	*Populus deltoides* W. Bartram ex Marshall	Eastern cottonwood
PRUANG	*Prunus angustifolia* Marshall	Chickasaw plum
QUEALB	*Quercus alba* L.	White oak
QUEFAL	*Quercus falcata* Michx.	Southern red oak
QUELYR	*Quercus lyrata* Walter	Overcup oak
QUEMAC	*Quercus macrocarpa* Michx.	Bur oak
QUEMIC	*Quercus michauxii* Nutt.	Swamp chestnut oak
QUENIG	*Quercus nigra* L.	Water oak
QUEPAG	*Quercus pagoda* Raf.	Cherrybark oak
QUEPHE	*Quercus phellos* L.	Willow oak
QUERSP	*Quercus* sp. L.	Oak

Table A-2, continued.

Species code	**Scientific name**	**Common name**
QUESHU	*Quercus shumardii* Buckley	Shumard's oak
RUBUSP	*Rubus* sp. L.	Blackberry
RUDHIR	*Rudbeckia hirta* L	Blackeyed Susan
RUMCRI	*Rumex crispus* L.	Curly dock
SCHSCO	*Schizachyrium scoparium* (Michx.) Nash	Little bluestem
SMIBON	*Smilax bona-nox* L.	Saw greenbrier
SMIROT	*Smilax rotundifolia* L.	Common greenbrier
SOLASP	*Solanum* sp.	Nightshade
SOLCAN	*Solidago canadensis* L.	Canada goldenrod
SORHAL	*Sorghum halepense* (L.) Pers.	Johnsongrass
STEMED	*Stellaria media* (L.) Vill.	Common chickweed
TRIFSP	*Trifolium* sp. L.	Clover
TRIVES	*Trifolium vesiculosum* Savi	Arrowleaf clover
TOXRAD	*Toxicodendron radicans* (L.) Kuntze	Poison ivy
ULMALA	*Ulmus alata* Michx.	Winged elm
ULMPAR	*Ulmus parvifolia* Jacq.	Chinese elm
VICISP	*Vicia* sp. L.	Vetch
VICVIL	*Vicia villosa* Roth	Winter vetch
VITROT	*Vitis rotundifolia* Michx.	Muscadine

Appendix 2. Selected photos of reclaimed sites planted in mixed-pine hardwood and unmined forested reference sites on Beckville lignite coal surface mine in Panola County, Texas.

Figure A2.1. Mixed site planted in 1982 (28 years old).

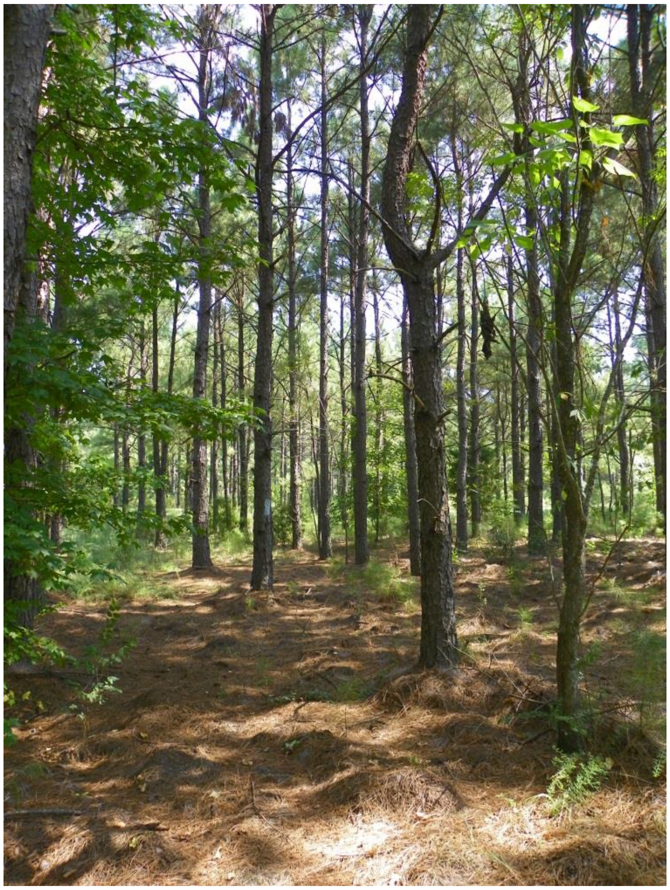

Figure A2.2. Mixed site planted in 1986 (24 years old).

Appendix 2, continued.

Figure A2.3. Mixed site planted in 1987 (23 years old).

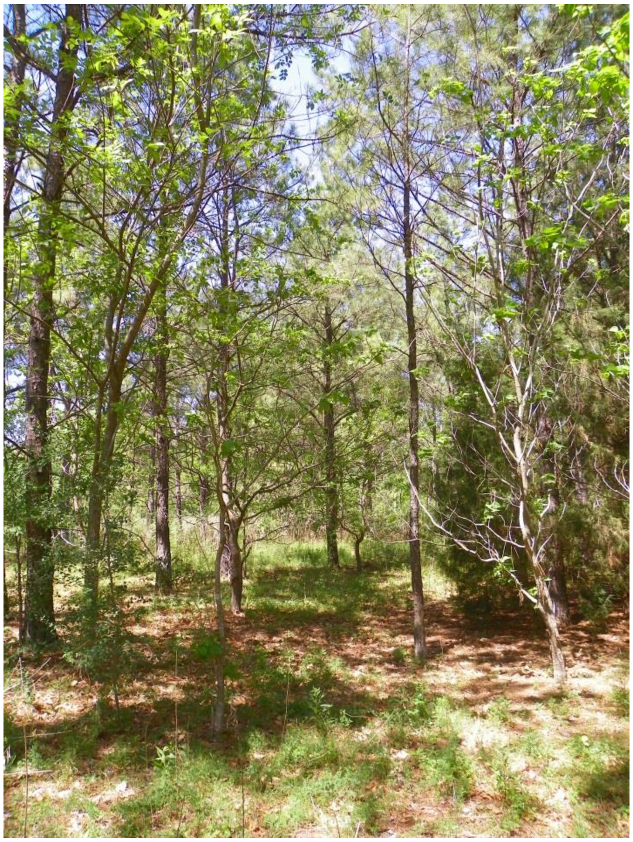

Figure A2.4. Mixed site planted in 1987 (23 years old).

Appendix 2, continued.

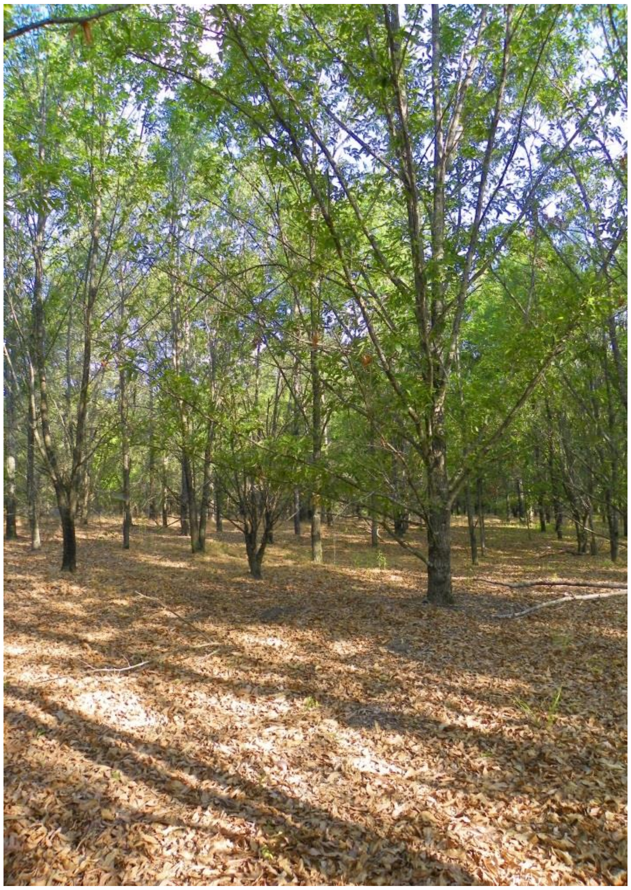

Figure A2.5. Mixed site planted in 1992 (18 years old).

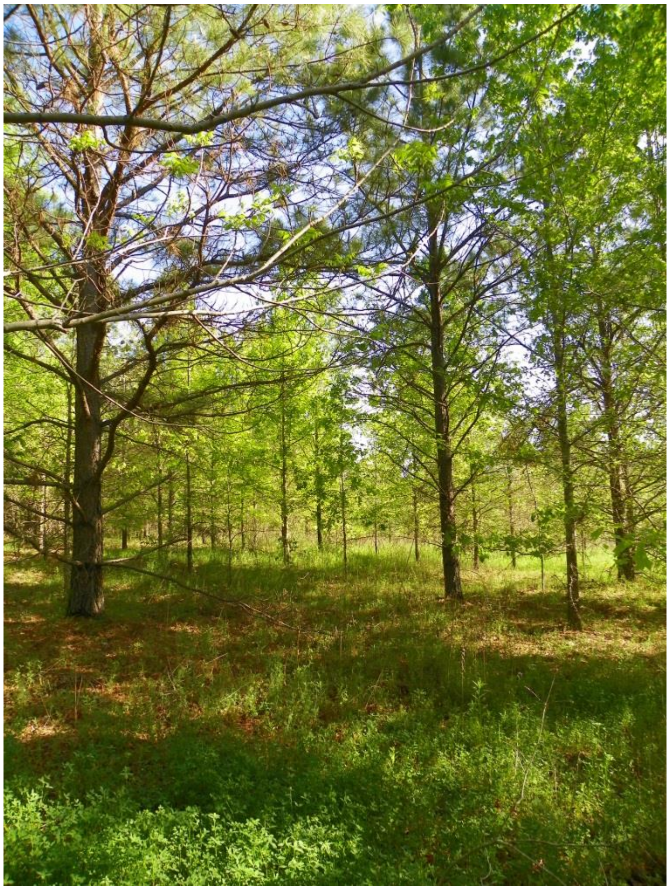

Figure A2.6. Mixed site planted in 1995 (15 years old).

Appendix 2, continued.

Figure A2.7. Mixed site planted in 1997 (13 years old).

Figure A2.8. Mixed site planted in 1998 (12 years old).

Appendix 2, continued.

Figure A2.9. Mixed site planted in 2001 (9 years old).

Figure A2.10. Mixed site planted in 2005 (5 years old).

Appendix 2, continued.

Figure A2.11. Reference site.

Figure A2.12. Reference site.