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Christy Christian

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

Hans M. Williams

Kenneth W. Farrish

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Vegetative Community Development Over 30 Years within Pine Plantations on Reclaimed Mine Land in East Texas

Christian CL, Oswald BP*, Williams HM and Farrish KW

Division of Environmental Science, Arthur Temple College of Forestry and Agriculture, Stephen F Austin State University, Nacogdoches, TX 75962, USA

Abstract

Reclamation of surface mines to plantation forests is a management option that reestablishes both economic and ecological functions after mining. This study investigated vegetative community characteristics (composition, richness, importance) over time in loblolly pine (*Pinus taeda* L.) plantations established over a thirty-year period on reclaimed lignite coal surface mine land in East Texas, United States. The open landscape of newly planted loblolly pine plantations on reclaimed mine land was amenable to shade-intolerant herbaceous and grass species but, when the canopy closed, favored woody species (trees, shrubs, vines) within two decades after stand establishment. Given that these plantations were established on sites generally described as dry to mesic uplands, species composition was generally congruent with East Texas ecology. Community composition, species richness and species importance were discussed, and loblolly pine growth data and vegetative community characteristics of unmined loblolly pine plantation sites in East Texas were compared to reclaimed sites. Surface mined lands reclaimed to plantation forests are ideal locations to conduct further research on how biodiversity and other ecosystems services can be improved while maintaining intended economic and ecological purposes.

Keywords: Loblolly pine; *Pinus taeda*; Reclamation; Surface mining; Ecosystem services; Biodiversity

Introduction

Reclamation of surface mines to plantation forests reestablishes both economic and ecological functions after mining. Increasing consumer demand for wood products necessitates using a greater proportion of land for plantation forests [1]. In 2010 reports, planted forests accounted for 7% of forests globally, up from 3% in 1999 reports and 8.3% of U.S. forests, up from 6% in 1990 [1,2]. These planted forests were included in the 30% of all US forests with designated primary use for production of "wood, fiber, bioenergy and/or non-wood forest products" [2]. Plantation forests consisting of pine species with significant economic demand are a commonly utilized post-mining land use. Restoration of ecosystem services is a desirable outcome of mine reclamation. Although differences exist in comparison to natural forests, plantation forest ecosystems can provide long-term forest-based ecosystem services such as wood production, habitat for native flora and fauna, watershed protection and improved water quality and carbon storage [1,3,4]. Also, biodiversity in plantation forests is of increasing interest [1,5-8].

Many studies have investigated soils, vegetation, water quality and more on un-reclaimed and reclaimed mine lands both pre- and post-SMCRA (Surface Mining Control and Reclamation Act of 1977) [3,4]. 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 achieve more successful post-mining land uses [3,4]. Long-term studies of vegetative community development on reclaimed mine land have been invaluable in adjusting reclamation practices, and several (11 to 55 years post-mining) have been conducted within the US [9-13]. Although no long-term studies for East Texas (Piney woods vegetation area) have been performed, a few were conducted in east-central Texas (Post Oak Savannah/Black land Prairie vegetation area) [14-16]. Several short-term vegetation-related studies on reclaimed mine land were conducted in East Texas; these included research on short-term 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 [17-24]. However, none of these studies addressed plant communities as a whole or over time.

In Texas, current lignite coal mine permits cover nearly 132,000 ha of land, including 1,363 ha disturbed by mining activity in 2014 [25]. In East Texas, loblolly pine (*Pinus taeda* L.) plantations are commonly established on reclaimed mine land as a designated post-mining land use ("forestry"). Some literature was available for vegetative community ecology of loblolly pine plantations in East Texas [26-31], but information about long-term vegetative community development of pine plantations on reclaimed mine land is limited to this study [32]. The objectives of this study were to determine vegetative community characteristics (composition, richness, importance) over time in loblolly pine plantations established over a 30-year time frame (1980 to 2009) on reclaimed lignite coal surface mine land in East Texas, USA. This study provided baseline ecological information about these plant communities that may assist land managers and researchers in adjustment of vegetative reclamation techniques as desired to improve reclamation success, economic benefits and provision of ecosystem services on these reclaimed mine lands.

Methods

Study area

This study was conducted on Luminant Mining Company

***Corresponding author:** Oswald BP, Division of Environmental Science, Arthur Temple College of Forestry and Agriculture, Stephen F Austin State University, Nacogdoches, TX 75962, USA, Tel: 9364682275; E-mail: boswald@sfasu.edu

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property at Beckville and Tatum mines in Panola County, Texas, USA (approximately lat 32°10' N, long 94°20' W). Post-SMCRA reclamation activities occurred within the study area over the past 30 years, including post-mining establishment of loblolly pine plantations. 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 land); and major over story species consisting of pines, oaks, hickories and maples [33]. The "subtropical" climate was characterized by annual rainfall of 42 to 46 in (≈107 to 117 cm), mean annual temperature of 66°F (≈19°C), and mean frost free period of 230 to 245 days [34].

Generally, pre-mine soils consisted of soil associations 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"; Nahatche-Mantachie-Urbo, "nearly level, slightly acid to strongly acid, loamy to clayey soils on bottom lands" [35]. A mixed overburden reclamation technique was used at these mines, 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, un-eathered soils).

Study sites

Fifty-six reclaimed mine sites planted as loblolly pine plantation stands were sampled (30 Beckville, 26 Tatum). For each mine (Beckville and Tatum), study sites were randomly selected to include stands covering a 30-year period (1980-2009) and were grouped into six age categories (i.e. 1 to 5 year, 6 to 10 year, 11 to 15 year, 16 to 20 year, 21 to 25 year, 26 to 30 year). If available, five stands were randomly chosen within each age category (at least one per year as possible). No stands aged 26 to 30 years were available at Tatum. Eleven sites were thinned (11 Beckville, 4 Tatum), ranging in age from 14 to 30 year with only two sites younger than age 22. One Beckville stand (BP8301) contained thinned and unthinned portions.

Each mine's data was analyzed separately for statistical analyses because available study sites were not evenly distributed by age among the two mines, and data skewing toward one mine or the other may have occurred with combined data. Study sites were not chosen based on stand management techniques, and, given the length of time covered by this study and frequent changes in post-SMCRA reclamation techniques, management methods may have varied among study sites (e.g. initial cover crop, seedling type, planting density, thinning). Other than items specifically discussed, management techniques were not accounted for. Study sites in which thinning activity had occurred were not excluded from this study as thinning is an inevitable management event in pine plantations. This study does not cover a true chrono sequence of 30 years, which would require repeated sampling of the same physical locations; a pseudo-chrono sequence was constructed using available reclaimed pine stands 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 stands within the following age ranges, respectively: 1 to 10 year, 11 to 20 year and 21 to 30 year.

Vegetation

One plot was established in each stand using a modified-Whittaker plot design (20 m × 50 m rectangular plot containing nested rectangular subplots of three sizes) (Figure 1) [36,37]. The 50 m side of the plot was situated parallel to the slope of the site to ensure that vegetative samples captured as much heterogeneity as possible. Understory, mid-story and over story strata were sampled for vegetation parameters and defined by vegetation height: understory (≤ 1 m), mid-story (>1 m to ≤ 6 m) and over story (>6 m) (Figure 1). Vascular vegetation was identified to species, as possible, for all strata, following the USDA PLANTS Database for scientific name and authority [38]. Visual estimates of species cover (%) were recorded for understory and mid-story strata, and over story 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 mid-story and over-story strata and converted to stems ha-1. Height of each over story individual was measured by range pole (≤ 7 m) or clinometer (>7 m). It should be noted that diameter, height and stem count data were collected for all loblolly pine individuals, regardless of strata; for individuals, shorter than breast height (1.37 m), root collar diameter was measured and used in place of dbh as needed.

Species composition (i.e. presence), species richness, and species importance values (IV) were obtained from field data. Species IV are unit less numbers that indicate the overall contribution of an individual species to a community relative to all other species in the community [39]. The original definition of IV is the sum of relative cover, relative density, and relative frequency [39], and was used for mid-story and over story. 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, mid-story and over story IV.

Data analysis included nonmetric multidimensional scaling (NMS), an ordination statistical technique performed using PC-ORD 6 statistical software [40]. Species codes displayed on ordination graphs are defined in Table A-1 (Supplementary Information, Appendix). City-block distance measures were used for two reasons: 1) the sparsity of the

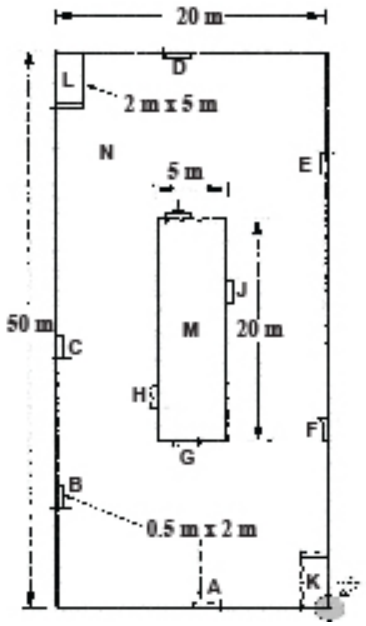

Figure 1: Layout of the modified-Whittaker plot design (Stohlgren et al.). Alphabetical labels and location of GPS coordinates were added. Vegetation was sampled in subplots and strata based on vegetation height as follows: understory (≤ 1 m), "A" through "J"; midstory (>1 m to ≤ 6 m), "K" through "M";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

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.

Results

Predictably, mean loblolly pine height, diameter and basal area showed increasing trends over time (Figures 2-4). However, a decrease in basal area values was observed in the oldest age category sampled at each mine (Figure 4). Density increased over time until a noticeable decrease after two decades of growth (Figure 5).

Species composition

A strong chronological trend in species composition was observed along Axis 1 (represents site age), with older sites generally grouped on the left side of the graph and younger sites on the right (Figures 6 and 7). Over time, species composition became more similar between stands, as evidenced by loosely grouped younger stands and tightly grouped older stands. At Tatum, one 9-year old stand was grouped with the oldest stands and had unique species composition as compared to other younger sites.

Generally, woody vine species (e.g. saw greenbrier (*Smilax bona-nox* L.), Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.), poison ivy (*Toxicodendron radicans* (L.) Kuntze)) were strongly associated with older sites (species lines point toward older sites), and herbaceous and grass species (e.g. coastal bermudagrass (*Cynodon dactylon* (L.) Pers.), Johnsongrass (*Sorghum halepense* (L.) Pers.), camphorweed (*Heterotheca subaxillaris* (Lam.) Britton & Rusby)) were strongly associated with younger sites (species lines point toward younger sites) (Figures 6 and 7). Woody shrub and tree species were generally not associated with younger sites (e.g. American beautyberry (*Callicarpa americana* L.), yaupon (Ilex vomitoria Aiton), eastern redcedar (*Juniperus virginiana*

Mine	Understory stratum	Midstory stratum	Overstory stratum	All strata combined
Beckville	97	43	12	104*
(30 stands, 1 to 30 yr old)				
Tatum	86	21	5	86**
(26 stands, 1 to 24 yr old)				

*49% of species present in <4 stands; **50% of species present in <4 stands.

Table 1: Combined plant species richness data for reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands on two lignite coal surface mines in Panola County, Texas, USA.

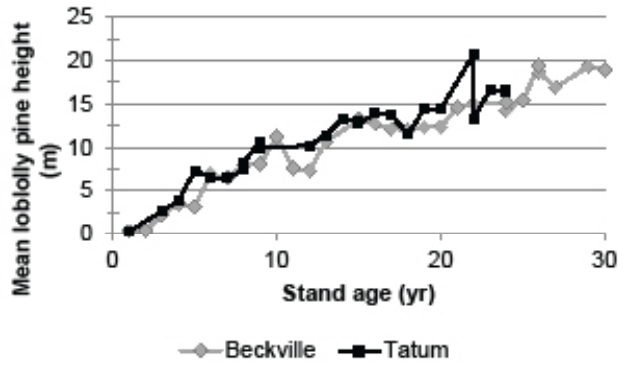

Figure 2: Mean height (m) of loblolly pine (*Pinus taeda* L.) individuals in reclaimed mine sites planted as loblolly pine plantation stands aged 1 to 30 years at Beckville and Tatum lignite coal surface mines (Panola County, Texas, U.S.A.).

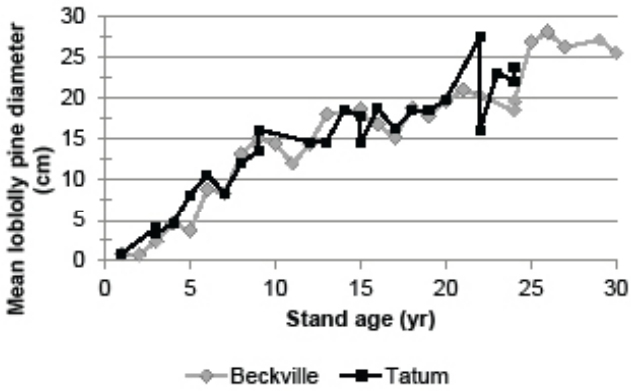

Figure 3: Mean diameter (cm) of loblolly pine (*Pinus taeda* L.) individuals in reclaimed mine sites planted as loblolly pine plantation stands aged 1 to 30 years at Beckville and Tatum lignite coal surface mines (Panola County, Texas, USA).

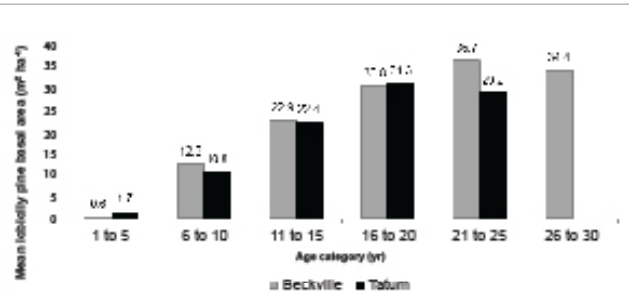

Figure 4: Mean loblolly pine (*Pinus taeda* L.) basal area (m^2 ha^{-1}) by age category in reclaimed mine sites planted as loblolly pine plantation stands aged 1 to 30 years at Beckville and Tatum lignite coal surface mines (Panola County, Texas, USA).

L.), wax myrtle (*Morella cerifera* (L.) Small), water oak (*Quercus nigra* L.), sweetgum (*Liquidambar styraciflua* L.)) (species lines point away from younger sites). The variability in species composition shown on Axis 2 was generally related to herbaceous species found in the understory (e.g. goatweed (*Croton capitatus* Michx.), Canada goldenrod (*Solidago canadensis* L.), Carolina horsenettle (*Solanum carolinense* L.)). Ordination graphs of species presence data were updated to note whether stands were thinned (Figures 8 and 9). Most thinned Beckville stands and three of four thinned Tatum stands were 1) grouped closely together and 2) plotted among unthinned older and middle-aged sites; these data indicated thinned stands were similar in species composition to each other and to unthinned sites of similar age.

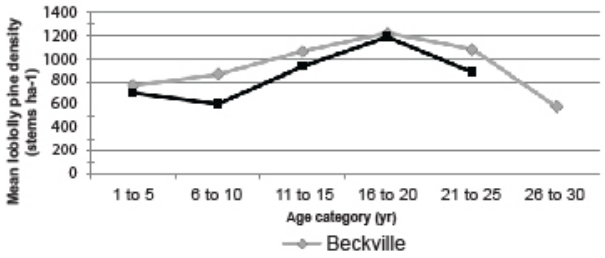

Figure 5: Mean loblolly pine (*Pinus taeda* L.) density (stems ha^{-1}) by age category in reclaimed mine sites planted as loblolly pine plantation stands at Beckville and Tatum lignite coal surface mines (Panola County, Texas, USA).

Species richness

Total species richness for all strata combined was 104 at Beckville and 86 at Tatum (Table 1). Generally, species richness was greatly increased by rarer species that only occurred in 20% or less of all sites at each mine (71 species at Beckville, 60 species at Tatum) (Supplementary Information, Appendix, Table A-2). Species richness increased over time at both mines, especially in the understory, as a greater variety of volunteer species became established (Figure 10 and 11). After 25 years, an increase in mid-story richness was noticeable at Beckville. Over story richness did not increase until approximately two decades after stand establishment due to loblolly pine dominance. Over story species observed with loblolly pine included tree species such as sugarberry (*Celtis laevigata* Willd.), American elm (*Ulmus americana* L.), sweetgum, southern red oak (*Quercus falcata* Michx.) and cherrybark oak (*Quercus pagoda* Raf.). However, though categorized as over story species, it should be noted that their numbers were few and their mean heights were generally at least 10 m less than loblolly pine. Smaller-stature tree species observed in over story included eastern redbud (*Cercis canadensis* L.), eastern redcedar and red maple (*Acer rubrum* L.).

Species importance value

Similarities existed between the two mines in regard to important species with loblolly pine and eastern redcedar being the most important tree species and southern dewberry (*Rubus trivialis* Michx.), Johnsongrass, bahiagrass (*Paspalum notatum* Flueggé) and Canada goldenrod being the most important understory species, especially in

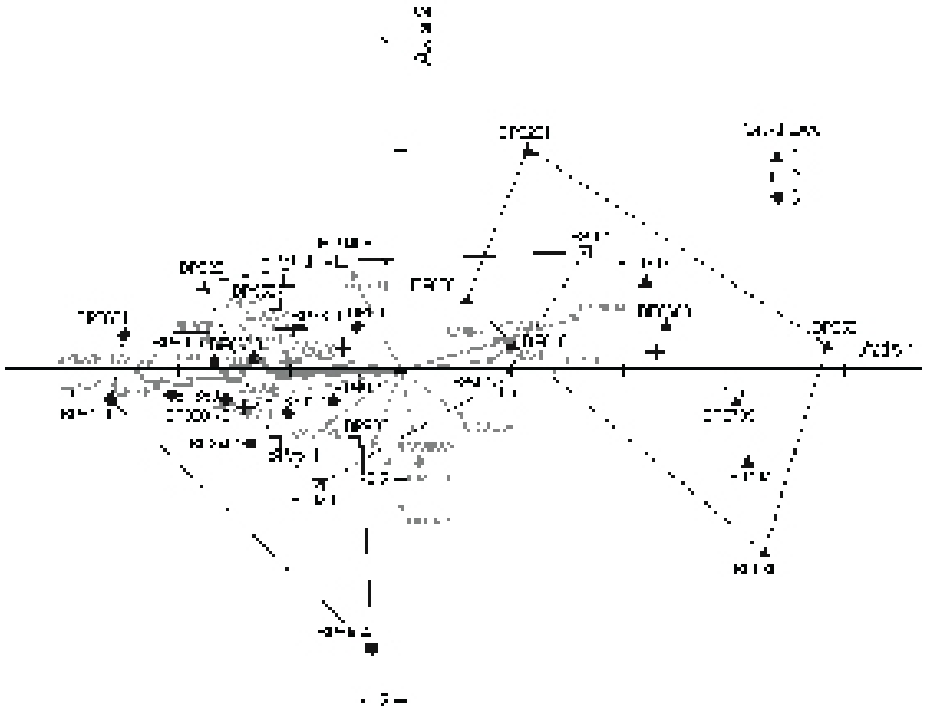

Figure 6: Nonmetric multidimensional scaling (NMS) ordination of reclaimed mine sites planted as loblolly pine (Pinus taeda L.) plantation stands (outlier BP0906 omitted) at Beckville lignite coal surface mine (Panola County, Texas, U.S.A.) based on species presence (i.e., species composition) and including all vegetation strata (understory, midstory, overstory). Stands represented by triangles and stand name (BP=Beckville pine, first two numbers indicate year of stand establishment between 1980 and 2009, last two numbers indicate randomly assigned stand number). Stands with similar species composition plotted relatively close together and dissimilar stands plotted relatively far apart. Species represented by gray 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. Site legend: 1=sites aged 1 to 10 years; 2=sites aged 11 to 20 years; 3=sites aged 21 to 30 years.

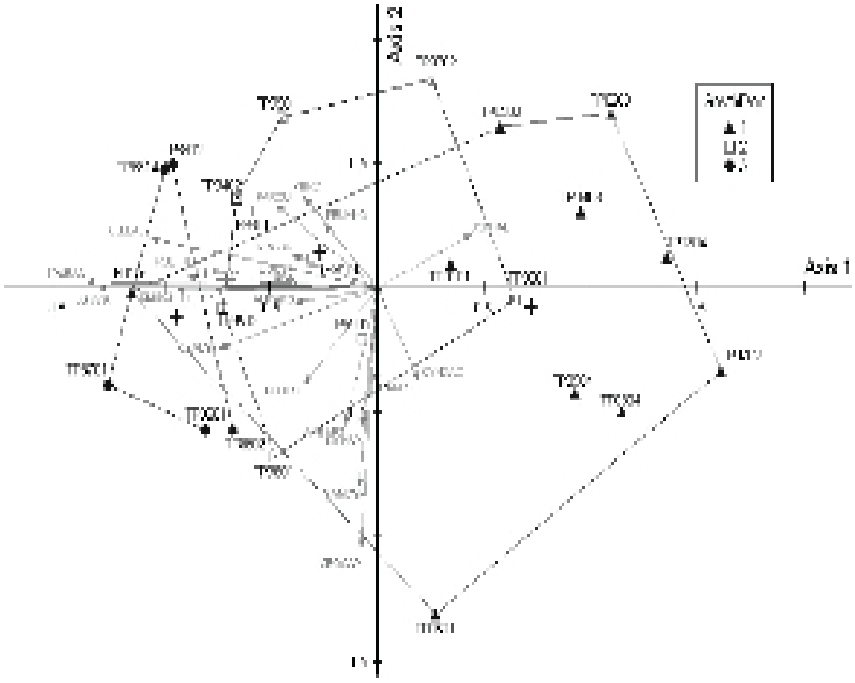

Figure 7: Nonmetric multidimensional scaling (NMS) ordination of reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands (outliers TP9001 and TP0602 omitted) at Tatum lignite coal surface mine (Panola County, Texas, USA) based on species presence (i.e., species composition) and including all vegetation strata (understory, midstory, overstory). Stands represented by triangles and stand names (TP=Tatum pine, first two numbers indicate year of stand establishment between 1986 and 2009, last two numbers indicate randomly assigned stand number). Stands with similar species composition plotted relatively close together and dissimilar stands plotted relatively far apart. Species represented by gray 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. Site legend: 1=sites aged 1 to 10 years; 2=sites aged 11 to 20 years; 3=sites aged 21 to 30 years.

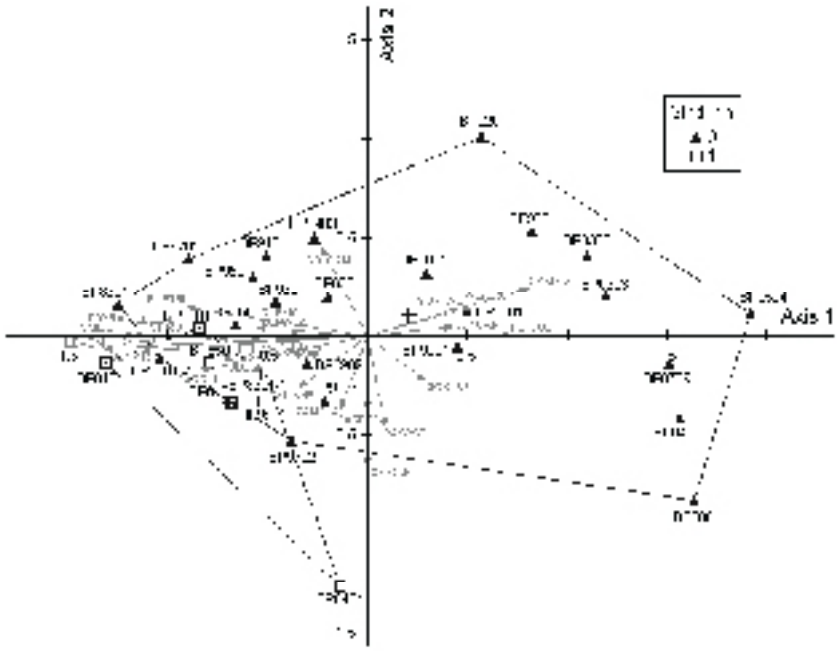

Figure 8: Nonmetric multidimensional scaling (NMS) ordination of reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands (outlier BP0906 omitted) at Beckville lignite coal surface mine (Panola County, Texas, USA) based on thinning activity and species presence (i.e., species composition) and including all vegetation strata (understory, midstory, overstory). Stands represented by triangles and stand name (BP=Beckville pine, first two numbers indicate year of stand establishment between 1980 and 2009, last two numbers indicate randomly assigned stand number). Stands with similar species composition plotted relatively close together and dissimilar stands plotted relatively far apart. Species represented by gray 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. Site legend: 0=unthinned; 1=thinned at some point in time after stand establishment.

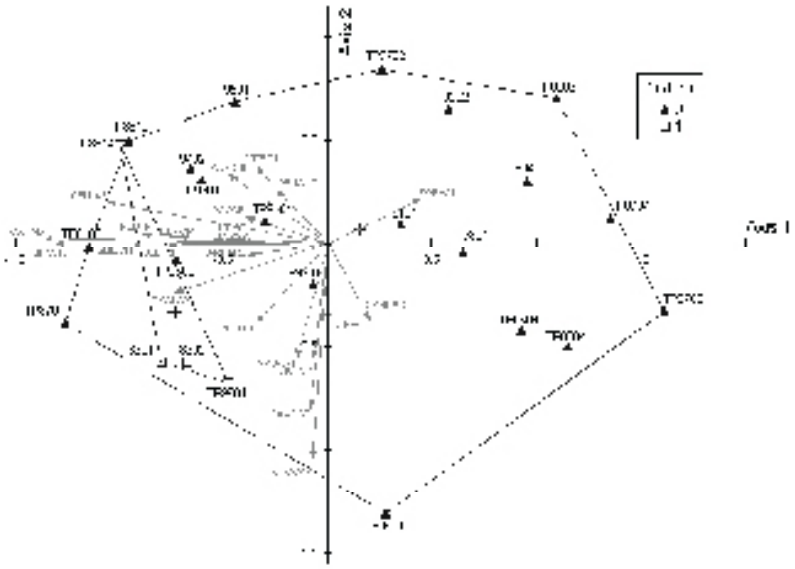

Figure 9: Nonmetric multidimensional scaling (NMS) ordination of reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands (outliers TP9001 and TP0602 omitted) at Tatum lignite coal surface mine (Panola County, Texas, U.S.A) based on thinning activity and species presence (i.e. species composition) and including all vegetation strata (understory, midstory, overstory). Stands represented by triangles and stand name (TP=Tatum pine, first two numbers indicate year of stand establishment between 1986 and 2009, last two numbers indicate randomly assigned stand number). Stands with similar species composition plotted relatively close together and dissimilar stands plotted relatively far apart. Species represented by gray 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. Site legend: 0=unthinned; 1=thinned at some point in time after stand establishment.

younger sites (Tables 2 and 3). Several woody shrubs were especially important in the mid-story stratum of middle-aged sites at both mines, including eastern baccharis (*Baccharis halimifolia* L.), yaupon, American beauty berry and wax myrtle. In some cases, woody vine species (e.g. Japanese honeysuckle (*Lonicera japonica* Thunb.), poison ivy) were more important in older stands due to a more developed mid-story and greater understory cover.

Discussion

The open landscape of newly planted loblolly pine plantations on reclaimed mine land was amenable to shade-intolerant herbaceous and grass species but shifted to a closed canopy within two decades after stand establishment, which favored woody species (trees, shrubs, vines). At Beckville, among the 25 species with greatest understory IV (out of 97 species observed in understory) was a mixture of shade-intolerant herbaceous species, woody vines and large tree species, highlighting the shifting species importance over time as a closed canopy forest environment developed. Dominance of woody shrubs in the mid-story at both mines was also indicative of formation of closed canopy forest with multi-layer structure, especially apparent with dominance of shade-tolerant shrubs like American beautyberry and wax myrtle. Important Beckville mid story shrub species varied in cover over time; shade-intolerant eastern baccharis was more abundant in younger stands, and yaupon and wax myrtle were more abundant in shaded older stands.

Over time, species composition became more similar, and species commonly associated with forests in East Texas became successfully established, often within two decades. Given that these plantations were established on sites generally described as dry to mesic uplands, species composition was generally congruent with East Texas ecology, as described by Van Kley [41]. For instance, the assemblage of important species at Beckville (loblolly pine, eastern redcedar, yaupon) and dominance by oaks and blackberry (Rubus sp.) were similar to area ecology. Southern red oak and water oak accounted for 73% of total oak IV for Beckville, which was logical since these species tolerance ranges include drier upland to mesic sites. Tatum species composition did not closely match Beckville because sampled Tatum stands covered a shorter time span (24 years versus 30 years); differences between mine sites over time will likely lessen.

Species richness data indicated that, while loblolly pine was dominant throughout the 30-year period, over time, other over story species made inroads and the mid-story stratum filled in. At Tatum, it is likely that an additional five to ten years of growth in the oldest stands will realize greater over story richness, as was observed in the oldest Beckville stands. Mean mid-story richness increased in the oldest Tatum stands and included species likely to reach over story height in the future (e.g. sugarberry, eastern redcedar, southern red oak). Increased understory richness corresponded with mean loblolly pine height reaching around 10 meters, which occurred between 10 to 15 years after stand establishment; increased shading due to a taller canopy led to occurrence of a greater variety of species in the understory stratum and exclusion of shade-intolerant understory species.

Although ordination graphs based on species presence indicated thinned stands were similar in species composition to each other and to unthinned sites of similar age, further analysis of Beckville site BP8301 revealed vegetative differences between thinned (BP8301-1) and unthinned (BP8301-2) portions of the site. A greater variety of woody vine species was present in the unthinned plot; differences from the thinned plot included understory presence of peppervine (*Ampelopsis arborea* (L.) Koehne), presence of trumpet creeper (*Campsis radicans* (L.) Seem. ex Bureau) in all three strata and over story presence of poison ivy. Eastern baccharis was found in both understory and mid-story of the thinned portion while winged sumac (*Rhus copallinum* L.) was found in understory and mid-story of the unthinned portion;

Common name	Scientific name	Number of stands where observed	Total species importance value
Loblolly pine	*Pinus taeda* L.	30	13,409
Eastern redcedar	*Juniperus virginiana* L.	20	4,299
Yaupon	*Ilex vomitoria* Aiton	20	4,127
Eastern baccharis	*Baccharis halimifolia* L.	19	4,114
Poison ivy	*Toxicodendron radicans* (L.) Kuntze	18	2,879
Southern dewberry	*Rubus trivialis* Michx.	26	2,831
Wax myrtle	*Morella cerifera* (L.) Small	13	2,512
Southern red oak	*Quercus falcata* Michx.	15	2,505
Johnsongrass	*Sorghum halepense* (L.) Pers.	22	2,474
Canada goldenrod	*Solidago canadensis* L.	23	2,471
Sugarberry	*Celtis laevigata* Willd.	15	2,134
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.	15	1,921
Bahiagrass	*Paspalum notatum* Flueggé	17	1,885
Woodsorrel	*Oxalis* sp. L.	17	1,858
Coastal bermudagrass	*Cynodon dactylon* (L.) Pers.	16	1,830
Rosette grass	*Dichanthelium* sp. (Hitchc. & Chase) Gould	18	1,829
Blackberry	*Rubus* sp. L.	14	1,767
Japanese honeysuckle	*Lonicera japonica* Thunb.	12	1,732
Saw greenbrier	*Smilax bona-nox* L.	17	1,709
Water oak	*Quercus nigra* L.	14	1,621
Common persimmon	*Diospyros virginiana* L.	13	1,537
American beautyberry	*Callicarpa americana* L.	13	1,511
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	14	1,439
Goatweed	*Croton capitatus* Michx.	13	1,361
Privet	*Ligustrum* sp. L.	10	1,336
Sweetgum	*Liquidambar styraciflua* L.	7	1,306
Muscadine	*Vitis rotundifolia* Michx.	11	1,107
Peppervine	*Ampelopsis arborea* (L.) Koehne	9	1,106
Sericea lespedeza	*Lespedeza cuneata* (Dum. Cours.) G. Don	10	1,061
Winged elm	*Ulmus alata* Michx.	8	1,050
Camphorweed	*Heterotheca subaxillaris* (Lam.) Britton & Rusby	9	935
Wild carrot	*Daucus carota* L.	8	812
Thistle	*Cirsium* sp. Mill.	8	804

Table 2: Total species importance values (understory, midstory and overstory importance values combined) for plant species observed on more than 20% of reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands aged 1 to 30 years at Beckville lignite coal surface mine (Panola County, Texas, USA).

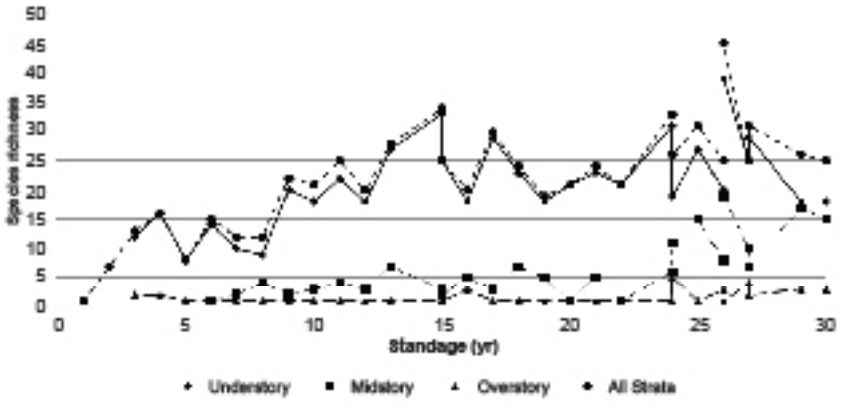

Figure 10: Species richness over time by stratum for reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands aged 1 to 30 years at Beckville lignite coal surface mine (Panola County, Texas, U.S.A).

eastern baccharis is a shrub species more indicative of open and/or disturbed sites while winged sumac tends to be present in more shaded environments. Although several understory species were common to both plots, the thinned plot contained several herbaceous species indicative of open and/or disturbed sites (thistle (Cirsium sp. Mill.), goatweed, everlasting (Gamochaeta sp. Weddell), switchgrass (*Panicum*

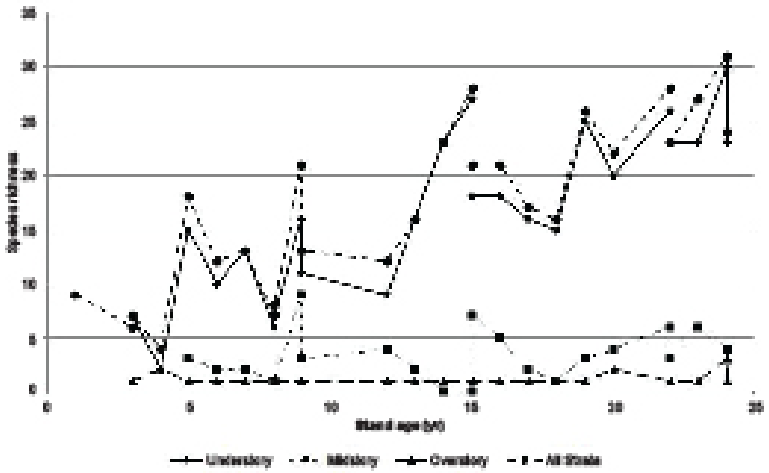

Figure 11: Species richness over time by stratum for reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands aged 1 to 24 years at Tatum lignite coal surface mine (Panola County, Texas, USA).

Common name	Scientific name	Number of stands where observed	Total species importance value
Loblolly pine	*Pinus taeda* L.	26	10,700
Bahiagrass	*Paspalum notatum* Flueggé	23	2,962
Eastern redcedar	*Juniperus virginiana* L.	13	2,461
Johnsongrass	*Sorghum halepense* (L.) Pers.	19	2,442
Southern dewberry	*Rubus trivialis* Michx.	17	2,060
Canada goldenrod	*Solidago canadensis* L.	19	1,989
American beautyberry	*Callicarpa americana* L.	9	1,760
Sugarberry	*Celtis laevigata* Willd.	15	1,703
Wax myrtle	*Morella cerifera* (L.) Small	8	1,611
Yaupon	*Ilex vomitoria* Aiton	10	1,584
Woodsorrel	*Oxalis* sp. L.	15	1,551
Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch.	14	1,551
Poison ivy	*Toxicodendron radicans* (L.) Kuntze	15	1,547
Coastal bermudagrass	*Cynodon dactylon* (L.) Pers.	12	1,462
Saw greenbrier	*Smilax bona-nox* L.	12	1,320
Goatweed	*Croton capitatus* Michx.	9	1,118
Eastern baccharis	*Baccharis halimifolia* L.	8	1,101
Honeylocust	*Gleditsia triacanthos* L.	8	1,100
Sweetgum	*Liquidambar styraciflua* L.	8	1,000
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash	9	999
Peppervine	*Ampelopsis arborea* (L.) Koehne	6	812
Southern red oak	*Quercus falcata* Michx.	6	721
Blackjack oak	*Quercus marilandica* Münchh.	7	704
Blackberry	*Rubus* sp. L.	6	701
Privet	*Ligustrum* sp. L.	6	603
Muscadine	*Vitis rotundifolia* Michx.	6	601

Table 3: Total species importance values (understory, midstory and overstory importance values combined) for plant species observed on more than 20% of reclaimed mine sites planted as loblolly pine (*Pinus taeda* L.) plantation stands aged 1 to 24 years at Tatum lignite coal surface mine (Panola County, Texas, USA).

virgatum L.), bahiagrass, crowngrass (Paspalum sp. L.), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), Canada goldenrod) while the unthinned plot contained several tree and shrub species that could be expected in the understory of a closed canopy forest (sugarberry, common persimmon (*Diospyros virginiana* L.), yaupon, eastern redcedar, water oak).

Data source	Age range (yr)	Number of trees measured (n)	Diameter (cm)				Height (m)			
			Mean	s	Min.	Max.	Mean	s	Min.	Max.
Beckville	6 to 30	2290	19.1	5.3	10.2	39.9	12.9	3.4	4.6	21.2
Tatum	6 to 24	1685	18.3	4.6	10.2	36.1	12.7	3.3	4	23.9
Unmined*	4 to 30	236	21.1	6.1	10.2	38.9	16.6	4	5.7	25.2

Table 4: Comparison of loblolly pine (*Pinus taeda* L.) growth data for reclaimed mine sites planted as loblolly pine plantations (Beckville and Tatum Mines in Panola County, Texas, USA) and unmined, semi-intensive plantation locations in the East Texas region, USA. Mined and unmined plantations were of similar age range and varied management. Diameter measured as dbh (diameter at breast height), and trees smaller than 10.2 cm dbh not included.

Site name		Species richness
Cherokee	CR mean	10.7
	CR-1*	6
(1-year post-thinning)	CR-2*	12.6
	CR-3*	6
	CR-4*	13.4
	CR-5*	15.4
	SU mean	11.8
	SU-1*	11
	SU-2*	12.5
	SU-3*	9.9
	SU-4*	10.3
	SU-5*	15.3
Beckville	Beckville mean	27.4
	BP-9301	30
	BP-9403	20
	BP-9507	25
	BP-9511*	34
	BP-9702	28
Tatum	**Tatum mean**	**21**
	TP-9301	17
	TP-9402	21
	TP-9501	21
	TP-9502	28
	TP-9601*	23
	TP-9702	16

Table 5: Species richness for unmined, thinned, 13 to 17-year-old loblolly pine (*Pinus taeda* L.) plantation stands in Cherokee County, Texas, USA (Ott; Oswald et al.) and reclaimed mine sites planted as loblolly pine plantation stands (thinned and unthinned, 13 to 17 years old) on lignite coal surface mine land (Beckville/Tatum, Panola County, Texas, USA).

At Beckville, loblolly pine was often the only over story species present during the first 25 years after establishment. In most stands older than 25 years, loblolly stems had been thinned, and this allowed richness to increase in both mid-story and over story strata, especially as species like sugarberry, cherrybark oak and eastern redcedar reached over story height. Mid-story density also increased after thinning, given that loblolly pine dominance also suppressed the growth of mid-story species until about 25 years post-establishment, which was when mid-story richness increased. At both mines, decreased over story density in older stands was generally attributed to thinning activity that occurred in 60% of Tatum stands older than 20 years and 100% of Beckville stands 25 years and older. Three of four thinned Tatum stands had similar species composition to each other and were fairly dissimilar to other unthinned stands in their understory composition. These three stands contained unique combinations of herbaceous species not found in unthinned stands (goatweed, everlasting and sedge (Carex sp.) in all three sites and annual ragweed (*Ambrosia artemisiifolia* L.) and rosette grass (Dichanthelium sp.) in two sites); goatweed, everlasting and annual ragweed are commonly found in open and/or disturbed sites.

Loblolly pine growth data were compared to diameter and height of loblolly pine grown on various unmined semi-intensive plantations in East Texas (Table 4) [42]. Although mean diameter and mean height for mined Beckville/Tatum sites were less than unmined sites (approximately 2 to 3 cm less in diameter and 4 m less in height), growth data were encouragingly comparable overall, suggesting that these mined sites produced merchantable trees near par to unmined sites.

A study in Cherokee County, Texas, USA (Piney woods vegetation area) examined biodiversity in 13 to 17 year old loblolly pine plantations that had undergone mid-rotation thinning within the past year [30,31]. As feasible, data of Beckville/Tatum sites and Cherokee sites were compared to ascertain whether vegetative similarities existed between mined and unmined loblolly pine plantations. Out of 108 species/genera observed on Cherokee sites, 36 (33%) were also found in Beckville/Tatum sites. A likely reason for the other two-thirds of Cherokee species lacking in Beckville/Tatum stands was placement of Cherokee plots on tertiary stream slopes that included measurements from more moist soil conditions on mid-slope and slope bottom areas while Beckville/Tatum plots were on upland sites.

Half of the important herbaceous and shrub species/genera at Cherokee were also important at Beckville/Tatum (yaupon, wax myrtle, wood sorrel, Virginia creeper, blackberry, poison ivy, greenbrier (*Smilax sp*. L.)), which revealed some substantial similarity in composition between the mined and unmined plantations. Species richness in both thinned and unthinned Beckville/Tatum sites was higher at both 1-year and 3-years post-thinning than at Cherokee (Table 5). Some of this difference in richness was likely due to the short amount of time since disturbance by thinning activity in Cherokee sites as mean site richness improved by approximately 5 species between 1 and 3 years post-thinning; most 13 to 17-year-old Beckville/Tatum stands had never been thinned.

Data from Ott, Oswald et al., and Coble and Hilpp are only some of the data available on pine growth and community development aspects of loblolly pine plantation ecosystems in East Texas [30,31,42]. Further detailed vegetation community data for loblolly pine plantations on reclaimed Beckville/Tatum mine land in East Texas are available in Christian [32], and other data exist for East Texas pine plantations [26-29]. A meta-analysis or other synthesis of these data is suggested to attain further understanding of these plantation communities and further discern how mined and unmined plantations compare to one another.

Despite the popular application of terms such as “impoverished”, “tree farm” and “biological desert” to plantation forests, it is important to realize that the plantation forest’s state of affairs is hardly bleak. Many

studies have provided evidence of divers ecological functions occurring within plantation forests, which is preferable to relatively meager ecological functions provided by deforested and other degraded lands [1,5-8]. The biodiversity of plantation forests spans many taxa and, even if not a defined ecosystem type, plantation forests are functioning communities of flora and fauna. Plantation forests can contribute positively to biodiversity by providing habitat where native organisms can more easily recolonize, adding additional large scale features to surrounding landscape and acting as buffer zones and corridors between natural forest and non-forest. Surface mined lands reclaimed to plantation forests are ideal locations to conduct further research on how biodiversity and other ecosystem services can be improved while maintaining intended economic and ecological purposes.

Conclusions

Overall, reclaimed mine land in the study area was found to be amenable to establishment of productive loblolly pine plantations based on vegetative community characteristics and development over time. Major species were congruent with those common in forest communities of East Texas, and loblolly pine was observed to establish and maintain dominance as was intended in these plantations; neither of these points were observed to be grossly affected by past mining activity. Richness in all three vegetation strata increased over time despite the reclaimed mine sites being initially planted as a loblolly pine monoculture. Pine growth data was found to be fairly comparable to growth data in unmined plantations, supporting the validity of reclaimed mine lands as suitable locations for productive pine plantations. As compared to unmined loblolly pine plantations, reclaimed sites exhibited some similarity in overall vegetative composition, greater plant species richness, and congruence of important herbaceous and shrub species. Further study of the East Texas loblolly pine plantation ecosystem in both mined and unmined settings would be valuable in attaining continued improvement of economic benefits, ecosystem services and biodiversity of this increasingly utilized landscape type.

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