SESSION 8: REVEGETATION ECOLOGY

Page No.

The Potential for Using Wildflower Species to Increase Natural Habitat in Contour Surface Mine Reclamations.
John R. Heckman, Karen D. Holl, Mara Sabre, Robert B. Atkinson, John Cairns, Jr. 453

Predicting Grass Stand Adequacy from Early Stand Parameters.
R.E. Ries 462

Vegetation Diversity within Native and Reclaimed Coal Mine Sites: Environmental Factors and Seasonal Variability.
Brenda K. Schladweiler, George F. Vance 472

Natural and Planted Flora of the Log Mountain Surface-Mined Demonstration Area, Bell County, Kentucky.
Ralph L. Thompson, Gary L. Wade, R. Allen Straw 484

The Relative Merits of Dolomitic and Calcitic Limestone in Detoxifying and Revegetating Acidic, Nickel- and Copper-Contaminated Soils in the Sudbury Mining and Smelting Region of Canada.
Derek McHale, Keith Winterhalder 504

Ontogeny of Accidental Wetlands and Hydric Soil Development in Surface Mined Landscapes.
Robert B. Atkinson, W. Lee Daniels, John Cairns, Jr. 516

AMERICAN SOCIETY • SURFACE MINING and RECLAMATION •

THE POTENTIAL FOR USING WILDFLOWER SPECIES TO INCREASE NATURAL HABITAT IN CONTOUR SURFACE MINE RECLAMATION

by

John R. Heckman, Karen D. Holl, Mara Sabre, and John Cairns, Jr.

Abstract. While non-native herbaceous species are commonly used for mine reclamation, these species have low wildlife and aesthetic value and may inhibit long-term succession. The goal of this study was to determine the suitability of wildflowers for surface mine reclamation in the Appalachian mountains. A seed mixture composed of native and naturalized wildflower species was compared to the standard revegetation mixture by testing greenhouse germination rates of all species in both mine spoils and potting soil and establishing field plots at reclamation sites in southwestern Virginia. In May 1993, two 9-m^2 (97-ft^2) plots were seeded with each revegetation mixture on four slopes with different aspects. Vegetation cover and composition were recorded in all plots during the 1993 and 1994 field seasons. Wildflower species had germination rates ranging from 0-52%. In field studies, all but 2 of the 14 species of wildflowers seeded became established in study plots, while only 4 of the 8 species in the standard mixture were recorded. Cover was highly variable among plots on different aspects seeded with the same mixture. In most cases, total vegetative cover did not differ significantly between plots seeded with different mixtures. Some native and naturalized wildflower species appear to have potential for use in mine reclamation and could be included with standard revegetation mixtures in order to provide more native diversity. However, further research is necessary due to a number of factors confounding these results, including the low seeding rates used, drought conditions during the 1993 field season, and problems with regrowth of previous vegetation.

Additional Key Words: biodiversity, restoration.

Introduction

Large areas of land in the Appalachian region of United States have been disturbed by coal surface mining. According to the Office of Surface Mining, in Virginia alone nearly 50,000 ha (123,000 acres) have been disturbed by mining since passage of the Surface Mining Control

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[3]The authors thank Ken Hyer for field assistance. For assistance on various aspects of the project, the help of Robert Lyons, Eric Smith, and Tom Wieboldt is greatly appreciated. Funds were provided by the Mobil and Du Pont Education in Aid programs and the Virginia Tech Graduate Student Assembly. Penn Virginia provided lodging for researchers.

and Reclamation Act (1977). The majority of these areas was revegetated using a few non-native grasses and legumes, including red top, Kentucky-31 tall fescue, orchard grass, clover, sweet clover, and birdsfoot trefoil. While these species provide rapid cover for erosion control and are inexpensive to seed, they provide little wildlife value and may inhibit long-term succession (Brenner et al. 1984; Burger and Torbert 1990; Hughes 1992).

In recent years, interest has increased in using wildflowers to revegetate disturbed areas such as landfills and roadsides. Wildflowers not only improve the aesthetic quality of an area, but they provide nectar and forage resources for wildlife and allow for the establishment of later successional plant species (Luken 1990). The goal of this project was to test the potential for using a number of native and naturalized wildflower and grass species for mine reclamation.

Site Description

This research was performed in Wise County, Virginia. The sites are located on the Powell River Project research area (PRP), an approximately 700-ha (1700-acre) area, about 125 ha (310 acre) of which have been mined. The PRP is a cooperative research program administered by Virginia Tech. The pre-mining soil in this area is comprised of acidic and infertile sandstones, siltsones, and shales (Daniels and Amos 1985).

The areas where test plots were located had been seeded prior to initiation of the experiment. North and south facing aspects were seeded in spring 1992; cover was predominantly birdsfoot trefoil, Kentucky 31-tall fescue, and perennial rye (*Lolium perenne*) at the initiation of the study. East and west facing slopes were seeded a few months before the start of the experiment and annual rye was just beginning to emerge.

Methods

Seed Selection and Preparation

The standard seed mixture consisted of species commonly used for mine reclamation in the region (Table 1). A list of native and naturalized wildflowers and grasses that would be tolerant of open canopy and drought conditions was compiled based on information provided by local horticulturalists and naturalists and a number of regional floras (Wofford 1993; Harvill et al. 1992; Radford et al. 1968). The preliminary wildflower species list was reduced to species for which seeds could be obtained from wildflower seed companies in the United States (Table 1).

Germination Studies

In March 1993, germination tests were conducted on seeds from different sources to determine germination rates. One hundred seeds of each species from both the standard and wildflower species mixtures were sown in two soil types in 0.093-m^2 (1-ft^2) flats in greenhouses. Soil types included a control potting soil (a 3:1:1 mixture of peat, perlite, and vermiculite), and soil collected from the top 5 cm of areas adjacent to the experiment plots. Seeds in each flat were watered daily, and the number of germinating seeds was counted every 3 to 4 days for approximately 30 days.

Site Preparation

In April 1993, two 10 x 5-m (33' x 15') plots were marked on each of four aspects, north, south, east, and west, on shallow slopes of reclaimed mine sites at the PRP. Two 9-m^2 sub-plots were marked in each of the plots with a space of 0.5 m (1.6-ft) separating the sub-plots. Permanent sub-plots of 1-m^2 (11-ft^2) were marked at the center of each 9-m^2 sub-plot for cover surveys. In

total, each mixture was seeded in eight sub-plots at each site.

The standard revegetation mixture from hydroseeding conducted the previous year began to emerge in March. In April, plots were sprayed with a glyphosate herbicide (Roundup®, Monsanto) to eradicate preexisting vegetation. Roundup® is a topically applied, systemic herbicide that kills nonwoody plants; however, it does not affect seed viability. A 0.5% solution of concentrate was mixed with water on site, and plots were sprayed using a backpack sprayer. Each block was sprayed twice, with an interval of 12 days between sprayings. All vegetation soon displayed symptoms of chlorosis and died within 14 days of spraying.

In May, each 9-m^2 sub-plot was seeded with either the standard or wildflower revegetation mixture. Seed mixtures were preweighed for each sub-plot, with seeding densities for the wildflower mixture calculated according to standard specifications from national wildflower seed companies. Most companies recommended sowing 100-120 seeds per 0.093 m^2 (1 ft^2) to provide maximum coverage of disturbed areas. Pure live seeds estimates were not used because they were not available from all companies. Grasses were seeded at a density of 270 gm/ha (0.25 lb/acre) for each species. One species, showy evening primrose, was only seeded on north and south facing aspects because of a shortage of seed. Seed amounts in the standard mixture were determined differently because the donated seeds had arrived premixed. An estimation of the number of seeds was made based on the number of seeds commonly found per gram of each species and then multiplied by the number of seeds needed to complement the number of seeds being seeded in the wildflower mixture. A total of approximately 11610 seeds were mixed with 500 g (1 lb) coarse construction sand and spread by hand broadcasting on each 9-m^2 sub-plot.

Table 1. Percent germination of 100 seeds of each species in the standard reclamation and wildflower mixture in potting soil and mine soil.

Scientific name[1]	% Germination PS[2]	MS
STANDARD MIX		
Annual rye	87	93
Birdsfoot trefoil	65	62
Clover	64	71
Foxtail millet	62	50
Kentucky-31 tall fescue	69	63
Orchard grass	85	67
Red top	64	71
Sweet clover	69	57
WILDFLOWER MIX		
Annual sunflower	4	4
Bergemont	49	0
Big bluestem	29	37
Black-eyed susan	57	28
Catchfly	78	52
Cornflower	70	28
Dame's rocket	60	0
Lance-leaved coreopsis	51	48
Little bluestem	14	33
New England Aster	55	14
Perennial lupine	37	17
Plains coreopsis	71	38
Showy evening primrose	53	11
Stiff goldenrod	57	0

[1]Common names and addresses of seed suppliers listed in Appendix 1
[2]PS = potting soil; MS = mine soil

No fertilizers nor irrigation was applied to plots.

Vegetation Measurements and Analyses

The plots were monitored biweekly between late May and early September in 1993 and 1994. On each sampling date, percent cover and species richness of planted species were recorded in the 1 m^2 at the center of sub-plot. Percent cover and composition of naturally invading species were also recorded, but these data are not presented here.

Results of species richness and cover measurements were combined for north and south aspects, as well as east and west aspects, as results were similar. Species richness values include observations from the entire field season, while cover measurements from mid-August are reported.

Soil Analyses

In May 1993 and August 1994, composite soil samples were taken from each experimental plot. All analyses were done by the Virginia Tech Soil Testing Laboratory.

Results

Germination rates for species in the standard mixture were all ≥50% and were similar in both potting and mine soils (Table 1). Germination rates for species in the wildflower mixture were mostly ≥50% in potting soil but ≤50% in mine soils. Germination rates for species in the wildflower mixture were lower in mine soils for all species except the two grasses, little bluestem and big bluestem. One species, annual sunflower, had a 4% germination rate in both potting and landfill soil.

In the field experiments, species richness was significantly higher in wildflower plots in all cases except east and west plots in 1993 (Table 2). However, this would be expected as more wildflower species were planted. The percent of seeded species that germinated was also higher in wildflower plots. This difference was statistically significant on north and south facing plots in 1993 (Table 2).

Only four of eight species in the standard reclamation mixture became established, and one species, foxtail millet, was only observed in two plots in year 1 (Table 3). Dominant species in standard mixture plots in both 1993 and 1994 were birdsfoot trefoil and clover. Twelve of fourteen species in the wildflower mixture became established (Table 3). Only stiff goldenrod and little bluestem were not recorded in experimental plots. Lance-leaved coreopsis, plains coreopsis, and black-eyed Susan were widespread in both years. Two annuals, cornflower, and catchfly, were common in year 1, but were rarely observed in the year 2. Big bluestem, New England aster, Dame's Rocket and bergemont were not observed in year 1, but became established in year 2.

Total cover of planted species for both seed mixtures was low in both years, but increased from 1993 to 1994 (Table 4). Cover was much higher in north and south plots than in east and west plots, which may be due to reoccurrence of previously established vegetation on north and south plots. In 1994, cover levels were significantly higher in north and south plots seeded with the standard reclamation mixture. However, these plots were dominated by birdsfoot trefoil, which partially regrew from plants seeded before the study.

Soil pH, nitrate, and organic matter levels were much lower on east and west facing slopes at the time of seeding, while phosphorus, potassium, and calcium levels were similar (Table 5). None of these variables changed greatly within the 15-month study period. Seed mixture did not have a significant effect on any of the variables measured.

Discussion

Results of field studies suggest that a number of native and naturalized wildflower species have potential for revegetating mined areas, despite the many obstacles to establishing vegetation on these sites, such as low pH, soil compaction, elevated surface temperatures, water stress, and low nutrients. All but two of the wildflower and native grass species became established in experimental plots. Cover levels were similar in areas seeded with the standard reclamation and wildflower mixtures.

Table 2. Mean species richness and percent of seeded species that germinated for standard and wildflower mixtures in 1993 and 1994.

Year	Aspect	Species richness[1] Standard	Wildflower	p[2]	% of species germinating Standard	Wildflower	p
1993	North/south	2.3 ± 0.5	6.0 ± 0.8	***	28 ± 7	39 ± 4	*
	East/west	2.0 ± 0.0	4.0 ± 2.0	NS	25 ± 1	31 ± 16	NS
1994	North/south	2.3 ± 1.0	6.0 ± 1.4	**	29 ± 12	43 ± 10	NS
	East/west	2.3 ± 1.0	6.0 ± 1.4	**	31 ± 13	46 ± 10	NS

[1]Mean ± standard deviation
[2]NS = p>0.05, *p<0.05, **p<0.01, ***p<0.001

Table 3. Frequency and cover measurements for standard reclamation and wildflower species seeded on mine sites.

Scientific name	Number of plots[1] 1993	1994	Cover ranking[2] 1993	1994
STANDARD MIX				
Annual rye	-	-	-	-
Birdsfoot trefoil	8	8	3	4
Clover	8	4	3	1
Foxtail millet	2	1	-	-
Kentucky-31 tall fescue	-	-	-	-
Orchard grass	-	-	-	-
Red top	-[3]	-	-	-
Sweet clover	1	4	1	2
WILDFLOWER MIX				
Annual sunflower	6	-	1	-
Bergemont	-	5	-	2
Big bluestem	-	7	-	1
Black-eyed susan	8	8	1	2
Catchfly	3	-	1	-
Cornflower	6	1	2	1
Dame's rocket	6	2	1	1
Lance-leaved coreopsis	8	7	1	2
Little bluestem	-	-	-	-
New England Aster	-	4	-	2
Perennial lupine	3	2	1	1
Plains coreopsis	8	5	1	1
Showy evening primrose[4]	4	2	-	-
Stiff goldenrod	-	-	-	-

[1]Number of plots out of a total of eight in which each species was recorded
[2]Average cover of each species in mid-August using ranking system: 0-1% = 1, 1-5% = 2, 5-10% = 3, >10% = 4
[3]Represents no appearance of the species within the experimental plot
[4]Only seeded in four plots on north and south facing slopes

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Appendix 1. Species scientific names and seed suppliers.

Common Name	Scientific Name	Seed Provider
STANDARD MIX		
Annual rye	*Secale cereale*	1
Birdsfoot trefoil	*Lotus corniculatus*	1
Clover	*Trifolium* spp.	1
Foxtail millet	*Setaria italica*	1
Kentucky 31-tall fescue	*Festuca arundinacea*	1
Orchard grass	*Dactylis glomerata*	1
Red top	*Agrostis alba*	1
Sweetclover	*Melilotus* spp.	1
WILDFLOWER MIX		
Annual sunflower	*Helianthus annuus*	2
Bergemont	*Monarda fistulosa*	3
Big bluestem	*Andropogon gerardii*	2
Black-eyed susan	*Rudbeckia hirta*	4
Catchfly	*Silene armeria*	2
Cornflower	*Centaurea cyanus*	4
Dame's rocket	*Hesperis matronalis*	4
Lance-leaved coreopsis	*Coreopsis lanceolata*	4
Little bluestem	*Schizachrium scoparius*	3
New England aster	*Aster novae-angliae*	2
Perennial lupine	*Lupinis perennis*	4
Plains coreopsis	*C. tinctoria*	4
Showy evening primrose	*Oenothera speciosa*	5
Stiff goldenrod	*Solidago rigida*	5

[1]Country Boy
1811 Gate City Hwy.
Bristol, TN 24201

[2]Applewood Seed Co.
5380 Vivian St
Arvada, CO 80002

[3]Prairie Nursery
P. O. Box 306
Westfield, WI 53946

[4]Lofts
P. O. Box 146
Bound Brook, NY 08805

[5]S&S Seeds
P. O. Box 1275
Carpenteria, CA 93013

PREDICTING GRASS STAND ADEQUACY FROM EARLY STAND PARAMETERS[1]

by

R. E. Ries[2]

Abstract. Early evaluation of grass stand establishment is important for making timely decisions on reseeding or proper management that will enhance the new grass stand. A field study with 5 species, 11 seeding dates per year, and 3 replications was conducted to determine which dates resulted in the best stands when direct seeded into wheat stubble using the same seeding techniques at each date. Seedings were made during the seeding years of 1987, 1988, and 1989. Stands were monitored for 5 years, 2 years after each seeding year. The number of grass seedlings m^{-2} was measured 45 days after emergence. This early stand parameter was correlated with the number of grass plants m^{-2}, number of grass stems m^{-2}, and grams of grass dry matter m^{-2} measured 2 years after the seeding year. The highest correlation coefficients ($P<0.01$) were between the number of grass seedlings m^{-2} 45 days after emergence and the number of grass stems m^{-2} 2 years after seeding for smooth bromegrass, western wheatgrass, crested wheatgrass, and sideoats grama. Correlation coefficients were 0.69, 0.59, 0.71, and 0.41, respectively. The highest correlation coefficient (0.71, $P<0.01$) for blue grama was between the number of grass seedlings m^{-2} 45 days after emergence and the number of grass plants m^{-2} 2 years after seeding. Predictions of expected grass stems m^{-2} at 2 years after seeding and actual measured stems m^{-2} at 2 years were compared with a standard number of stems need for a successful stand. A decision on stand success made from the seedlings m^{-2} at 45 days after emergence was correct 100, 85, and 76% of the time for smooth bromegrass, western wheatgrass, and crested wheatgrass, respectively. For blue grama, prediction of stand success from the number of seedlings present 45 days after emergence was correct 79% of the time. Two year success estimates were not determined for sideoats grama because the relationship of seedlings m^{-2} and stems m^{-2} was only significant 1 out of 3 seeding years. Based on these results, a reasonable estimate of stand adequacy at 2 years after seeding may be predicted by the number of grass seedlings counted at 45 days after emergence.

Additional Key Words: seedlings m^{-2}, stems m^{-2}, plants m^{-2}, grams m^{-2}, regression equation, parameter correlations, smooth bromegrass, sideoats grama, western wheatgrass, blue grama, crested wheatgrass.

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Introduction

Monitoring changes occurring in vegetative communities has been recognized as the key to natural resource management (Bonham 1989). Changes occurring in grass stands are an indication that management changes may be needed to initiate and maintain productive stands. The relationship of early stand characteristics with productive and established stand characteristics is important to early determination of grass seeding success or failure. Early detection of seeding failures or marginal grass stands can result in timely decisions to reseed or apply proper management that will enhance the young grass stand. Vallentine (1979) indicated that monitoring new grass seedings should begin as soon as reliable data can be measured. Data evaluation indicating when monitoring of new grass stands should begin is scarce. Little information is available in the literature concerning the relationship of early grass stand parameters with the parameters that characterize an established and productive grass stand. Cook and Stubbendieck (1986) recommended that stand establishment measurements of perennial plants seeded in the semi-arid range should start near the end of the second growing season. According to their experience, only tentative data on new stand characteristics could be obtained during the first growing season. Ries and Svejcar (1991) reported data that suggest new stands of crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] and blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] could be considered established 21 days after emergence under the specific environmental conditions of their study. The purpose of this current paper is to characterize the relationships between grass stand parameters found during early and late stand development.

Study Area and Methods

This study was conducted at the USDA-ARS Northern Great Plains Research Laboratory, Mandan, North Dakota, to evaluate 11 seeding dates per year over 3 seeding years. The study was conducted on a Parshall fine sandy loam soil (coarse-loamy, mixed *Pachic Haploborolls*) on nearly level terrain. Monoculture grass seedings were made directly into spring wheat stubble with a double disk cone seeder with depth bands and packer wheels. Seedings were made August 15, September 4 and 24, October 9, November 1, April 1 and 21, May 9 and 26, June 10, and July 1 during the seeding years of 1987 (1986-87), 1988 (1987-88), and 1989 (1988-89). All species were seeded at 9 kg ha^{-1} pure live seeds at a depth of about 13 mm. Species studied included 3 cool-season grasses, smooth bromegrass [*Bromus inermis* Leyss., 'Lincoln'], western wheatgrass [*Agropyron smithii* Rydb., 'Rodan'; syn. = *Pascopyron smithii* (Rydb.) Löve], and crested wheatgrass, [*Agropyron desertorum* (Fisch. ex Link) Schult.) 'Nordan']. Two warm-season grasses were also evaluated; sideoats grama [*Bouteloua curtipendula* (Michx.) Torr., 'Pierre'], and blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud., native collection].

Plots (3 m wide and 7.6 m long) were arranged in a randomized complete block design, split/split plot in time with 3 replications. Whole plots were years, with the first split species and the final split seeding date. Grass stands were sampled for seedling density (plants m^{-2}) 45 days after emergence was observed by counting the seedlings present on 5 randomly located 30.5 by 30.5 cm plots for each species and seeding date. The stands were sampled again during the growing season at near peak biomass accumulation (between July 1-15) 1 and 2 years after the seeding year. Measurements of grass plant density (plants m^{-2}), stem density (stems m^{-2}), and dry matter

(grams m^{-2}) were taken by counting the number of grass plants and grass stems, and then clipping and oven drying (60°C for 48 h) grass plants sampled from 5 randomly located 30.5 by 30.5 cm plots for each species and seeding date.

Environmental conditions during the study were monitored by a weather station located on the study area following National Weather Bureau standards. Weather conditions measured included air temperature at 2 m above the soil, soil temperature at 16 mm-soil depth, precipitation, and free water evaporation from a Class A pan.

The grass species studied did not respond in the same manner to study conditions; therefore, correlation/regression analyses were conducted by species. Each seeding year included 11 seeding dates and 3 replications for a total of 33 observation. Since weather conditions and seedling response at each seeding date within each seeding year were different, an average function was developed by including data from all 3 years for a total of 99 observations. The number of grass seedlings m^{-2} counted at 45 days after emergence was correlated with the number of grass plants m^{-2}, number of grass stems m^{-2}, and grams of grass dry matter m^{-2} measured in each stand at near peak biomass accumulation 1 and 2 years after the seeding year.

Regression equations for the parameters with the highest correlation coefficients that were significant for all 3 seeding years were determined. The number of grass stems m^{-2} expected 2 years after the seeding year were predicted for smooth bromegrass, western wheatgrass, and crested wheatgrass by the regression equation developed for the relationship of the number of grass stems m^{-2} at 2 years (Y) with the number of grass seedlings m^{-2} at 45 days after emergence (X). The number of grass plants m^{-2} expected 2 years after seeding for blue grama were predicted by the regression equation for the relationship of the number of grass plants m^{-2} at 2 years (Y) with the number of grass seedlings at 45 days after emergence (X). A standard of 11 plants m^{-2} (Great Plains Council 1966) at 45 days after emergence was accepted as a measure of a successful grass seeding. The same regression equations were used to predict the expected number of stems m^{-2} or number of plants m^{-2} (blue grama) after 2 years that would be expected from a successful stand with 11 plants m^{-2} at 45 days after emergence. The predicted and actual measured stems m^{-2} or plants m^{-2} during the growing season 2 years after seeding were compared with the expected stems m^{-2} or plants m^{-2} for a successful stand. When either the actual or predicted values was less than the successful stand density, an error in estimating stand success from 45 days after emergence data occurred. Thirty-three stands minus the number of errors equalled the number of successful stands predicted from 45 days after emergence data. The number of successful stands predicted divided by 33 equalled the percent success.

The relationships of all combinations of average grass plants m^{-2} with grass stems m^{-2} with grams of grass dry matter m^{-2} measured 2 years after seeding were also quantified by correlation analysis. Relationships of all combinations of average grass plants m^{-2} with grass stems m^{-2} with grams of grass dry matter m^{-2} measured at 1 year and 2 years after seeding were also established by correlation analysis.

Results and Discussion

Weather during this 5 year study was variable among months as is common for the semi-arid area of the Northern Great Plains. Air temperatures for August through October were lower than long-term averages for the study area, while air temperatures for April through July were above the long-term

average (Table 1). Mean soil temperatures at the 16 mm-soil depth were warmest during July with an average of 25.6 C (Table 1).

Soil temperatures for August and June were 23.2 and 23.7 C, respectively. During the months of August and May precipitation was highest at 60 and 61 mm, respectively. August precipitation was 10 mm higher than the long-term average, while the May precipitation was about equal to the long-term average. The greatest amount of free water evaporation during the study was observed during July and was only 6 mm more than the long-term average. April and June free water evaporation were also above the long-term average during this study (Table 2).

Table 1. Range, average (1986-91), and long-term average mean monthly air and soil temperatures (°C).

Month	Mean Air Temp. @ 2 m			Mean Soil Temp. @ 16 mm		
	Range	Avg.	LTA[1]	Range	Avg.	LTA[2]
Aug	18 to 22	19.7	20.4	20 to 27	23.2	--
Sep	11 to 16	13.9	14.0	12 to 18	16.1	--
Oct	5 to 7	6.5	7.8	7 to 9	7.6	--
Nov	-4 to 2	-1.1	-1.8	1 to 2	0.5	--
Apr	6 to 10	7.7	5.3	9 to 12	10.3	--
May	13 to 16	14.1	12.5	16 to 19	17.5	--
Jun	18 to 25	20.1	19.4	21 to 30	23.7	--
Jul	21 to 24	22.2	21.6	24 to 29	25.6	--

[1] LTA = long-term average--78 years (1914-1991).
[2] LTA not available.

Table 2. Range, average (1986-91), and long-term average monthly precipitation and free water evaporation (mm).

Month	Precipitation			Free Water Evaporation		
	Range	Avg.	LTA[1]	Range	Avg.	LTA[2]
Aug	38 to 99	60	50	115 to 231	182	203
Sep	1 to 108	38	40	80 to 154	126	130
Oct	0 to 6	4	21	--	--	--
Nov	0 to 71	18	11	--	--	--
Apr	0 to 58	22	39	112 to 174	139	106
May	20 to 88	61	57	131 to 185	158	173
Jun	4 to 112	52	89	186 to 282	213	195
Jul	21 to 95	44	57	164 to 287	238	232

[1] LTA = long-term average--78 years (1914-1991).
[2] LTA = long-term average--28 years (1964-1991).

The largest significant correlation coefficients ($P<0.01$) were for the number of seedlings m^{-2} 45 days after emergence and the number of stems m^{-2} 2 years after the seeding year for smooth bromegrass, western wheatgrass, crested wheatgrass, and sideoats grama. Coefficients were 0.69, 0.59, 0.71, and 0.41, respectively (Bold numbers in Table 3). Number of seedlings m^{-2} at 45 days after emergence was most highly correlated with the number of plants m^{-2} 2 years after seeding for blue grama ($r = 0.71$, $P<0.01$, Table 3). Correlation coefficients for these relationships for individual study years are shown in Table 4.

Table 3. Correlation coefficients (r) for seedlings m^{-2} at 45 days after emergence with grass stand parameters at 2 years after seeding for all 3 seeding years (n=99).

	Parameters		
Species	plants m^{-2}	stems m^{-2}	grams m^{-2}
Smooth bromegrass	0.54**	**0.69****	0.56**
Western wheatgrass	0.52**	**0.59****	0.47**
Crested wheatgrass	0.69**	**0.71****	0.41**
Sideoats grama	0.39**	**0.41****	0.20*
Blue grama	**0.71****	0.64**	0.36**

**P<0.01 -- Bold type indicates largest r value.
*P<0.05

Table 4. Correlation coefficients (r) for seedlings m^{-2} at 45 days after emergence with stems m^{-2} or plants m^{-2} (Bogr) at 2 years after seeding.

Species	1987	1988	1989	1987-89 Avg.
Smooth bromegrass	0.63**	0.69**	0.44*	0.69**
Western wheatgrass	0.75**	0.60**	0.40*	0.59**
Crested wheatgrass	0.75**	0.78**	0.59**	0.71**
Sideoats grama	0.30^{ns}	0.15^{ns}	0.54**	0.41**
Blue grama	0.62**	0.80**	0.68**	0.71**
# of observations	n=33	n=33	n=33	n=99

**P<0.01
*P<0.05

Most of the correlation coefficients were significant during each year except for sideoats grama where coefficients were nonsignificant during the 1987 and 1988 seeding years. Because of the insignificance of this relationship during some years, the regression equation was not used to predict stand parameters 2 years after seeding (Table 5). The equations used to predict future stand parameters for smooth bromegrass, western wheatgrass, crested wheatgrass, and blue grama are presented in Table 5.

Table 5. Regression equations quantifying the relationship of stems m^{-2} or plants m^{-2} at 2 years after seeding with seedlings m^{-2} present at 45 days after emergence (n=99)[1,2,3].

smooth bromegrass	
stems m^{-2} @ 2 yrs. = 270.43 + 4.11 (seedlings m^{-2} @ 45 days)	r^2 = 0.48**
western wheatgrass	
stems m^{-2} @ 2 yrs. = 374.49 + 7.27 (seedlings m^{-2} @ 45 days)	r^2 = 0.35**
crested wheatgrass	
stems m^{-2} @ 2 yrs. = 544.53 + 6.80 (seedlings m^{-2} @ 45 days)	r^2 = 0.50**
blue grama	
plants m^{-2} @ 2 yrs. = 5.10 + 0.18 (seedlings m^{-2} @ 45 days)	r^2 = 0.50**

[1] P>T = 0.0001 for intercept.
[2] P>T = 0.0001 for regression coefficient.
[3] P>F = 0.0001 for overall equation.
**P<0.01

These equations were used to predict the expected number of stems m^{-2} or plants m^{-2} (blue grama) 2 years after seeding from seedlings m^{-2} data measured 45 days after emergence. Correct predictions of stand success based on the number of stems m^{-2} were made 100, 85, and 76% of the time using the regression equations for smooth bromegrass, western wheatgrass, and crested wheatgrass, respectively. Correct predictions of stand success were made 79% of the time based on the number of plants m^{-2} expected for blue grama. Based on these results, a reasonable estimate of stand adequacy at 2 years after seeding may be predicted by the number of seedlings present 45 days after emergence.

There was also a highly significant relationship between the number of stems m^{-2} and grams dry matter m^{-2} 2 years after seeding (Table 6). For all species, a measure of stems m^{-2} strongly reflected grams dry matter m^{-2}. This suggests that a good estimate of grams of grass dry matter m^{-2} for a 2 yr old stand could be obtained from the counted number of stems m^{-2} rather than the clipping, oven drying, and weighing usually required when stand production is of interest.

Table 6. Correlation coefficients (r) for stems m^{-2} with grams dry matter m^{-2} at 2 years after seeding (n=99).

Species	grams m^{-2}
smooth bromegrass	0.74**
western wheatgrass	0.92**
crested wheatgrass	0.78**
sideoats grama	0.74**
blue grama	0.78**

**P<0.01

The parameters of plants m^{-2}, stems m^{-2}, and grams dry matter m^{-2} measured 1 year after seeding were significantly correlated with the same parameter measured 2 years after seeding. The highest correlation coefficients were 0.77 and 0.73 for the number of stems m^{-2} (year 1 with year 2) for smooth bromegrass and western wheatgrass, respectively (Bold numbers in Table 7).

Table 7. Correlation coefficients (r) between grass stand parameters measured 1 year and 2 years after seeding (n=99).

	Species				
	Smooth bromegrass	Western wheatgrass	Crested wheatgrass	Sideoats grama	Blue grama
	plants m^{-2}				
Year 1	37	32	28	15	13
Year 2	25	49	29	13	11
r	0.59**	0.42**	**0.89****	**0.88****	**0.88****
	stems m^{-2}				
Year 1	268	277	488	286	343
Year 2	476	665	1040	356	610
r	**0.77****	**0.73****	0.80**	0.56**	0.87**
	grams m^{-2}				
Year 1	130	56	122	43	17
Year 2	299	204	351	118	74
r	0.63**	0.71**	0.47**	0.70**	0.78**

**P<0.01 -- Bold type indicates largest r value.

Correlation coefficients of 0.89, 0.88, and 0.88 were obtained for the number of plants m^{-2} (year 1 with year 2) for crested wheatgrass, sideoats grama, and blue grama, respectively (Bold numbers in Table 7). The number of stems m^{-2} was better related between year 1 and year 2 for the two rhizomatous species, while the number of plants m^{-2} was better related between year 1 and year 2 for the bunch-grass type species. This occurs because of the difficulty in identifying individual plants for rhizomatous species while counting the number of stems of rhizomatous species is readily repeatable. Similar information was reported by Cook and Stubbendieck (1986) and Bonham (1989). The significant correlations between year 1 and year 2 stand parameters support the concept that valid evaluation of grass stand success can be made 1 year after seeding when this period includes a winter dormant period (McWilliams 1955 and Cook and Stubbendieck 1986).

Summary

A good evaluation of stand parameters best used in evaluating grass stand success have been found from this study. Seedlings m^{-2} present 45 days after emergence were a reliable measure that correlated well with stems m^{-2} 2 years after seeding for smooth bromegrass, western wheatgrass, crested wheatgrass, and sideoats grama. Seedlings m^{-2} 45 days after emergence were better correlated with plants m^{-2}

than stems m^{-2} after 2 years for blue grama. A significant relationship between stems m^{-2} and grams dry matter m^{-2} 2 years after seeding was found. Data also showed that stand parameters 1 year after seeding were highly correlated with the same parameters 2 years after seeding, further suggesting that stand success can be evaluated 1 year after seeding when this year includes a dormant period. Stems m^{-2} 1 year and 2 years after seeding were more highly correlated for rhizomatous species; while, plants m^{-2} 1 year and 2 years after seeding were more highly correlated for bunchgrass species.

Results from this study are encouraging that good estimates of stand success may be made as early as 45 days after emergence. Estimates made in our study were quite successful and can be used along with good observations and judgment when evaluating stands as early as 45 days after grass seedling emergence. The r^2 for our study range from 0.35 to 0.50 for the relationship of seedlings m^{-2} 45 days after emergence with stems or plants m^{-2} 2 years after seeding. Except for sideoats grama, the relationship was significant in each seeding year. The goal now is to improve these r^2 numbers by adding secondary stand parameters that may further define the establishment level of the grass seedlings at 45 days after emergence. Addition of specific weather conditions may also increase these initial r^2 numbers. Both secondary stand parameters or weather conditions may improve the relationship of seedlings m^{-2} 45 days after emergence with the success of the stands 1 year or 2 years after seeding.

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VEGETATION DIVERSITY WITHIN NATIVE AND RECLAIMED COAL MINE SITES: ENVIRONMENTAL FACTORS AND SEASONAL VARIABILITY[1]

by

Brenda K. Schladweiler and George F. Vance[2]

Abstract Within arid and semiarid environments of western North America, vegetation composition, i.e., quantity and quality of plant species, can be highly variable on native lands and reclaimed coal mine sites. Therefore, we examined the vegetation composition within 23 native and 79 reclaimed plots at two active coal mines in the Powder River Basin, Wyoming. Cool season, warm season and annual grasses, annual and perenial forbs, and half and full shrubs were inventoried and sampled once in 1991 and twice during 1992 and 1993. Seasonal variation was determined based on site data and plant sampling during early (May) and late (July and August) growth stages. General conclusions drawn from vegetation cover results, i.e., species composition, diversity, and trends, suggest the following relations. Based on age of reclaimed areas, species composition changed from early successional plants to longer-lived individuals. Diversity of the seeded areas reflected actual seed mixes with some invasion based on reclamation method such as direct haul topsoil versus stockpiled topsoil and post-management techniques (e.g. livestock grazing). On native areas, lifeform category cover percentages, e.g., annual grasses and forbs, varied with climate factors such as precipitation and temperature. Such factors had a strong influence on the presence of certain plant species. Due to the extreme variability in weather conditions over the three-year project, we can only conclude that much of the vegetation variability was due to weather conditions.

Additional Key Words: Species Composition, Diversity, Trends, Lifeforms, Grasses, Forbs, Shrubs, Weather, Native, Reclaimed

Introduction

The Powder River Basin (PRB) coal region currently contains twenty-one active or proposed coal mines on a north-south trend within a 700 square mile area surrounding the towns of Gillette and Wright, Wyoming. Based on funding from the Abandoned Coal Mine Lands Research Program (ACMLRP), an intensive three-year study was conducted from 1991 to 1993 to determine the relationship between soil Se levels and plant uptake levels at native and reclaimed areas at two active coal mines within the PRB.

The main objective of this three-year study was to identify possible plant and soil Se relationships. A secondary role of that project was to determine differences in Se uptake between species growing on either native or reclaimed areas.

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This paper presents results of the 1991 through 1993 vegetation sampling programs. Results presented are preliminary as detailed statistical analysis of the specific vegetation encountered during the sampling has not been completed.

Methodology

Fieldwork was conducted on two active mines south of Gillette, Wyoming, within the PRB coal region of northeastern Wyoming. These two mines were ARCO's Black Thunder Mine (BTM), approximately 55 miles southeast of Gillette, and Coal Creek Mine (CCM), approximately 30 miles southeast of Gillette. Vegetation sampling was conducted in 1991 through 1993. Vegetation was sampled once in 1991 and twice in 1992 and 1993; the dual sampling in 1992/1993 was conducted to determine seasonal differences, i.e., May to late July/August.

Twenty-three native area (13 from BTM and 10 from CCM) sample locations were sampled during all three years. Reclaimed area sampling locations were: 79 (71 from BTM and 8 from CCM) in 1991 and 1993, and 52 (44 from BTM and 8 from CCM) in 1992. Within native areas, sample locations were randomly chosen to represent all vegetation types present on the active mine permit areas.

Sample locations were placed among reclaimed areas ranging from 2 to 10 years since revegetation. Sample locations were marked with steel metal fence posts, which were located 7.5 m south of the actual sample location, to prevent any deleterious effects on the vegetation from grazing animals.

Vegetation sampling was conducted at each of the 79 sample locations in 1991 and 1993; questionable vegetation analysis reduced the number of original 1991 sample locations. According to the original purpose of the study, a five to ten gram vegetation sample for selenium content was collected within a 3.5 m radius from the center of the site. Sampled plants included the dominant four species, based on a visual determination of relative site cover, and a composite grass sample designed to simulate herbivore grazing. General plant cover was visually estimated using a system that grouped plants into the following gross cover percent categories: <1, 1-10, 11-25, 26-50, 51-75, 76-100. It is this vegetation cover from which species composition and diversity were derived and are summarized in this paper.

Results

Based on a review of the compilation of the total number of species encountered during sampling by mine, type, and sampling period (Table 1), some conclusions can be drawn. One observation is the extremes in diversity between native and reclaimed areas. The number of species encountered on reclaimed areas at the Coal Creek Mine were approximately 50 to 70% of the number encountered during sampling of native areas. For the Black Thunder Mine, only 50 to 80% of the total number of species observed on native areas were determined in surveys of reclaimed areas. This is primarily due to the reduced number of species within a seed mix, but is also likely a product of topsoil stripping and placement, i.e., direct haul versus stockpiled material. The direct haul material is not stored and would contain a much greater source of viable seeds from recently stripped areas. Perennial forb reduction was noticeable at both Black Thunder and Coal Creek Mines.

In addition to the change in the number of species encountered during sampling, lifeforms generally changed as well. Prior to disturbance, the major lifeform categories at the Black Thunder Mine in terms of number of species encountered were cool season grasses, annual forbs, and perennial forbs. Annual forbs were conspicuously limited at the Coal Creek Mine, which may indicate less disturbance either from oilfield activity, grazing

Table 1. Number of different species encountered by lifeform category for each sampling period. Note: 1991 Black Thunder data based on selenium sampling, not cover estimates, which were done in 1992 and 1993.

Sampling Date	Mine	Type	CSG	WSG	AG	AF	PF	HS	FS	SUC	TOTAL
1991	BTM	N	4	0	0	0	2	1	1	0	8
		R	11	5	5	16	11	3	5	1	57
	CCM	N	19	1	3	10	33	4	3	1	74
		R	16	4	3	14	11	2	2	1	53
Early	BTM	N	15	2	1	17	37	4	2	1	79
1992		R	14	4	3	16	14	3	4	1	59
	CCM	N	14	1	2	2	35	5	3	1	63
		R	16	2	1	7	8	2	1	0	39
Late	BTM	N	14	4	2	11	33	3	2	1	70
1992		R	13	6	4	13	11	3	4	1	55
	CCM	N	15	1	3	3	39	5	3	1	70
		R	14	2	2	7	9	2	2	0	38
Early	BTM	N	14	2	3	13	38	3	1	1	75
1993		R	12	4	3	17	17	3	4	1	61
	CCM	N	16	1	3	7	44	5	4	1	81
		R	16	3	2	9	15	3	3	1	52
Late	BTM	N	19	5	3	19	42	4	1	1	94
1993		R	11	5	3	12	11	3	4	1	50
	CCM	N	11	1	1	3	20	4	3	1	44
		R	10	1	1	4	9	2	2	0	29

MINE: BTM = Black Thunder Mine; CCM = Coal Creek Mine
TYPE: N = Native; R = Reclaimed
LIFEFORM: CSG = Cool Season Grass; WSG = Warm Season Grass; AG = Annual Grass; AF = Annual Forb; PF = Perennial Forb; HS = Half Shrub; FS = Full Shrub; SUC = Succulent; TOTAL = Total Species

pressure, or roads. Cool season grasses were also a significant part of the overall numbers of species at the Coal Creek Mine. Curiously, the number of warm season grasses went up on the reclaimed areas versus native areas at the Coal Creek Mine; however, cover percentages were not similar to native areas.

Weather patterns played a significant role in the distribution of lifeform category numbers during the sampling years. During 1991, late spring rains and cooler temperatures favored cool season grass and annual forb growth. During 1992, temperature

Table 2. Examples of vegetation diversity and percent cover on old (reclaimed >5 years from time of sampling) and young (reclaimed <5 years from time of sampling) areas. Note: 1991 Black Thunder data based on selenium sampling, not cover estimates, which were done in 1992 and 1993.

Reclamation	Vegetation Species	1991	Early 1992	Late 1992	Early 1993	Late 1993
		% Vegetation Cover				
Old	Agrdas	0-1	10-25	1-10	1-10	10-25
	Agrsmi	10-25	1-10	10-25	10-25	10-25
	Agrtra	0-1			1-10	
	Stivir	0-1	1-10	1-10	1-10	1-10
Young	Agrcri		0-1	0-1	0-1	0-1
	Agrdas	1-10	1-10	1-10	1-10	1-10
	Agrsmi	1-10	1-10	1-10	1-10	1-10
	Agrtra	1-10	1-10	10-25	10-25	1-10
	Oryhym	0-1	0-1	0-1	1-10	0-1
	Sticom		0-1		1-10	
	Bougra	0-1	1-10	0-1	0-1	
	Medsat	1-10	1-10	0-1	10-25	1-10
	Ratcol	0-1	0-1	0-1	1-10	0-1
	Cerlan	0-1	1-10	0-1	0-1	0-1
	Atrcan	0-1	0-1	0-1	1-10	0-1
	Opupol	0-1	0-1	0-1	0-1	0-1

and moisture averages for June and July were reversed, which resulted in reduced growth of cool season grasses and a greater abundance of warm season grasses. During 1993, higher amounts of moisture were noted in the earlier part of the growing season, which resulted in increased cool season grass and perennial forb growth for that year.

Species diversity within reclaimed areas generally reflect the seed mix used in revegation practices specific to the different mines and to age of reclamation. This was especially apparent in older reclaimed areas, i.e., greater than 5 years old at the time of sampling, which generally reflect less diverse seed mixes or a lack of innovative reclamation practices such as dual seeding of cool season grasses separate from shrubs and warm season grasses (Table 2). For example, at the Black Thunder Mine, the number of species encountered in one sampling period ranged from approximately 10 in older seeded areas to approximately 30 in newer seeded areas.

Table 3. Comparison of Big Sagebrush Grasslands at Black Thunder and Coal Creek Mines. Note: no cover estimates were done in 1991 at the Black Thunder Mine.

Mine	Vegetation Species	1991	Early 1992	Late 1992	Early 1993	Late 1993
		% Vegetation Cover				
Black	Agrsmi		0-1	1-10	1-10	0-1
Thunder	Carste		1-10		0-1	0-1
NATIVE	Koemac		0-1	0-1	1-10	1-10
	Stivir		0-1	1-10	1-10	1-10
	Bougra		0-1	1-10	1-10	1-10
	Gaucoc		1-10	0-1	1-10	0-1
	Vicame		0-1	0-1	1-10	0-1
	Arttri		1-10	1-10	10-25	1-10
Coal	Agrdas	1-10	1-10	1-10	1-10	0-1
Creek	Agrsmi		1-10	0-1	0-1	0-1
NATIVE	Carfil		0-1	0-1	0-1	
	Koemac	1-10	1-10	1-10	1-10	0-1
	Stivir	1-10	1-10	1-10	1-10	1-10
	Bougra			0-1	0-1	0-1
	Oxylam	1-10	1-10	0-1	1-10	0-1
	Artfri		1-10	1-10	1-10	0-1
	Arttri	1-10	1-10	1-10	1-10	1-10

The two mines sampled in this study varied greatly in their overall plant species composition. Soils at the Black Thunder Mine tend to be sandier; historically high grazing pressure has resulted in an increase in pricklypear cactus and warm season grasses. Soils at the Coal Creek Mine are heavier, i.e., clayier; grazing pressure at Coal Creek has favored increased sagebrush cover. Table 3 is a comparison of the plots, one at each mine, that were located in the same native vegetation type, i.e., Big Sagebrush Grassland.

Plant cover percentages varied both between years and seasons. Cool season grass cover declined from the early to late sampling periods while warm season grass cover increased. Overall, annual forb and annual grass cover declined also over that same time interval, although this was species specific, especially with forbs. Perennial forb cover also generally declined over a season due to reduced leaf area.

Yearly variations were primarily due to differences in amount and timing of precipitation. Differences in later growth season precipitation such as found in 1992 was due not only to regional weather patterns but to thunderstorm placement as well. This could create large differences between the two mines, even though they are only approximately 20 miles apart. Weather within the Powder River Basin during 1991 was unusually cool and wet during April and May and extended to the end of June. During 1992, April and May were above normal for temperature and provided little or no precipitation while June and July were below normal for temperature and above average for precipitation. In many respects, the spring and summer sampling periods were practically reversed during 1992 despite the calendar months.

Overall plant species observed for each mine, type, and sampling period are found in Table 4. Some of the differences described above are evident in this table. For example, the following observations are based on the number of species encountered (not cover percentages). More cool season grasses and warm season grasses were observed in Coal Creek reclaimed than Coal Creek native sites. Annual forbs were limited in Coal Creek native, while annual grasses were more numerous in Coal Creek native versus reclaimed sites. The diversity of perennial forbs and half shrubs is higher on the Coal Creek native sites. Full shrubs were also more dominant on Coal Creek native lands.

At the Black Thunder Mine the diversity in cool season grasses and annual forbs between native and reclaimed areas was mixed; however, diversity of warm season grasses increased on Black Thunder reclaimed sites. Annual grasses were slightly more predominant on Black Thunder reclaimed sites. The number of perennial forbs encountered increased on native sites with time. With the exception of broom snakeweed, half shrubs were generally equal between Black Thunder native and reclaimed sites; however, full shrubs increased on Black Thunder reclaimed sites.

Discussion

The previously described results indicate the importance of seasonality on collecting vegetation data within a given year and overall weather conditions between years. It is extremely important to note weather patterns, especially temperature and monthly precipitation amounts and distribution. This is true, not only in sampling for selenium content of vegetation, but also for overall species diversity and composition.

In addition to the selenium information derived from this project, some useful trend information was documented. Trend information is highly useful to mining personnel and regulators who ultimately must decide on bond release criteria. Longterm vegetation composition data, for three or more consecutive years (as was done in this project) or for three years spread over a ten year bonding period, is extremely important in indicating overall vegetation patterns. Successes and failures can be documented and management strategies adjusted accordingly.

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Table 4. Plant species observed on native and reclaimed areas at Coal Creek and Black Thunder Mines during 1991 to 1993. Note: 1991 Black Thunder data based on selenium sampling, not cover estimates, which were done in 1992 and 1993.

			Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
Code	Scientific Name	Common Name	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993
Cool Season Grasses																						
Agrcri	Agropyron cristatum	Crested Wheatgrass					X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Agrdas	Agropyron dasystachyum	Thickspike Wheatgrass	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Agrine	Agropyron inerme	Beardless Wheatgrass	X						X	X	X								X	X		X
Agrint	Agropyron intermedium	Intermediate Wheatgrass						X		X	X											
Agrsmi	Agropyron smithii	Western Wheatgrass	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Agrspi	Agropyron spicatum	Bluebunch Wheatgrass	X	X	X	X	X		X	X	X	X						X	X	X	X	X
Agrtra	Agropyron trachchycaulum	Slender Wheatgrass	X					X	X	X	X	X						X	X	X	X	X
Agrtri	Agropyron trichophorum	Pubescent Wheatgrass																X	X	X		
Broine	Bromus inermis	Smooth Brome						X	X	X	X	X						X	X	X	X	X
Carfil	Carex filifolia	Threadleaf Sedge	X	X	X	X	X							X	X	X	X					
Carste	Carex stenophylla	Elk Sedge	X	X	X	X								X	X	X	X					
Disspi	Distichlis spicata	Inland Saltgrass	X	X	X	X	X									X	X					
Elycin	Elymus cinearus	Basin Wildrye	X						X	X	X											
Horjub	Hordeum jubatum	Foxtail Barley	X					X										X	X			
Koemac	Koeleria macrantha	Prairie Junegrass	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X		X	
Oryhym	Oryzopsis hymenoides	Indian Ricegrass	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X
Poaamp	Poa ampla	Big Bluegrass	X	X	X	X	X	X	X	X	X			X			X					
Poacan	Poa canbyi	Canby Bluegrass	X	X	X	X								X	X	X	X				X	X
Poacus	Poa cusickii	Cusick Bluegrass						X	X		X			X								
Poafen	Poa fendleriana	Fendler Bluegrass												X		X	X					
Poajun	Poa juncifolia	Alkali Bluegrass	X	X	X	X																
Poapra	Poa pratensis	Kentucky Bluegrass	X		X	X		X						X			X					
Poasan	Poa sandbergii	Sandberg Bluegrass	X	X	X	X								X	X	X	X		X		X	
Poasp	Poa sp.	Bluegrass				X		X				X	X	X	X	X	X			X		
Schpan	Schedonnardus paniculatus	Tumblegrass													X	X	X					
Sticom	Stipa comata	Needle and Thread	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	
Stivir	Stipa viridula	Green Needlegrass	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	

Table 4. Continued

Code	Scientific Name	Common Name	Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
			1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	
Warm Season Grasses																						
Andsco	Andropogon scoparius	Little Bluestem						X			X				X			X	X	X	X	X
Boucur	Bouteloua curtipendula	Sideoats Grama						X	X	X	X	X						X		X		X
Bougra	Bouteloua gracilis	Blue Grama	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X
Callon	Calamovilfa longifolia	Prairie Sandreed						X									X	X	X	X	X	X
Spoair	Sporobolus airoides	Alkali Sacaton													X	X	X			X		
Spocry	Sporobolus cryptandrus	Sand Dropseed												X			X	X	X	X	X	X
Annual Grasses																						
Brojap	Bromus japonicus	Japanese Brome	X	X	X	X	X	X		X	X				X	X	X	X	X	X	X	X
Brotec	Bromus tectorum	Cheatgrass Brome	X	X	X	X		X				X		X	X	X	X	X	X	X	X	X
Fescot	Festuca occidentalis	Sixweeks Fescue	X		X	X										X	X	X				
Triaes	Triticum aestivum	Cultivated Wheat						X	X	X	X							X	X		X	
Annual Forbs																						
Alydes	Alyssum desertorum	Desert Alyssum	X					X			X						X	X				
Alyaly	Alyssum alyssoides	Pale Alyssum						X		X	X				X	X	X				X	X
Alyspp	Alyssum spp.	Alyssum						X	X										X			
Cammic	Camelina microcarpa	Littleseed Falseflax	X			X	X	X		X	X	X		X	X	X	X	X	X	X	X	X
Chealb	Chenopodium album	Lambsquarters						X	X	X	X			X			X		X	X	X	X
Chelep	Chenopodium leptophyllum	Chenopodium												X			X		X			
Chensp.	Chenopodium sp.	Chenopodium						X							X			X		X	X	
Cirsium	Cirsium sp.	Thistle					X							X	X							
Cirvul	Cirsium vulgare	Bull Thistle	X			X								X	X	X	X					
Despin	Descurainia pinnata	Pinnate Tansymustard						X	X	X	X	X		X		X	X	X	X	X	X	
Dessop	Descurainia sophia	Tansymustard	X																X		X	X
Gnapal	Gnapthalium palustre	Cudweed												X		X	X					

Table 4. Continued

Code	Scientific Name	Common Name	Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
			1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	
Kocsco	Kochia scoparia	Kochia						X	X	X	X			X	X	X	X	X	X	X	X	X
Lacser	Lactuce serriola	Prickly Lettuce										X		X	X		X					
Lepden	Lepidium densiflorum	Prairie Peppergrass			X	X								X		X	X	X	X	X	X	X
Lapred	Lappula redowskii	Stickseed									X			X	X	X	X	X	X	X	X	
Luppus	Lupinus pusillis	Lupine												X	X	X	X	X			X	X
Meloff	Melilotus officinalis	Yellow Sweetclover	X	X	X	X	X	X	X	X	X	X						X	X	X	X	X
Micgra	Microsteris gracilis	Microsteris												X		X	X					
Phalin	Phacelia linearis	Phacelia												X		X	X					
Plapat	Plantago patagonica	Pursh's Plantain	X	X	X	X								X	X	X	X	X	X	X	X	
Polavi	Polygonum aviculare	Prostrate Knotweed						X	X									X				
Salaus	Salsola australis	Russian Thistle						X	X	X	X				X		X	X	X	X	X	X
Sisalt	Sisymbrium altissimum	Tumbling Hedgemustard						X							X				X	X	X	X
Sisloe	Sisymbrium loeselii	Hedgemustard																X	X		X	X
Solros	Solanum rostratum	Nightshade						X														
Thlarv	Thlaspi arvense	Field Pennycress	X			X		X														
Perennial Forbs																						
Achmil	Achillea millefolium	Common Yarrow	X	X	X	X	X	X			X			X	X	X	X	X	X			
Alltex	Allium textile	Prairie Onion	X	X	X	X					X			X		X	X				X	X
Antpar	Antennaria parvifolia	Little Pussytoes			X	X										X						
Arehoo	Arenaria hookeri	Hooker Sandwort	X	X	X	X	X		X					X	X	X	X				X	
Arnica	Arnica sp.	Arnica												X	X	X	X					
Artlud	Artemisia ludoviciana	Louisiana Sagewort				X								X	X	X	X		X			
Astbis	Astragalus bisulcatus	Two-grooved Milkvetch	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Astcic	Astragalus cicer	Cicer Milkvetch	X					X	X	X	X	X				X		X	X	X	X	X
Astfal	Astragalus falcatus	Aster	X		X	X																

Table 4. Continued

Code	Scientific Name	Common Name	Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
			1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	
Astmol	Astragalus mollis	Milkvetch	X	X	X	X																
Astpur	Astragalus purshii	Wooly Milkvetch	X			X	X															
Astspa	Astragalus spatulatus	Spoonleaf Milkvetch	X	X	X	X	X							X	X	X	X					
Astspp	Astragalus sp.	Milkvetch	X											X	X		X			X		
Cirarv	Cirsium arvense	Canadian Thistle			X	X								X		X	X					
Comumb	Comandra umbellata	Bastard Toadflax		X	X	X								X	X	X	X					
Crepis	Crepis sp.	Hawksbeard												X	X	X	X					
Crycel	Cryptantha celosioides	Cryptantha	X	X		X																
Cryspp	Cryptantha sp.	Cryptantha					X							X	X	X	X					X
Dalcan	Dalea candida	Prairie Clover													X	X	X					
Equlae	Equisetum laevigatum	Horsetail												X	X	X	X					
Erigeron	Erigeron sp.	Fleabane												X			X			X		
Eripum	Erigeron pumilus	Daisy Fleabane	X	X	X	X								X	X							
Erioch	Erigeron ochroleucus	Fleabane		X		X	X				X			X	X	X	X					
Gaucoc	Gaura coccinea	Scarlet Gaura	X	X	X	X	X							X	X	X	X	X				
Glylep	Glycyrrhiza lepidota	Wild Licorice	X	X	X	X	X															
Grisqu	Grindelia squarrosa	Curlycup Gumweed	X	X	X	X	X															
Hapnut	Haplopappus nuttalianus	Nuttal goldenweed	X	X	X	X	X															
Hetvil	Heterotheca villosa	Wooly Goldenaster												X	X	X	X					
Ipocon	Ipomopsis congesta	Ipomopsis		X	X	X																
Ivaaxi	Iva axillaris	Iva	X		X	X																
Lesare	Lesquerella arenosa	Sand Bladderpod	X	X	X	X																
Lewred	Lewisia rediviva	Bitterroot		X	X	X																
Lomfoe	Lomatium foeniculaceum	Biscuitroot				X								X		X	X					
Lomori	Lomatium orientale	Lomatium	X	X	X	X					X			X	X	X	X					

Table 4. Continued

Code	Scientific Name	Common Name	Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
			1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	
Lupinus	Lupinus sp.	Lupine												X	X	X	X					
Lygjun	Lygodesmia juncea	Skeletonweed												X	X	X	X					
Macgri	Macaeranthera grindelioides	Machaeranthera												X		X	X					
Medsat	Medicago sativa	Alfalfa				X	X	X	X	X	X	X						X	X	X	X	X
Musdiv	Musineon divaricatum	Biscuitroot	X	X	X	X										X	X	X				
Oencae	Oenothera caespitosa	Primrose	X	X	X	X															X	
Oenosp.	Oenothera sp.	Primrose												X		X	X					
Onovic	Onobrychis viciifolia	Sanfoin						X	X	X	X	X						X	X	X	X	X
Oxylam	Oxytropis lambertii	Lambert Locoweed		X	X	X	X										X					
Oxytropis	Oxytropis sp.	Locoweed												X		X	X					
Penalb	Penstemon albus	White Beardtongue		X	X	X									X	X	X		X		X	
Peneri	Penstemon eriantherus	Beardtongue		X	X	X					X			X	X	X	X					
Petsp	Petalostemon sp.	Petalostemon												X	X		X					
Phlhoo	Phlox hoodii	Hood's Phlox	X	X	X	X	X							X	X	X	X					
Picopp	Picrodeniopsis oppositifolia	Picrodeniopsis	X	X	X	X	X	X	X	X	X	X		X	X	X	X					
Psoarg	Psoralea argophylla	Silverleaf Scurfpea				X								X	X	X	X					
Psoralea	Psoralea sp.	Scurfpea														X	X		X			
Psoesc	Psoralea esculenta	Indian Beardroot	X	X	X																	
Ratcol	Ratibida columnifera	Prairie Coneflower						X		X	X	X						X	X	X	X	X
Sencan	Senecio canus	Senecio	X	X	X	X																
Solmis	Solidago missouriensis	Prairie Goldenrod	X	X	X	X																
Sphcoc	Sphaeralcea coccinea	Scarlet Globemallow	X	X	X	X	X						X	X	X	X	X	X	X		X	
Taroff	Taraxacum officinale	Dandelion	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X
Therho	Thermopsis rhombifolia	Yellow Pea	X	X	X	X								X	X	X	X				X	X
Tradub	Tragapogon dubius	Yellow Salsify	X	X	X	X	X	X				X		X	X		X	X	X	X	X	X

Table 4. Continued

Code	Scientific Name	Common Name	Coal Creek Native					Coal Creek Reclaimed					Black Thunder Native					Black Thunder Reclaimed				
			1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	Late 1993	1991	Early 1992	Late 1992	Early 1993	
Trirep	Trifolium repens	Clover						X	X	X	X											
Vicame	Vicia americana	American Vetch	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X	
Half Shrub																						
Artfri	Artemisia frigida	Fringed Sagewort	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Atrgar	Atriplex gardneri	Gardner's Salatbush	X	X	X	X	X				X			X	X	X	X	X	X	X	X	X
Cerlan	Ceratoides lanata	Winterfat												X			X	X	X	X	X	X
Gutsar	Gutierrezia sarothrae	Broom Snakeweed	X	X	X	X	X	X		X	X	X		X	X	X	X					
Xylgla	Xylorrhiza glabriuscula		X	X	X	X	X															
Full Shrub																						
Arttri	Artemisia tridentata	Big Sagebrush	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
Artcan	Artemisia cana	Silver Sagebrush	X	X		X	X											X	X	X	X	X
Atrcan	Atriplex canescens	Fourwing Saltbush	X		X	X	X	X	X	X	X							X	X	X	X	X
Chrnau	Chrysothamnus nauseosus	Rubber Rabbitbrush									X							X	X	X	X	X
Roswoo	Rosa woodsii	Wood's Rose		X	X	X												X				
Symocc	Symphoricarpos occidentalis	Western Snowberry												X	X							
Succulent																						
Opupol	Opuntia polyacantha	Plains Pricklypear	X	X	X	X	X	X	X		X			X	X	X	X	X	X	X	X	X

NATURAL AND PLANTED FLORA OF THE LOG MOUNTAIN SURFACE-MINED DEMONSTRATION AREA, BELL COUNTY, KENTUCKY[1]

by

Ralph L. Thompson, Gary L. Wade, and R. Allen Straw[2]

Abstract. A descriptive study of the naturally invading and planted flora was conducted during 1984-1985 on a 14- and 21-year-old contour surface mine, the 14.2 ha Log Mountain Demonstration Area (LMDA), in Bell County, Kentucky. Six habitats are designated from areas created from coal mining; the 1963 bench, 1970 bench, bench highwalls, mine outslopes, mine seeps, and coal haul-telephone microwave tower road. Twenty-four of 25 woody and herbaceous species (11 indigenous, 13 non-indigenous) have persisted from plantings by personnel of the Northeastern Forest Experiment Station, USDA Forest Service. We recommend 11 native and exotic woody and herbaceous species for planting on coal surface-mined areas. An annotated list of vascular plants comprises 360 taxa (286 indigenous, 74 non-indigenous) in 224 genera from 82 families. Taxa consist of 1 Lycopodiophyta, 1 Equisetophyta, 8 Polypodiophyta, 7 Pinophyta, and 343 Magnoliophyta. The most species-rich families are the Asteraceae (64), Poaceae (39), Fabaceae (20), Cyperaceae (16), Rosaceae (13), and Lamiaceae (11). A total of 155 Bell County distribution records were documented. Three threatened Kentucky species (*Gentiana decora, Liparis loeselii, Silene ovata*) were present in refugial habitats created by surface mining. The high species richness has resulted from native and naturalized invading species from the environs, native and exotic planted species, and species from the remnant seed bank. Forest vegetation is a complex mosaic of natural and semi-natural plant communities on the unplanted and planted areas of LMDA .

Additional Key Words: biodiversity, plant invasion, plant succession, reclamation, refugium.

Introduction

Coal mine operators have been required to reclaim and revegetate surface-mined spoils even before the passage of Public Law 95-87, the Surface-Mining Control and Reclamation Act of 1977 (SMCRA). From 1963-1971, the Northeastern Forest Experiment Station, USDA Forest Service, Berea, Kentucky, cooperated with several private coal companies in the planting of native and exotic reclamation species on five surface-mined sites in eastern Kentucky. Four of these surface-mined areas were selected as pre-SMCRA demonstration or research sites by the Federal-State Interagency Research Coordinating Committee (FSIRCC). Reclamation goals were to prevent erosion and siltation, foster soil development and forest succession, provide suitable wildlife habitat, determine potential species for forest products, and contribute to landscape aesthetics.

We inventoried the entire flora of the Log Mountain Demonstration Area (LMDA), a 14- and 21-year-old pre-SMCRA contour surface-mined site in Bell County, Kentucky, during 1984-1985. The LMDA constitutes 14.2 ha; a 9.1 ha area mined in 1963 and an additional 5.1 ha area mined in 1970. The original 9.1 ha area was selected by the FSIRCC in 1965 for reclamation plantings toward forestry postmining land use.

Our study objectives at LMDA were to: 1) report the success of planted native and exotic species after 14 and 21 years; 2) describe the establishment of native and exotic volunteer species; 3) describe the plant communities and plant succession in the different surface-mined habitats; and, 4) compile an annotated list of vascular plants.

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Complete floristic inventories, vegetation development studies, and success of natural and planted species observations have also been made on an 18-year-old area-type mine in Laurel County (Thompson et al. 1984), and on a 12-year-old contour surface-mined area in Rockcastle County (Thompson and Wade 1991). Assessments of experimental plantings at the Laurel County site and at a 20-year-old mined site in Bell County have revealed the potential of those sites for forestry, wildlife habitat, soil building, and site stabilization (Wade et al. 1985, 1986).

Methods

We collected representative vascular plant specimens approximately every two weeks during the growing season from March 1984 through October 1985. Voucher specimens were processed according to standard herbarium procedures and deposited in the Berea College Herbarium (BEREA). Manuals used for plant identification were Gleason and Cronquist (1963) and Strausbaugh and Core (1978). Plant classification and nomenclature follow Gleason and Cronquist (1991).

The LMDA is divided into two contour-mined sites; "Site A" which was mined in 1963, and "Site B" which was mined in 1970. Reclamation woody plantations within these two sites are designated as "Areas 1-10." The physical environments which have developed on LMDA are designated as "habitats." In some cases, these "habitats" may cross the boundaries of both site A and B, and different area designations may overlap, e.g., mine highwalls, outslopes, and seeps.

Table 1 shows the pH of 30 soil samples from the surface layer (0-17 cm) in nine plantation areas in July 1985 at LMDA. Soil samples were analyzed from seven plantation areas on the 1963 site A bench, the mixed pine plantation above the 1963 highwall, and the 1970 site B bench (Dan Childress, NRCS Scientist, unpublished data 1985).

Table 2 reports the complete inventory of the entire 1963 site A bench in August 1985 for total seedlings, saplings, and trees by diameter at breast height (dbh). This census includes planted Areas 1-9. Percentage composition or relative density was calculated from the tree population results according to Brower and Zar (1977).

Table 3, the annotated list of vascular plants, is arranged alphabetically by division, family, and species. All non-indigenous taxa, naturalized or introduced, are preceded by an asterisk (*). Those non-indigenous taxa planted as reclamation species are preceded by a (+). Native reclamation species planted on LMDA are coded by a circle (o). Bell County distribution records are indicated with a dagger (†). These county records are based on herbarium specimens on deposit at (BEREA), the University of Tennessee Herbarium (TENN), and the University of Kentucky Herbarium (UK), and on literature citations (Braun 1943, Ettman 1976, Cranfill 1980, Hinkle 1975, Beal and Thieret 1986, Pounds et al. 1987). Vernacular or common names follow Strausbaugh and Core (1978), Gleason and Crinquist (1991), and Swink and Wilhelm (1994).

From field reconnaissance, we identified six different habitats on LMDA based on the effects of 1963 and 1970 mining procedures, reclamation processes, topographic terrain features, and present plant communities. In Table 3, these six habitats are designated as: 1=1963 mine bench, 2=1970 mine bench, 3=mine highwalls, 4=mine outslopes, 5=mine seeps, and 6=coal haul-telephone microwave tower road.

Relative abundance for each taxon was determined by field observations from each habitat. Each taxon was compared with numbers of individuals or colonies from other taxa of similar growth habit and duration. In Table 3, the abundance scale values are: Rare (R)=1-5 individuals or isolated colonies, Infrequent (I)=6-25 individuals or colonies, Occasional (O)=26-100 individuals or colonies; Frequent (F)=100s of individuals or colonies; and Abundant (A)=1000s of individuals or colonies.

The evaluation of native and planted species and plant successional trends are based upon our personal observation, tree sampling data, and unpublished planting documentation from the USDA Forest Service Northeastern Forest Experiment Station, Berea, Kentucky.

Log Mountain Demonstration Area

The Environmental Site

The LMDA, is a WNW-trending, 14.2-ha contour surface-mined area, which is located 18 km west of Middlesboro off Kentucky Highway 74 in southwestern Bell County. The mine lies within the Log Mountains at Maiden Ridge at latitude 36° 37' 05" N and longitude 85° 51' 01" W. Elevation of the study site ranges from 850 m on the 1963 lower outslope to 908 m at the ridge crest bordered by the coal haul-telephone microwave tower road (Fig. 1).

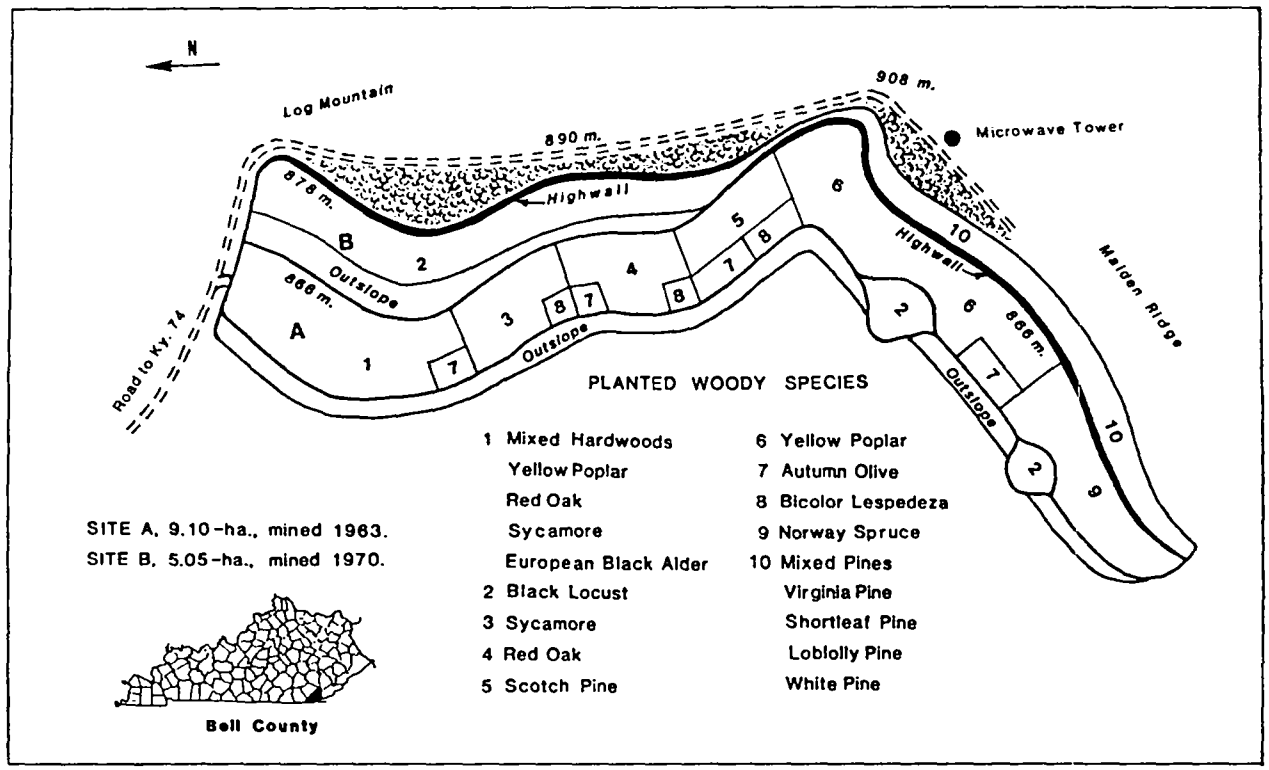

Figure 1. Log Mountain Demonstration Area, Bell County, Kentucky

Physiography and Vegetation. Fenneman (1938) described the Log Mountains as a small mountain range near the middle of the broad syncline between the Cumberland Mountains and Pine Mountains of the Appalachian Plateaus Province. The upper slope and ridgetop forest of the Log Mountains are described as the All Deciduous Mixed Mesophytic Community Type of the Mixed Mesophytic Forest Region by Braun (1950). The Cumberland Mountains have been described as the richest center of the Mixed Mesophytic Forest where several important canopy trees characteristically share dominance (Braun 1950).

Geology. Bedrock of Log Mountain and Maiden Ridge belongs to the Bryson Formation of the Lower to Middle Pennsylvanian Series of the Pennsylvanian System. The lithology of the 112 m thick Bryson Formation consists of siltstones, claystones, sandstones, and four coal beds. The Red Springs coal bed, the major coal seam of 1.0-2.0 m, forms the basement layer of the formation. A thin, unnamed coal rider in sandstone-filled channels lies above the Red Springs coal bed (Rice and Maughan 1978).

Soils. The surface-mined soils in the Log Mountain region have been classified as part of the Fairpoint soils series, a loamy-skeletal, mixed, nonacid, mesic Typic Udorthents. These soils are nonacid (pH 6.6-7.3) very deep (>60 inches), well-drained, and moderately permeable. They are found in coal-mined mountain ridges and slopes within the Cumberland Mountains (Childress 1992).

Climate. The nearest United States Weather Bureau station is located at Middlesboro at 358 m elevation. During the 1961-1990 period, the mean annual precipitation was 130 cm including a mean of 37 cm snowfall. Mean annual temperature was 13.3°C with the mean winter minimum -4°C and the mean summer maximum 23°C. The mean growing season (based on 0°C) was 170 days (University of Kentucky Agricultural Weather Center 1995).

LMDA Mined Sites

Surface-mining was done at two different time periods at LMDA. In 1963, Site A , an area of 9.1 ha was created by the contour mining of the Red Springs coal bed. A 16 m WNW vertical highwall was formed by the final mining cuts. The nearly level bench extends from the highwall to a steep 35-50 percent outslope at 866 m elevation. This outslope was produced from excess overburden spoils pushed over unmined forest soils.

In 1970, Site B, a tract of 5.1 ha, was formed by the contour mining of a thin, unnamed rider coal seam above the Red Springs coal bed. Part of the 1963 highwall was included in this mining. A second vertical W-trending 4 m highwall and a 2-6 percent sloping bench were created. Elevation varied from 878 m on the bench to 882 m at the top of the highwall. Additional mine spoils were displaced over the 1963 highwall area to form a steep 20-35 percent outslope down to the 1963 mine bench.

A continuous highwall was formed from the 1970 mining and 1963 mining of Log Mountain at the junction of the forested ridge top at Maiden Ridge. A compacted gravel-stone road initially used as a coal haul road presently serves as an access road from the telephone microwave tower to Kentucky Highway 74. This access road forms the eastern boundary of the LMDA and lies on the ridgetop of Log Mountain and Maiden Ridge (Fig. 1).

A 4.7 ha stand of mixed mesophytic hardwood forest lies above the highwall habitat between the access road. This forest has been disturbed from the mining processes by soil scraping, coal haul road construction, and past timbering practices. Wet seep pools have formed on the 1963 site A bench from the highwall in two planted areas, and on the 1970 site B bench at the highwall base.

From LMDA, we have designated six habitats from the 1963 and 1970 mining procedures, topographic features, reclamation processes, and existing plant communities: the 1963 mine bench, 1971 mine bench, mine highwalls, mine outslopes, mine seeps, and coal haul-telephone tower road.

LMDA Revegetation Efforts

Twenty-five species were planted during 1964, 1965, 1971, and 1984 on the LMDA. These species consisted of 11 native trees, four non-indigenous trees, two non-indigenous shrubs, and eight non-indigenous perennial herbs. All 25 species have been recommended for revegetation of surface-mined lands in the eastern United States (Vogel 1981).

In the spring of 1964, the 1963 site A mined area was seeded with Korean lespedeza (*Lespedeza stipulacea*) and tall fescue (*Festuca elatior*) for initial ground cover. In 1965, 10 demonstration areas were established and 13 woody species were planted to promote postmining forestry land use (Fig. 1). Four nitrogen-fixing tree and shrub species were planted on the bench; black locust (*Robinia pseudoacacia*), European black alder (*Alnus glutinosa*), bicolor lespedeza (*Lespedeza bicolor*), and autumn olive (*Elaeagnus umbellata*).

Nine native and non-indigenous tree species of potential forestry value were also planted in mixed hardwood, mixed pine, and individual hardwood and conifer plantations on the 1963 mined area. Yellow poplar (*Liriodendron tulipifera*), American sycamore (*Platanus occidentalis*), northern red oak (*Quercus rubra*), were planted in mixed hardwood blocks and on individual areas on the bench.

Table 1. LMDA soil pH from the surface layer (0-17 cm) at nine areas (Fig. 1).

Area	Mean pH Value	pH Range
1963 Bench Site A		
Area 1: Mixed hardwoods	5.3	4.9-6.6
Area 4: Northern red oak	6.4	6.1-6.6
Area 5: Scotch pine	6.1	6.0-6.1
Area 6: Yellow poplar	7.3	6.1-7.7*
Area 7: Autumn olive	7.4	7.2-7.6*
Area 8: Bicolor lespedeza	7.1	6.9-7.2*
Area 9: Norway spruce	4.9	4.8-5.1
1963 Highwall		
Area 10: Mixed Pine	4.3	4.0-4.9
1970 Bench Site B		
Area 2: Black locust	5.7	5.6-5.9

Code: Three samples from each area except six samples from Area 2; (*) carbonates present.

The non-native Scotch pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) were planted in individual bench areas. A mixed block of Virginia pine (*Pinus virginiana*), shortleaf pine (*P. echinata*), loblolly pine (*P. taeda*), and eastern white pine (*P. strobus*) was established above the highwall rim adjacent to the disturbed mixed mesophytic hardwood forest. In 1965, two perennial non-indigenous herbs, crown-vetch (*Coronilla varia*) and creeping foxtail (*Alopecurus arundinaceus*) were also seeded in two areas on the bench.

The 1970 site B was hydroseeded in 1971 on the bench and outslope with a grass-legume herbaceous mixture of tall fescue and nitrogen-fixing

species; sericea lespedeza (*Lespedeza cuneata*), red clover (*Trifolium pratense*), yellow sweet clover (*Melilotus officinalis*), white sweet clover (*M. alba*), and black locust. In 1984, seven tree species were interplanted in 48 plots with 24 seedlings each on the 1970 site B bench after herbiciding the herbaceous ground cover. These planted species were white ash (*Fraxinus americana*), northern red oak, saw-tooth oak (*Quercus acutissima*), black walnut (*Juglans nigra*), sugar maple (*Acer saccharum*), yellow poplar, and eastern white pine.

LMDA Minesoils

Minesoils are representative of the Fairpoint soil series derived from siltstone, sandstone, claystone, and coal intermixed with original forest soils. From the soil analysis of the 30 samples at LMDA, the mean pH value of the 1963 bench, 1970 bench, and 1963 highwall was 6.1 with a range from 4.0 to 7.7 pH. The mean pH value on the site A bench was 6.4 and varied from 4.9 to 7.7 with some free carbonates present. On the site B bench, the mean pH value was 5.7. The mean pH of the 1963 highwall mixed pine plantation was 4.3 and a range from 4.0-4.9 (Table 1). In general, the LMDA minesoils are less acid than unmined contiguous areas because of the basic nature of the carbonates contained in some of the Fairpoint soils (Dan Childress, NRCS Scientist, unpublished data 1995).

Results

LMDA Habitats

In 14 and 21 years after coal mining, a complex vegetational mosaic of natural and semi-natural plant communities is developing in the seven habitats from the mining effects and reclamation processes. Plant communities are progressing through various seral stages of secondary succession toward a young mixed hardwood forest throughout the planted and unplanted mine habitats.

1963 Site A Bench. Environments range from seasonally hydric sites near the highwall and open grassy xeric areas near the outslope to mixed mesic forested areas. A tree population analysis of 7,320 individuals reveals the development of a young mesophytic hardwood-dominated forest. Different degrees of canopy closure occur from volunteer native and exotic woody and herbaceous species from the contiguous forest environs, the nine woody plantations, and the existing spoil seed bank (Table 2). The highest species richness, 223 taxa, is found on this habitat (Table 3).

The most significant native trees colonizing the 1963 bench are white ash, yellow poplar, sugar maple, black locust, red maple (*Acer rubrum*), and Virginia pine (Table 2). Important nitrogen-fixing woody species spreading from the 1963 bench plantings are black locust, autumn olive, and European black alder. Shade-intolerant, mid-successional trees, sourwood (*Oxydendrum arboreum*), wild black cherry (*Prunus serotina*), eastern redbud (*Cercis canadensis*), white sassafras (*Sassafras albidum*), red elm (*Ulmus rubra*), blackgum (*Nyssa sylvatica*), and eastern red cedar (*Juniperus virginiana*), are volunteering on the bench (Table 2).

Shrubs present are American elderberry (*Sambucus canadensis*), wild hydrangea (*Hydrangea arborescens*), winged sumac (*Rhus copallina*), smooth sumac (*R. glabra*), and bicolor lespedeza. Characteristic woody vines on the bench are virgin's bower (*Clematis virginiana*), poison ivy (*Toxicodendron radicans*), moonseed (*Menispermum canadense*), Japanese honeysuckle (*Lonicera japonica*), glaucous greenbrier (*Smilax glauca*), common greenbrier (*S. rotundifolia*), summer grape (*Vitis aestivalis*), and Virginia creeper (*Parthenocissus quinquefolia*).

The numerically most important herbs are members of the Asteraceae, Poaceae, Fabaceae, Cyperaceae, and Rosaceae. Representative mesic woodland herbs include eulalia (*Microstegium vimineum*), pale jewelweed (*Impatiens pallida*), white snakeroot (*Eupatorium rugosum*), joe-pye weed (*E. fistulosum*), late boneset (*E. serotinum*), crownbeard (*Verbesina alternifolia*), sweet cicely (*Osmorhiza claytonii*), honewort (*Cryptotaenia canadensis*), black raspberry (*Rubus occidentalis*), wood nettle (*Laportea canadensis*), climbing buckwheat (*Polygonum scandens*), pokeweed (*Phytolacca americana*), Indian hemp (*Apocynum cannabinum*), cinnamon vine (*Dioscorea batatas*), deer-tongue panicum (*Panicum clandestinum*), cleavers (*Galium aparine*), spring beauty (*Claytonia virginica*), and violets (*Viola* spp.).

In drier exposed bench areas, herbs include tall fescue, broomsedge (*Andropogon virginicus*), hairy panic grass (*Panicum lanuginosum*), Kentucky bluegrass (*Poa pratensis*), Canadian goldenrod (*Solidago canadensis*), old-field goldenrod (*S. nemoralis*), rough goldenrod (*S. rugosa*), hairy white aster (*Aster pilosus*), ox-eye daisy (*Chrysanthemum leucanthemum*), wild carrot (*Daucus carota*), Allegheny blackberry (*Rubus allegheniensis*), northern dewberry (*R. flagellaris*), common cinquefoil (*Potentilla simplex*), wild strawberry (*Fragaria virginiana*), Japanese knotweed (*Polygonum cuspidatum*), sericea lespedeza, and Korean lespedeza.

Table 2. Tree population analysis on the1963 bench, Log Mountain Demonstration Area, Kentucky.

Species	Seedlings <1.0 m tall	Saplings <0.5	Decimenter Size Classes (dbh) 0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	Species Total	Percentage Composition
Fraxinus americana	286	1118	151	27	3	1	1586	21.67
o*Liriodendron tulipifera*	311	301	180	214	55	6	1067	14.58
Acer saccharum	453	528	57	2	0	0	1040	14.21
o*Robinia pseudoacacia*	203	325	130	89	51	14	812	11.09
Acer ruburm	317	377	54	4	1	0	753	10.29
+*Alnus glutinosa*	165	229	53	35	19	7	508	6.94
o*Pinus virginiana*	95	171	33	7	0	0	306	4.18
o*Platanus occidentalis*	52	125	37	21	1	0	236	3.22
+*Pinus sylvestris*	0	12	63	92	9	0	176	2.40
o*Quercus rubra*	31	86	31	9	1	0	158	2.16
Oxydendrum arboreum	58	97	2	0	0	0	157	2.14
+*Picea abies*	0	13	45	90	8	0	156	2.13
Prunus serotina	38	43	12	5	4	3	105	1.43
Salix nigra	24	45	5	3	0	0	77	1.05
Sassafras albidum	28	25	5	3	0	0	61	0.83
Cornus florida	2	30	4	0	0	0	36	0.49
Tilia americana	2	7	3	5	0	0	17	0.23
Nyssa sylvatica	7	5	1	3	0	0	16	0.22
Juniperus virginiana	1	11	2	0	0	0	14	0.19
Cercis canadensis	6	5	0	0	0	0	11	0.15
Ulmus rubra	1	5	0	0	0	0	6	0.08
Carya cordiformis	1	3	1	0	0	0	5	0.07
Liquidambar styraciflua	1	1	2	1	0	0	5	0.07
Quercus velutina	3	1	0	0	0	0	4	0.06
Aesculus flava	2	2	0	0	0	0	4	0.06
Betula lenta	1	1	0	0	0	0	2	0.03
Magnolia acuminata	1	1	0	0	0	0	2	0.03
Total Species: 27	2089	3567	871	610	152	31	7320	100.00

Code: (*) Percentage Composition=Relative Density (Brower and Zar 1977).
(+) Planted nonindigenous trees on bench.
(o) Planted native trees on bench.

The nine woody demonstration areas are discussed regarding the success of the planted species and the influence of native and exotic species. Three Kentucky endangered species are present on the 1963 bench habitat that were not encountered in the unmined environs.

Area 1: Mixed Hardwoods. The four tree species planted in blocks are yellow poplar, American sycamore, northern red oak, and European black alder. Yellow poplar is volunteering and reproducing on the bench while exhibiting excellent growth. American sycamore has persisted with only fair to good success and is not volunteering on the site. Northern red oak has rather poor growth and appears stunted. European black alder, an actinomycete nitrogen-fixing tree, is spreading vegetatively and by seed although some older trees are senescent. Crown-vetch plantings have spread but are suppressed by the lush, dense growth of mesic woodland herbs. Two endangered species for Kentucky, ovate-leafed catchfly (*Silene ovata*) and Appalachian showy gentian (*Gentiana decora*), are growing in the mixed hardwoods plantation at the base of the 1970 outslope.

Area 2: Black Locust. The stand has good growth in height, 6-8 m, and is present in all size classes from 1-5 dm dbh on the bench (Table 2). Planted and volunteer trees have reproduced vegetatively and from seed. Black locust is especially important where bench soils have slumped onto the 1963 outslope.

Area 3: American sycamore. Sycamore ranges from 4-7 m in height and 1-2 dm dbh, but only had fair growth success. Area 3 appears to have droughty, shallow soil with a good stand of tall fescue, sericea lespedeza, Korean lespedeza, and white sweet clover.

Area 4: Northern red oak. Most red oak has rather poor growth with most trees less than 3 m tall and only a few trees 1-2 dm dbh.

Area 5: Scotch pine. This introduced pine has exhibited good growth with 9-11 m height and several trees in the 2-3 dm dbh size class. Although ovulate cones are produced, Scotch pine is not reproducing from seeds in cones (Table 2). Tall fescue dominates under trees, and several woodland herbs are present near the outslope. A wet seep depression near the highwall contains several wetland species. Creeping foxtail has locally become established and expanded its area from the Scotch pine plantation into the yellow poplar plantation (Thompson and Thieret 1986a).

Area 6: Yellow poplar. Some trees of yellow poplar have excellent growth with some 8-14 m tall and 3-4 dm dbh. It is also an important invading species. Several mesic woodland herbs are present along the outslope as well as wetland herbs from the highwall seep habitats, the yellow poplar plantation, and the Scotch pine plantation.

Area 7: Autumn olive. This actinomycete nitrogen-fixing species has migrated from its plantation and spread into adjacent Areas 3, 6, and 9. Autumn olive characteristically has some dieback, but is readily reproducing vegetatively and from seed.

Area 8: Bicolor lespedeza. Nitrogen-fixing bicolor lespedeza has migrated from subplots 3, 4, and 5 and spread into Areas 1 and 6. As it has spread, considerable root resprouting has occurred from old decadent stems.

Area 9: Norway spruce. This introduced spruce has growth comparable to the Scotch pine. Some taller trees are 12-13 m high and several are in the 2-3 dm dbh class. Although Norway spruce is producing ovulate cones, it is not reproducing from seeds.

1970 Site B Bench. The 1970 bench is rather open, dry, and grassy with numerous dense black locust and blackberry thickets near the outslope and highwall. A good ground cover has developed from the hydroseeded tall fescue, sericea lespedeza, Korean lespedeza, red clover, and black locust. The annual white and yellow sweet clovers have thinned out, but are still persisting. Black locust developed dense seedling thickets within six to eight years and has currently formed a partially closed canopy. The seven tree species interplanted in the 1984 plots have not had enough time to influence the bench vegetation. In one year, white ash, yellow poplar, and sugar maple are growing well; but, northern red oak, black walnut, and eastern white pine are barely persisting. Saw-tooth oak did not survive in any of the one-year-old tree plots.

Plant communities are composed mostly of volunteering, mid-successional, native woody plants and invading native and exotic herbaceous species. Successional trees invading the 1970 bench include red maple, white ash, yellow poplar, sugar maple, wild black cherry, and sourwood. Allegheny blackberry is the pre-eminent perennial forming dense thickets with glaucous greenbrier, northern dewberry, black raspberry, and multiflora rose (*Rosa multiflora*).

Several important herbs include tall fescue, broomsedge, oat poverty grass (*Danthonia compressa*), orchard grass (*Dactylis glomerata*), sericea lespedeza, cinquefoil (*Potentilla simplex*), wild strawberry (*Fragaria viginiana*), and sticktights. Hairy white aster, Canadian goldenrod, and slender goldenrod are the most important members of the Asteraceae. The site B bench has the second highest species richness with 160 taxa (Table 3).

Highwalls. Characteristic shade-intolerant woody invaders on the open highwall rim crest and in talus areas include Virginia pine, black locust, red maple, blackgum, sourwood, sassafras, and some shortleaf pine. Seral shrubs in open, grassy areas are poison ivy, winged sumac, smooth sumac, glaucous greenbrier, lowbush blueberry (*Vaccinium pallidum*), and St. Andrews-cross (*Hypericum stragulum*). Perennial herbs on the steep highwall slope and upper rim include oat poverty grass, broomsedge, hairy panicum, Allegheny blackberry, old-field goldenrod, tickseed sunflower (*Coreopsis major*), and Small's ragwort (*Senecio anonymus*). Steep highwall talus and crevices are colonized by patches of the naturalized common dandelion (*Taraxacum officinale*), coltsfoot (*Tussilago farfara*), and Japanese knotweed. Ninety-eight taxa were recorded from the highwalls (Table 3).

Area 10: Mixed pines. The only plantation that was not established on the 1963 site A bench was a block plantation of Virginia pine, shortleaf pine, loblolly pine, and eastern white pine. This mixed pine area was planted above the site A highwall adjacent to the disturbed mixed mesophytic hardwood forest. The forest soils are mostly unmined. The mean pH value is 4.3 and ranges from

Table 3. Annotated Vascular Plant List, Log Mountain Demonstration Area, Bell County, Kentucky.

Family	Species	Common Name	Habitats	1	2	3	4	5	6
POLYPODIOPHYTA (True Ferns)									
Aspleniaceae (Spleenwort Family)									
	Asplenium platyneuron (L.) Oakes.	Ebony Spleenwort.		R	R	-	-	-	-
	Polystichum acrostichoides (Michx.) Schott.	Christmas Fern.		I	-	R	-	-	-
	Thelypteris hexagonoptera (Michx.) Weath.	Broad Beech Fern.		R	-	-	-	-	-
	T. noveboracensis (L.) Nieuwl.	New York Fern.		R	I	-	-	-	-
Ophioglossaceae (Adder's Tongue Family)									
	Botrychium dissectum Spreng.	Cut-leaved Grape Fern.		R	-	-	-	-	-
	B. virginianum (L.) Sw.	Rattlesnake Fern.		-	-	-	R	-	-
Osmundaceae (Royal Fern Family)									
	Osmunda cinnamomea L.	Cinnamon Fern.		-	-	-	-	R	-
Polypodiaceae (Polypody Family)									
	Polypodium virginianum L.	Common Polypody.		-	-	-	R	-	-
EQUISETOPHYTA (Horsetails)									
Equisetaceae (Horsetail Family)									
	†*Equisetum arvense* L.	Common Horsetail.		-	-	-	-	I	-
LYCOPODIOPHYTA (Lycopods)									
Lycopodiaceae (Clubmoss Family)									
	†*Lycopodium digitatum* Dillen.	Southern Ground-cedar.		I	-	I	-	-	-
PINOPHYTA (Conifers)									
Cupressaceae (Cypress Family)									
	†*Juniperus virginiana* L.	Eastern Redcedar.		I	R	R	-	-	-
Pinaceae (Pine Family)									
	†+*Picea abies* (L.) Karst.	Norway Spruce.		O	-	-	-	-	-
	†o*Pinus echinata* P. Mill.	Shortleaf Pine.		-	I	I	-	-	-
	†o*P. strobus* L.	Eastern White Pine.		-	R	I	-	-	-
	†+**P. sylvestris* L.	Scotch Pine.		O	-	-	-	-	-
	†o*P. taeda* L.	Loblolly Pine.		-	-	R	-	-	-
	o*P. virginiana* L.	Virginia Pine		F	O	I	O	-	-
MAGNOLIOPHYTA (Flowering Plants)									
Aceraceae (Maple Family)									
	Acer negundo L.	Boxelder.		R	-	-	-	-	-
	A. rubrum L.	Red Maple.		A	A	A	O	-	-
	o*A. saccharum* Marsh.	Sugar Maple.		A	F	F	O	-	-
Anacardiaceae (Sumac Family)									
	†*Rhus copallina* L.	Winged Sumac.		R	O	I	I	-	-
	†*R. glabra* L.	Smooth Sumac.		-	I	I	-	-	-
	Toxicodendron radicans (L.) Kuntze.	Poison Ivy.		I	I	I	I	-	I
Apiaceae (Parsley Family)									
	Cryptotaenia canadensis (L.) DC.	Honewort.		I	-	-	-	-	-
	**Daucus carota* L.	Wild Carrot.		O	O	O	-	-	I
	Osmorhiza claytonii (Michx.) Clarke.	Hairy Sweet Cicely.		I	-	-	-	-	-
	†*Sanicula canadensis* L.	Black Snakeroot.		R	-	-	-	-	-
	†*Thaspium barbinode* (Michx.) Nutt.	Hairy Meadow Parsnip.		I	-	-	-	-	-
	Zizia aptera (Gray) Fern.	Heart-leaved Meadow Parsnip.		-	R	R	-	-	-
Apocynaceae (Dogbane Family)									
	Apocynum cannabinum L.	Indian Hemp.		O	O	I	-	R	-
Araceae (Arum Family)									
	Arisaema triphyllum (L.) Schott.	Jack-in-the-Pulpit.		R	-	-	-	-	-
Aristolochiaceae (Birthwort Family)									
	Asarum canadense L.	Wild Ginger.		R	-	R	-	-	-
Asclepiadaceae (Milkweed Family)									
	†*Asclepias exaltata* L.	Poke Milkweed.		-	R	-	-	-	R
	A. quadrifolia Jacq.	Whorled Milkweed.		R	-	-	-	-	-

†*A. syriaca* L. Common Milkweed.	I	I	I	-	-	-
Asteraceae (Aster Family)						
†**Achillea millefolium* L. Yarrow.	I	R	-	-	-	I
Ambrosia artemisiifolia L. Common Ragweed.	O	O	-	-	-	F
A. trifida L. Giant Ragweed.	O	O	-	-	-	O
Antennaria plantaginifolia (L.) Rich. Pussy-toes.	-	-	I	-	-	-
†**Arctium minus* Schk. Common Burdock.	-	-	-	-	-	R
†**Artemisia vulgaris* L. Mugwort.	-	-	-	-	-	R
Aster cordifolius L. Heart-leaved Aster.	R	-	-	-	-	-
A. divaricatus L. White Wood Aster.	R	-	-	-	-	-
A. dumosus L. Bushy Aster.	-	R	R	-	-	-
A. lowrieanus Porter Smooth Heart-leaved Aster.	-	-	R	-	-	-
A. lateriflorus (L.) Britt. Calico Aster.	-	-	I	-	-	I
†*A. phlogifolius* Muhl. Phlox-leafed Aster.	-	-	R	-	-	-
†*A. pilosus* Willd. White Heath Aster.	O	O	O	I	-	I
A. undulatus L. Wavy-leaved Aster.	-	O	I	-	-	-
Bidens polylepis S. F. Blake. Bur Marigold.	O	O	O	-	I	-
Cacalia atriplicifolia L. Pale Indian Plantain.	-	-	-	-	R	-
**Chrysanthemum leucanthemum* L. Ox-eye Daisy.	O	O	I	I	-	-
**Cichorium intybus* L. Chicory.	-	-	-	-	-	R
†**Cirsium arvense* (L.) Scop. Field Thistle.	-	O	-	-	-	O
†*C. discolor* (Muhl.) Spreng. Pasture Thistle.	-	I	-	-	-	O
†**C. vulgare* (Savi) Tenore. Bull Thistle.	-	-	-	-	-	R
†*Conyza canadensis* (L.) Cronq. Horseweed.	-	O	-	-	-	O
Coreopsis major Walt. Forest Tickseed.	-	-	O	I	-	-
†*Erechtites hieracifolia* (L.) Raf. Fireweed.	-	R	-	-	-	I
Erigeron annuus (L.) Pers. Annual Fleabane.	O	O	O	-	-	O
E. philadelphicus L. Philadelphia Fleabane.	I	-	-	I	-	-
E. strigosus Muhl. Daisy Fleabane.	I	O	I	-	-	O
Eupatorium fistulosum Barratt. Hollow Joe-pye Weed.	O	O	-	-	-	O
E. purpureum L. Purple Joe-pye Weed.	-	-	-	R	-	-
E. rugosum Houtt. White Snakeroot.	F	O	O	A	-	-
E. serotinum Michx. Late Boneset.	O	-	-	-	O	-
†*E. sessilifolium* L. Upland Boneset.	R	-	-	-	-	-
Gnaphalium obtusifolium L. Old-field Balsam.	I	I	-	-	-	-
Helianthus microcephalus T. & G. Small-headed Sunflower.	I	I	R	O	-	-
†*H. tuberosus* L. Jerusalem Artichoke.	R	-	-	-	-	I
Hieracium gronovii L. Hairy Hawkweed.	R	-	I	-	-	-
H. paniculatum L. Panicled Hawkweed.	-	-	I	-	-	-
H. scabrum Michx. Rough Hawkweed.	-	R	R	-	-	-
H. venosum L. Rattlesnake Hawkweed.	-	-	I	-	-	-
Krigia biflora (Walt.) S. F. Blake. False Dandelion.	R	-	-	I	-	R
†*Lactuca biennis* (Moench) Fern. Tall Blue Lettuce.	-	-	-	-	-	R
L. canadensis L. Canadian Wild Lettuce.	-	-	-	I	-	O
L. floridana (L.) Gaertn. Florida Blue Lettuce.	-	-	I	I	-	-
†**L. saligna* L. Willow Lettuce.	-	-	-	-	-	R
†**L. serriola* L. Prickly Lettuce.	-	R	-	-	-	I
†*Polymnia uvedalia* L. Bear's Foot.	-	-	-	I	-	-
Rudbeckia hirta L. Black-eyed Susan.	I	R	-	-	-	R
†*Senecio anonymus* Wood. Appalachian Groundsel.	O	O	O	O	-	-
†*Silphium trifoliatum* L. Whorled Rosin-weed.	R	-	-	R	-	-
Solidago arguta Ait. Cut-leaved Goldenrod.	O	O	O	I	-	-
S. bicolor L. Silver-rod.	R	-	I	-	-	-
S. caesia L. Blue-stemmed Goldenrod.	R	-	-	-	-	-
†*S. canadensis* L. Canada Goldenrod.	F	O	F	I	-	I
S. erecta Pursh. Slender Goldenrod.	-	R	-	-	-	-
†*S. flexicaulis* L. Broad-leaved Goldenrod.	O	I	-	O	-	-
†*S. gigantea* Ait. Late Goldenrod.	-	-	-	-	I	-
S. nemoralis Ait. Old-field Goldenrod.	O	O	O	O	-	-

S. rugosa Mill. Rough Goldenrod.	I	I	I	O	-	-
†*S. sphacelata* Raf. Short-pappus Goldenrod.	R	-	-	-	-	-
**Sonchus asper* (L.) Hill. Spiny Sow Thistle.	-	-	-	-	-	I
**Taraxacum officinale* Weber. Common Dandelion.	-	-	-	I	-	I
†**Tussilago farfara* L. Coltsfoot.	-	-	I	-	-	-
Verbesina alternifolia (L.) Britt. Wingstem.	O	R	-	O	O	O
Vernonia gigantea (Walter) Trel. Tall Ironweed.	O	I	O	-	-	-
Balsaminaceae (Touch-Me-Not-Family)						
Impatiens capensis Meerb. Spotted Jewelweed.	I	-	-	F	-	-
I. pallida Nutt. Pale Jewelweed.	F	R	F	F	-	-
Berberidaceae (Barberry Family)						
Caulophyllum thalictroides (L.) Michx. Blue Cohosh.	-	-	-	R	-	-
Podophyllum peltatum L. May Apple.	R	-	-	I	-	
Betulaceae (Birch Family)						
†+**Alnus glutinosa* (L.) Gaertn. European Black Alder.	F	-	-	-	-	-
Betula lenta L. Sweet Birch.	R	-	-	R	-	-
Brassicaceae (Mustard Family)						
**Barbarea vulgaris* R. Br. Yellow Rocket.	I	I	-	-	-	R
†*Cardamine concatenata* (Michx.) Schwartz. Slender Toothwort.	I	-	-	R	-	-
**C. hirsuta* L. Hairy Bittercress.	O	O	-	-	-	O
†**Lepidium campestre* (L.) R. Br. Field Cress.	-	-	-	-	-	R
†*L. virginicum* L. Common Peppercress.	-	-	-	-	-	I
Campanulaceae (Bellflower Family)						
†*Campanula americana* L. Tall Bellflower.	O	-	-	O	-	-
C. divaricata Michx. Appalachian Bellflower.	-	-	R	-	-	-
Lobelia inflata L. Indian Tobacco.	I	-	-	-	-	O
†*L. siphilitica* L. Great Blue Lobelia.	I	-	-	-	I	-
Caprifoliaceae (Honeysuckle Family)						
**Lonicera japonica* Thunb. Japanese Honeysuckle.	I	I	-	O	-	-
Sambucus canadensis L. American Elderberry.	O	I	I	O	I	-
Triosteum perfoliatum L. Late Horse Gentian.	-	R	-	-	-	-
Caryophyllaceae (Pink Family)						
**Cerastium vulgatum* L. Mouse-ear Chickweed.	R	O	-	-	-	O
**Dianthus armeria* L. Deptford Pink.	-	-	-	-	-	R
†*Paronychia* canadensis (L.) Wood. Tall Forked Chickweed.	-	-	-	R	-	-
Silene ovata Pursh. Ovate-leaved Catchfly.	R	-	-	-	-	-
†*S. virginica* L. Fire Pink.	-	-	R	-	-	-
†**Stellaria media* (L.) Vill. Common Chickweed.	R	O	-	-	-	O
S. pubera Michx. Great Chickweed.	-	-	-	R	-	-
Celasteraceae (Staff Tree Family)						
†**Euonymus fortunei* (Turcz.) Hand. & Maz. Winter Creeper.	-	-	-	R	-	-
Chenopodiaceae (Goosefoot Family)						
Chenopodium album L. Lamb's Quarters.	-	R	-	-	-	R
Clusiaceae (Mangosteen Family)						
†*Hypericum canadense* L. Canadian St. John's Wort.	-	-	-	-	O	-
H. stragulum P. Adams & Robson. St. Andrew's Cross.	I	-	I	-	-	-
†*H. mutilum* L. Weak St. John's Wort.	R	-	-	-	O	-
H. punctatum Lam. Spotted St. John's Wort.	O	I	-	-	-	-
Commelinaceae (Spiderwort Family)						
**Commelina communis* L. Asiatic Dayflower.	I	-	-	-	-	-
†*Tradescantia subaspera* Ker-Gawl. Broad-leafed Spiderwort.	-	-	I	R	-	-
Convolvulaceae (Morning Glory Family)						
Calystegia sepium (L.) R. Br. Hedge Bindweed.	-	-	-	-	-	I
Cornaceae (Dogwood Family)						
Cornus florida L. Flowering Dogwood.	O	O	I	O	-	-
Nyssa sylvatica Marsh. Black Gum.	O	O	F	F	-	-
Crassulaceae (Stonecrop Family)						
Sedum ternatum Michx. Wild Stonecrop.	-	-	-	R	-	-

Cuscutaceae (Dodder Family)						
†*Cuscuta pentagona* Engelm. Prairie Dodder.	I	-	-	-	I	-
Cyperaceae (Sedge Family)						
†*Carex atlantica* L.H. Bailey. Atlantic Star Sedge.	-	-	-	-	O	-
†*C. blanda* Dewey. Common Wood Sedge.	R	-	I	-	-	-
C. digitalis Willd. Narrow-leaved Wood Sedge.	R	-	I	-	-	-
C. frankii Kunth. Frank's Sedge.	R	-	-	-	O	-
C. laxiflora Lam. Beech Wood Sedge.	-	-	R	-	-	-
C. lurida Wahl. Yellow-green Sedge.	O	-	-	-	F	-
†*C. purpurifera* Mack. Purple-leaved Sedge.	-	-	-	R	-	-
C. virescens Muhl. Slender Green Sedge.	-	-	R	-	-	-
C. vulpinoidea Michx. Brown Fox Sedge.	O	-	-	-	F	-
Cyperus strigosus L. Long-scaled Nut Sedge.	-	-	-	-	R	-
Eleocharis ovata (Roth) R. & S. Oval Spike Rush.	-	-	-	-	O	-
Fimbristylis autumnalis (L.) R. & S. Autumn Sedge.	-	-	-	-	O	-
Rhynchospora capitellata (Michx.) Vahl. Brown Beakrush.	-	-	-	-	O	-
†*Scirpus atrovirens* Willd. Dark Green Bulrush.	-	-	-	-	I	-
S. cyperinus (L.) Kunth. Woolgrass.	-	-	-	-	F	-
Dioscoreaceae (Yam Family)						
**Dioscorea batatas* Decne. Cinnamon Vine.	O	O	-	O	-	-
D. villosa L. Wild Yam.	R	-	-	I	-	-
Elaeagnaceae (Oleaster Family)						
†+**Elaeagnus umbellata* Thunb. Autumn Olive.	F	-	-	-	-	-
Ericaceae (Heath Family)						
Chimaphila maculata (L.) Pursh. Spotted Wintergreen.	-	-	I	-	-	-
Oxydendrum arboreum (L.) DC. Sourwood.	F	O	O	O	-	-
Vaccinium pallidum Ait. Lowbush Blueberry.	R	-	I	-	-	-
Euphorbiaceae (Spurge family)						
†*Acalypha rhomboidea* Raf. Three-seeded Mercury.	-	I	-	-	-	I
Euphorbia corollata L. Flowering Spurge.	-	R	-	-	-	-
E. maculata L. Spotted Spurge.	-	I	-	-	-	I
E. nutans Lagasca. Eyebane.	-	-	-	-	-	I
Fabaceae (Pea Family)						
Amphicarpaea bracteata (L.) Fern. Hog Peanut.	I	-	-	I	-	-
Cercis canadensis L. Eastern Redbud.	I	I	-	R	-	-
Chamaecrista nictitans (L.) Moench. Wild Sensitive Plant.	-	-	-	-	-	I
†+**Coronilla varia* L. Crown-vetch.	O	-	-	-	-	-
†*Desmodium glabellum* (Michx.) DC. Smooth Tick Trefoil.	I	O	-	-	-	-
D. glutinosum (Muhl.) Wood. Pointed Tick Trefoil.	-	-	-	R	-	-
D. paniculatum (L.) DC. Panicled Tick Trefoil.	O	F	-	-	-	-
†+**Lespedeza bicolor* Turcz. Bicolor Lespedeza.	F	-	-	-	-	-
†+**L. cuneata* (Dum.-Cours.) G. Don. Sericea Lespedeza.	F	A	-	I	-	I
†+**L. stipulacea* Maxim. Korean Lespedeza.	F	A	-	-	-	-
†**Medicago lupulina* L. Black Medick.	-	R	-	-	-	I
†+**Melilotus alba* Medic. White Sweet Clover.	I	O	-	-	-	-
†+**M. officinalis* (L.) Pallas. Yellow Sweet Clover.	I	I	-	-	-	-
†o*Robinia pseudoacacia* L. Black Locust.	A	A	O	A	-	-
**Trifolium campestre* Schreb. Low Hop Clover.	R	O	-	-	-	R
**T. hybridum* L. Alsike Clover.	R	I	-	-	-	-
+**T. pratense* L. Red Clover.	O	O	-	-	-	-
†**T. repens* L. White Clover.	O	O	-	-	-	R
Vicia caroliniana Walt. Carolina Wood-vetch.	-	R	-	-	-	-
†**V. sativa* L. Common Vetch.	R	I	-	-	-	-
Fagaceae (Beech Family)						
Fagus grandifolia Ehrh. American Beech.	R	-	-	-	-	-
Quercus alba L. White Oak.	R	R	-	-	-	-
Q. prinus L. Chestnut Oak.	R	-	-	-	-	-
o*Q. rubra* L. Northern Red Oak.	O	R	-	-	-	-
Q. velutina Lam. Black Oak.	R	-	-	-	-	-

Gentianaceae (Gentian Family)						
Gentiana decora Pollard. Appalachian Gentian.	R	-	-	-	-	-
Geraniaceae (Geranium Family)						
Geranium maculatum L. Wild Geranium.	I	-	-	R	-	-
Hamamelidaceae (Witch Hazel Family)						
Liquidambar styraciflua L. Sweetgum.	R	-	-	-	R	-
Hippocastanaceae (Buckeye Family)						
Aesculus flava Ait. Yellow Buckeye.	R	-	-	-	-	-
Hydrangeaceae (Hydrangea Family)						
Hydangea arborescens L. Wild Hydrangea.	O	I	I	O	-	-
Iridaceae (Iris Family)						
†*Sisyrinchium angustifolium* P. Mill. Narrow Blue-eyed Grass.	I	-	R	-	-	-
Juglandaceae (Walnut Family)						
†*Carya cordiformis* (Wang.) K. Koch. Bitternut Hickory.	R	-	-	-	-	-
C. ovalis (Wang.) Sarg. Sweet Pignut Hickory.	R	-	-	-	-	-
†o*Juglans nigra* L. Black Walnut.	R	R	-	-	-	-
Juncaceae (Rush Family)						
Juncus acuminatus Michx. Sharp-fruited Rush.	-	-	-	-	O	-
J. effusus L. var. *solutus* Fern. & Wieg. Soft Rush.	-	-	-	-	F	-
J. marginatus Rostk. Grass-leaved Rush.	-	-	-	-	O	-
J. tenuis Willd. Path Rush.	R	-	-	-	I	I
†*Luzula multiflora* (Retz.) Lejeune. Common Wood Rush.	R	-	-	-	-	-
Lamiaceae (Mint Family)						
Collinsonia canadensis L. Richweed.	I	-	-	-	-	-
†*Hedeoma pulegioides* (L.) Pers. American Pennyroyal.	-	-	R	-	-	-
**Lamium purpureum* L. Purple Dead Nettle.	-	-	-	-	-	R
Lycopus virginicus L. Bugleweed.	-	-	-	-	O	-
Monarda clinopodia L. Basil Bee Balm.	-	-	-	R	-	R
†*M. fistulosa* L. Wild Bergamot.	R	-	-	I	-	-
†**Prunella vulgaris* L. Selfheal.	O	O	-	-	-	R
†*Pycnanthemum incanum* (L.) Michx. Hoary Mountain Mint.	-	R	I	-	-	I
Salvia lyrata L. Lyre-leaved Sage.	I	-	-	-	I	-
Scutellaria elliptica Muhl. Hairy Skullcap.	R	-	-	R	-	-
†*Stachys nuttallii* Shuttlw. ex Benth. Nuttall's Hedge Nettle.	I	-	-	I	-	-
Lauraceae (Laurel Family)						
Sassafras albidum (Nutt.) Nees. White Sassafras.	O	O	O	O	-	-
Liliaceae (Lily Family)						
†**Allium vineale* L. Field Garlic.	I	R	-	-	-	-
†*Erythronium americanum* Ker-Gawl. Yellow Trout Lily.	I	-	-	-	-	-
†**Hemerocallis fulva* L. Orange Day-lily.	-	-	-	R	-	-
†**Narcissus pseudonarcissus* L. Daffodil.	-	-	-	R	-	-
†*Polygonatum biflorum* (Walt.) Ell. True Solomon's Seal.	R	-	-	I	-	-
Smilacina racemosa (L.) Desf. False Solomon's Seal.	I	-	-	I	-	-
Trillium grandiflorum (Michx.) Salisb. Large White Trillium.	R	-	-	-	-	-
Uvularia grandiflora Smith. Bellwort.	R	-	-	-	-	-
Linaceae (Flax Family)						
†*Linum striatum* Walt. Stiff Yellow Flax.	-	R	-	-	-	-
L. virginianum L. Slender Yellow Flax.	-	R	-	-	R	-
Magnoliaceae (Magnolia Family)						
o*Liriodendron tulipifera* L. Yellow Poplar.	F	F	O	O	-	-
†*Magnolia acuminata* L. Cucumber-tree.	I	-	-	I	-	-
Menispermaceae (Moonseed Family)						
†*Menispermum canadense* L. Canadian Moonseed.	R	-	-	-	-	-
Oleaceae (Olive Family)						
o*Fraxinus americana* L. White Ash.	A	F	O	A	-	-
Onagraceae (Evening Primrose Family)						
Circaea lutetiana L. var. *canadensis* L. Enchanter's Nightshade.	I	-	-	-	-	-
†*Epilobium coloratum* Biechler. Cinnamon Willow Herb.	-	-	-	-	I	-
†*Ludwigia alternifolia* L. Seedbox.	-	-	-	-	I	-

Oenothera biennis L. Evening Primrose.	-	R	-	-	-	R
Orchidaceae (Orchid Family)						
Aplectrum hyemale (Muhl.) Torr. Cranefly Orchid.	R	-	-	-	-	-
Goodyera pubescens (Willd.) R. Br. Rattlesnake Plantain.	R	-	-	-	-	-
Habenaria lacera (Michx.) Lodd. Ragged Fringed Orchid.	R	-	-	-	-	-
†*Liparis loeselii* (L.) L. Rich. Green Twayblade.	-	-	-	-	O	-
Spiranthes lacera (Raf.) Raf. Slender Ladies' Tresses.	-	-	R	-	-	-
Oxalidaceae (Wood Sorrel Family)						
**Oxalis corniculata* L. Creeping Wood Sorrel.	-	-	-	-	-	R
†*O. grandis* Small. Large Yellow Wood Sorrel.	I	-	-	-	-	-
O. stricta L. Common Wood Sorrel.	-	-	-	-	-	I
Paeoniaceae (Peony Family)						
†**Paeonia officinalis* L. Common Peony.	-	-	-	R	-	-
Papaveraceae (Poppy Family)						
Sanguinaria canadensis L. Bloodroot.	R	-	-	-	-	-
Phytolaccaceae (Poke Family)						
†*Phytolacca americana* L. American Pokeweed.	-	O	I	O	-	I
Plantaginaceae (Plantain Family)						
**Plantago lanceolata* L. English Plantain.	I	O	-	-	-	O
P. rugelii Decne. Rugel's Plantain.	I	I	-	-	-	O
Platanaceae (Plane Tree Family)						
†o*Platanus occidentalis* L. American Sycamore.	F	O	I	O	O	-
Poaceae (Grass Family)						
**Agrostis gigantea* Roth. Redtop.	O	I	-	-	O	-
A. perennans (Walt.) Tuckerm. Autumn Bentgrass.	-	-	O	-	-	R
†+**Alopecurus arundinaceus* Poir. Creeping Foxtail.	O	-	-	-	I	-
Andropogon virginicus L. Broomsedge.	F	F	O	-	-	I
Brachyelytrum erectum (Schreb.) Beauv. Awned Woodgrass.	-	-	-	R	-	-
†**Bromus japonica* Thunb. Japanese Chess.	I	O	-	-	-	I
B. pubescens Muhl. Woodland Brome.	-	-	-	R	-	-
†**Dactylis glomerata* L. Orchard Grass.	O	O	-	-	-	R
†*Danthonia compressa* Aust. Mountain Oatgrass.	O	I	F	R	-	-
†**Digitaria ischaemum* Schreb. Smooth Crabgrass.	I	I	-	-	-	O
†**Echinochloa crusgalli* (L.) Beauv. Barnyard Grass.	I	-	-	-	O	-
†*Elymus hystrix* L. Bottlebrush Grass.	R	-	-	-	-	-
†*E. virginicus* L. Virginia Wild Rye.	I	-	-	-	-	-
†**Elytrigia repens* (L.) Nevski. Quackgrass.	-	R	-	-	-	R
†*Eragrostis capillaris* (L.) Nees. Lacegrass.	-	-	-	-	-	I
†*E. frankii* C. A. Mey. Sandbar Lovegrass.	-	-	-	-	-	R
†+**Festuca elatior* L. Tall Fescue.	A	A	I	O	-	I
Leersia virginica Willd. White Grass.	-	-	-	-	O	-
**Microstegium vimineum* (Trin.) Camas. Eulalia.	A	A	O	A	-	I
†*Muhlenbergia frondosa* (Poir.) Fern. Satin Grass.	-	-	-	-	I	-
†*M. schreberi* J. F. Gmel. Nimblewill.	-	R	-	-	-	-
†*Panicum boscii* Poir. Wide-leafed Panic Grass.	O	O	-	I	-	-
†*P. capillare* L. Old Witch Grass.	-	R	-	-	-	R
†*P. clandestinum* L. Deer-tongue Panic Grass.	F	O	-	O	O	-
†*P. commutatum* Schultes. Ashe's Panic Grass.	O	I	-	O	-	-
P. dichotomiflorum Michx. Spreading Witch Grass.	-	-	-	-	I	I
P. dichotomum L. Forked Panic Grass.	-	-	-	-	F	-
†*P. lanuginosum* Ell. Hairy Panic Grass.	F	O	I	F	-	-
P. polyanthes Schultes. Small-fruited Panic Grass.	O	O	-	O	-	-
**Phleum pratense* L. Timothy.	I	O	-	-	-	-
†*Poa alsodes* A. Gray. Grove Bluegrass.	-	-	-	R	-	-
†**P. compressa* L. Canada Bluegrass.	I	I	-	-	-	I
†*P. cuspidata* Nutt. Short-leaved Bluegrass.	-	-	-	R	-	-
**P. pratensis* L. Kentucky Bluegrass.	O	O	-	-	-	I
†**Setaria faberii* Herrm. Nodding Foxtail.	O	-	I	-	-	I
**S. glauca* (L.) Beauv. Yellow Foxtail.	R	-	-	-	-	R

†*Sphenopholis obtusata* (Michx.) Scribn. Prairie Wedgegrass.	I	I	R	-	-	-
†*Sporobolus vaginiflorus* (Torr.) Wood. Dropseed.	-	-	R	-	-	O
†**Triticum aestivum* L. Wheat.	-	R	-	-	-	-
Polemoniaceae (Phlox Family)						
Phlox amplifolia Britt. Wide-leaved Phlox.	I	-	-	-	-	-
Polygalaceae (Milkwort Family)						
†*Polygala senega* L. Seneca Snakeroot.	I	I	-	-	-	-
Polygonaceae (Smartweed Family)						
**Polygonum aviculare* L. Common Knotweed.	-	-	-	-	-	R
+**Polygonum cuspidatum* Sieb. & Zucc. Japanese Knotweed.	O	O	O	O	-	-
P. pensylvanicum L. Pennsylvania Pinkweed.	-	I	-	-	-	I
**P. persicaria* L. Lady's Thumb.	-	-	-	-	-	I
†*P. punctatum* Ell. Dotted Smartweed.	-	-	-	-	R	I
P. sagittatum L. Arrow-leafed Tearthumb.	-	-	-	-	I	-
P. scandens L. Climbing False Buckwheat.	F	I	-	F	-	O
P. virginianum L. Virginia Knotweed.	R	-	-	-	-	-
†**Rumex crispus* L. Curly Dock.	I	I	-	-	R	I
**R. obtusifolius* L. Bitter Dock.	I	I	-	-	-	I
Portulacaceae (Purslane Family)						
Claytonia virginica L. Spring Beauty.	I	-	-	-	-	-
Primulaceae (Primrose Family)						
†*Lysimachia quadrifolia* L. Whorled Loosestrife.	-	-	I	-	-	I
L. tonsa (Wood) Kunth. Appalachian Loosestrife.	-	I	I	-	-	I
Ranunculaceae (Buttercup Family)						
†*Anemone virginiana* L. Thimbleweed.	I	O	-	I	-	-
†*Anemonella thalictroides* (L.) Spach. Rue Anemone.	I	I	-	-	-	-
†*Clematis glaucophylla* Small. Glaucous-leaved Clematis.	-	-	-	-	-	I
C. virginiana L. Virgin's Bower.	A	A	-	A	-	I
†*Delphinium tricorne* Michx. Dwarf Larkspur.	R	-	-	-	-	-
Ranunculus abortivus L. Small-flowered Buttercup.	O	O	-	-	-	I
†*R. hispidus* Michx. Hispid Buttercup.	I	I	-	O	-	-
R. recurvatus Poir. Hooked Crowfoot.	I	I	-	-	-	-
Thalictrum dioicum L. Early Meadow-rue.	I	I	-	O	-	-
Rosaceae (Rose Family)						
†*Agrimonia rostellata* Wallr. Beaked Agrimony.	O	I	-	O	-	I
Fragaria virginiana Duchesne. Virginia Strawberry.	F	F	O	-	-	I
Geum canadense Jacq. White Avens.	O	-	-	O	-	-
Potentilla canadensis L. Canada Cinquefoil.	I	O	O	-	-	I
†**P. norvegica* L. Rough Cinquefoil.	-	I	-	-	-	I
**P. recta* (L.) Raeusch. Upright Cinquefoil.	I	-	-	-	-	-
†*P. simplex* Michx. Common Cinquefoil.	O	O	I	-	-	I
Prunus serotina Ehrh. Wild Black Cherry.	I	I	-	-	-	-
†**Rosa multiflora* Thunb. Multiflora Rose.	I	I	-	I	-	-
Rubus allegheniensus Porter. Allegheny Blackberry.	A	A	I	F	O	I
†*R. flagellaris* Willd. Common Dewberry.	O	F	I	O	-	I
†*R. occidentalis* L. Black Raspberry.	O	O	I	O	-	-
†*Spiraea tomentosa* L. Pink Steeplebush.	-	-	-	-	O	-
Rubiaceae (Madder Family)						
Galium aparine L. Annual Cleavers.	F	F	-	A	-	I
G. latifolium Michx. Wide-leafed Bedstraw.	-	-	-	I	-	-
†*G. triflorum* Michx. Sweet-scented Bedstraw.	O	-	-	O	-	-
Hedyotis caerulea (L.) Hook. Spring Bluets.	O	O	O	-	-	R
H. purpurea (L.) T. & G. Large Summer Bluets.	I	I	-	-	-	-
Salicaceae (Willow Family)						
†*Salix nigra* Marsh. Black Willow.	F	-	-	-	F	-
†*S. sericea* Marsh. Silky Willow.	F	-	-	-	F	-
Saxifragaceae (Saxifrage Family)						
Heuchera americana L. Common Alum-root.	-	-	R	-	-	-

Scrophulariaceae (Figwort Family)						
Aureolaria laevigata (Raf.) Raf. Smooth False Foxglove.	-	-	-	R	-	-
†*Mimulus ringens* L. Common Monkey-flower.	-	-	-	-	I	-
Pedicularis canadensis L. Wood Betony.	R	-	-	-	-	-
†*Penstemon brevisepalis* Pennell. Appalachian Beard-tongue.	-	R	I	-	-	R
**Verbascus thapsus* L. Common Mullein.	-	-	-	-	-	R
†**Veronica arvensis* L. Corn Speedwell.	-	O	-	-	-	I
†**V. hederaefolia* L. Ivy-leafed Speedwell.	R	R	-	-	-	-
**V. officinalis* L. Common Speedwell.	I	I	-	-	-	-
Simaroubaceae (Quassia Family)						
**Ailanthus altissima* (Mill.) Swingle. Tree-of-heaven.	-	-	R	-	-	-
Smilacaceae (Greenbrier Family)						
†*S. glauca* Walt. Glaucous Greenbrier.	F	F	I	O	-	I
S. herbacea L. Herbaceous Carrion Flower.	R	-	-	-	-	-
†*S. rotundifolia* L. Common Greenbrier.	F	F	O	I	-	-
Solanaceae (Nightshade Family)						
†*Datura stramonium* L. Jimson Weed.	-	-	-	-	-	R
†*Solanum americanum* Mill. Black Nightshade.	-	-	-	-	-	R
S. carolinense L. Horse Nettle.	-	I	-	-	-	I
Tiliaceae (Linden Family)						
Tilia americana L. American Basswood.	I	-	-	I	-	-
Typhaceae (Cattail Family)						
†*Typha latifolia* L. Common Cattail.	-	-	-	-	A	-
Ulmaceae (Elm Family)						
†*Ulmus rubra* Muhl. Red Elm.	I	R	-	I	-	-
Urticaceae (Nettle Family)						
†*Laportea canadensis* (L.) Wedd. True Nettle.	O	-	-	F	-	-
Pilea pumila (L.) A. Gray. Clearweed.	O	O	-	O	-	-
Verbenaceae (Vervain Family)						
Verbena urticifolia L. Hairy White Vervain.	I	-	-	-	R	-
Violaceae (Violet Family)						
†*Hybanthus concolor* (Forster) Spreng. Green Violet.	R	-	-	-	-	-
†*Viola canadensis* L. Canada Violet.	O	I	-	F	-	-
†*V. eriocarpa* Schwein. Smooth Yellow Violet.	I	I	-	I	-	-
†*V. hirsutula* Brainerd. Southern Woolly Violet.	-	R	I	-	-	-
†*V. rostrata* Pursh. Long-spurred Violet.	I	-	-	-	-	-
V. rotundifolia Michx. Round-leafed Yellow Violet.	R	-	-	-	-	-
†*V. sororia* Willd. Common Blue Violet.	F	O	R	O	-	-
†*V. palmata* L. Lobed Violet.	-	I	I	I	-	-
Vitaceae (Grape Family)						
Parthenocissus quinquefolia (L.) Planch. Virginia Creeper.	I	R	I	O	-	-
Vitis aestivalis Michx. Summer Grape.	I	R	-	O	-	-
Habitat Total Species:	223	160	98	109	53	104

Code: (†) Bell County records; (+) Introduced planted taxa; (o) Native planted taxa; (*) Non-indigenous taxa.
Relative abundance values: R=rare; I=infrequent; O=occasional; F=frequent; A=abundant.
Habitats: 1=1963 bench; 2=1970 bench; 3=highwalls; 4=outslopes; 5=seeps, 6=access road.
[Note: Methods section].

4.0-4.9 which is the overall lowest pH sampled (Table 1). Virginia pine exhibits vigorous reproduction and growth. It has spread by seed to the outslopes, highwalls, the 1963 bench (Table 2), the 1970 bench and into the mixed hardwood forest. Nearly all the loblolly pine and eastern white pine and most of the shortleaf pine were destroyed by the mining of the 1970 area. Only three loblolly pines and 10 eastern white pine have persisted on this highwall plantation. Shortleaf pine has some seedling and sapling reproduction evident on the highwall and on the 1970 bench. Shrubs and herbs in this dry exposed area are representative of the species of the general highwall habitat.

Outslopes. The 1964 outslope plantings of tall fescue and Korean lespedeza have exhibited fair to good success. Black locust was heavily seeded in 1965 on the steep 1963 outslope after slumping of the bench occurred in 1964. Bench plantings of European black alder, autumn olive, and bicolor lespedeza have spread onto the outslope as have yellow poplar, white ash, sugar maple, and red maple. Shrubs and vines include wild hydrangea, poison ivy, common elderberry, virgin's bower, multiflora rose, and Japanese honeysuckle. The herbaceous layer is dominated by pioneer planted and volunteer species in the Poaceae, Asteraceae, Fabaceae, and Rosaceae. A total of 109 taxa were recorded from the outslopes (Table 3).

The black locust stand on the 1970 site B outslope at LMDA was one of several sites in the black locust provenance studies by Ashby et al. (1985). Black locust was initially hydroseeded in 1971 on the 1970 outslope and bench. By 1977, black locust seedlings had grown through the tall fescue and sericea lespedeza to form dense seedling thickets. This black locust stand had a density of 716 trees per hectare with a third of the trees dead in 1982. Most of the 482 live black locust trees per hectare were less than 1.0 dm dbh. The shade-tolerant tall fescue dominated about one-third of the open areas. A rich cover of white snakeroot, orange jewelweed (*Impatiens capensis*), pokeweed, eulalia, and other woodland herbs covered the remainder of the area (Ashby et al. 1985).

Sugar maple, red maple, white ash, and other more shade-tolerant volunteers, were replacing black locust. However, invasion was meager partly because of the vigorous herbaceous cover and scarcity of seed sources (Ashby et al. 1985). Other invading trees documented in the stand were yellow poplar, wild black cherry, sourwood, blackgum, sassafras, autumn olive, red elm, and Virginia pine. Vines and shrubs included virgin's bower, American elderberry, wild hydrangea, summer grape, Virginia creeper, poison ivy, and common greenbrier (Ashby and Vogel, USDA, unpublished data 1992).

LMDA Seeps. Wet seep pools are found on the 1963 site A bench in Scotch pine plantations of Area 5, yellow poplar plantations of Area 6, and on the 1970 site B bench at the highwall base. These wet depressions retain water throughout most of the growing season and support wetland vegetation. We collected 53 species from the seeps (Table 3). The woody plant zone is dominated by black willow (*Salix nigra*), silky willow (*S. sericea*), and pink steeplebush (*Spiraea tomentosa*). At the border of the woody zone is a common cattail (*Typha latifolia*)-woolgrass (*Scirpus cyperinus*) emergent zone. Other emergent species are soft rush (*Juncus effusus*), blunt spikerush (*Eleocharis ovata*), and blue-green bulrush (*Scirpus atrovirens*).

Wet meadow species adjacent to the tree and emergent zones comprise the sedge (*Carex*)-rush (*Juncus*) zone. Wetland indicator herbs include yellow-green sedge (*Carex lurida*), Frank's sedge (*C. frankii*), fox sedge (*C. vulpinoidea*), beakrush (*Rhynchospora capitellata*), sharp-pointed rush (*Juncus acuminatus*), seedbox (*Ludwigia alternifolia*), great blue lobelia (*Lobelia siphilitica*), marsh St. John's-wort (*Hypericum mutilum*), bugleweed (*Lycopus virginicus*), deer-tongue panicum, and common horsetail (*Equisetum arvense*).

Two unique plants for Kentucky are present in the sedge-rush zone. Creeping foxtail (*Alopecurus arundinaceus*), recorded only from North Dakota and Newfoundland, is becoming naturalized at LMDA (Thompson and Thieret 1986a). The rare green twayblade (*Liparis loeselii*), is a new distribution record which was previously known from only a single county in Kentucky (Thompson and MacGregor 1986b).

Coal Haul-Telephone Microwave Tower Road. This highly compacted access road is maintained in an early, pioneer seral stages from the continual disturbance by vehicles. Indicator herbs are mainly composed of many weedy native and exotic annuals, biennials, and perennials of the Asteraceae, Poaceae, Fabaceae, Rosaceae, and Polygonaceae. A few herbs found are common ragweed (*Ambrosia artemisiifolia*), daisy fleabane (*Erigeron annuus*), horseweed (*Conyza canadensis*), Korean lespedeza, sericea lespedeza, wild carrot, English plantain (*Plantago lanceolata*), milk spurge (*Euphorbia nutans*), smooth crabgrass (*Digitaria ischaemum*), nodding foxtail (*Setaria faberii*), and tall fescue. This ruderal habitat had 104 taxa recorded (Table 3).

LMDA Flora Summary

The annotated list is composed of 360 specific and infraspecific taxa in 224 genera from 82 families. A total of 74 species (20.6%) were non-indigenous introduced or naturalized (Table 3). Vascular plants consist of 1 Lycopodiophyta, 1 Equisetophyta, 8 Polypodiophyta, 7 Pinophyta, and 343 Magnoliophyta (82 Liliopsida, 261 Magnoliopsida). The largest plant families numerically are the Asteraceae (64), Poaceae (39), Fabaceae (20), Cyperaceae (16), Rosaceae (13), Lamiaceae (11), and Polygonaceae (10). Three threatened Kentucky species, Appalachian showy gentian, green twayblade, and ovate-leaved catchfly, are found in habitats created by surface mining. A total of 155 (43.1%) were Bell County distribution records (Table 3).

Discussion

Planted Species Evaluation

Twenty-four of 25 reclamation species (96.0%) originally planted during 1964, 1965, 1971, and 1984, are persisting at the LMDA through 1985. Several legumes are contributing to soil enrichment and community development. Several hardwoods and conifers are important to plant community structure and for potential forestry products. Woody and herbaceous exotic species are becoming locally naturalized and important in revegetation and plant succession on LMDA.

We recommend eleven successful planted species at LMDA for other contour surface-mined areas or similarly disturbed areas in the Cumberland Mountains. The plantings of tall fescue, sericea lespedeza, and Korean lespedeza, have been important for initial plant cover and site development throughout the LMDA habitats. Crown-vetch, red clover, white sweet clover, and yellow sweet clover, have enhanced overall cover, but to a lesser degree than tall fescue, sericea lespedeza, and Korean lespedeza. European black alder, autumn olive, and bicolor lespedeza are important soil enrichment species spreading on outslopes and benches. Black locust has significantly influenced the development of the young hardwood forest. This important early pioneering species contributes to soil nitrogen-fixation processes, litter production from dead trees, and serves as a nurse tree for other species.

Sugar maple, yellow poplar, and white ash are important volunteers in secondary succession throughout the LMDA habitats. Virginia pine is an important invader in other mine habitats. Shortleaf pine has been less successful in survival and migration. Eastern white pine and loblolly pine have not survived well partly because of destruction during remining in 1970. Scotch pine and Norway spruce on the 1963 bench have potential for forest products although these introduced trees are not reproducing from their own seed sources.

We do not highly recommend some woody plantings that have persisted at LMDA until more experimental planting research has been done or other potential choices have been tried. American sycamore and northern red oak have not grown as well as several other planted hardwood trees on the 1963 bench. American sycamore, northern red oak, and black walnlut are not growing well on the 1984 block plots on the 1970 bench, although it is too early for final evaluation. The only planted species not recommended for planting is saw-tooth oak which did not survive at LMDA.

LMDA as a Refugium for Rare Species

The Log Mountain Demonstration Area has provided new habitats for at least three Kentucky "endangered" plant species. The second Kentucky documentation of the green twayblade (*Liparis loeselii*) was recorded in the sedge-rush 1963 bench seeps (Thompson and MacGregor 1986b). The ovate-leaved catchfly (*Silene ovata*) and the Appalachian showy gentian (*Gentiana decora*), were found on the 1963 bench (Table 3).

Wade and Thompson (1993) reported that five pre-SMCRA surface-mined sites in Kentucky have provided important habitats for certain rare plant species not found in the undisturbed or non-mined environs. All five revegetated pre-SMCRA coal-mined sites in the Cumberland Mountains and Cumberland Plateau have provided habitats for one or more Kentucky endangered or threatened species listed by Warren et al. (1986). None of these rare Kentucky species were found in the adjacent non-mined environs of these coal mined sites during the initial or subsequent reconnaissances. While presence of these rare species outside of the immediate environs is unreported or unknown, the establishment of rare species has occurred in habitats created on the pre-SMCRA coal mined areas in the Cumberland Mountains and Cumberland Plateau. The potential status of these rare species is not predictable because of continual vegetation development, potential environmental changes, or anthropogenical effects in the future (Thompson and Wade 1991).

We classify these restricted habitats created by pre-law surface mining in Kentucky as "refugia" where rare species have become established. These unique habitats have served as suitable refuges for certain rare plants that might otherwise have become more rare or even extirpated from the region. In Europe, abandoned rock quarries (Usher 1979, Wartner 1983), and surface-mined lands (Bruns 1986, Dahl and Juerging 1982, Sanderson 1992) have served as refugia for many rare species not found elsewhere.

LMDA Floristic Richness

Species richness is a measure of success in the reclamation process in conjunction with natural plant succession. At the LMDA, the 360 species are comparable to two other pre-law coal mined sites in the Cumberland Plateau of Kentucky. A total of 350 species were found on an 18-year-old area-type surface mine of 14.0 ha in Laurel County (Thompson et al. 1984); 272 species were present on a 12-year-old contour surface-mined area of 2.5 ha in

Rockcastle County (Thompson and Wade 1991). The Asteraceae, Poaceae, Fabaceae, Cyperaceae, and Rosaceae, were also the largest families on the other four pre-SMCRA mines sites in eastern Kentucky (Wade and Thompson 1993). The 360 species at LMDA represent 11.5% of the total flora for Kentucky based on Browne and Athey (1992).

A species-area curve was derived to compare species that were "found" with those "expected" in different-sized areas within the Western and Mixed Mesophytic Forest Region (Wade and Thompson 1991, 1993). We found that the actual species richness at the LMDA is only two percent less than species richness expected. At four other pre-SMCRA Kentucky surface-mined sites, species richness ranged from only three to 12 percent less than predicted. The 155 distribution records indicate the sparseness of plant collections and botanical exploration in Bell County.

LMDA Vegetation and Secondary Succession

The contour-mining and reclamation efforts have created six physical habitats with minesoils significantly different from the non-mined contiguous ridgetops of the disturbed mixed mesophytic hardwood forest. While contour-mining disturbance at LMDA removed most of the original soils with the geologic substrate, seed bank diaspores or propagules were intermixed with surface minespoils. Planted nitrogen-fixing trees and herbs helped ameliorate the rapidly weathering minesoils. Planted exotics and native invaders have influenced the species composition during the early secondary successional stages. Shade-intolerant, pine and hardwood seedlings have become established from wind-transported seeds and fruits.

The disturbed mixed mesophytic hardwood forest above the highwall is important as diaspore or propagule source for overall high species richness and natural successional trends at the LMDA. This forest has a well-developed canopy with seedlings and saplings evident, a sparse subcanopy and shrub layers, and a rich herbaceous layer. Important trees are sugar maple, red maple, yellow poplar, American basswood (*Tilia americana*), yellow buckeye (*Aesculus flava*), white ash, sourwood, red pignut hickory (*Carya ovalis*), white oak (*Quercus alba*), chestnut oak (*Q. prinus*), and northern red oak. Flowering dogwood (*Cornus florida*) and eastern redbud are two important subcanopy trees. Shrubs and vines are common greenbrier, glaucous greenbrier, Virginia creeper, summer grape, and wild hydrangea.

The forest vegetation at LMDA is a complex mosaic of natural and semi-natural plant communities in various of secondary seral stages in the LMDA habitats. Plant communities are the result of habitat diversity created by surface-mining, reclamation, and minesoil characteristics. High species richness is a function of volunteering species from the environs, planted reclamation species, and the remnant seed bank of the pre-mining habitats at LMDA. Species richness, vegetation development, and habitat diversity at LMDA are comparable to other pre-SMCRA surface-mined area in the Cumberland Plateau of Kentucky (Thompson et al. 1984, 1986c, Thompson and Wade 1991, Wade and Thompson 1993).

Conclusions

Several interrelated factors have been ascertained from descriptive research data of the pre-SCMRA Log Mountain Demonstration Area:

1. Habitat diversity created by pre-law coal surface mining supports a high species richness comparable to the contiguous non-mined environs.
2. Habitats from pre-SMCRA mining serve as refugia for certain rare plants that are not present in the unmined contiguous habitats or environs.
3. The entire flora is derived from the remnant seed bank, native and exotic invaders from the environs, and the planted native and exotic reclamation species.
4. Plant communities are developing mainly through seral stages of secondary succession with the strong influence of the natural invading and planted native and exotic flora.
5. Vegetation is a complex mosaic of natural and semi-natural plant communities progressing toward a young mixed hardwood forest on the planted and unplanted surface-mined habitats.
6. Twenty-four of 25 native and exotic species have persisted from plantings by personnel of the USDA Forest Service.
7. Nitrogen-fixing species important for soil and site enrichment are black locust, European black alder, autumn olive, bicolor lespedeza, sericea lespedeza, Korean lespedeza, and red clover.
8. Native trees recommended as reclamation plantings for vegetational development are black locust, white ash, yellow poplar, sugar maple, and Virginia pine.
9. Naturalized herbaceous taxa recommended for reclamation ground cover and pioneer species are tall fescue, sericea lespedeza, Korean lespedeza, and red clover.
10. Introduced woody trees recommended for potential forestry products are Norway spruce and Scotch pine.

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THE RELATIVE MERITS OF DOLOMITIC AND CALCITIC LIMESTONE IN DETOXIFYING AND REVEGETATING ACIDIC, NICKEL- AND COPPER-CONTAMINATED SOILS IN THE SUDBURY MINING AND SMELTING REGION OF CANADA[1]

by
Derek McHale and Keith Winterhalder[2]

Abstract. Soils in the Sudbury mining and smelting region have been rendered phytotoxic and barren by acidification and particulate metal contamination, but can be detoxified and revegetated by the surface application of ground limestone. On certain barren sites, plant growth is better on soil treated with dolomitic limestone than with calcitic limestone, and greenhouse experiments using mung beans (*Vigna radiata*) have shown superior root and shoot growth on certain contaminated soils when the limestone is dolomitic rather than calcitic. Results of experiments with species used in revegetation (*Agrostis gigantea* and *Lotus corniculatus*) suggest that leguminous species are more sensitive to Ca:Mg ratio than grasses, that the plant response to this ratio is greater at lower liming levels, and that the response is more marked on more toxic soils. The effects of calcium:magnesium ratio of the limestone used in revegetating acidic, metal-contaminated soils are clearly complex, interactive and difficult to interpret. Further studies are needed, but meanwhile it is recommended that the practice of using dolomitic limestone to detoxify barren Sudbury soils be continued, since there is a risk of induced magnesium deficiency at certain sites when calcitic limestone is used.

Additional Key Words: Ca:Mg ratio, liming rate, *Agrostis gigantea*, *Lotus corniculatus*

Introduction

Until recently, 10,000 ha of barren, phytotoxic land encircled the three Sudbury smelters (Coniston, Copper Cliff and Falconbridge). The barren soils, ranging in pH from 3.5 to 4.5, and with copper and nickel contents frequently exceeding 1,000$\mu g \cdot g^{-1}$, are the result of the effects of a century of mining and smelting activity, including SO_2 fumigation and copper, nickel, and iron particulate fallout from the smelters.

The construction of a 380m smokestack at the Copper Cliff smelter, plant closures, legislated reductions in SO_2 emissions, and improved emission control technology, have brought about a steady decline in atmospheric SO_2 and in particulate emissions from the smelters since 1972. A detectable rise in soil pH and fall in soil metal levels has occurred (Gundermann and Hutchinson 1993; Dudka *et al.* 1995), but recolonization of the barrens has been mostly confined to species that have evolved metal tolerance, such as *Deschampsia caespitosa* (Cox and Hutchinson 1980), *Agrostis gigantea* (Hogan *et al.* 1977), *Agrostis scabra* (Archambault and Winterhalder 1995), *Poa compressa* (Rauser and Winterhalder

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1985) and *Betula pumila* (Roshon 1988), and there are still areas close to the smelters that are devoid of vegetation. In these acid soils, aluminum ions are liberated from aluminosilicate minerals, as are copper and nickel ions from particulate smelter fallout. Seeds germinate, but unless the plant is from metal-tolerant stock, root growth is inhibited and the roots are unable to penetrate the soil.

Ground limestone, when applied to the surface of the toxic soil, acts as a 'Trigger Factor' (Winterhalder 1983), initiating spontaneous colonization by metal-intolerant plants from a local seed source. The stony mantle that covers these eroded, glacial till-derived soils traps limestone particles and seeds, acting as a protective mulch to the young seedlings. The soil is effectively detoxified, despite a modest pH rise of as low as one unit (e.g. from 4.5 to 5.5), allowing the seedling to develop a deep root system, protecting it against drought and frost-heaving, and enabling it to reach bases and other nutrients deeper in the profile. Ultimately, the leaf litter provides insulation, thereby reducing frost damage, while the humus helps to complex potentially toxic metals.

Winterhalder (1995) has suggested five possible components of the complex mechanism of detoxification. Precipitation of copper and nickel from solution is probably relatively rare, since a pH of above 5.5 is rarely achieved. However, the Al^{3+} ions that result from the hydrolysis of clay minerals are hydroxylated and rendered less toxic as the pH rises. Calcium ions enhance the plasma membrane integrity of root hair cells (Epstein 1961), and the abundant calcium ions reduce metal uptake by the roots by competitive exclusion (Kinraide and Parker 1987).

The amelioration of metal toxicity by calcium is well documented. Increased calcium can reduce the detrimental effects of aluminum on soybean (Lund 1970; Brady *et al.* 1993) and nickel toxicity in corn (Robertson 1985). Calcium-nickel interactions can be complex, and Knight and Crooke (1956) found that the calcium uptake of oat plants, but not of tomato plants, was higher in nickel-contaminated soils .

Quite fortuitously, the limestone that has been used in Sudbury's Regional Land Reclamation Program has been dolomitic, with a Ca:Mg ratio of approximately 2:1.

Calcium and magnesium levels in Sudbury soils are within the normal range for soil in a temperate region (Hazlett *et al.* 1983), despite a century of acid leaching, probably because both Ca and Mg are components of the emissions of the Copper Cliff smelter, at rates of over 300 $kg \cdot day^{-1}$. It therefore seems unlikely

that plants on Sudbury soils would suffer from a simple deficiency of calcium or magnesium. Nevertheless, Winterhalder (1983) suggested that the beneficial effects of liming Sudbury barren soils involved both neutralization and a calcium nutrition effect. Later (Winterhalder 1993), it was suggested that calcium:magnesium balance might play a critical role in the nutrition of plants in limed Sudbury soils.

Tan *et al.* (1992), when examining a variety of sorghum genotypes which had different sensitivities to acid soils, found that the benefit of liming is increased when there is an adequate magnesium supply. It is therefore possible that the exclusive use of calcitic limestone on Sudbury soils would bring about a calcium-magnesium imbalance and consequent induced magnesium deficiency, in which the superabundance of calcium ions would exclude magnesium uptake by competing on the root exchange sites, since magnesium is less competitive than calcium and aluminum under acid conditions (Sumner *et al.* 1991). In addition to its nutritional role, possible beneficial effects of magnesium include interaction with potentially toxic metals. Proctor and McGowan (1976) showed a clear alleviation of Ni toxicity by Mg in oats, and Robertson (1985) showed that both calcium and magnesium provided protection to corn roots against nickel poisoning, although at higher levels Mg itself became toxic unless alleviated by the appropriate Ca balance.

Previous studies on the effects of Ca and Mg have focused on agricultural plant species growing in soils which are acidic and therefore contain elevated levels of soluble aluminum, or else on serpentine soils which have a neutral to basic pH, high levels of nickel, chromium and magnesium, and low levels of calcium (Johnston and Proctor 1981). The Sudbury area soils are unique in being acidic like the former but metal-contaminated like the latter. The purpose of this paper is to examine the relative merits of dolomitic and calcitic limestone, with respect to the Ca:Mg ratio within the limestone, for detoxifying and revegetating acidic, nickel- and copper-contaminated soils in the Sudbury region.

Plant Growth Experiments

At the beginning of the investigation, several exploratory experiments were carried out to test the hypothesis that the two limestone types could have differential ameliorative capacities. Two examples follow.

1. Mung bean (*Vigna radiata*) on semi-barren soil. Mung bean seedlings were grown in soil collected from a semi-barren birch woodland 6 km south-west of the Falconbridge smelter and 6 km

north of the Coniston smelter (Maki Road). The four treatments were: no limestone (control), calcitic limestone, 50:50 calcitic:dolomitic limestone, and dolomitic limestone. A total of 1.5 g of limestone was mixed into 150 g of soil in each pot. As shown in Figure 1, both root and shoot growth were significantly greater in the dolomitic containing treatments than in the calcitic or control treatments.

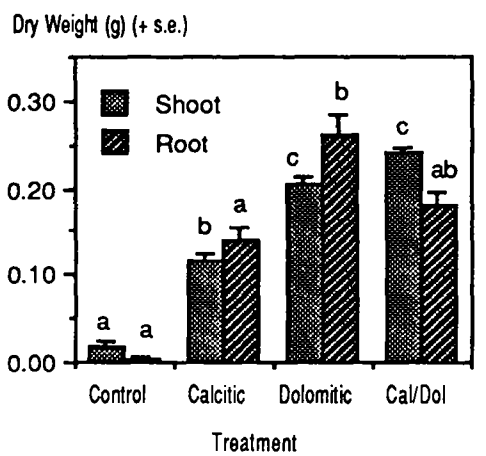

Figure 1. Mean *Vigna radiata* shoot and root dry weights in Maki Road soil under different limestone treatments (vertical bars represent standard error). Means for shoots or roots with the same superscript are not significantly different ($p<0.05$).

2. Redtop (*Agrostis gigantea*) on barren soil. Mung bean is a convenient experimental species, but has no relevance to the revegetation program. Therefore seedlings of redtop, a major revegetation grass species, were grown in barren soils from 10 km northeast of the Copper Cliff and 2 km south of the Falconbridge smelter, respectively, using the same protocol as above, except that 1.0 g of limestone was mixed into 150 g of soil. In neither soil did shoot biomass show significant response to dolomitic limestone, and the only significant root response was that seen in Copper Cliff soil (Figure 2), where the response was once again significantly greater in dolomitic treatments than in the control and calcitic treatments.

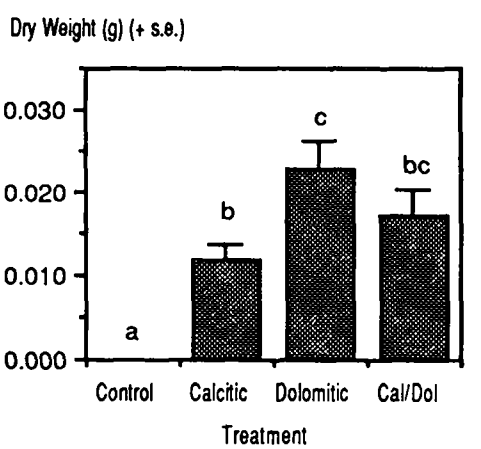

Figure 2. Mean *Agrostis gigantea* root dry weights in Copper Cliff soil under different limestone treatments (vertical bars represent standard error). Means with the same superscript are not significantly different ($p<0.05$).

Two additional, more comprehensive experiments were then carried out, the first looking at early seedling root and shoot growth under two lime types, and the second at longer term

growth under widely varying Ca:Mg ratios.

3. Petri dish bioassay using redtop (*Agrostis gigantea*) on three barren soils. Three barren soils from the vicinity of each of the three smelters (Table 1) were used in a Petri dish root/shoot growth bioassay.

Table 1. Chemical characteristics of soils used in Petri dish bioassay (Mean ± standard deviation for three samples at each smelter). Within rows, data followed by the same letter are not significantly different at the 5% level (Tukey Multiple Range Test). O.M. = Organic Matter, W.S. = Water Soluble, Ext. = Weak Acid Extractable, Tot. = Total.

	Falconbridge	Copper Cliff	Coniston
pH	3.75a	4.00b	3.85ab
O.M.	6.95%a	7.86%a	10.74%b
W.S.			
Ni	3.6±3.7a	11.9±5.5b	16.2±21.6c
Cu	2.95±1.4a	7.9±3.4b	16.8±4.5c
Al	11.0± 8.3a	29.24±9.1ab	64.8±60.4b
Ca	31.8±41.2a	42.35±41.4a	60.3±72.8a
Mg	4.1±2.7a	4.2±1.70a	6.2±6.8a
Ext.			
Ni	8.6±8.34a	20.0±12.0a	17.8±26.5a
Cu	71.0±32.5a	105.3±28.8a	176.3±76.2b
Al	381.3±230.4a	981.2±364.6b	1215.6±283.2b
Ca	74.0±77.7a	76.7±34.4a	105.2±110.7a
Mg	5.9±3.9a	6.9±5.5a	8.0±7.5a
Tot.			
Ni	410.3±191.0a	506.9±259.0a	611.6±314.2a
Cu	450.8±128.0a	484.3±131.9a	806.6±431.1b
Al (%)	4.3±0.3a	5.7±0.7b	5.3±0.8b
Ca (%)	2.9±3.2a	3.5±0.7a	2.7±1.7a
Mg (%)	2.0±0.3a	3.5±0.4b	3.6±1.7b

Values in $\mu g \cdot g^{-1}$ except where indicated.

40 g of each soil were placed in a filter paper lined perforated plastic Petri dish which was then placed in a larger glass Petri dish. The treatments were: no limestone (control), calcitic limestone, and dolomitic limestone, the limestone being applied by sprinkling 0.2 g onto the soil surface. Glass fibre filter paper was placed over the soil, and the soil was wetted from below. Twenty-five seeds of *Agrostis gigantea* were placed on the surface of each glass fibre filter paper.

The seeds were kept in darkness for 4 days, then in a 12 hour light/dark cycle for a further 12 days, after which the roots and shoots were measured to the nearest millimetre. In the case of the unlimed soils (data not shown), a gradient existed in the toxicity of the unlimed soils with respect to both the root and shoot growth of *Agrostis gigantea*. The roots in the Falconbridge soil were significantly longer than those in the other two soils. The shoot lengths were significantly the longest in the Falconbridge soil and the shortest in the Coniston soil, with the shoots in the Copper Cliff area soil being intermediate in length, but not significantly different from the others. In all cases there was a significant difference between the controls and the lime treatments.

In the limed treatments (Figure 3), there was no significant difference in root growth between limestone types for any

of the soils, but the fact that the Coniston soil was the most inhibitory to root growth, even after liming, was clear.

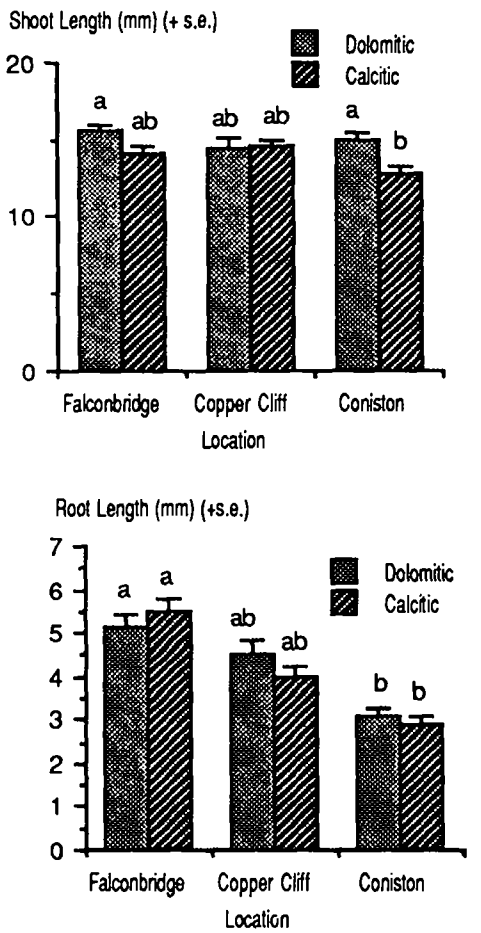

Figure 3. Mean shoot lengths (above) and root lengths (below) of young *Agrostis gigantea* seedlings grown on three Sudbury soils under different limestone treatments (vertical bars represent standard error). Means with the same superscript are not significantly different ($p<0.05$).

However, shoot growth showed a significant response to the dolomitic treatment on the Coniston soil, but not on the Falconbridge or Copper Cliff soil.

4. Ca:Mg Ratio Pot Experiment. Seeds of redtop and birdsfoot trefoil (*Lotus corniculatus* - a major leguminous species in revegetation) were sown in two contaminated soils (Coniston and Falconbridge) and a control soil (Cartier, 44 km northwest of the Copper Cliff smelter), each of which had been treated with finely-powdered calcium carbonate-dolomitic limestone combinations to give equal neutralization, but with Ca:Mg ratios of 1:0, 192:1, 96:1, 48:1, 24:1, 8:1, 4:1 and 2:1, respectively. Two neutralization levels were employed (0.2 g limestone•pot^{-1}, giving a pH of approximately 4.0, and 0.8 g limestone•pot^{-1} giving a pH of approximately 5.5). The experiment was replicated five times, and after 2 months of growth, roots and shoots were harvested and dry weights determined.

Results for the two plant species were analyzed separately, as were the two lime rates (moderate and low). Ca:Mg ratio had no significant effect on root or shoot growth of *Agrostis gigantea* at either lime rate on any soil, and for *Lotus corniculatus* there was no significant difference between treatments at the moderate lime rate for any soil. However, at the low lime rate, Ca:Mg ratio significantly influenced shoot mass in *Lotus corniculatus* in the Coniston area soil, with significantly higher shoot mass at Ca:Mg ratios of 4:1 or less (Figure 4).

Leaf chlorosis was consistently present in both contaminated soils at the low lime rate, but more intense under the higher calcium regimes.

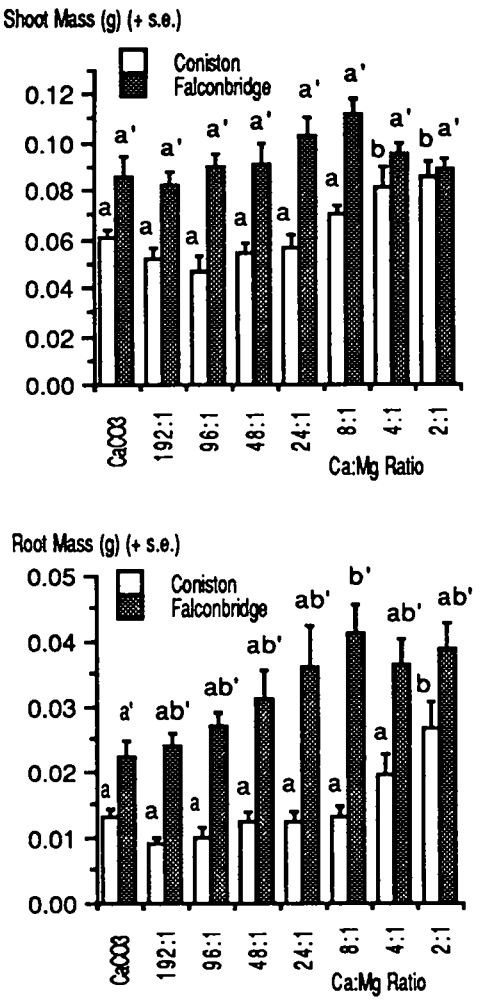

Figure 4. The effect of Ca:Mg ratio at low liming rate on the growth of birdsfoot trefoil shoots (above) and roots (below) on Coniston and Falconbridge soils (vertical bars represent standard error). Means with the same superscript are not significantly different ($p<0.05$).

Also at the low lime rate, Ca:Mg ratio significantly influenced root mass in *Lotus corniculatus* in both Coniston and Falconbridge soils (Figure 4). The uncontaminated Cartier soil showed no response to either the lime rate or the calcium-magnesium ratio for either species.

Discussion

The dramatic response of the mung bean seedlings to the dolomitic limestone treatment in the first experiment strongly supported the hypothesis, based on previous anecdotal evidence, that Ca:Mg balance can play an important nutritional and/or anti-toxic role on certain Sudbury area soils. However, redtop did not give the same consistent results on two different toxic soils in the second experiment. Indeed, the fact that the only significant response of redtop was that shown by roots in the Copper Cliff soil, whereas in the Maki Road soil the greater response of mung bean was evident in the shoots, suggests that the phenomenon is species and/or soil dependent.

There was a clear gradient in the toxicities of the three un-limed Sudbury area soils, with Coniston being the most toxic, followed by Copper Cliff, and finally Falconbridge. The Coniston area soil consistently had higher levels of copper and nickel, and a higher percentage of organic matter. Although all of the contaminated soils were barren when collected, they possessed different degrees of toxicity. It is still not clear

which of these factors is interacting with the limestone to produce the differential responses.

In the third experiment, a contradictory situation arose, in which there was no significant root response to dolomitic limestone in any of the soils, but a definite shoot response on the Coniston soil, which also appeared to be the most toxic. The difference here could have been soil-related. At higher soluble metal concentrations, the competition for exchange sites could reduce the magnesium available to the shoots, resulting in a lime induced magnesium deficiency, but at slightly lower metal levels the ameliorating effects on the metal toxicity in the rhizosphere would be the over-riding factor. Furthermore, the Coniston soil had the highest organic matter content. Although organically bound copper is less rhizotoxic than the ionic form, it is possible that it could be taken up by the plants and translocated where metal ions could not, as shown in the case of EDTA-chelated copper in *Triticum aestivum* by Taylor and Foy (1985). Alternatively, the difference could be the result of the fact that the organs measured were radicles and first leaves, rather than mature root and shoot systems, as well as the fact that length, rather than biomass, was measured.

In the fourth experiment, an interesting difference between the behaviour of the grass (redtop) and the legume (birdsfoot trefoil) appeared, in that there was no significant response to dolomitic limestone in redtop at any liming level in any soil, whereas birdsfoot trefoil shoots showed a significant response at the low liming level. Similar results were found by Edmunds *et al.* (1983) in a study on the effect of calcitic limestone on ryegrass and white clover grown on a New Zealand yellow-brown loam. After examining yield and internal magnesium concentrations, they showed that magnesium concentration in the grass decreased in proportion to increasing yield, suggesting a dilution effect. In the clover, however, magnesium concentration decreased with plant yield reduction, suggesting that the calcitic limestone had an antagonistic effect on magnesium uptake. One consistent feature in the Sudbury and New Zealand experiments has been the apparent greater sensitivity to Ca:Mg ratio of leguminous species, compared to grasses, possibly due to the lower ability monocot roots have to bind cations such as calcium (Rorison and Robinson 1984).

McNaught *et al.* (1973) were able to demonstrate that liming with $Ca(OH)_2$ in a pasture made up of primarily white clover could reduce the tissue magnesium levels compared to magnesium-containing liming materials. The legume used in the

present study, *Lotus corniculatus*, may be particularly sensitive to the Ca:Mg ratio in the soil. In a study on acidic, infertile Appalachian soils, Baligar *et al.* (1985) examined the differences in growth and nutrient uptake in six legume species. The soils were limed with $Ca(OH)_2$, and the only species that did not respond positively to the lime was the birdsfoot trefoil. However, the liming reduced the magnesium levels in all legume species to low to deficient rates, although, unlike birdsfoot trefoil, the other legumes, including white clover, responded with increased yield. Clearly, response of legumes to liming is species-specific, but the nature of the species-specific response factor or factors is not known.

It may be helpful to attempt to interpret the results of these experiments in the light of the two probable functions of the limestone - the amelioration of rhizotoxicity with its concomitant root growth inhibition, and the reduction of metal uptake (particularly of nickel) and concomitant effects on shoot growth and vigour. The amelioration of root toxicity would involve such things as the hydroxylation of aluminum ions and competitive exclusion of metals by base ions, whereas shoot effects would involve mechanisms that reduce nickel uptake such as magnesium:nickel interactions, plasma membrane integrity effects and (once again) competitive exclusion. On this basis one would expect response to dolomitic limestone to be expressed in the leaves more than in the roots, and this is indeed the case in three of the four experiments. The reduced shoot growth of *Lotus corniculatus* in the Coniston area soil at the higher calcium-magnesium ratios could be the result of a lime induced magnesium deficiency. Because the Mg^{2+} ion is also involved in the amelioration of nickel toxicity (Robertson 1985), its effectiveness is reduced when it is in lower concentrations, relative to calcium.

On the other hand, the presence of an increased response to the lower Ca:Mg ratios in the roots of the *Lotus corniculatus* growing in the Falconbridge soils, but not in the shoots, would indicate a reduction in copper and aluminum toxicity afforded by the higher magnesium concentrations.

Christenson *et al.* (1973) examined oat plants growing in acid soils amended with different calcium and magnesium sources. They showed that a high Ca:Mg ratio suppressed magnesium uptake, although low pH had a greater effect on magnesium uptake than did calcium source. This could explain, in part, the fact that birdsfoot trefoil only responded to dolomitic limestone at a low liming rate. Sumner *et al.* (1978) showed that, in highly weathered soils which have been limed with finely ground

limestone, the amount of exchangeable Mg increases to roughly pH 6, then decreases, as the pH approaches neutrality. Thus, as the pH of an acid soil is adjusted towards pH 6, a greater proportion of the magnesium will be held on exchange sites, rather than in the soil solution, making it more available to the plants (Sumner *et al.* 1991). While on the exchange sites, the competitive disadvantage of the magnesium is lost, and the lime induced deficiency no longer exists. This was observed in the last Sudbury experiment, in that there were no significant responses to Ca:Mg ratios at the higher lime rate. Tan *et al.* (1991) also found that, on aluminum toxic soils, there was a significant response of aluminum sensitive sorghum genotypes to the addition of magnesium at low rates of liming, but as the lime rate increased the effectiveness of the magnesium was reduced. In the light of Sumner *et al.*'s (1991) observations, it is possible that, if the Sudbury soils were limed to above pH 6, there would be a decrease in available magnesium, resulting in a reduced yield.

The importance of soil toxicity level was again apparent in the Ca:Mg ratio experiment. There was a strong response in the highly toxic Coniston soil, whereas there was little response in the less toxic Falconbridge soil. Shoot growth responded significantly to Ca:Mg ratio in the Coniston soil, but not in the Falconbridge soil. Root growth in the toxic Coniston soil was highest at the 2:1 ratio, while in Falconbridge soil it peaked at 8:1. Plants on the uncontaminated Cartier soil did not respond to either liming rate or Ca:Mg ratio.

Since other authors have demonstrated lime induced magnesium deficiency in various soil types and plant species, the fact that it is not evident in all Sudbury area soils indicates that there are other factors operating. From the experiments so far conducted, it is clear that the effects of the calcium-magnesium ratio in limestone are complex and interactive, and it is difficult to identify which factors in the soil are reacting with which elements of the limestone. There is evidence, however, that there is a relationship between the phytotoxicity of limed acid metal-contaminated soils and the calcium-magnesium ratio of the limestone employed. Further studies are needed to further define this relationship.

It is recommended that the practice of using dolomitic limestone to detoxify barren Sudbury soils be continued, since there is a risk of induced magnesium deficiency at certain sites when calcitic limestone is used.

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ONTOGENY OF ACCIDENTAL WETLANDS AND HYDRIC SOIL DEVELOPMENT IN SURFACE MINED LANDSCAPES

by

Robert B. Atkinson, W. Lee Daniels, and John Cairns, Jr.

Abstract. Reducing conditions are periodically present in hydric soils and are essential for chemical processes that support wetland functions and values. Indicators of these conditions, i.e., redoximorphic features, can be useful in determining the presence of a hydric soil. However, young wetlands, i.e., those recently formed, may not possess reducing conditions and/or may not exhibit redoximorphic features. Few studies have addressed the time needed for hydric soil development. In this study, we present data on redoximorphic features, including chroma and oxidized rhizospheres, gathered from two sets of wetlands in southwestern Virginia, including (1) constructed wetlands that are 3 years old and (2) accidental wetlands that are 10 to 30 years old. Under conditions described for these sites, there is strong evidence that discernable redoximorphic features form in accidental wetlands within 10 years, but not within 3 years in constructed wetlands. Since accidental wetlands have been in existence for longer than most man-made wetlands, they provide clues to the development of hydric soils in recently constructed wetland systems.

Additional Key Words: litter, hydrophytic vegetation, redoximorphic features, sedimentation, SMCRA, wetlands.

Introduction

Small depressions that formed accidentally following contour surface mining in southwestern Virginia may meet all three criteria to be considered wetlands, according to the Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987), which is the delineation manual currently in use. According to this manual, accidental wetlands (referred to as "man-induced") may not exhibit hydric soil indicators for "hundreds of years." A more accurate and precise estimate of time required for establishment of hydric soil indicators is needed (1) to aid in delineation of recently formed wetlands and (2) to aid in structural and functional assessment of constructed wetlands by providing evidence of functions that depend on reducing soil conditions.

Many wetland functions depend upon hydric soils. Hydric soils influence decomposition rate (Reddy et al. 1986) and distribution of organic matter (Megonigal and Day 1988), as well as plant distributions (Pearsall 1938). Many nutrients and other chemicals are transformed in wetlands, including nitrogen (Broadbent and Clark 1965), phosphorus, and iron (Gambrell and Patrick 1978). Pesticide and metal transformations also take place in hydric soils (Gambrell and Patrick 1978). Considerable methane is oxidized in hydric soils and may influence atmospheric gas balances (King et al. 1990).

Under certain conditions, soil redox potential decreases and hydric

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soil indicators begin to develop. The rate of oxygen diffusion in soil decreases by a factor of approximately 10,000 once a soil becomes saturated (Gambrell and Patrick 1978). Aerobic soil microbes consume organic matter and use oxygen preferentially as an electron acceptor. Some oxygen demand can also be attributed to oxidation of reduced elements diffusing up from anaerobic layers (Simpson 1978). Microbial activity and chemical transformations continue to occur under anaerobic conditions and the redox potential of the soil is lowered, i.e., reducing conditions become established (Ponnamperuma 1972).

Once reducing conditions become established for sufficient frequency and duration each year, several years may be required for redoximorphic features such as low chroma and oxidized rhizospheres (iron oxide coatings on fine roots) to develop.

Naturally occurring wetlands typically exhibit redoximorphic features within 25 cm of the surface or just below the A horizon, which are used in wetland delineation (Vepraskas 1995). Specifically, matrix chroma must be 1 or less if no color pattern (depletions and masses) occurs (Environmental Laboratory 1987; Federal Interagency Committee for Wetland Delineation 1989). According to the Environmental Laboratory (1987), wetlands that have been "incidentally created by human activities" are considered "atypical situations." This section states that hydric soil indicators may be lacking, and delineation may not require that hydric soil indicators be present. Thus, assessments of constructed wetlands, including wetlands constructed as mitigation for destruction of natural wetlands, may not currently consider soil chroma and oxidized rhizospheres for measuring success. This paper provides information on the time required for development of redoximorphic features in small depressions in southwestern Virginia.

Site Description

Accidental Wetlands

Contour surface mining for coal disturbed over 385,000 ha in the Appalachian Mountains prior to enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Topographic features left by mining included vertical "high walls" and fairly flat "benches" consisting of severely compacted spoil with bulk density of 1.7 g/cc (Daniels and Amos 1982). Sediment was deposited over compacted mine spoil in many small depressions on benches. As a result, wetland hydrology became established and hydrophytic vegetation colonized the depressions (Atkinson and Cairns 1994). Over time, these conditions led to lowered soil redox potential and establishment of redoximorphic features in the accidental wetlands we studied.

Table 1. Indicator categories and probability of a plant species occurring in a wetland (Reed 1988)

Indicator Category	Wetland Frequency
Obligate wetland	>99%
Facultative wetland	67-99%
Facultative	34-66%
Facultative upland	1-33%
Obligate upland	<1%

Sites were located in Wise County in southwestern Virginia. Selection criteria included the presence of hydrophytic vegetation and depressional wetland hydrology and the absence of significant acid mine drainage inputs. Each wetland exhibited two plant community types: (1) a community dominated by obligate wetland plants and (2) a community dominated by facultative wetland plants (Table 1).

Year of accidental wetland formation ranged from 1965 to 1986. Maximum water depth in accidental wetlands ranged from 89 cm in site 3 to 8 cm in site 2 (Table 2). Aboveground biomass estimates in 1994 for the facultative wetland community were 442 g/m^2 and were 398 g/m^2 for the obligate wetland community. Total precipitation over a 7-year period

Table 2. Site reference number, hydrology (sources of water, duration dry, and hydrology modifier), and age (year formed) for 12 accidentally formed wetlands in this study

Site	Inlets/ outlets	Water depth[1]	Draw-down[2]	Hydrology[3]	Year formed
1	No/no	40	0.0	PEMe	1978
2	Temp/temp	7.9	66	PEMb,a	1986
3	Temp/perm	89	0.0	PEMe	1974
4	No/temp	18	25	PEMc	1974
5	No/no	18	13	PEMc	1973
6	No/temp	62	13	PEMc	1973
7	Temp/temp	20	4.2	PEMd	1983
8	Perm/perm	44	0.0	PEMe	1974
9	Temp/temp	8.4	21	PEMc	1965
10	Temp/temp	60	4.2	PEMd	1970s
11	No/no	32	8.3	PEMd	1970s
12	Temp/temp	73	0.0	PEMe	1970s

[1]Maximum measured depth in cm
[2]Percent of three growing seasons without inundation
[3]Modifiers based on Cowardin et al. (1979)include PEM=palustrine system and emergent class; water regime modifiers include: a=temporarily flooded, b=seasonally flooded, c=semipermanently flooded, d=intermittently exposed, and e=permanently flooded

(1988 to 1994) in Wise, VA, showed significantly low precipitation in 1989 and 1993 (Fig. 1). Mean monthly maximum temperatures during that period ranged from a low in February of 7°C to a high in July of 27°C(National Weather Service Cooperative Observer, Wise, VA; Fig. 2).

Most of the adjacent uplands were characterized by herbaceous species, including *Festuca elatior*, *Lespedeza cuneata*, *Trifolium repens*, and *Solidago gigantea*. Terrestrial vegetation dynamics in the region are discussed elsewhere by Holl and Cairns (1994).

Constructed Wetlands

In 1992, six wetlands were constructed at two sites by excavating depressions and creating small berms. Mean wetland size was approximately 10 m x 30 m, and maximum depth was approximately 1 m. Because of the small size, data collection was limited to nondestructive techniques, e.g., vegetation cover estimates and soil probes. Species with highest modified importance values (sum of relative cover and relative frequency) were *Echinochloa walteri*, *Eleocharus obtusa*, *Scirpus cyperinus*, and *Typha latifolia*.

The Powell River Project (PRP) in Wise County, VA, was the site of three constructed wetlands. Sedimentation rates were low since wetland construction occurred after the site had been revegetated with the perennial ryegrass *Lolium perenne* and various legumes (Fabaceae). Three wetlands were also constructed near Wise, VA. Sedimentation rates were much higher at this site since wetland construction coincided with final grading and preceded revegetation efforts.

Methods

Twelve accidental wetlands in Wise County, VA, were studied between 1992 and 1995. Parallel transects and permanent plots were established and monitored for 3 years. Accidental wetland sampling was conducted within two communities: (1) a community dominated by obligate wetland plants and (2) a community dominated by facultative wetland plants. Constructed wetland sampling was not conducted on a community basis due to

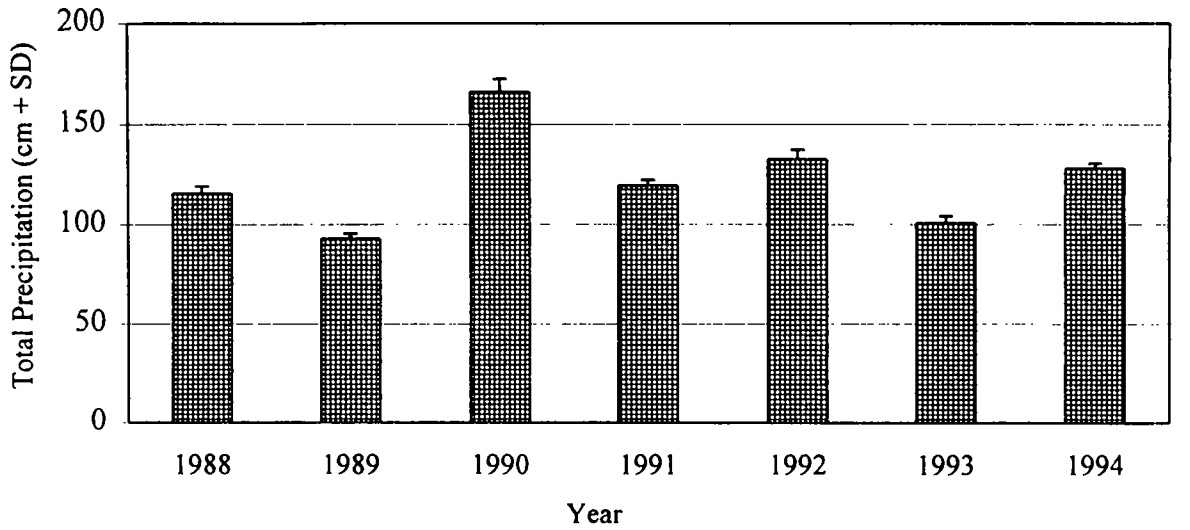

Fig. 1. Annual precipitation totals during a 7-year period (1988-1994) recorded in Wise, VA

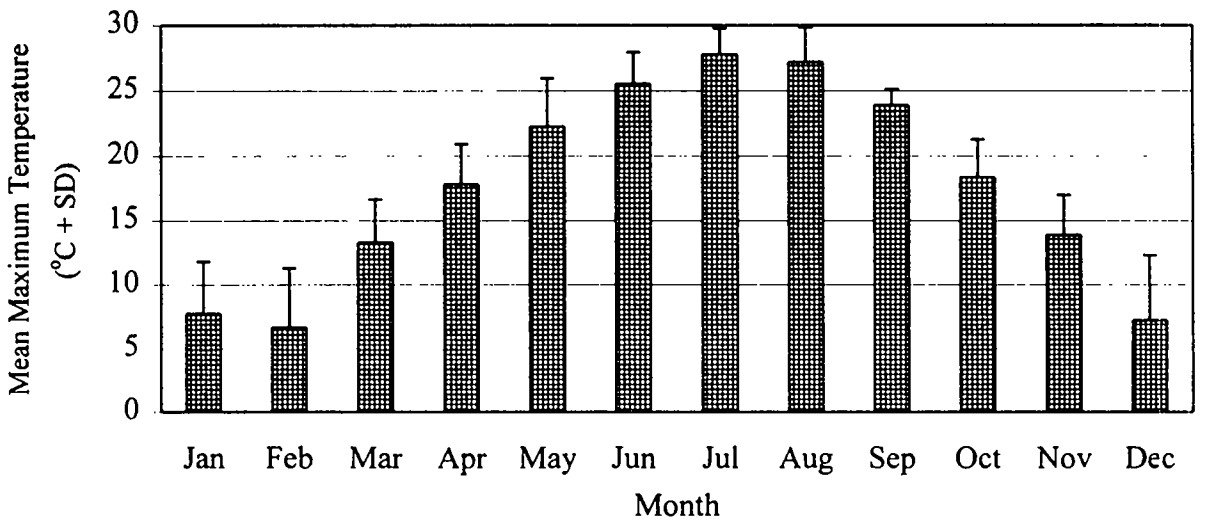

Fig. 2. Mean monthly maximum temperatures during a 7-year period (1988-1994) recorded in Wise, VA

small dimensions and poorly defined vegetative zonation. Several parameters were studied and those that aid in characterizing soils are described here.

Soil value and chroma, prevalence of oxidized rhizospheres, and presence of iron depletions and masses were assessed at a minimum of two plots within each accidental wetland community and within the deeper portion of each constructed wetland. Soil samples were extracted by shovel and were broken open manually for inspection. Value and chroma estimates were made using a wetted sediment sample in full sun using a Munsell Soil Color Chart. Oxidized rhizosphere frequency and intensity were assessed by visual inspection. No iron depletions and masses were detected in any soil samples in this study, although low chroma matrices were commonly described.

Water depth at the deepest point in each accidental wetland was measured biweekly during each growing season from 1992 through 1994. Each accidental wetland was assigned a water regime modifier based on the classification scheme set forth in Cowardin et al. (1979). Elevation in all plots was measured using a transit and stadium rod, and the mean of three estimates was calculated for each plot. Plot depth was calculated based on elevation and biweekly water depth estimates. Water depth in constructed wetlands was also measured biweekly. Sediment depth was measured using a soil probe penetrated to depth of compacted mine spoils, and the mean of three estimates was determined for each plot. Grand means were calculated for each community in the accidental wetlands and for each constructed wetland site. Soil particle size analyses were conducted at each accidental wetland and were compared to published data on upland soils that was also collected at PRP by Daniels and Amos (1982).

Litter estimates were made in both communities within the 12 accidental wetlands in 1994. Litter, including surficial organic material as well as standing dead biomass, was collected in 0.25-m^2 quadrats, dried, and weighed. No quantitative estimates of litter were made in constructed wetlands; however, cover estimates were made from 1-m^2 quadrats along two belt transects in each of the six constructed wetlands.

Belowground biomass estimates were made in both communities within the 12 accidental wetlands in 1994. All plant biomass between underlying compacted mine spoils and the litter layer were collected within 0.25-m^2 quadrats. No attempt was made to separate live and dead roots. Material was washed and sieved through a #10 seive, dried, and weighed. Because of the small dimensions of constructed wetlands, no estimates of belowground biomass were made at these sites.

Results

Accidental Wetlands

Redoximorphic features were present in all 12 accidental wetlands in this study. Low chroma (1 or less) matrices and oxidized rhizospheres were common in accidental wetlands; however, no pattern of iron depletions and masses was observed in any wetlands in this study (Fig. 3).

Hydric soil criteria for chroma were met in all 12 obligate wetland communities and 11 of 12 facultative wetland communities (Fig. 4). A chroma of 0 was common in the obligate wetland community of all four accidental wetlands that exhibited permanent inundation and in site 11, which was inundated throughout the study except for July, 1993, during a drought. Only the facultative wetland community at site 10 failed to meet the chroma criterion of 1 or less. Mean soil chroma in the obligate wetland community (0.67; SD 0.70) was somewhat lower than for the facultative wetland community (1.1; SD 0.68)(Fig. 4).

Oxidized rhizospheres were present at all accidental wetlands except site 12. Obligate wetland communities that exhibited chroma greater than 0 were found to have "prevalent and bright" oxidized rhizospheres. Oxidized rhizospheres were described as "absent" (sites 8, 10, and 12) or "present and dull" (sites 1, 3, and 11) in obligate wetland communities that exhibited chroma of 0. Oxidized rhizospheres in the facultative wetland community were described as "prevalent and bright" for all accidental wetlands except site 12, which exhibited dense growth of a moss, *Sphagnum* sp., associated with negligible mineral material above compacted mine spoil.

The duration criterion for wetland hydrology (Environmental Laboratory 1987) was exhibited by all accidental wetlands except site 2. Water regime modifiers for accidental wetlands included permanently flooded (4 sites), intermittently exposed (3 sites), semipermanently flooded (4 sites), and seasonally flooded (site 2)(Table 2). After August, 1992, inundation was not detected at site 2, which is the youngest of the 12 accidental wetland sites (formed 1986)(Table 2). Precipitation totals for 1993 were the second lowest on record in Virginia (National Oceanic and Atmospheric Administration 1993). Surface water disappeared from 8 of the 12 accidental wetlands during

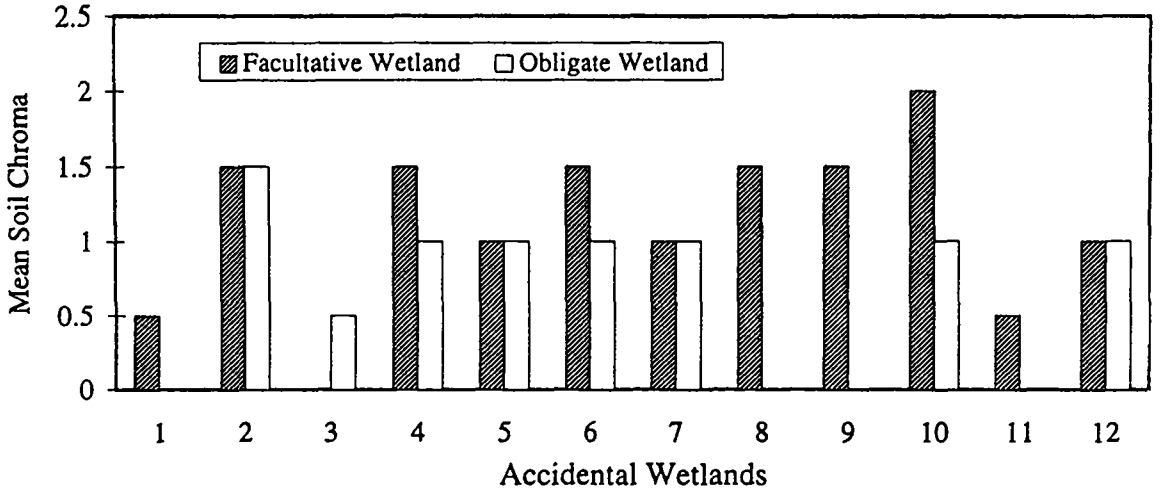

Fig. 3. Mean soil chroma for facultative wetland and obligate wetland communities at 12 accidental wetlands

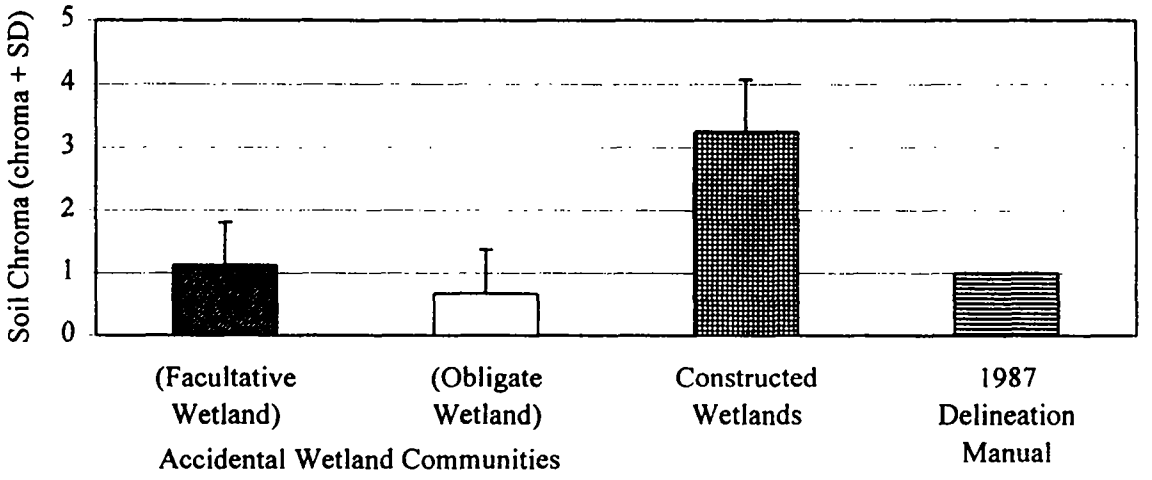

Fig. 4. Mean soil chroma for accidental wetlands, constructed wetlands, and maximum according to the 1987 delineation manual

1993, but inundation was reestablished during the 1993 growing season except at sites 2, 4, and 9. Precipitation in 1994 was within the range considered normal, and inundation was reestablished at sites 4 and 9, but not site 2.

Hydrology also differed within accidental wetlands. Mean water depth in obligate wetland communities (25 cm) was 24 cm deeper than mean facultative wetland community water depth (1 cm)(Fig. 5). Thus, inundation periods were shorter for facultative wetland communities than for obligate wetland communities in most sites. Soil saturation may have persisted longer than inundation, but was not quantified in this study.

Sediment depth in accidental wetlands differed both among and within the two communities. Mean sediment depth for both communities was greatest at site 10, which functioned as a sediment retention pond throughout this study. Sediment depth exceeded the maximum measured depth of 80 cm in five of the six

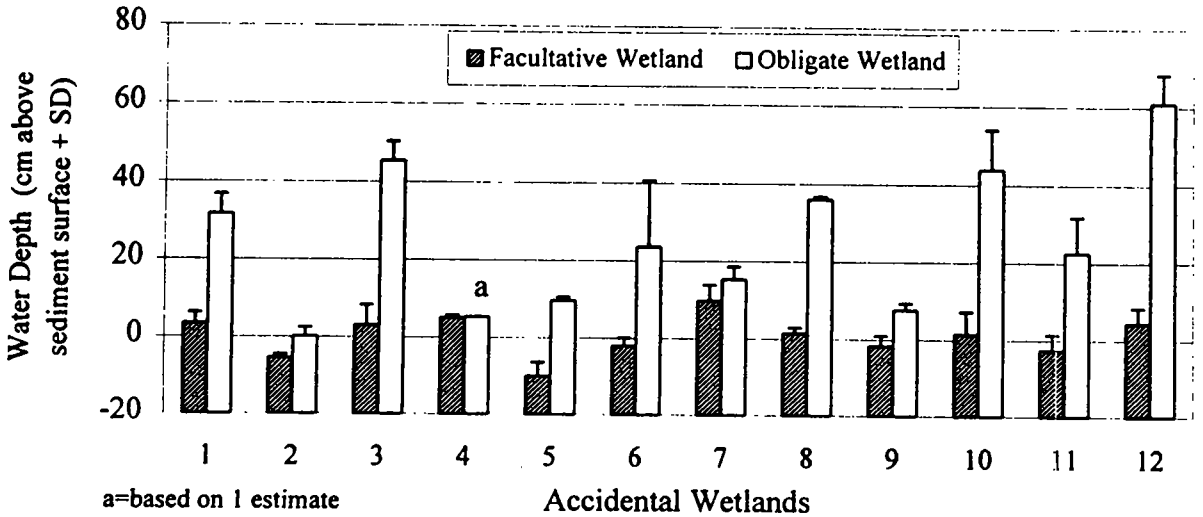

Fig. 5. Mean water depth from April through September, 1994, for facultative wetland and obligate wetland communities at 12 accidental wetlands

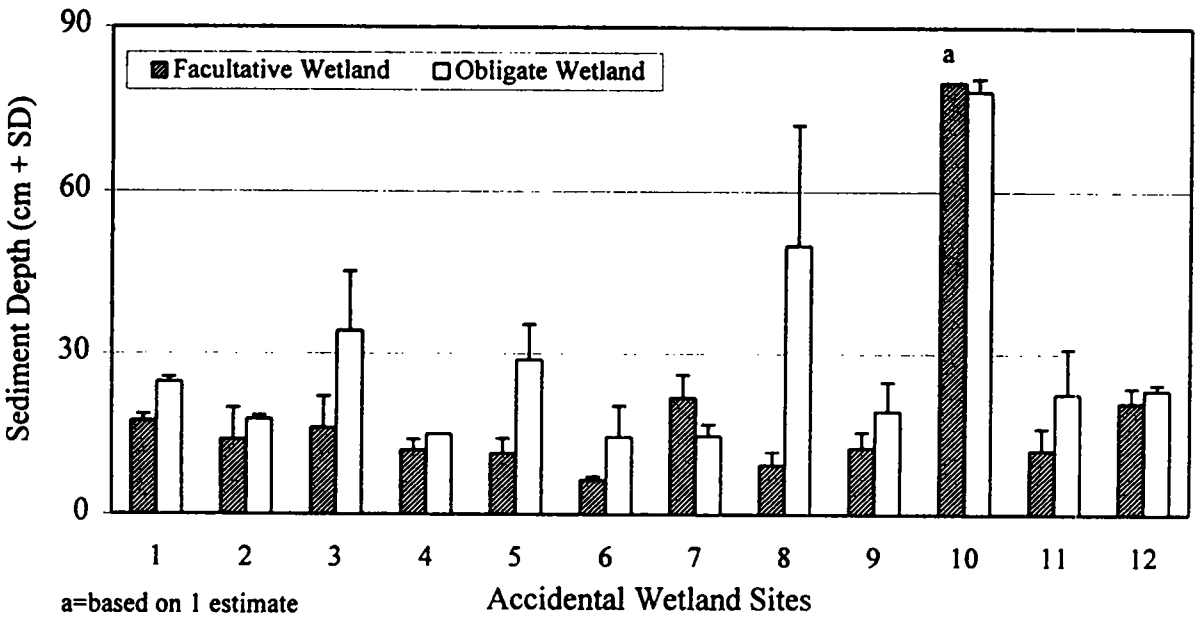

Fig. 6. Sediment depth for facultative wetland and obligate wetland communities at 12 accident wetland sites

plots where measurements were taken at site 10. Mean sediment depth was lowest at site 6 for both the facultative wetland (6 cm) and obligate wetland (14 cm) communities. In 10 of the 12 accidental wetlands, obligate wetland sediment depth exceeded that for the facultative wetland. Median sediment depth for facultative wetland communities was 13 cm compared to 23 cm for obligate wetland communities (Fig. 6). Particle size analyses for accidental wetlands indicated a significantly higher percent clay (31%) than that for upland areas (15%). Silt content in accidental wetlands (58%) was also somewhat higher than that for uplands (41%)(Fig. 7).

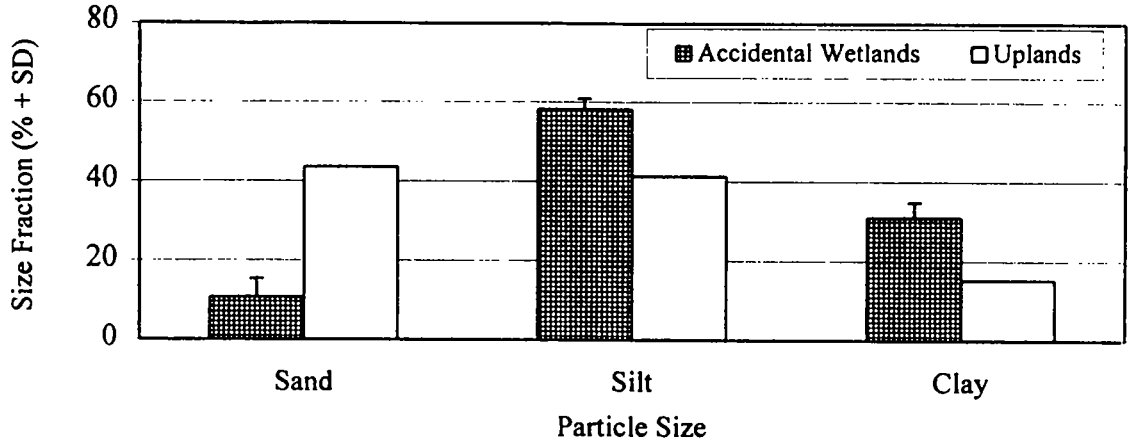

Fig. 7. Particle size analysis for accidental wetlands (this study) and for uplands at the Powell River Project (Daniels and Amos 1982)

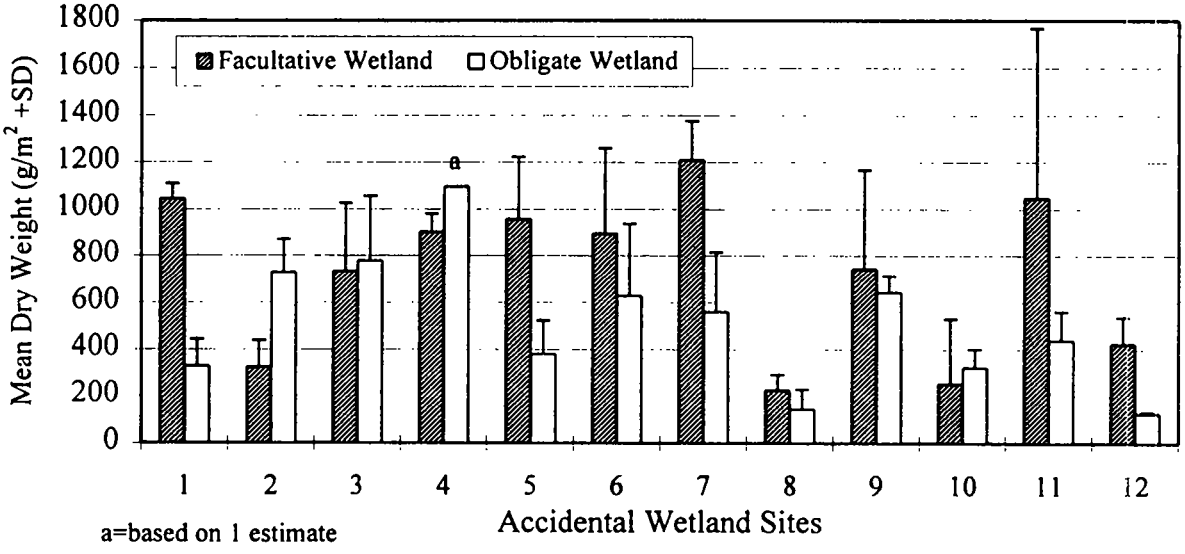

Fig. 8. Mean dry weight of litter for facultative wetland and obligate wetland communities at 12 accidental wetlands

Mean litter content in accidental wetlands was 621 g/m² in 1994. Facultative wetland litter content (730 g/m²) was significantly greater than litter content in obligate wetland communities (514 g/m²). Litter content was lowest in site 8 (184 g/m²), which was found to have the highest diversity and abundance of aquatic macroinvertebrates (Jones 1995; Fig. 8).

Dense root mat formations with negligible accumulated mineral material were common in the facultative wetland plant community. Belowground biomass in accidental wetlands was higher in the facultative communities, 442.5 g/m², than in obligate wetland communities, 398.4 g/m². Site 2 was the most recently formed accidental wetland (1986) and exhibited the lowest mean belowground biomass in the facultative wetland community (135.2 g/m²)(Fig. 9).

Constructed Wetlands

Soil chroma was 3 to 4 in all six newly constructed wetlands in this study. In all three constructed

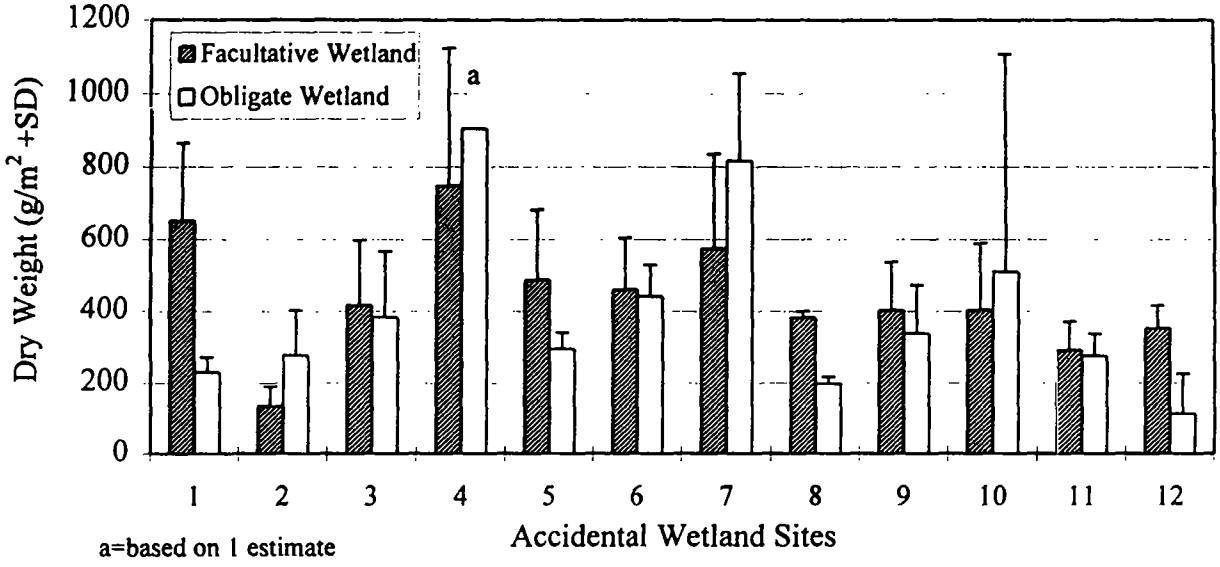

Fig. 9. Mean dry weight of biomass (belowground) for facultative wetland and obligate wetland communities at 12 accidental wetlands

wetlands near Wise, VA, oxidized rhizospheres were present, but were described as "infrequent and dull." No oxidized rhizospheres were found in the three constructed wetlands at PRP. Mean vegetative cover (68%) was significantly greater at the Wise constructed wetlands than at the PRP constructed wetlands (9%).

Sediment depth in constructed wetlands was significantly different among the PRP and Wise constructed wetlands. The mean sediment depth for PRP constructed wetlands was 5.8 cm compared to 19.3 cm for the Wise constructed wetlands (Fig. 10).

Discussion

The hydric soil criteria for chroma (1 or less) and, to a lesser extent, oxidized rhizospheres (Environmental Laboratory 1987) were met by both facultative and obligate wetland communities in all 12 accidental wetlands, including site 2. Since site 2 was formed in 1986, one can infer that a low soil chroma can be exhibited in less than 10 years after a depression becomes established. The minimum time required for chroma of 1 to be exhibited within small depressions is greater than 3 years, based on the survey of six constructed wetlands in this study. Oxidized rhizospheres may form more quickly. They were described as "present and dull" in two of the newly constructed wetlands.

The minimum time required for development of low chroma is probably even shorter, since site 2 failed to exhibit inundation during or after drought conditions began in spring 1993; and, since precipitation in 1989 was even lower than for 1993 in Wise County (National Weather Service Cooperative Observer, Wise, VA), site 2 probably was not inundated in 1989.

The issue of low chroma color development in these materials is complicated by the fact that some of the mine spoil strata encountered are reduced and gray when mined and freshly deposited (Daniels and Amos 1981). However, these reduced sandstones and siltstones are typically chroma 2 or higher, and weathering for even a few years raises the matrix chroma to 3 or 4 under well drained conditions. Thus, the higher chroma sediment colors observed in the constructed wetlands corroborates our assumption that the low chromas (<1.0) observed in the accidental wetlands we surveyed reflect the development of hydric soil conditions rather than simple preservation of relic parent material colors.

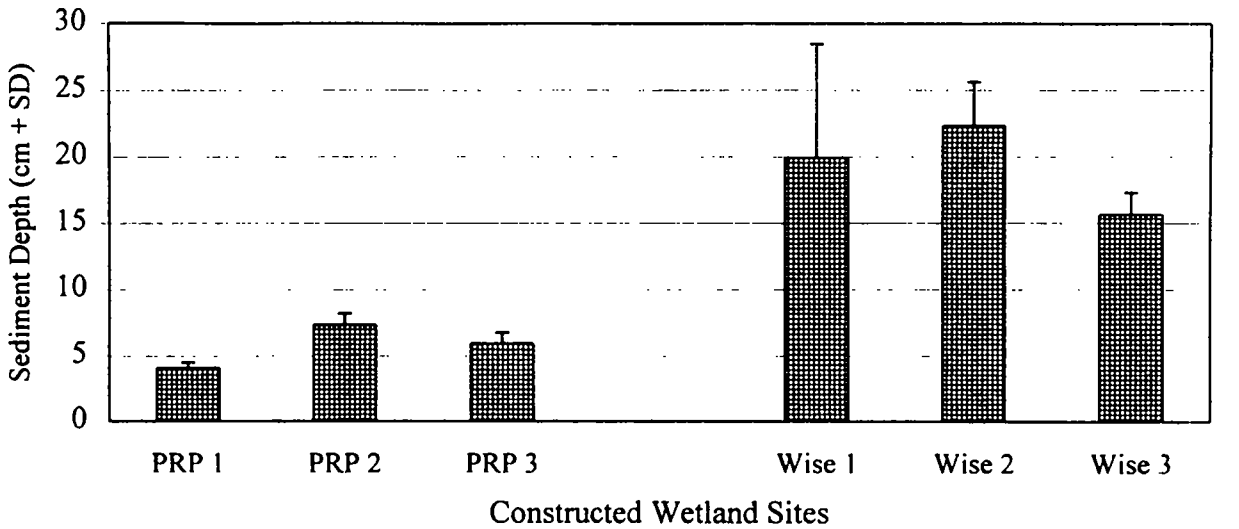

Fig. 10. Mean sediment depth in constructed wetlands at two sites, Power River Project (PRP) and near Wise, VA (Wise)

Mitsch and Gosselink (1993) list three conditions for establishment of low chroma: (1) sustained anaerobic conditions, (2) sufficient organic matter to support microbial activity, and (3) adequate soil temperature. These conditions were met to differing extents in all 12 accidental wetlands and influence the time required for development of hydric soil indicators.

Wetland hydrology, especially the duration of inundation, appeared to influence soil chroma. Sites having permanently flooded water regimes were found to exhibit lower chroma than sites with either intermittently exposed or semipermanently flooded conditions (Fig. 11). Water depth did not appear to influence chroma, except for the fact that deeper portions of a wetland may be inundated for longer periods of time. For example, facultative wetland communities were not inundated for as long as the associated obligate wetland communities and exhibited higher chroma.

The actual duration of wetland hydrologic conditions cannot be quantified for the accidental wetlands since there is no data to indicate how much time was required for an impervious layer to form. Particle size analysis in accidental wetlands indicated a significantly higher clay content when compared to spoil material on upland benches (Daniels and Amos 1981), which may have limited infiltration rates. Constructed wetlands at PRP failed to form an impervious layer in the first 2 years after construction, and there was considerable fluctuation in water depth. The shrink-swell characteristics of sediments appeared to permit infiltration following drawdown events.

Vepraskas and Wilding (1983) noted that soils saturated for 120 days failed to show chroma below 3 when organic matter content was less than 1%. Organic matter was measured in both litter and belowground biomass compartments for both communities in the 12 accidental wetlands. The supply appears to be ample to support microbial metabolism, but may have been limiting during early stages of wetland development. There are two possible roles for organic matter in hydric soil development in accidental wetlands. First, organic matter is required for microbial metabolism, which leads to iron reduction and lower chroma. Organic matter may have been available early in accidental wetland development since wind dispersed seeds, e.g., *Typha latifolia* and *Scirpus cyperinus*, could colonize sediments quickly.

Second, the water holding effects of organic matter can increase the duration of soil saturation. Since accidental wetlands form in

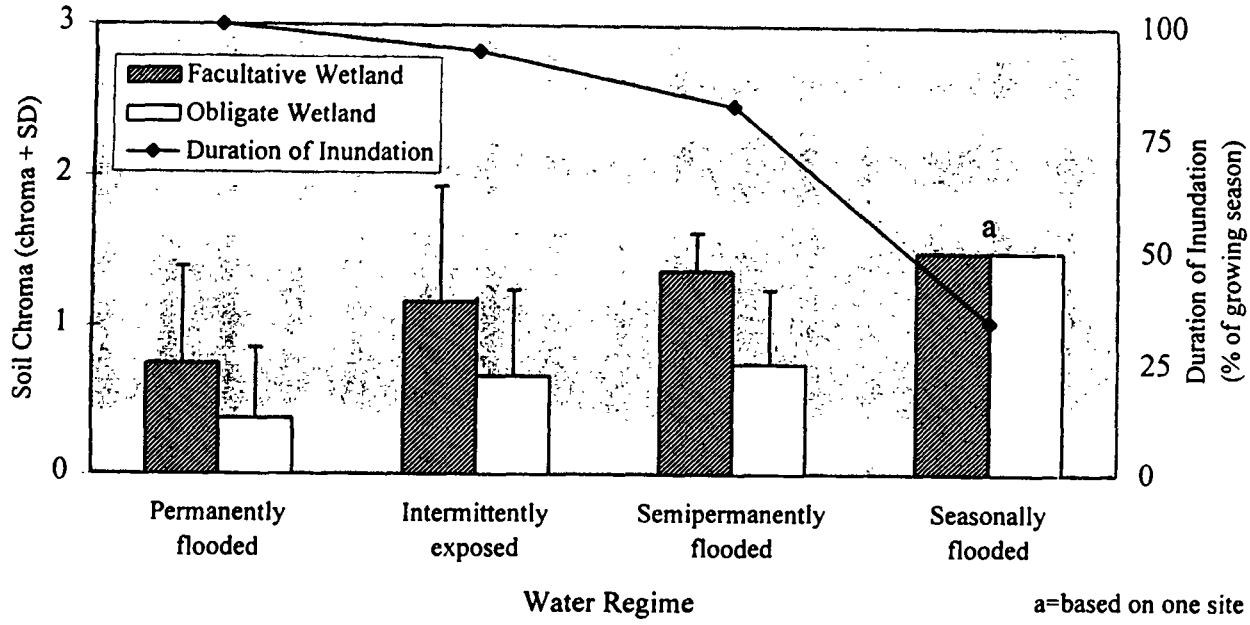

Fig. 11. Soil chroma for four accidental wetlands arranged by water regime (based on Cowardin et al. 1979)

small depressions, export of organic matter is low. Since mean accidental wetland litter content was high (621 g/m^2 in 1994), absence of inundation for short periods during the growing season may not have led to significant soil aeration. Macroinvertebrates were abundant in some accidental wetlands (e.g., site 8), but they should not inhibit development of hydric soil indicators for several reasons. By reducing the detritus size and increasing surface area, macroinvertebrates facilitate microbial action. The faster mineralization of nutrients should also yield greater primary productivity and organic matter accumulation.

Thus, sedimentation appears to play an important role in accidental wetland formation and development. Sediment deposition can influence hydrology by creating an impervious layer that establishes inundation. Sediment provides a substrate for seeds of hydrophytes and a plant growing medium. If plant growth provides adequate litter following senescence, there will be sufficient substrate to support microbial metabolism and adequate water holding capacity to limit diffusion of oxygen. In addition, it is the supply of iron with sediment that supports color development and provides an indication of oxidation and reduction processes.

Other Hydric Soil Indicators

Oxidized rhizospheres were found to be "prevalent and bright" in most accidental wetlands. The ability of hydrophytes to aerate the soil adjacent to roots has been described for many species (Conway 1940, Bartlett 1961, Armstrong and Boatman 1967). The two communities found in accidental wetlands in this study were identified based on the dominant species. The obligate wetland community was dominated by species which occur in wetlands >99% of the time, and the facultative wetland community is dominated by species that occur in wetlands 67-99% of the time (Reed 1988).

Oxidized rhizospheres were missing under three distinct conditions observed in this study. First, oxidized rhizospheres were either lacking, infrequent, or dull in the six newly constructed wetlands. Oxidation of iron adjacent to roots of hydrophytes appears to require time to become visible. Bartlett (1961) extracted reduced iron from soil to show that some iron oxidizes around

the surface of roots during a single growing season, but did not address the establishment of a visible layer of oxidized iron around roots. Second, oxidized rhizospheres were absent or dull in obligate wetland communities that exhibited a permanently flooded water regime. Oxygen may have been released by roots more slowly at these greater depths, and, since oxygen and redox potential decreases with depth, oxygen may be consumed more quickly under these conditions. Third, oxidized rhizospheres were absent at the facultative wetland community in site 12. This community exhibited high organic matter content and negligible mineral material; thus, iron was probably not available for oxidation.

There was no evidence of iron depletions and masses in this study. These features either have not had sufficient time to form, or conditions are not conducive to mottle development. Color patterns associated with iron depletions and masses become established where water levels fluctuate (Ponnamperuma 1972). The absence of these color patterns may, therefore, be a result of stable water tables in the small depressions, modulated by litter content and slow infiltration rates.

Soil temperature was not measured in this study, but several years of temperature data were obtained from the local Climatological Observer in Wise, VA. Mean monthly maximum temperatures ranged from a low in February of 7°F to a high in July of 27°F). Since water depth in the accidental wetlands ranged from 8 to 89 cm, light penetration to the bottom seems likely. However, vegetative cover of *Typha latifolia* was extensive in many obligate wetland communities, and shading could reduce soil temperatures. It appears that the 12 accidental wetlands were in similar geographic and topographic positions and would experience similar soil temperatures; however, future studies should monitor soil temperature.

Conclusion

Wetland construction has increased in the United States following implementation of Section 404 of the Clean Water Act (1977). However, most construction attempts have occurred in the last 10 years, and monitoring has been limited. Accidental wetlands provide an age class from 10 to 30 years post formation and provide clues to depressional wetland ontogeny. In particular, redoximorphic features, including low chroma matrices and oxidized rhizospheres, were formed within this time period. Newly constructed wetlands showed that certain hydric soil indicators, i.e., oxidized rhizospheres, can form within 3 years.

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