RESTORING FOREST COMPOSITION AND STRUCTURE OF RIPARIAN CORRIDORS IN THE MISSOURI OZARKS

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by

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

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Presented by Kyle L. Steele

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DEDICATION

I dedicate this work to my family, past and present, many of whom have had the rewarding opportunity to spend all or part of their lives working and living on the land. A heartfelt thanks also to Amber for her caring support over the past two years.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Purpose / Objectives / Hypotheses

There is considerable interest in restoring bottomland plant communities throughout the Central Hardwood Forest Region. Large-scale conversion of Ozark bottomland forests to agriculture began in the early 1800's (Jacobson and Primm 1994) and was a common practice into the middle part of the Twentieth Century. Overall, greater than eighty-five percent of Missouri's historically forested floodplains have been cleared (Dey et al. 2001). State and federal land management agencies in Missouri are currently working to lessen the negative effects of riparian degradation on watershed health. Objectives for this effort include improving water quality, limiting soil erosion, stabilizing streambanks, improving aquatic stream habitat, and restoring riparian fish and wildlife habitat. As part of this work there is a great amount of interest in restoring native hardwoods to old-field bottomlands (i.e., afforestation), but there is very little information providing successful management techniques. Management considerations include managing competing vegetation, selecting seedling stock type, planting technique, protecting seedlings from wildlife damage, and matching species to site. Thoughtful management and appropriate research will become increasingly important in order for Missourians to meet their conservation goals.

The purpose of this study was to evaluate current afforestation methods in Missouri and to recommend reasonable and effective management approaches for restoring native forest composition and structure of riparian corridors in the Ozark physiographic region.

Objectives and Hypotheses

1) Compare the effect of five vegetation management treatments on the survival and growth of out-planted bare-root tree seedlings of thirteen bottomland hardwood species native to the Missouri Ozarks (Tables 1 and 2).

   Hypotheses:

   a) Cover-crop treatments will provide better survival and growth than will the use of herbicide only, with the Roundup®-only treatment resulting in the least success.
   b) The majority of tree species planted will result in comparable survival, but the light-seeded, early-successional species will exhibit the best growth.
   c) Total density of competing vegetation will be the greatest in the redtop treatment, and lowest in the herbicide-only treatments.
   d) Density of competing vegetation by height class will be the greatest in the herbicide only treatments and least in the cover-crop treatments.

2) Compare the effect of five vegetation management treatments on the contribution of natural tree regeneration.

Hypotheses:

a) Stems per hectare of natural regeneration will be greatest in the cover-crop treatments and lowest in the herbicide only treatments.

b) Light-seeded, early successional species will be the predominate species group, with very few hardmast producers.

c) Distance from the nearest intact forest edge as a covariate in the analysis, will be a significant contributor to the variation of naturally-volunteering tree seedlings.

3) Compare the effect of five vegetation management treatments on the response of the vegetation community.

Hypotheses:

a) The herbicide only treatments will have more perennial plants than the cover-crop treatments, which will contain more annual and biennial species.

b) The Poast Plus® treatment will have a significantly lower graminoid component than the Roundup®-only treatment.

c) The highest richness and diversity will occur within the herbicide-only treatments, with Poast Plus® having the greatest values.

d) Foliar coverage of exotic species will be the most prevalent in the Roundup®-only treatment and the least in the cover-crop treatments.

e) The Poast Plus® treatment will have the highest floristic quality index, while the redtop will have the lowest.

f) The Poast Plus® treatment will accommodate the greatest number of native Ozark bottomland plant species. The cover-crop treatments will contain the least.

Table 1. Five vegetation management treatments used in this study. Roundup® site preparation was conducted prior to planting all cover-crops.

Designation	Treatment
Treatment 1	Roundup® site preparation only.
Treatment 2	Roundup® site preparation + growing season application of Poast Plus®, a grass-selective, post-emergent herbicide.
Treatment 3	Redtop (*Agrostis gigantea* Roth) cover-crop.
Treatment 4	Large white clover (*Trifolium repens* var. *giganteum* L.) cover-crop with winter wheat (*Triticum aestivum* L.) nurse-crop.
Treatment 5	Virginia wild rye (*Elymus virginicus* L.) cover-crop with Korean Lespedeza (*Kummerowia stipulacea* [Maxim.] Makino) nurse-crop.

Table 2. Thirteen native bottomland hardwood species included in this study.

Common Name	Scientific Name	Species Group
Bur oak	*Quercus macrocarpa* Michx.	Oak hardmast
Swamp white oak	*Q. bicolor* Willd.	
White oak	*Q. alba* L.	
Northern red oak	*Q. rubra* L.	
Pin oak	*Q. palustris* Muenchh.	
Shumard oak	*Q. shumardii* Buckl.	
Pecan	*Carya illinoinensis* (Wangenh.) K. Koch	Other hardmast
Black walnut	*Juglans nigra* L.	
Green ash	*Fraxinus pennsylvanica* Marsh.	Light-seeded or softmast
White ash	*F. americana* L.	
American sycamore	*Platanus occidentalis* L.	
Eastern cottonwood	*Populus deltoides* Batr.	
Hackberry	*Celtis occidentalis* L.	

Study Areas and Site Selection

This study was conducted at three locations that were selected based upon geographic distribution, location, current and former land condition, and land ownership type. Each site is managed by the Missouri Department of Conservation (MDC) and is located in three different Ecological Subsections within the Ozark Highlands Ecological Section (Figure 1, Nigh and Schroeder 2002). Study areas were confined to the Ozarks because of the distinctive topographic nature and area-specific land management questions occurring in the region. Waterways in the region flow through a highly-dissected, unglaciated, ancient landscape. Upland forest soils throughout the Ozarks are mainly composed of highly-weathered residuum and hillslope sediments, largely resting above Ordovician-age sandstones and dolomites (Meinert et al. 1997). Age and degree of weathering produce acidic soils with relatively low base saturation.

Accordingly, alluvial sediments transported and deposited along Ozark bottomlands reflect this character. Compared to surrounding regions, fluvial soils in these floodplains tend to be coarsely-grained and droughty. Streams adjacent to Ozark riparia are mostly spring-fed and carry very little suspended sediment (Nigh and Schroeder 2002). Drainage systems are characterized as “open,” with a brief water residence time. Due to its central location in North America, Missouri experiences weather regimes from the warm, moist gulf to the south; cold arctic winds from the north; and arid heat from the west (Nelson 2005). As a result, the climate here can be extremely variable, with summers often hot and dry, resulting in difficult growing conditions for Ozark forests. Consequently, a distinctive, yet complex and variable array of plant and animal communities have developed along the seasonally flooded terrain of the Ozarks (Nigh et al. 2002). The stream systems associated with this study are 2nd or 4th order, as outlined by the stream classification system developed by Strahler (1957). Each research plot is located on well-developed and relatively stable point-bar floodplains or terraces that are subjected to occasional to infrequent flooding.

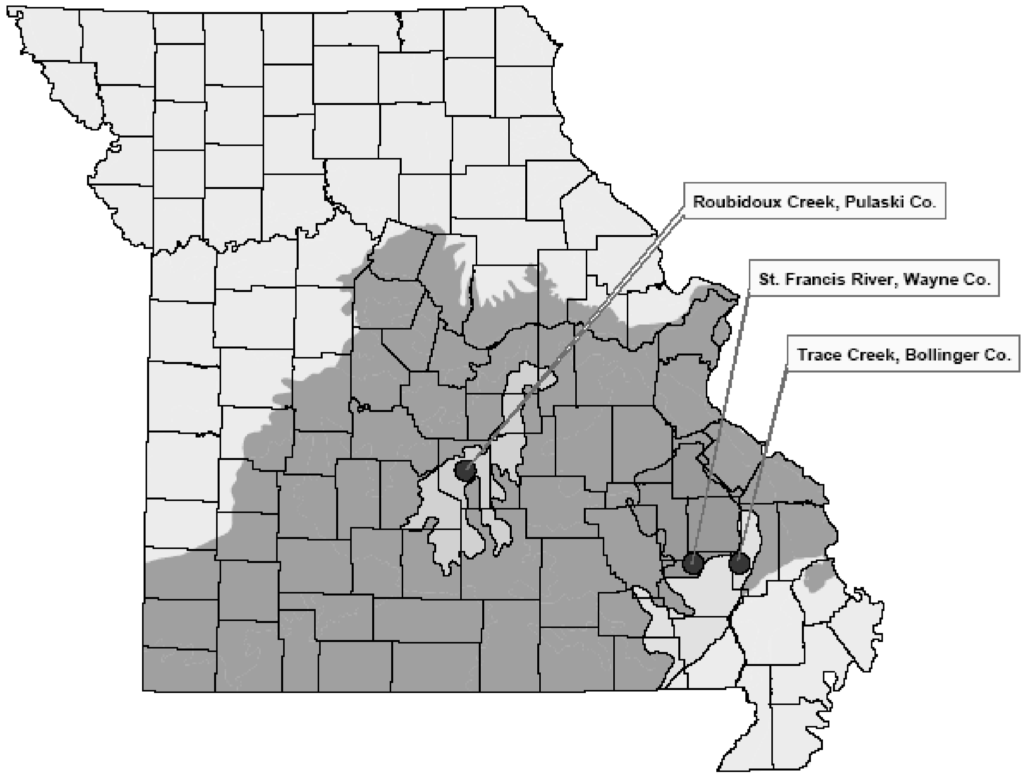

Figure 1. Ozark Highlands Ecological Section (dark gray); filled circles indicate location of project sites within three different Ecological Subsections, including the Gasconade River Hills (Roubidoux Creek), St. Francis Knobs and Basins (St. Francis River), and the Black River Ozark Border (Trace Creek).

Site 1 - Roubidoux Creek, Pulaski Co., Missouri (T36N R12W S24 NW1/4 of NE1/4)

The Roubidoux Creek site is located in Pulaski County, less than 2 km north of the city limits of Waynesville, MO. This site lies within the Gasconade River Hills Subsection and Middle Gasconade River Oak Woodland/Forest Breaks Land-type Association (LTA, Nigh and Schroeder 2002). Mean annual precipitation is 102-109 cm, with an average growing season of 210 days (Nigh and Schroeder 2002). Roubidoux Creek is a 4^{th} order stream, and drains into the Gasconade River approximately 2.5 km downstream from the site. Specifically, the site is located within the 72 ha Roubidoux Creek Conservation Area. Soil series occurring here are Kickapoo, Relfe, and Sandbur and drainage classes are well-drained, excessively well-drained, and somewhat excessively well-drained, respectively. Soil textural classes are either coarse-loamy or sandy-skeletal. Resulting from these soil characteristics, the Roubidoux Creek site is likely the droughtiest and more prone to volatile growing conditions than the other two sites. In recent years, the area was hayed by a local farmer. Prior to site establishment, vegetation was largely composed of a variety of cool-season pasture-grasses and other old-field weeds. In comparison to other sites, this area had an abundance of noxious, exotic plant species. The majority of the site is surrounded by a forested buffer, averaging 30 m in width, and therefore, adjacent stream banks are covered and stable. Also noteworthy is that flooding occurs naturally in this subsection, as there are no flood control structures in the entire basin (Nigh and Schroeder 2002).

Site 2 - St. Francis River, Wayne Co., Missouri (T29N R05E Sec09 NE1/4 of SW1/4)

The St. Francis River site is located in Wayne County, approximately 19 km east of Piedmont, MO. The site lies within the St. Francis Knobs and Basins Subsection and the St. Francis Dolomite Glade/Oak Woodlands Basin LTA (Nigh and Schroeder 2002). Mean annual precipitation here is 117 cm, with an average growing season of 205-210 days (Nigh and Schroeder 2002). The St. Francis River is a 4^{th} order stream and eventually flows into the Lake Wappappello reservoir to the south. Specifically, the study area is located within the 101 ha "St. Francis River Preferred Lease" owned by the United States Army Corps of Engineers and managed by the MDC. Soil series occurring at this site are Bucklick, Crider, Fourche, Freeburg, Raccoon, and Secesh. Textural classes are either fine or fine-silty, and range from poorly-drained to well-drained. During the years leading up to planting, the area was managed as a cattle pasture. Prior to site preparation, initial field vegetation consisted primarily of tall fescue (*Festuca arundinacea* Schreb.). These fields are adjacent to the west side of the river and consist of very little woody vegetation. The majority of this site lies on a terrace landform approximately 6 m above the normal stream channel, with bare uncovered/unstable eroding cut-banks. Consequently, this well-developed part of the watershed rarely receives enough drainage to inundate the floodplain. In this way, the St. Francis site differs from the others. Bottomland pastures in the Ozarks are often located on these landforms, above the active floodplain.

Site 3 - Trace Creek, Bollinger Co., Missouri (T30N R08E S09 NW1/4 of NW1/4)

Trace Creek is located in Bollinger County, approximately 19 km directly west of Marble Hill, MO. This site lies within the Black River Ozark Border Subsection and the Wappappello Oak-Pine Woodland/Forest Hills LTA (Nigh and Schroeder 2002). Mean annual precipitation is 124 cm, with an average growing season of 215-225 days (Nigh and Schroeder 2002). Trace Creek is a 2nd order stream, and drains into the Castor River approximately 5 km downstream from the site. The site is located within the 3925 hectare Castor River Conservation Area. Soil series occurring here are Razort, Secesh, and Tilk. All are well-drained, floodplain soils ranging from fine-loamy to loamy-skeletal and coarse-loamy in texture. In addition, a sizeable portion of this site is mapped as a "slough," which is a former stream channel that cuts across the floodplain. During the ten years prior to site establishment, the area was seasonally hayed by a local farmer. Prior to planting, site vegetation was composed of a nearly pure stand of tall fescue. Trace Creek's floodplain along this reach is barely above the bankfull level of the river. Consequently, due to current bank erosion problems and the high amount of coarse fluvial surface deposition, this site in particular seems to be more prone to frequent, intense flooding. Much of the edge of the site is directly adjacent to the stream, which consists of unstable/uncovered and rapidly eroding streambanks.

Literature Review

Historically, well-developed floodplain ecosystems composed of alluvial soils have represented an important part of the landscape for human use and development (Brady and Weil 2002). This is particularly visible in the Ozarks, where pastures and cropping are often more suited to bottomland soils. In Missouri, mature hardwood forests once thrived in these parts of the landscape (Nigh et al. 1992). Large-scale conversion of Ozark bottomland forests to agriculture began as early as the early 1800's (Jacobson and Primm 1994) and continued to be a common practice into the middle part of the Twentieth Century. Most of this land has been utilized as cattle pasture, which in addition to forest clearing, can negatively affect other riparian vegetation and influence soil movement, water quality, and stream habitat dynamics. These pastures now contain a variety of cool-season grasses, with tall fescue being the most prominent.

Overall, the loss of riparian forests in the Ozarks has resulted in accelerated bank erosion, channel destabilization, increases in stream temperature, and loss of aquatic and riparian fish and wildlife habitat (Roell 1994). These land management concerns have prompted government agencies and private landowners to restore riparian forests throughout the Midwest. Unfortunately many of these attempts have resulted in poor or mixed success (Dey et al. 2001, Dey et al. 2008, Dugger et al. 2004, Kabrick et al. 2006, Kabrick and Dey 2001, Lockhart in review, Stanturf et al. 2001). Methods for restoring bottomland hardwoods have not yet been fully developed. Important considerations for management include: species-site suitability, seedling stock type, wildlife damage, tree planting technique, and ground cover management.

Artificial Hardwood Regeneration

Regeneration of oak dominated forests has been a concern in the United States since the early part of the Nineteenth Century (Clark 1993). Since the 1970's considerable research and management interest has been directed towards solving the problems associated with oak forest regeneration. Although the exact mechanisms of artificial regeneration failures remain somewhat unknown, plausible causes include: seed predation, climatic change, damage to seedlings by insects and wildlife, competition, long-term changes in disturbance patterns, and other ecological considerations (Lorimer 1993). In general, there are a variety of silvicultural practices that can be applied to forests to ensure successful tree regeneration. Specifically, working in old field situations requires its own unique approach, as these are some of the most severely degraded ecosystems on the landscape. Therefore, I will begin by defining *reforestation* as the replacement of a tree crop by natural or artificial means on land from which an immediate previous forest has been removed (e.g. following a clearcut or shelterwood, etc., Allaby 2004). Conversely, *afforestation* is the planting of trees where they have not grown for long time periods (i.e. agricultural fields that were historically forested, Allaby 2004). The implications of this research are concerned with the afforestation (e.g., artificial regeneration). Much focus of afforestation practices has been placed on planting hard-mast-producers (i.e., oaks and pecan), as these species do not have seed-dispersal characteristics conducive to rapid natural regeneration in old fields. Conversely, light-seeded species are thought to naturally volunteer from adjacent forests. However, recent literature suggests that relying on the natural establishment of light-seeded, wind-dispersed species into agricultural forest conversions may be impractical. Stanturf et al. (2000) found that in oak afforestation sites in the Lower Mississippi Alluvial Valley, species such as green ash, elms (*Ulmus* spp.), American sycamore, sweetgum (*Liquidambar styraciflua* L.), and red maple (*Acer rubrum* L.) may only produce natural regeneration at a maximum of 100 m from the edge of an intact forest. As a result, there is increasing interest in including these species to bottomland plantings that historically included only hard-mast species like oaks, black walnut, and pecan (Lockhart et al. in review). However, there is little information about the artificial regeneration of many of the light-seeded species.

In selecting species to be used for a restoration project, Clewell et al. (2004) state that native species should be used to the greatest practicable extent. This requires consideration of region, state, county, and when possible, individual watershed species distributions. Also, ensuring successful establishment requires carefully matching the ecological requirements and tolerances of the species to the environmental conditions of the planting site (Allen et al. 2004). Specifically, species selected should be suitable for tolerance to flood regime, soil characteristics, and to the landforms where trees will be planted (Stanturf et al. 2000). These variables, along with shade tolerance ratings should be considered (Clatterbuck and Meadows 1993). Overall, failure to consider native species distributions and species-site relationships will inevitably reduce success. When in doubt, a manager should select a variety of appropriate species with varying life history characteristics to lessen the chance of planting failure.

Once species are selected, one needs to determine the most effective and economically-viable planting method. Options include direct-seeding, planting bare-root seedlings, using containerized stock, or planting stem cuttings. Direct-seeding includes the collection of sound seed material and physically planting them in situ. Bare-root seedlings are generally one or two-year-old seedlings planted from seed at a tree nursery and are termed “bare-root” because they were separated from the soil in which they were initially grown (Kennedy 1993). Seedlings are then packaged together in bundles and placed in coolers until time-of-planting. Container-grown seedlings are produced by growing seeds in individual containers, usually in climate-controlled greenhouses (Nyland 1996). These seedlings are generally not removed from containers until time-of-planting in the field. Finally, stem cuttings are 25-35 cm long branches cut from one-year-old vigorously-growing branches on intact trees (Dir and Heuser 1987). When planted at an afforestation site, cuttings will root to produce genetically-identical clones of the mother plant. Stem-cuttings are generally only used for a limited number of species, such as those in the Salicaceae family (i.e., cottonwoods, aspen and willows). In the Central Hardwood Region, eastern cottonwood is the only tree species planted on a large-scale with stem cuttings.

There are many advantages and disadvantages associated with each method of artificial regeneration. In general, direct-seeding is the most cost-effective and least time-consuming (Kennedy 1993). However, this method also tends to result in lower survival and growth, and requires extensive knowledge of seed characteristics conducive to seedling success. Bare-root seedlings have higher success rates than direct-seeding, are widely available, have higher success rates, and are less expensive and less difficult to plant and transport than container seedlings (Nyland 1996). However, bare-root stock requires more input than direct-seeding and are smaller than container seedlings. Finally, container seedlings take less time to produce, have larger initial diameters and have well-developed root systems, thus making them more likely to survive and grow in field conditions (Dey et al. 2003). Nevertheless, container seedlings are extremely time-consuming and expensive to produce on a large scale, and can cost many times the price per seedling as compared to bare-root stock (Nyland 1996). In Missouri, bundles of bare-root seedlings at the state-owned George O. White State Tree Nursery are available for as little as $0.28/seedling. In comparison, when purchasing containerized stock from local nurseries, costs are between $15-25/seedling.

An additional advantage in using bare-root seedlings is that there are a greater number of species available for use (Stanturf 2000), which has allowed this study to include over a dozen species. Examining a larger number of species will provide information for managers seeking to restore a variety of tree species. Also, including a variety of site-appropriate tree species in an afforestation project will promote a more complex forest structure that enhances the suitability of restoration sites for wildlife (Twedt and Wilson 2002a). Using exclusively oaks and pecans will likely result in slower development of forest structure than if interplanted with others. In comparison, using a greater assortment of species will positively affect the re-colonization of forest bird species by more quickly developing suitable vertical forest structure (Twedt and Wilson 2002b).

Dey et al. (2008) estimates that more than 98 percent of artificial regeneration in the eastern United States is done via bare-root seedling stock. Missouri is likely no exception, as bare-root stock is by far the most commercially-available and abundantly utilized means of tree planting in the state. Accordingly, this research will focus almost completely on bare-root tree planting in order to examine the effectiveness of current operational planting techniques used in the Central Hardwood Region.

Vegetation Management in Tree Plantings

Vegetation management is an extremely important part of any afforestation project, and only second to species-site concerns (Van Sambeek and Garrett

2004). Much research attests to the idea that oak plantings probably cannot be established without intensive site preparation, herbaceous weed control, and continued release from invading competitors (Miller 1993). This can be especially true in the Ozarks, where the majority of sites are infested with species like tall fescue, which has shown to significantly reduce the growth of most hardwood species in the Central Hardwood Region (Van Sambeek and Garrett 2004). Even in areas without tall fescue, many other old-field weedy plants will vigorously compete with planted seedlings for moisture, nutrients, and growing space. In addition, many grasses and forbs that persist in these situations tend to release chemical substances into the soil that act to inhibit germination and/or growth of other plants (Allaby 2004). There are numerous noxious weedy plants that are suspected to incur this type of competition. Examples include tall fescue, many goldenrod species (*Solidago* spp. L.), some nutsedges (*Cyperus* spp. L.), and spotted knapweed (*Centaurea biebersteinii* DC.).

The primary objective of any ground cover management in a hardwood planting is to reduce tree competition for water and nutrients and to minimize labor and equipment costs. Types of management implicit in this study are the use of herbicides and cover-crops. To gain the greatest positive effects on tree success, management of this type should be used during the first 1-3 years following site establishment (Miller 1993). Site preparation methods typically include a late-summer or early-spring application of Roundup® prior to planting the site (Miller 1993). Often, this is the only management conducted in such plantings in the Ozark region. However, it is anticipated that follow-up applications with other types of herbicides will prove a worthwhile investment, both in terms of tree growth and producing a more preferred vegetation complex. Additionally, Dey et al. (2008) suggested that managers should consider follow-up herbicide application during the two to five years following planting in order to control vegetation that is capable of killing trees. Often, grass-selective herbicides are used that will not affect trees or other forbs in a particular management scheme. Also, grasses tend to be more competitive than broad-leaved legumes or other forbs, and thus, selective removal of resident grasses should improve tree growth (Van Sambeek et al. 2004). In the Ozark region, many of the old-field weedy plants that invade following the removal of tall fescue are often exotic grass species. For this reason, one treatment in this study will include a follow-up application of Poast-Plus®, a grass-selective herbicide that is readily available to Missouri land managers. In addition to tall fescue, examples of grass species that may be important to control are: Johnson grass (*Sorghum halepense* (L.) Pers.), reed canary grass (*Phalaris arundinacea* L.), bromes (*Bromus* spp. L.), foxtails (*Setaria* spp. P.Beauv.), crabgrass (*Digitaria* spp. Haller), Kentucky bluegrass (*Poa pratensis* L.), and other cool-season pasture grasses.

Cover-crops, or “living mulches,” are another viable option for bottomland hardwood establishment. These ground covers are used to suppress competing vegetation and improve tree survival and growth (Van Sambeek and Garrett

2004). In addition, cover-crops may be used for soil conservation and to improve water quality (Dey et al. 2008). A variety of options are available for planting with proven benefits. Redtop grass has been successfully implemented on bottomland hardwood plantings in Missouri (Dey et al. 2003) and is proven to be easily established with a minimal investment and high success, with very little follow-up management. Although there are no data published on this subject, redtop is thought to be easily eliminated once trees become well-established. In addition, production of a thick and relatively low growing redtop sod in tree plantings can reduce herbivory damage to seedlings caused by cottontail rabbits (*Sylvilagus flormdanus*), which can often cause large-scale planting failure depending on vegetation, habitat and other site characteristics (Dey et al. 2003). However, it is possible that redtop, or other grass cover-crops, can compete in a similar fashion to resident vegetation. Often, the nitrogen-fixing properties of leguminous ground-covers may be a more suitable option. With successful propagation, legumes have proven more successful in hardwood tree plantings than both grasses and resident vegetation (Van Sambeek and Garrett 2004). Specifically, this study has included large white clover (*Trifolium repens* var. *giganteum* L.) as one of the cover-crop treatments. In addition to lower tree competition and nitrogen-fixing abilities, white clover provides great nutrition and habitat for a variety of wildlife species (Barnes et al. 1995) of interest to many Missouri landowners. Examples include whitetail deer (*Odocoileus virginianus*), wild turkey (*Meleagris gallopavo*), bobwhite quail (*Colinus virginianus*), mourning doves (*Zenaida macroura*), cottontail rabbit, and other small mammals

(Stubbendieck et al. 2003). One possible disadvantage of using white clover as a living mulch is that it is more difficult to establish compared to many grass sods (Barnes et al. 1995).

An additional concern with the use of cover-crops such as white clover or redtop is that each are non-natives and have the ability to spread unintentionally. To date there has been very little research in using native species for this type of work (personal communication: Jerry Van Sambeek). Many have speculated that Virginia wild rye may be a good option due to its general distribution and growth habit. In Missouri, Virginia wild rye naturally grows in a variety of settings, from intact riparian communities, to glades and old fields (Yatskievych 1999), and often grows in a near monoculture. A concern of using Virginia wild rye is that there may not be adequate and/or viable seed sources in Missouri in comparison to using agronomic crops, which has been the focus of nearly all agronomic research and development in the seed production field (personal communication: Jerry Van Sambeek).

CHAPTER II

BOTTOMLAND HARDWOOD REGENERATION IN OLD-FIELD RIPARIAN ECOSYSTEMS

Introduction

In Missouri, mature hardwood forests were once abundant in floodplains of the Ozark region (Nigh et al. 1992). Large-scale conversion of Ozark bottomland forest to agriculture began in the early 1800’s (Jacobson and Primm 1994) and continued to be a common practice into the middle of the Twentieth Century. Loss of riparian forests in the Ozarks has accelerated bank erosion, destabilized stream channels, increased stream temperature, and degraded aquatic and riparian fish and wildlife habitat (Roell 1994). Overall, greater than 85 percent of the original floodplain forests in Missouri have been converted to some other use (Dey et al. 2001). Currently, there is considerable interest in replanting hardwoods in old fields and former pastures along riparian corridors in Missouri, and throughout the Central Hardwood Forest Region.

Recently, a number of federal and state-wide efforts to re-establish bottomland hardwoods have largely had mixed or poor success (Kabrick et al. 2007, Dugger et al. 2004, Dey et al. 2001, Kabrick and Dey 2001, Stanturf et al. 2001). Species are often planted in site conditions that do not match their silvical and life-history characteristics, which often results in poor survival and growth. In addition, extreme competition for above- and below-ground resources, and production of allelochemicals by resident vegetation inhibit normal growth of natural and planted native tree seedlings (Van Sambeek et al. 2004, Kruse and Groninger 2003, Lawson et al. 1999). Other issues that have led to poor seedling establishment include wildlife herbivory, planting technique, seed source genetics, and seedling stock type. Overall, methods for restoring bottomland hardwoods have not yet been fully developed.

To date, most riparian afforestation projects have focused on planting hard mast producing species, such as oaks (*Quercus* spp. L.), pecan (*Carya illinoinensis* (Wangenh.) K. Koch), and black walnut (*Juglans nigra* L.). Light-seeded species thought to have lower wildlife and economic value are often omitted, in part because of the assumption that these species will naturally establish themselves. However, Allen (1997) and Stanturf et al. (2000) suggested that relying on the natural establishment of light-seeded, wind-dispersed species into agricultural forest conversions may be impractical or unsuccessful. Consequently, there is increasing interest in including these species in bottomland plantings (Lockhart et al. in review, Ouchley et al. 2000, Twedt and Portwood 1997). However, there is little information about the artificial regeneration of most light-seeded species.

Ground cover vegetation management is an extremely important part of any afforestation project, and only second to species-site considerations (Van Sambeek and Garrett 2004). Ground cover vegetation management can be used to reduce competition for water and nutrients and to minimize labor and equipment costs, particularly during the first years following tree planting (Dey et al. 2008, Miller 1993).

Types of management include mechanical or chemical control of competing vegetation, and planting cover-crops. Mechanical control includes mowing; a common practice managers use to facilitate chemical treatments and help locate newly planted trees. However, mowing itself is ineffective for controlling competing vegetation to improve seedling survival and growth (Van Sambeek and Garrett 2004).

Chemical methods include application of a variety of pre- and post-emergent herbicides, including those that can be applied over trees, such as grass-selective herbicides. Broad-spectrum herbicides such as glyphosate (Roundup®) are commonly used and applications in hardwood plantings have been demonstrated to increase tree seedling growth rates. Grass-selective herbicides such as sethoxydim (Poast Plus®) have not been as widely evaluated and there is little published information about whether tree seedling growth is enhanced by their application (Van Sambeek and Garrett 2004).

Cover-crops have also been shown to be effective in suppressing competing vegetation, leading to improved tree survival and growth (Van Sambeek and Garrett 2004). In addition, cover-crops may be used for soil conservation and water quality improvement (Dey et al. 2008). Specifically, grass species such as redtop (*Agrostis gigantea* Roth) have been successfully established in bottomland hardwood plantings in Missouri with minimal investment, high success, and little follow-up management (Dey et al. 2003). Other options for cover-crops include legumes with nitrogen-fixing properties and wildlife food value, such as clovers (*Trifolium* spp. L., Pederson 1995). Legumes have often proven more successful in hardwood tree plantings than both grasses and resident vegetation (Van Sambeek and Garrett 2004). However, most cover-crops used in hardwood tree plantings are agricultural crops or forages. To date, there has been little research in using native bottomland species as cover-crops in tree plantings, particularly where restoring plant communities is a priority. Many have speculated that Virginia wild rye (*Elymus virginicus* L.) may be a suitable option because of its general distribution and growth habit. In Missouri, Virginia wild rye grows in a variety of settings, from intact riparian communities, to glades and old fields (Yatskievych 1999).

My objective was to compare the survival and height growth of two chemical and three cover-crop management practices on thirteen species of seedlings to identify successful afforestation methods for use in old-field riparian ecosystems of the Ozark Highlands. Vegetation control and cover-crop treatments were selected to compare commonly-used methods to others that have remained relatively untested. The chemical control methods included glyphosate, the standard herbicide commonly applied in cost-share plantings, and a combination of glyphosate and sethoxydim, a grass-selective herbicide that has the potential to control noxious grasses such as Johnson grass (*Sorghum halepense* (L.) Pers.). Our cover-crop management treatments included large white clover (*Trifolium repens* var. *giganteum* L.), which has known growth benefits in tree plantings, to the less-studied redtop grass, and to Virginia wild rye, which is native to bottomlands throughout eastern North America. Our tree species included bottomland oaks and other hard-mast species, as well as a number of softmast and light-seeded tree species that have received little research attention.

Study Areas

This study was conducted at three locations selected based upon their geographic distribution, placement within watershed, current and former land condition, and land ownership type. All sites were located within the Ozark Highlands Ecological Section, as described by Nigh and Schroeder (2002, Figure 2). Study areas were confined to this region because of the distinctive topographical characteristics and area-specific land management questions occurring here. Pre-treatment vegetation at all sites consisted of near monocultures of tall fescue (*Festuca arundinacea* Schreb.), which is the predominate pasture grass in the region, due to its tolerance to a wide range of soils, drought, intermittent fertilization, and intense grazing practices (Sleper and Buckner 1995). In addition, tall fescue is strongly allelopathic, and the millions of hectares of this species greatly suppress natural tree regeneration, planted seedlings, and native ground flora in old fields throughout Missouri (Van

Sambeek et al. 2004, Missouri Department of Conservation 1987). Mean annual precipitation is 102-124 cm, with an average growing season of 205-225 days (Nigh and Schroeder 2002). Waterways within this region flow through a highly-dissected, unglaciated, ancient landscape. Upland forest soils throughout the Ozarks are mainly composed of highly-weathered residuum and hillslope sediments, largely resting above Ordovician-age sandstones and dolomites (Meinert et al. 1997). Age and degree of weathering produce acidic soils with relatively low base saturation. Accordingly, alluvial sediments transported and deposited along Ozark bottomlands reflect this character. Streams adjacent to Ozark riparia are mostly spring-fed and carry little suspended sediment (Nigh and Schroeder 2002). Here, drainage systems are characterized as "open," with a brief water residence time. Compared to surrounding regions, fluvial soils are coarsely-grained and droughty. Stream systems of this study were 2nd and 4th order (Strahler 1957). Each research plot was located on well-developed and relatively stable point-bar floodplains subject to occasional to infrequent flooding. Prior to site establishment, Missouri Department of Natural Resources soil scientists mapped the soils at each site at a highly detailed scale of 1:2,000 (Table 3). Sites were located on floodplain or terrace landforms. Soil orders consisted of Entisols and Alfisols and ranged from excessively well-drained with sandy-skeletal texture, to somewhat poorly-drained with fine-silty texture. Planting area at each site ranged from 1.5 to 2 hectares.

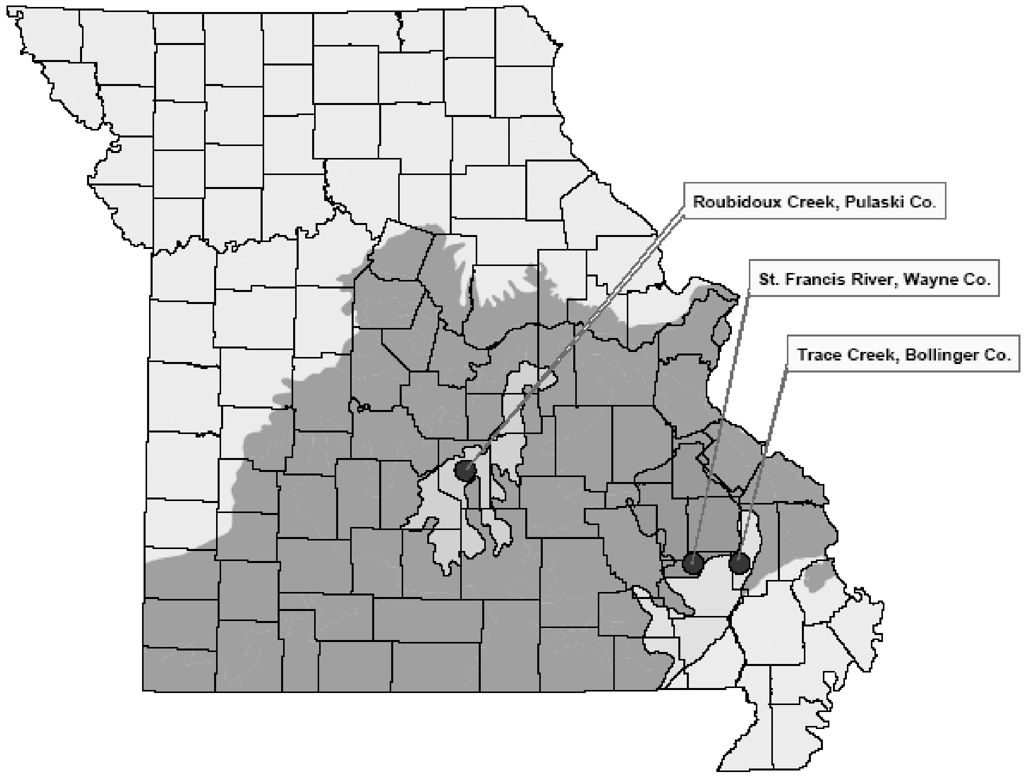

Figure 2. Ozark Highlands Ecological Section (dark gray); filled circles indicate location of project sites within three different Ecological Subsections, including the Gasconade River Hills (Roubidoux Creek), St. Francis Knobs and Basins (St. Francis River), and the Black River Ozark Border (Trace Creek).

Table 3. Soils and associated physical characteristics of each study area.

Study site	Soil series	Landform type	Drainage class	Taxonomic class
St. Francis River	Bucklick	footslope	well	Fine, mixed, active, mesic Typic Hapludalfs
	Crider	footslope	well	Fine-silty, mixed, active, mesic Typic Paleudalfs
	Fourche	terrace	moderately well	Fine-silty, mixed, active, mesic Gic Paleudalfs
	Freeburg	terrace	somewhat poorly	Fine-silty, mixed, superactive, mesic Aquic Hapludalfs
	Raccoon	terrace	poorly	Fine-silty, mixed, superactive, mesic Typic Endoaqualfs
	Secesh		moderately well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
Trace Creek	Razort	floodplain	well	Fine or coarse-loamy, mixed, active, mesic Mollic Hapludalfs
	Secesh	floodplain	well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
	Tilk	floodplain	well	Loamy-skeletal, siliceous, active, mesic Ultic Hapludalfs
Roubidoux Creek	Kickapoo	floodplain	well	Coarse-loamy, mixed, superactive, nonacid, mesic Typic Udifluvents
	Sandbur	floodplain	somewhat excessively	Coarse-loamy, siliceous, superactive, nonacid, mesic Mollic Udifluvents
	Relfe	floodplain	excessively	Sandy-skeletal, siliceous, mesic Mollic Udifluvents

Materials and Methods

We evaluated the two-year survival and growth of thirteen native tree species commonly used in bottomland plantings in the Ozark region (Table 4). Bare-root seedling stock was used, which is the most widely-available and commonly-used stock type in the region (Dey et al. 2008). All seedlings were planted in March or April of 2006. Seedlings were obtained from the George O. White State Tree Nursery near Licking, Missouri. All seedlings were 1-0 bare-root stock, with the exception of eastern cottonwood (*Populus deltoides* Batr. ex Marsh.), which were planted as 30-cm-long cuttings. Prior to planting, seedlings of all species were randomly packaged together to ensure random placement in the field.

All planting locations were initially sprayed with a two percent solution of glyphosate (41 percent a.i.) to eliminate pre-existing cool-season pasture grasses and other agricultural weeds. Treatments included: 1) Glyphosate site preparation only (hereafter referred to as "Roundup®-only"); glyphosate site preparation plus a: 2) single growing season application of a grass-selective post-emergent herbicide sethoxydim (13 percent a.i., hereafter referred to as "Poast Plus®"), 3) redtop cover-crop, 4) large white clover cover-crop with winter wheat (*Triticum aestivum* L.) nurse-crop, and 5) Virginia wild rye cover-crop with a Korean lespedeza (*Kummerowia stipulacea* [Maxim.] Makino) nurse-crop. Following the initial glyphosate application, fields receiving the three cover-crop treatments (hereafter referred to as "redtop," "clover," and "rye," respectively) were disked to a depth of seven centimeters. Seed was then broadcast by either a hand-spreader or tractor-mounted seeder prior to tree planting in March or April. Each treatment was planted separately at the following seed mixtures and rates: redtop at 11.1 kg/ha, large white clover at 4.5 kg/ha, winter wheat at 174 L/ha, Virginia wild rye at 17.8 kg/ha, and Korean lespedeza at 8.9 kg/ha. Following seeding, a section of chain-link fence was dragged behind an all-terrain vehicle to maximize seed-soil contact. The Poast Plus® treatment was left idle until the target grass species were actively growing (i.e., late May - early June). The Roundup®-only treatment was left idle for the remainder of the study.

Following cover-crop seeding, tree seedlings were planted during the same day using a tree planter. A minimum of twenty seedlings per species per treatment were planted (Table 2), for a total of 4,501 seedlings. Two species, swamp white oak and pin oak were only planted at two sites. Planting spacing was somewhat dependent upon site area, but was generally 3 x 3 m (i.e., 1111/ha). A work crew followed the tree planter and replanted any poorly-planted trees as needed. Following planting, initial height, diameter, and survival data were collected. All seedlings were re-measured in November 2006 at the completion of the first growing season and again in November 2007 following the second growing season.

Ground flora was inventoried during peak vegetative productivity of the growing season during 2006 and 2007 (i.e., middle July - early August), in order to quantify competing plant composition, abundance, and structure within each site and treatment type. Twenty-five to 30 1-m^2 sample quadrats were randomly assigned to each treatment per site. At each quadrat, percent cover by species was tallied for any plant located within the quadrat area to the nearest percent. Each species was tallied regardless of its vertical placement within the quadrat. Therefore, it was possible that with vertical layering of vegetation, the sum of all species together could equal more than 100 percent. Foliar coverage by height class was also measured using a 2.5-m-tall by 0.3-m-wide vegetation profile board, with alternating black and white painted bands at each 0.25-m interval (Nudds 1977). The profile board was oriented along the outside edge of the 1-m^2 quadrat frames used for the ground flora sampling. A metal tape was used to establish a pre-selected, unbiased random sampling point 15 m from the profile board. The amount of vegetation obscuring each 0.25-m interval on the profile board was estimated to the nearest percent for each plot. Observers ensured that their line-of-sight coincided directly with the height interval being measured. These data were collected at every other quadrat location.

Natural regeneration plots were established and inventoried following the second growing season to determine the contribution of tree regeneration from adjacent seed sources and to analyze differences by treatment type. Ten, 0.4-hectare plots were randomly placed in each treatment area. Tree species, number of stems, and height class (0-0.3 m, 0.3-0.9 m, and >0.9 m) were recorded. Plots were georeferenced so that the distance from plot centers to forest edge could be determined using GIS software and aerial photography.

Analyses

Data were analyzed using analysis of variance (ANOVA) with the SAS statistical software package (version 9.1, SAS Institute, Inc., Cary, NC, USA). The MIXED procedure was used for normally distributed data and data that could be normalized by transformation. The GLIMMIX procedure with specified data distribution was used for data that could not be normalized. For seedling survival and growth, a repeated measures split-plot design was used, with the five vegetation management treatments as whole plots and the thirteen tree species as split-plots. For survival, binary data were analyzed using the GLIMMIX procedure, using a "beta distribution" for the response variable and "logit" as the link function. For all repeated measures by year, compound symmetry and autoregressive covariance structures were evaluated, and the one with the lowest Akaike information criterion (AIC) score was selected. Fixed effects were treatment, species, and year. Ground flora and natural regeneration data were analyzed as an ANOVA randomized complete block design with response variables being percent cover and stems/plot, respectively. Distance to forest edge was included as a covariate in the natural regeneration analysis. For all analyses, site and all interactions with site were random effects in the error. For significant effects, Fisher's least significant differences were calculated using the least squares means for all mean separations. To graphically show the relationship between natural reproduction density with distance from forest edge, a normal Kernel regression with a bandwidth of 40 m was conducted, using the R statistical software package (version 2.6.2, The R Development Core Team).

Table 4. Species, number of seedlings, and species group (based on seed morphology) used in this study.

Common Name	Scientific Name	n	Species Group
Bur oak	*Quercus macrocarpa* Michx.	378	Oak hardmast
Swamp white oak	*Q. bicolor* Willd.	212	
White oak	*Q. alba* L.	367	
Northern red oak	*Q. rubra* L.	374	
Pin oak	*Q. palustris* Muenchh.	204	
Shumard oak	*Q. shumardii* Buckl.	373	
Pecan	*Carya illinoinensis* (Wangenh.) K. Koch	367	Other hardmast
Black walnut	*Juglans nigra* L.	430	
Green ash	*Fraxinus pennsylvanica* Marsh.	383	Light-seeded or softmast
White ash	*F. americana* L.	363	
American sycamore	*Platanus occidentalis* L.	375	
Eastern cottonwood	*Populus deltoides* Batr.	311	
Hackberry	*Celtis occidentalis* L.	364	

Results

Artificial Regeneration

After two growing seasons, survival of all planted seedlings was similar among treatments, and ranged between 81 percent in the Roundup®-only treatment and 87 percent in the Poast Plus® treatment (Tables 5 and 7). For all species and treatments combined, first-year survival was 93 percent, and decreased to 84 percent following the second growing season. However, highly significant differences occurred among species, and even among species within species groups (Tables 6 and 7). Ten of the thirteen species had greater than 92 percent survival after the first growing season. The survival of most species was significantly lower after the second growing season compared to the first. Most decreased 5 to 10 percent, but some species suffered greater mortality by the end of the second growing season including pecan (74 to 58 percent), sycamore (88 to 74 percent) and cottonwood (41 to 16 percent). Green ash and white ash had greater than 95 percent survival both years. Overall, the oaks, black walnut, and hackberry all had comparable survival both years, with second year survival ranging between 81 percent (pin and white oak) and 92 percent (swamp white oak).

Table 5. Percent seedling survival and standard error (SE) by treatment following two growing seasons across all species and locations. Letters indicate significant differences (α = 0.05).

Treatment type	Treatment	Mean Survival ± SE
		----percent----
Herbicide-only	Roundup®-only	81 ± 5 a
	Roundup® + Poast Plus®	87 ± 4 a
Cover-crops	Redtop	85 ± 4 a
	Clover	85 ± 4 a
	VA wild rye	83 ± 5 a

Table 6. Percent seedling survival and standard error (SE) by species and year within species group, and all seedlings by year. Uppercase letters indicate differences between years and lowercase letters indicate differences among species (α = 0.05).

Species Group	Species	Mean Survival ± SE ---------------year----------------- 1	 2
		-------------percent---------------	
Oak hardmast	Bur oak	95 ± 2 A ab	91 ± 5 B ab
	Swamp white oak	97 ± 2 A ab	92 ± 4 B ab
	White oak	93 ± 3 A bc	81 ± 8 B bc
	Northern red oak	95 ± 2 A ab	89 ± 5 B ab
	Pin oak	92 ± 4 A bc	81 ± 9 B bc
	Shumard oak	94 ± 3 A bc	87 ± 6 B b
Other hardmast	Pecan	74 ± 10 A d	58 ± 12 B d
	Black walnut	97 ± 1 A ab	89 ± 5 B ab
Light-seeded or softmast	Green ash	98 ± 1 A a	98 ± 1 A e
	White ash	96 ± 2 A ab	95 ± 3 A ae
	American sycamore	88 ± 5 A c	74 ± 10 B cd
	Eastern cottonwood	41 ± 12 A e	16 ± 7 B f
	Hackberry	95 ± 2 A ab	85 ± 7 B bc
	All	93 ± 3 A	84 ± 6 B

Table 7. Analysis of variance relating treatment, species, and year to seedling survival.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	17	1.07	0.4027
Species	12	28	17.72	<.0001
Treatment * Species	48	135	1.34	0.1000
Year	1	184	202.59	<.0001
Year * Treatment	4	182	1.52	0.1972
Year * Species	12	178	2.32	0.0087
Year * Treatment * Species	48	176	0.84	0.7546

Seedling height of all species combined among vegetation management treatments was only nominally different by treatment (Figure 2 and Table 8), with greater height growth in the cover-crop treatments than in the herbicide-only treatments. In general, the relationship was as follows: redtop and clover > rye > herbicide-only. There was not a significant treatment by year interaction.

Height among tree species by year varied greatly (Figure 2 and Table 8). Initially, the white oak group seedlings (Section *Quercus*) were the shortest, ranging from 34 to 44 cm. The red oak group seedlings (Section *Lobatae*) were all between 48 and 50 cm. During the first two growing seasons, these general relationships persisted but there were no great differences within the oak species groups. The most notable of the red oaks was pin oak which had the greatest growth increment and was nominally the tallest. Of the white oak group, swamp white oak had the greatest height growth. In addition, even though swamp white oaks were the shortest species when the study was initiated, they grew more than all six of the oak species. The other hardmast-producers (black walnut and pecan) were initially similar in height but differed in subsequent years. Black walnut gradually gained in height by the end of year two and pecan gradually died back. Of the light-seeded and softmast-producing species, sycamore was initially greater than the others at an average height of 79 cm. After two years of growth, surviving sycamore and cottonwood seedlings were significantly taller than the others, growing to 125 cm and 95 cm respectively. Sycamore had a marked difference in height growth from year one where it grew very little, to year two where it rapidly grew to its final average height of 125 cm. Although the ashes and hackberry each started between 53 and 55 cm, green ash grew to 78 cm, white ash to 69 cm, and hackberry progressively died back to nearly 40 cm.

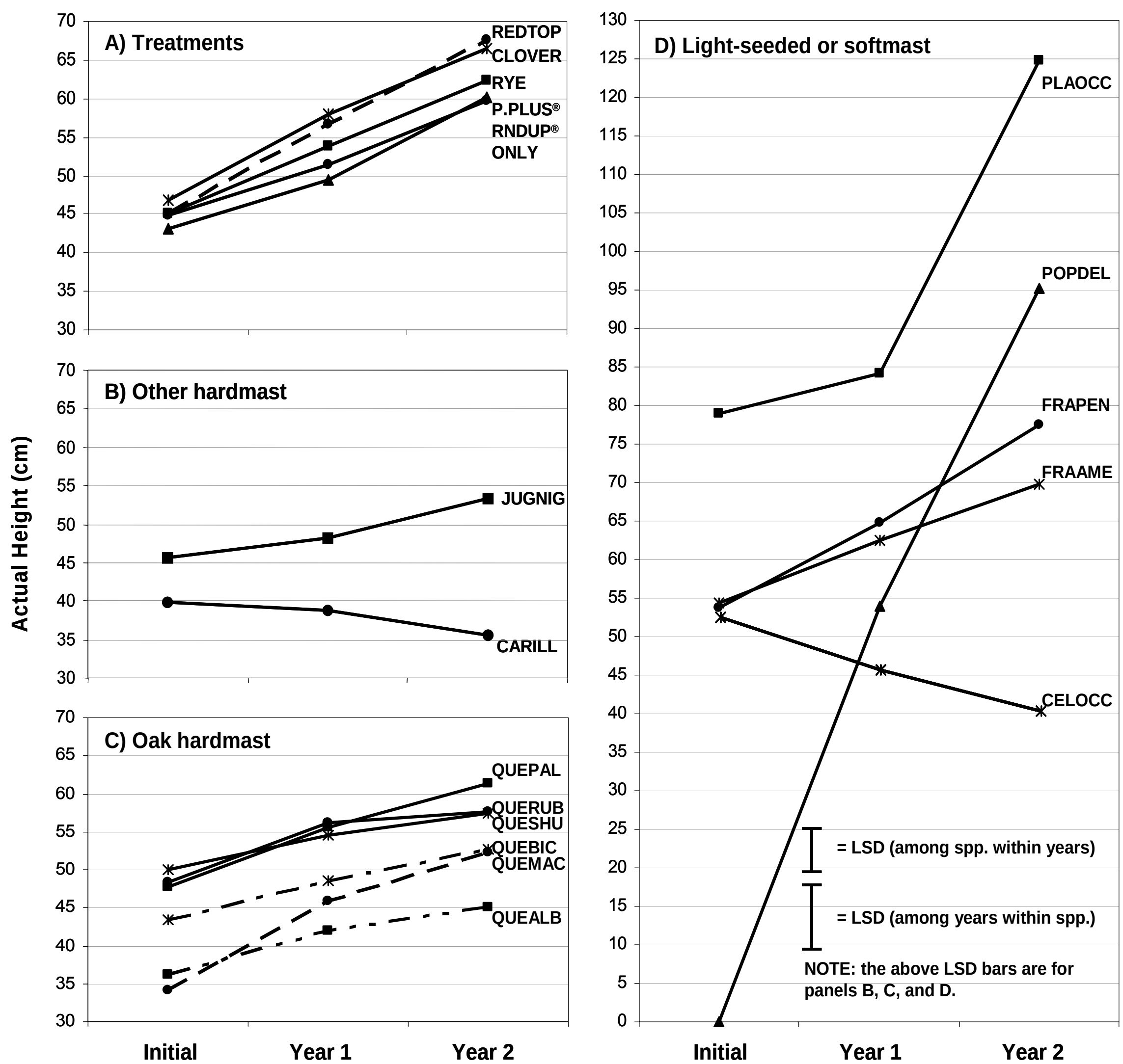

Figure 3. Average seedling height by year by treatment and species. Panel A) is height by treatment and panels B) through D) are height by species. Error bars (panel D) indicate least significant differences (LSD) for all species panels, and are used to compare all species in a single year and for a single species among years ($\alpha = 0.05$). In this case, species are noted using the first three letters of the genus followed by the first three letters of the species epithet.

Table 8. Analysis of variance relating treatment, species, and year to seedling height.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	8	3.39	0.0664
Species	12	110	114.07	<.0001
Treatment * Species	48	110	0.63	0.9624
Year	2	4	12.66	0.0186
Year * Treatment	8	16	1.05	0.4398
Year * Species	24	216	46.48	<.0001
Year * Treatment * Species	96	216	0.37	1.0000

Natural Regeneration

By the end of the second growing season, 27 tree species were identified during the natural regeneration inventory (Table 9). Of these, nine were in the hardmast group, eight in the softmast, and ten were light-seeded species. The majority of species encountered were elms, sycamore, persimmon, and green ash, which altogether totaled greater than 75 percent of all stems. The additional species individually comprised less than four percent of the total stems, respectively. Overall, light-seeded species comprised the majority of all stems with 67 percent. Of the remaining stems, softmast species were 20 percent and hardmast species were 13 percent. Of all stems, 70 percent were in the 0.3-0.9 m height class, followed by 23 percent in the <0.3 m class and seven percent in the >0.9 m class.

Significant differences for density of natural regeneration among treatments occurred for all stems (Tables 10 and 11), with similar trends occurring through most variables, including all the height classes and species group combinations. Natural regeneration was always greater in the herbicide-only treatments than in the cover-crop treatments. Data were generally aligned as follows: Poast Plus® > Roundup®-only > cover-crops. The proportion of total stems by treatment was: Poast Plus® (49 percent), Roundup®-only (28 percent), clover (8 percent), redtop (7 percent), and rye (7 percent). By site, St. Francis River had 44 percent of all stems, followed by Trace Creek (39 percent), and Roubidoux Creek (17 percent). The density of reproduction of light-seeded species was significantly greater in the herbicide treatments than in the cover-crop treatments. The softmast and hardmast-producers were nominally significantly greater by treatment with softmast species following the same trends as for the light-seeded species. However, unlike other species groups, the reproduction density of hardmast species was lowest in the Roundup®-only treatment.

The distance from plot center to the nearest intact forest edge ranged from five to 65 m, with an average distance of 25 m. The distance from plot center to forest edge was a highly significant covariate for the hardmast group and only nominally different for all stems together (Table 11). These relationships were negative, with fewer stems occurring farther from the forest edge (Figure 4). This effect was not significant for the softmast and light-seeded species.

Table 9. Proportion of all stems by species through all treatments of natural tree regeneration inventoried.

Common Name	Scientific Name	% of all stems	Species Group
Black walnut	*Juglans nigra* L.	4	Hardmast
Shumard oak	*Quercus. shumardii* Buckl.	4	
Shingle oak	*Q. imbricaria* Michx.	2	
Bur oak	*Q. macrocarpa* Michx.	1	
Hickory	*Carya* spp. Nutt.	1	
Willow oak	*Q. phellos* L.	<1	
Bitternut hickory	*C. cordiformis* (Wangenh.) K. Koch	<1	
Pecan	*C. illinoinensis* (Wangenh.) K. Koch	<1	
Ohio buckeye	*Aesculus glabra* Willd.	<1	
Persimmon	*Diospyros virginiana* L.	14	Softmast
Honey-locust	*Gleditsia triacanthos* L.	3	
Redbud	*Cercis canadensis* L.	1	
Hawthorn	*Crataegus* spp. L.	1	
Black cherry	*Prunus serotina* Ehrh.	1	
Sassafras	*Sassafras albidum* (Nutt.) Nees	1	
Eastern red cedar	*Juniperus virginiana* L.	<1	
Red mulberry	*Morus rubra* L.	<1	
American sycamore	*Platanus occidentalis* L.	26	Light-seeded
American elm	*Ulmus americana* L.	23	
Winged elm	*U. alata* Michx.	7	
Green ash	*Fraxinus pennsylvanica* Marsh.	6	
Box elder	*Acer negundo* L.	2	
Maple	*A.* spp. L.	1	
White ash	*F. americana* L.	<1	
Slippery elm	*U. rubra* Muhl.	<1	
Silver maple	*A. saccharinum* L.	<1	
American hornbeam	*Carpinus caroliniana* Walt.	<1	

Table 10. Natural regeneration density and standard error (SE) by treatment for all species combined and by species groups. Lowercase letters indicate significant differences among treatments within a species group (α = 0.05).

Species Group/ Treatment	Stems/ha ± SE	
All Species		
Roundup®-only	1265 ± 363	a
Poast Plus®	1791 ± 525	a
Redtop	291 ± 85	b
Clover	362 ± 106	b
VA wild rye	362 ± 107	b
Light-seeded		
Roundup®-only	1170 ± 353	a
Poast Plus®	1279 ± 384	a
Redtop	179 ± 54	b
Clover	235 ± 71	b
VA wild rye	214 ± 65	b
Hardmast		
Roundup®-only	32 ± 12	a
Poast Plus®	178 ± 68	a
Redtop	91 ± 35	a
Clover	93 ± 36	a
VA wild rye	69 ± 27	a
Softmast		
Roundup®-only	83 ± 58	a
Poast Plus®	356 ± 251	a
Redtop	52 ± 36	a
Clover	66 ± 47	a
VA wild rye	58 ± 41	a

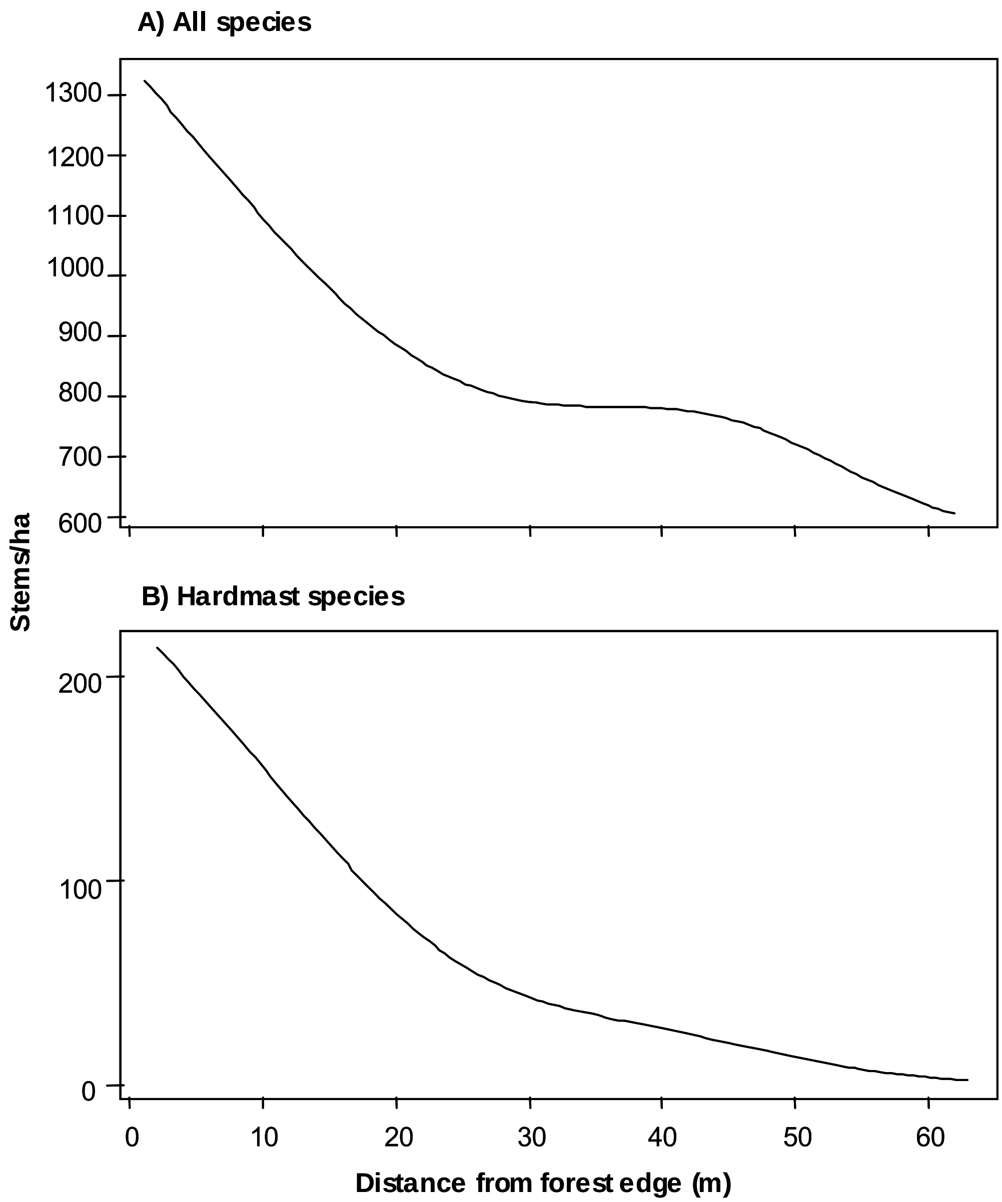

Figure 4. Relationship between natural regeneration density and distance from the nearest intact forest edge for all stems (panel A) and hardmast species (panel B).

Table 11. Analysis of variance relating treatment and distance to forest edge to naturally regenerating tree seedlings by species group.

Effect	Num DF	Den DF	F Value	Pr > F
All Species:				
Treatment	4	8	9.08	0.0049
Distance	1	104	3.54	0.0628
Light-seeded Species:				
Treatment	4	8	10.43	0.0029
Distance	1	134	0.43	0.5146
Softmast Species:				
Treatment	4	8	3.79	0.0547
Distance	1	133	0.24	0.6250
Hardmast Species:				
Treatment	4	9	2.94	0.0920
Distance	1	128	40.00	<.0001

Competing Vegetation

As expected, foliar cover differed among treatments during the first growing season following treatment establishment, but by the second growing season, cover of competing vegetation was similar (Table 12 and Figure 5). For the total foliar cover of vegetation in the first year, the Poast Plus® treatment was significantly lower than all treatments with the exception of clover, which was only significantly lower than rye. Amount of competing vegetation was similar among the Roundup®-only, rye, and redtop treatments for both years. For the herbicide-only treatments, the proportion of grasses compared to resident vegetation in the Poast Plus® treatment had over a four-fold decrease in comparison to grasses in the Roundup®-only treatment. For the cover-crops, the redtop sod obtained 33 percent coverage compared to resident vegetation by the first year and 50 percent coverage by the second year. The clover did not establish as well, being about a quarter of all vegetation the first year, and much less the next year. Finally, we did not detect Virginia wild rye during the first year and it had very low coverage during year two.

For foliar coverage of competing vegetation by height class, statistical analyses were not applied due to unusual data distributions. However, treatment estimates are graphically represented in Figure 6. Similar to the total foliar coverage results, there appear to be differences in the first year, but not the second. Specifically, in year one the Poast Plus® treatment had very short vertical competition in comparison to the Roundup®-only treatment, where vegetation often exceeded two meters in height. All other comparisons by treatment and year appeared to be similar.

Table 12. Analysis of variance relating treatment and year to total foliar coverage.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	8	1.45	0.3037
Year	1	2	1.00	0.4224
Year * Treatment	4	8	6.96	0.0102

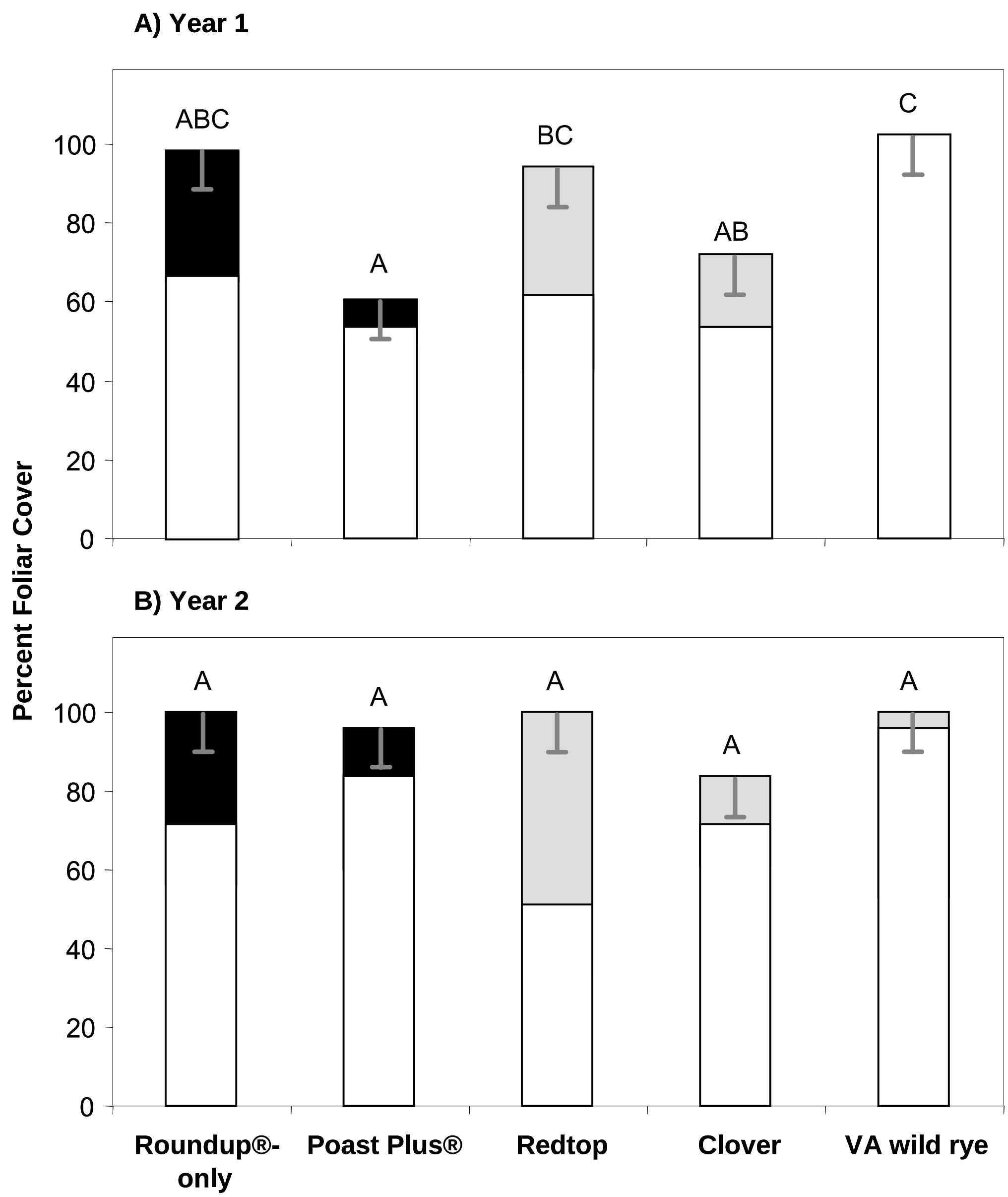

Figure 5. Mean ground flora foliar coverage with standard error bars by treatment, for A) the first growing season and B) the second growing season. Filled portion of the bars indicates the proportion of "target" vegetation for each treatment relative to resident vegetation. Grayed portions of bars show the percentage of cover-crops, while blackened portions show the percentage of grass species for the herbicide-only treatments. Letters indicate significant differences among treatments (α = 0.05).

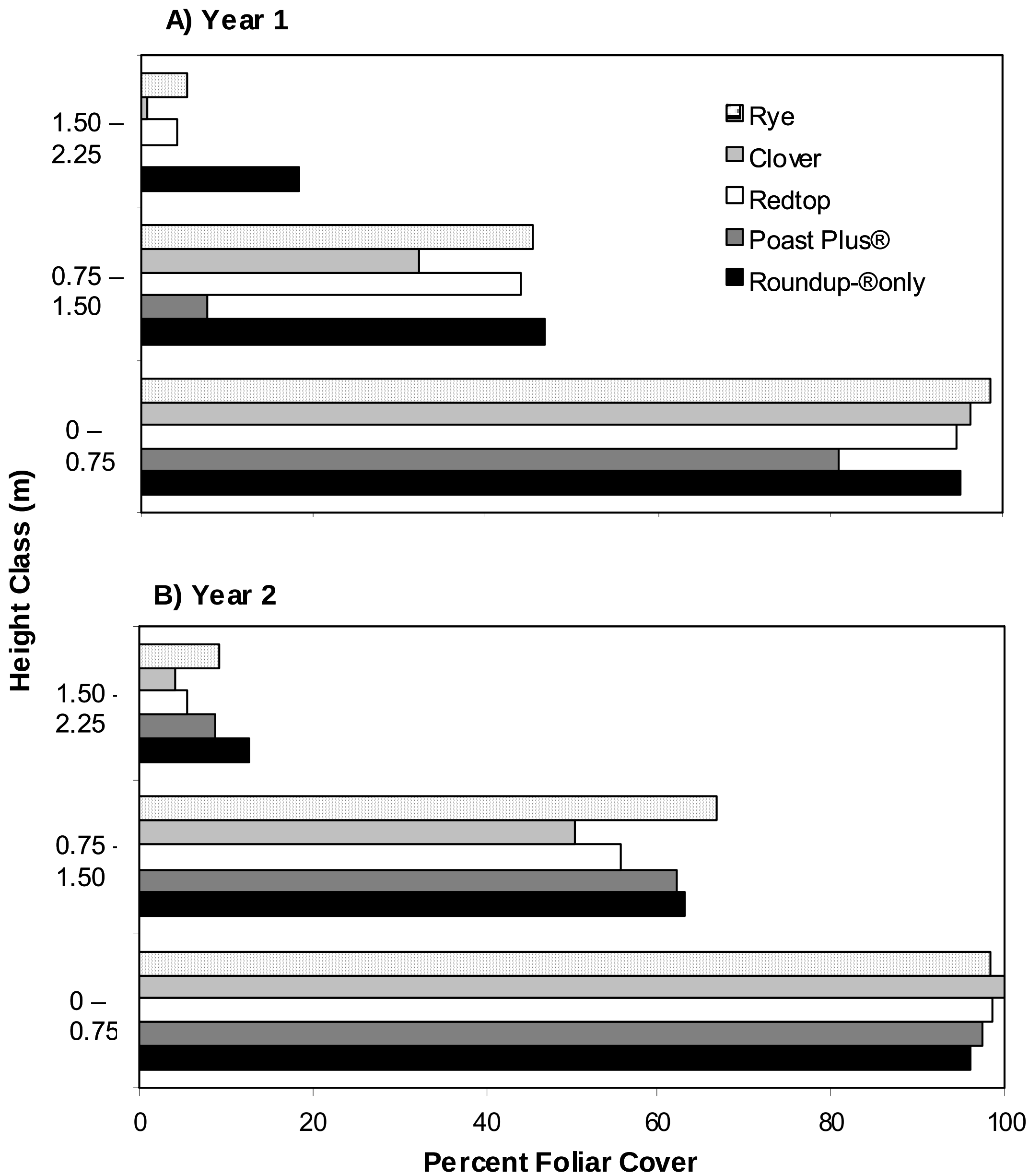

Figure 6. Foliar coverage by treatment of all competing vegetation at three 0.75 m vertical strata for A) the first growing season and B) the second growing season following establishment.

Discussion

There were nominal differences in seedling survival and growth of the various management treatments during the first two growing seasons of three bottomland tree plantings in the Missouri Ozarks. In general, seedling height growth patterns showed the following trend: redtop > clover > rye > Poast Plus® > Roundup®-only. Disking in the cover-crop treatments seemed to provide a slightly better planting medium which may lead to a more effective capture of adequate nutrients and moisture for young tree seedlings. Disking also slows the initial growth of resident vegetation early in the growing season, during the time many seedlings are developing their first flush. Seedling survival of all species combined was nearly the same in all treatments. Without further management, the redtop treatment is expected to be more successful than the others in coming years due to its ability to out-compete resident vegetation while also promoting good seedling survival and growth.

Of the cover-crops, the redtop sod germinated uniformly and very quickly established. This was consistent with our expectations based upon other published work using redtop in bottomland tree plantings in Missouri (Dey et al. 2004). The white clover germinated uniformly at all sites, but seemed to lose vigor during the summer, presumably due to heat and drought. Because white clover is a cool-season plant, it was not well represented during the ground flora inventories conducted during the mid summer. In comparison to using redtop, a stand of clover requires more maintenance and will likely only last a few years before re-planting may become necessary (Van Sambeek et al. 2007, Van Sambeek et al. 2003). Stevenson and Laidlaw (1985) also found that droughty conditions adversely affect development and persistence of stands of white clover. Consequently, the use of clover may not be feasible for some managers that cannot afford the time and effort for maintenance of a cover-crop. Regardless, white clover has been used with success in many other Midwestern tree plantings and has the added benefit of being a nitrogen-fixing plant, which can improve soil nutrient conditions for seedling success (Van Sambeek et al. 2003, Smith and Valenzuela 2002, Pederson 1995). The Virginia wild rye was established poorly at all sites, which resulted in elevated competing vegetation coverage consisting of nearly all resident, old-field vegetation. This could have been a result of planting methodology (e.g., burying seed), poor seed quality, or inadequate seed source. Nevertheless, several managers in Missouri have verbally reported successful establishment of Virginia wild rye, although its effect on the establishment and growth of trees remains relatively unstudied. Despite its poor success, this treatment still maintained reasonable seedling growth, and was nominally greater than both herbicide-only treatments.

For the herbicide-only treatments, there were no differences in seedling survival or growth using Roundup®-only as a site preparation versus site preparation followed by a first-season application of the grass-selective chemical, Poast Plus®. However, the foliar cover of competing vegetation was significantly less by using Poast Plus® during the first year. Not only were grass species nearly four times lower in the Poast Plus® treatment, but competing vegetation was shorter and total foliar coverage was lower as well. By the second year, grasses doubled in percent cover in the Poast Plus® treatments (but were half that of Roundup®-only) and there were no differences in total foliar cover. This suggests that in order to control competition with herbicides, vegetation management should occur in subsequent growing seasons. Overall, for all treatments in both years, competing vegetation at and above the average seedling height provided sufficient sunlight for most species to reach maximum photosynthesis, which is generally thought to be at least 1/3 full sunlight for northern red oak (Sander 1990) and most other oak species (Johnson et al. 2002).

According to the results of this study, choice of tree species is the most important factor in evaluating the initial success of riparian tree plantings. Overall survival was high, with 84 percent of all seedlings surviving after two growing seasons. However, among the thirteen species, seedling survival and height varied greatly during all years.

Six oak species were included in this study (three in the white oak group and three in the red oak group), all having somewhat different life histories and site requirements. Nevertheless, a characteristic common of all oak seedlings is that they allocate a greater proportion of carbon to root growth, resulting in a high root:shoot ratio, and consequently, production of a large taproot and delayed shoot growth (Johnson et al. 2002). This phenomenon can also cause recurring shoot dieback in order for oak seedlings to effectively allocate sufficient carbon to their roots (Johnson et al. 2002). As natural or planted seedlings, it is common during the early years following establishment for many oaks to grow only a few centimeters per year (Sander 1979), which is largely what was observed in this study. All of the oaks in our study had similar survival, ranging between 81 and 92 percent. However, there were differences in height among species for all years, with the white oak group generally being shorter than the red oak group species. Nonetheless, for swamp white oak, it is important to note that although being the shortest species planted initially, its height growth was the greatest of all oaks, and was the fourth best grower among all thirteen species in this study. In comparison to other species, swamp white oak appears to be both drought tolerant and flood tolerant, and does exceptionally well in bottomland oak plantings in Missouri (Kabrick et al. 2007, Dey et al. 2004). Pin oak also grew well and was the tallest oak at the conclusion of the study. Although pin oak is of scattered occurrence in the Ozark region, it is thought of as an acid-tolerant and sun-loving species (McQuilkin 1990), which complements the region and site characteristics well (Meinert et al. 1997). Pin oak has also been distinguished as a species that transports well as a seedling and seems to be a plausible option for use in bottomland hardwood plantings (Motsinger 2006, McQuilkin 1990, Moser 1978, Dickson et al. 1965). Northern red, Shumard, and bur oaks all had similar survival and heights. White oak was the shortest oak after both growing seasons, but height growth increment was similar to the aforementioned species.

Black walnut was similar to the oaks, having good survival and slow but steady growth. Walnut has very specific site requirements, and planting in locations with poor drainage and/or low depth to gravel will likely be unsuitable conditions for this species (Williams 1990). Among the additional species, there were great differences. Pecan performed very poorly, ending with nearly the lowest survival and growth. This is consistent with findings from other studies evaluating planted pecan seedlings (Kabrick et al. 2007, Stanturf et al. 1998). Pecan may be unsuitable for planting in many Ozark bottomlands, as it has been noted to have poor success in droughty conditions or when encountered with high aerial plant competition (Peterson 1990). This species has a scattered distribution in Missouri and is found in relatively few counties in the Ozark region.

Of the light-seeded or softmast species, hackberry had good survival but gradually died back in height, similar to pecan. In general, this species has been known to exhibit drought and flood tolerance and is moderately tolerant of shade (Krajicek and Wiliams 1990). Regardless of hackberry's high survival rate, negative growth occurred during both years, and it is likely that this species will have difficulty becoming part of the future forest. Hackberry may be poorly-suited for our study areas. According to Hodges (1997), hackberry occurs as a mid- to late-seral species in better-drained major bottoms of the Mississippi Alluvial Valley, and he does not note its occurrence in minor bottoms.

The ashes, especially green ash, had the highest survival of all species and each had significant increases in height. Green ash is a very adaptable species (Kennedy 1990), and in addition to being flood-tolerant, green ash seedlings appear to be well-adapted to successive droughty growing seasons that can occur in the Ozarks. Krinard et al. (1979) also reported that five-year-old green ash seedlings tolerated vegetation competition better than all other species that were tested, including sycamore, tulip-poplar (*Liriodendron tulipifera* L.), and several oak species. Despite this early success of the ashes, establishing them in bottomland plantings is questionable considering the likely spread of the Emerald Ash Borer (*Agrilus planipennis* Fairmaire) throughout North America.

Establishing eastern cottonwood with cuttings is considered an economical means of establishing this species, and early survival rates usually exceed 70 to 90 percent survival (Cooper 1990). However, this was not observed in our study, with a second-year survival rate 16 percent, which was the lowest survival of all species examined. There are a variety of reasons why this may have happened. In addition to the other stresses a seedling encounters in an afforestation planting, cuttings have the additional challenge of producing a root system after they are planted. Also during this time, young cottonwood roots are susceptible to heavy rains and intense radiant heat (Cooper 1990). It is likely that the drought conditions experienced during this study had a profound effect on this species. Cottonwood is one of the most shade-intolerant species in this region, and the thick growing season vegetation may have affected this species more than the other species. Also, it was found later that a small number of cuttings were inadvertently planted with the buds facing down, which probably caused lower survival and growth of those cuttings. Nevertheless, when cottonwoods did survive, they grew an average of nearly one meter after two growing seasons. Sycamore seedlings also had lower survival than most of the other species examined but it was still above 70 percent after two growing seasons. Survivors had rapid height growth, particularly during the second growing season when height increased by more than eight times more than during the first year. This delayed growth response is likely due to initial outplanting shock. In future years, it is anticipated that sycamore will continue to provide impressive growth, as it is among the fastest growing species in its range (Wells and Schmidtling 1990).

For natural regeneration, seedlings were notably more abundant in the herbicide-only treatments in comparison to the cover-crops. The vast majority of volunteer trees were of early-successional, and of light-seeded and softmast origin, which generally have epigeal seed germination (i.e., germination where cotyledons develop above ground, [Allaby 2004, Burns and Honkala 1990, Bazzaz 1979]). It was initially thought that the disking in the cover-crops would provide a more suitable seedbed for incoming seed. However, this was not the case. All treatments were initially sprayed with Roundup® during the late fall or early spring in order to kill cool-season grasses, and only the three cover-crop treatments were disked (for cover-crop seed broadcast). During herbicide application, existing seedlings were not actively growing and were likely not greatly affected.

After removing these grasses, suppressed seedlings were able to effectively compete for growing space and the seedbank was able to germinate. Conversely, the disking in the cover-crops likely smothered any existing seedlings and buried any epigeal seeds too deep to germinate.

As previously mentioned, the majority of species naturally regenerating were light-seeded or softmast seed producers and the most abundant of these were the elms, sycamore, and persimmon. Hardmast-producing species were uncommon and showed a significant negative relationship with increasing distance from the nearest intact forest edge. This was not important for the light-seeded and softmast species. However, when all species were grouped, a similar relationship occurred, although not as strong. In general, the strongest decreases in stem density occurred between five and 20 meters, after which, oak species become nearly absent. Although this study provides only two years of information following plantation establishment, these data suggest that supplemental planting of light-seeded species is necessary for them to become a component of the future forest.

Conclusions

Establishing hardwood seedlings in drought-prone regions like the Missouri Ozarks can be difficult. Even soil conditions in floodplains can be water-limiting for extensive periods of time. This, coupled with competition from aggressive, early-successional vegetation, deer and rabbit herbivory, and occasional seasonal flooding can prove challenging for regenerating old-field bottomlands.

It is likely that the species and treatment results reported here will change in coming years. However, initial stages of this type of restoration effort can have important long-term implications for the growth and development of riparian forests. Species like green ash, American sycamore, swamp white oak, and pin oak each exhibited high survival and growth under these difficult conditions and are easier to establish, while pecan, hackberry, and eastern cottonwood are difficult to establish.

Treatment effects were not important for seedling survival and only nominal for height. However, at all sites, the tall fescue was virtually eliminated using the Roundup® site preparation, and was less than five percent of the total cover the first year and eight percent the second year. Without the successful control of fescue, it is likely that seedlings would have suffered. Management treatments such as planting redtop or white clover cover-crops and conducting timely follow-up herbicide applications of Poast Plus® may result in a less dense and less competitive ground flora layer.

Although we show the development of natural regeneration in afforestation practices after only two years following treatment establishment, these data support the idea that natural regeneration, especially for the hardmast species, does not sufficiently stock a diversity of species to accomplish current management goals in Missouri. Planting species in addition to oaks will provide more immediate conservation assistance, better structural habitat for wildlife, more vegetation diversity, act as “nurse-trees” for better growth and development of the oaks, and produce earlier canopy development (Lockhart et al. in review, Ouchley et al. 2000, Allen 1997, Twedt and Portwood 1997).

Overall, annual follow-up management and selection of a variety of bottomland species native to your region is suggested to ensure successful establishment of a riparian afforestation project.

CHAPTER III

FLORISTIC ASSESSMENT OF RIPARIAN AFFORESTATION PRACTICES

Introduction

Desire to restore the function of riparian forest ecosystems has become a primary objective of many state, federal, and private land management agencies in the United States. There is a great deal of research and management underway attempting to improve management of these floodplain landscapes throughout the country (Lockhart et al. 2008, Shafroth et al. 2008, Steele et al. 2008, Kabrick et al. 2007, Henderson et al. 2005, Schulz et al. 2004, Jacobs et al. 2004, Sweeney et al. 2002). In the eastern U.S., much emphasis has been placed on planting native bottomland hardwood tree species in former agricultural fields. These afforestation practices generally consist of planting bare-root tree seedlings of a select number of hardmast-producing species, and managing vegetation with a number of pre- and post-emergent herbicides, or planting a perennial cover-crop to control competing vegetation (Dey et al. 2008).

In addition, many recent efforts to restore bottomland hardwoods have largely met with poor or mixed success, in large part due to competition by early-successional vegetation. The limitations that old-field vegetation provides for regenerating forest trees have been known for some time (Haney 1968, Richards 1973). Extreme competition for above- and below-ground resources and production of allelochemicals by resident vegetation inhibit normal growth of both natural and planted native tree seedlings (Van Sambeek et al. 2004, Kruse and

Groninger 2003, Lawson et al. 1999). Furthermore, these already degraded ecosystems can be vectors for invasion by exotic plant species (Orr et al. 2005). Monitoring herbaceous vegetation can help determine the prevalence of exotic species and subsequently, prescribe management activities that slow their spread. Thus, knowledge of the composition of herbaceous vegetation can subsequently direct future management decisions that may have a higher likelihood of improving restoration success (Baker and Van Lear 1998).

As part of most forest restoration work, many agencies have additional goals of restoring the composition, structure, and function of native ecosystems. Consequently, restoring the native tree species is only one component of the restoration goal. Although the effects of cover-crops and vegetation control methods on the survival and growth of planted hardwood seedlings in plantations and old-field plantings have been examined, there are relatively few studies that have considered the effects of these methods on the composition, structure, and diversity of the herbaceous vegetation in hardwood afforestation practices.

My objective was to assess the effect of two chemical and three cover-crop vegetation management treatments on the 1) physiognomic and structural characteristics of the vegetation, 2) species richness and diversity, 3) prevalence of exotic species, and 4) floristic quality of bottomland plant communities in afforestation plantings in the Missouri Ozarks.

Study Areas

This study was conducted at three locations selected based upon their geographic distribution, placement within watershed, current and former land condition, and land ownership type. All sites were located within the Ozark Highlands Ecological Section, as described by Nigh and Schroeder (2002, Figure 7). Study areas were confined to this region because of the distinctive topographical characteristics and area-specific land management questions occurring here. Pre-treatment vegetation at all sites consisted of near monocultures of tall fescue (*Festuca arundinacea* Schreb.), which is the predominate pasture grass in the region, owing to its tolerance to a wide range of soils, drought, intermittent fertilization, and intense grazing practices (Sleper and Buckner 1995). In addition, tall fescue is strongly allelopathic, and the millions of hectares of this species greatly suppress natural tree regeneration, planted seedlings, and native ground flora in old fields throughout Missouri (Van Sambeek et al. 2004, Missouri Department of Conservation 1987). Mean annual precipitation is 102-124 cm, with an average growing season of 205-225 days (Nigh and Schroeder 2002). Waterways within this region flow through a highly-dissected, unglaciated, ancient landscape. Upland forest soils throughout the Ozarks are mainly composed of highly-weathered residuum and hillslope sediments, largely resting above Ordovician-age sandstones and dolomites (Meinert et al. 1997). Age and degree of weathering produce acidic soils with relatively low base saturation. Accordingly, alluvial sediments transported and deposited along Ozark bottomlands reflect this character. Streams adjacent to

Ozark riparia are mostly spring-fed and carry little suspended sediment (Nigh and Schroeder 2002). Here, drainage systems are characterized as “open,” with a brief water residence time. Compared to surrounding regions, fluvial soils are coarsely-grained and droughty. Stream systems of this study were 2^{nd} and 4^{th} order (Strahler 1957). Each research plot was located on well-developed and relatively stable point-bar floodplains subject to occasional to infrequent flooding. Prior to site establishment, Missouri Department of Natural Resources soil scientists mapped the soils at each site at a highly detailed scale of 1:2,000 (Table 13). Sites were located on floodplain or terrace landforms. Soil orders consisted of Entisols and Alfisols and ranged from excessively well-drained with sandy-skeletal texture, to somewhat poorly-drained with fine-silty texture. Planting area at each site ranged from 1.5 to 2 hectares in size.

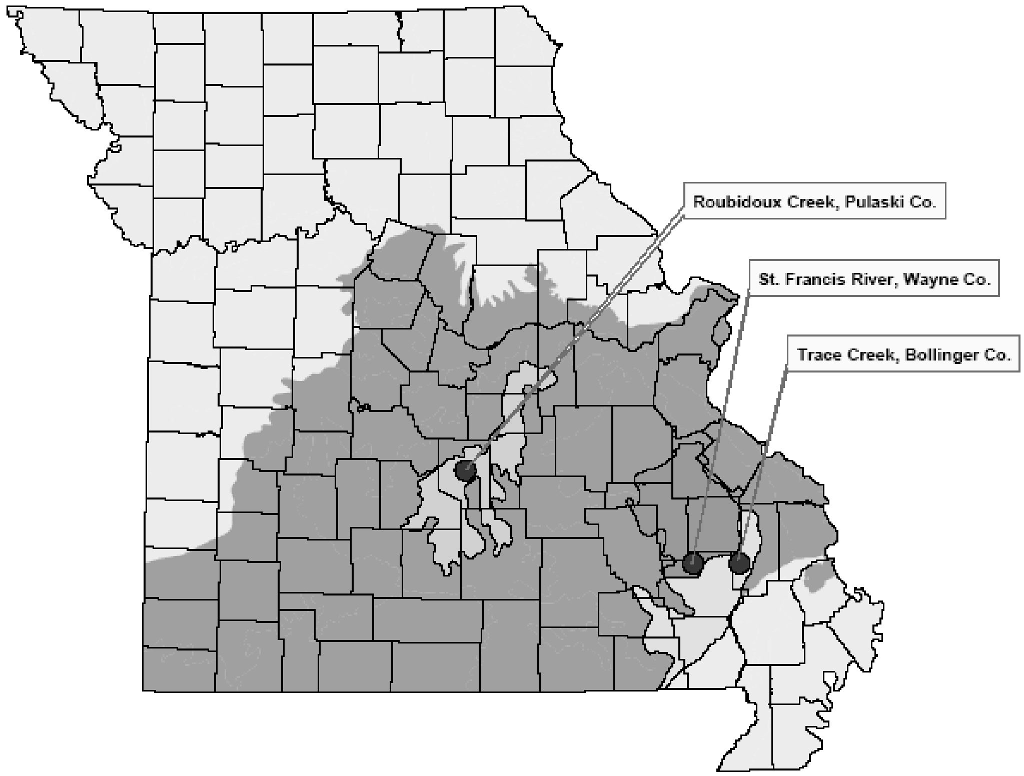

Figure 7. Ozark Highlands Ecological Section (dark gray); filled circles indicate location of project sites within three different Ecological Subsections, including the Gasconade River Hills (Roubidoux Creek), St. Francis Knobs and Basins (St. Francis River), and the Black River Ozark Border (Trace Creek).

Table 13. Soils and associated physical characteristics of each study area.

Study site	Soil series	Landform type	Drainage class	Taxonomic class
St. Francis River	Bucklick	footslope	well	Fine, mixed, active, mesic Typic Hapludalfs
	Crider	footslope	well	Fine-silty, mixed, active, mesic Typic Paleudalfs
	Fourche	terrace	moderately well	Fine-silty, mixed, active, mesic Gic Paleudalfs
	Freeburg	terrace	somewhat poorly	Fine-silty, mixed, superactive, mesic Aquic Hapludalfs
	Raccoon	terrace	poorly	Fine-silty, mixed, superactive, mesic Typic Endoaqualfs
	Secesh		moderately well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
Trace Creek	Razort	floodplain	well	Fine or coarse-loamy, mixed, active, mesic Mollic Hapludalfs
	Secesh	floodplain	well	Fine-loamy, siliceous, active, mesic Ultic Hapludalfs
	Tilk	floodplain	well	Loamy-skeletal, siliceous, active, mesic Ultic Hapludalfs
Roubidoux Creek	Kickapoo	floodplain	well	Coarse-loamy, mixed, superactive, nonacid, mesic Typic Udifluvents
	Sandbur	floodplain	somewhat excessively	Coarse-loamy, siliceous, superactive, nonacid, mesic Mollic Udifluvents
	Relfe	floodplain	excessively	Sandy-skeletal, siliceous, mesic Mollic Udifluvents

Materials and Methods

Composition and structure of the ground flora was evaluated during the first and second growing seasons following plantation establishment, in 2006 and 2007. All planting locations were initially sprayed with a two percent solution of glyphosate (41 percent a.i.) to eliminate pre-existing cool-season pasture grasses and other agricultural weeds. Treatments included: 1) Glyphosate site preparation only (hereafter referred to as "Roundup®-only"); glyphosate site preparation plus a: 2) single growing season application of a grass-selective post-emergent herbicide sethoxydim (13 percent a.i., hereafter referred to as "Poast Plus®"), 3) redtop cover-crop, 4) large white clover (*Trifolium repens* var. *giganteum* L.) cover-crop with winter wheat (*Triticum aestivum* L.) nurse-crop, and 5) Virginia wild rye cover-crop with a Korean lespedeza (*Kummerowia stipulacea* [Maxim.] Makino) nurse-crop. Following the initial glyphosate application, fields receiving the three cover-crop treatments (hereafter referred to as "redtop," "clover," and "rye," respectively) were disked to a depth of seven centimeters. Seed was then broadcast by either a hand-spreader or tractor-mounted seeder prior to tree planting in March or April. Each treatment was planted separately at the following seed mixtures and rates: redtop at 11.1 kg/ha, large white clover at 4.5 kg/ha, winter wheat at 174 L/ha, Virginia wild rye at 17.8 kg/ha, and Korean lespedeza at 8.9 kg/ha. Following seeding, a section of chain-link fence was dragged behind an all-terrain vehicle to maximize seed-soil contact. Tree seedlings were then planted during the same day using a tree planter on a 3 x 3 m spacing (i.e., 1111/ha). The Poast Plus® treatment was left idle until the target grass species were actively growing. The Roundup®-only treatment areas were left idle for the remainder of the study.

Ground flora was inventoried during peak vegetative productivity of the growing season during 2006 and 2007 (i.e., middle July - early August), in order to quantify competing plant composition, abundance, and structure within each site and treatment type. Twenty-five to 30 1-m^2 sample quadrats were randomly assigned to each treatment per site. At each quadrat, percent cover by species was tallied for any plant located within the quadrat area to the nearest percent. Each species was tallied regardless of its vertical location within the quadrat. Therefore, it was possible that with vertical layering of vegetation, the sum of all species together could equal more than 100 percent. In cases where plant species were unknown in the field, they were pressed and taken back to the office for further identification by Missouri Department of Conservation botanists. In addition to quadrat data, information was recorded for foliar coverage by height class using a 2.5-m-tall by 0.3-m-wide vegetation profile board, with alternating black and white painted bands at each 0.25-m interval (Nudds 1977). At each plot, the profile board was oriented along the outside edge of the 1-m^2 quadrat frames used for the ground level sampling. Based on a specified azimuth, a logger's tape was used to establish a random, unbiased sampling point at a distance of 15 m. The amount of vegetation obscuring each 0.25-m interval on the profile board was estimated to the nearest percent for each plot. Observers ensured that their line-of-sight coincided directly with the height interval being measured. These data were collected at every other quadrat location.

Analyses

Data were analyzed with analysis of variance (ANOVA) with a randomized complete block design, using the SAS statistical software package (version 9.1, SAS Institute, Inc., Cary, NC, USA). The MIXED procedure was used for normally distributed data and data that could be normalized by transformation. The GLIMMIX procedure with specified data distribution was used for data that could not be normalized. For all repeated measures by year, compound symmetry and autoregressive covariance structures were evaluated, and the one with the lowest Akaike information criterion (AIC) score was selected. Fixed effects were treatment and year. For all analyses, site and all interactions with site were random effects in the error. For significant effects, Fisher's least significant differences were calculated using the least squares means for all mean separations.

For physiognomic plant groups the percent relative cover was calculated by 1) perennial, annual, and biennial species, and by 2) grass, forb, sedge, tree/shrub, and woody vines. To quantify the density of vegetation by height class, the 0.25-m intervals were grouped into three larger classes, 0-0.75 m, 0.75-1.50 m, and 1.50-2.25 m. Due to unusual data distributions or the descriptive nature of some research questions, statistical tests were not conducted for the afforementioned physiognomic plant groupings and foliar coverage by height class. Descriptive information by study area were calculated at the site level, whereas all other analyses were calculated at the quadrat level, and then averaged by site, treatment, and year.

To determine diversity of plant composition, Shannon-Wiener and Simpson's diversity indices were used as the response variable in the analyses. Indices were initially calculated for each quadrat, then averaged across each site, treatment, and year combination. The Shannon-Wiener function considers the uncertainty that exists in correctly predicting the next species encountered, provides a strong indication of community evenness, and puts greater emphasis on rare species (Krebs 1998). The maximum Shannon-Wiener value for a particular study area can be calculated by taking the $\log_n$ of the total species richness. Conversely, the Simpson's diversity index is the probability that two plants being picked at random will be of a different species, and is more sensitive to the common species (McCune and Grace 2002), and the maximum value is always 1.0. For each index, a higher number equals greater diversity. These indices were calculated using the following equations; where p_i is the relative cover belonging to the *i*-th species:

Shannon-Wiener index (H') = $-\Sigma\, p_i \log_{10} p_i$

Simpson's diversity index ($1 - D$) = $1 - \Sigma\, p_i^2$

Using data from the second growing season in 2007, rank-abundance curves were created to graphically describe the evenness of species distribution and relative abundance of dominant species within the plant community (Molles 1999, Kent and Coker 1992). The top ten species were ranked by their relative abundance for each site/treatment combination, and arithmetic means were calculated for each rank number across all sites by treatment to provide an average treatment value.

To examine the effect of treatments on exotic species abundance, the percent foliar cover of exotic species was used as the response variable in the analysis. Exotic foliar coverage was calculated for each quadrat, then averaged by site, treatment and year.

To assess and compare the quality of native Ozark bottomland vegetation, we used the floristic quality index developed by Wilhelm (1977) and Swink and Wilhelm (1979, 1994). Using this method, each plant species is assigned an integer from 0 to 10 based on its tolerance to disturbance and its fidelity to intact ecological communities (Taft et al. 1997). A coefficient of “0” indicates an exotic species or highly invasive native species while a coefficient of “10” denotes a species that is highly conservative and found only in very specific, undisturbed plant communities. These “coefficients of conservatism (C)” are generally described by a panel of regional botanical experts and were described by Ladd (1993) for the Missouri flora. The floristic quality index (FQI) uses the mean conservatism (which is the arithmetic mean of the C-values for all species occurring in sample area) multiplied by the square root of the total species richness of the sample area. Greater FQI's indicate a more intact native plant community. This method was originally developed for the Illinois Natural History Survey and used for prioritizing the designation and restoration of State Natural Areas, but has since been successfully adapted and tested in many regions, including Florida, Kansas, Michigan, Mississippi, Missouri, North Dakota, Ohio, Pennsylvania, Wisconsin and Ontario, Canada (Bourdaghs et al. 2006, Jog et al. 2006, Miller and Waldrop 2006, Herman 2005, Andreas et al. 2004, Cohen et al. 2004, Bernthal 2003, Mushet et al. 2002, Francis et al. 2000, Swink and Wilhelm 1994, Ladd 1993). FQI is particularly effective in comparing the flora of different locations and documenting change in plant communities over time, and therefore, is a useful quantitative index for use in ecological restoration. Further explanation of this method can be found in Taft et al. (1997). As a response variable in the analysis, FQI was calculated for each quadrat, then averaged by site, treatment and year.

Results

Overall, some 240 species were encountered through both years of data collection (Appendix A). Most were broad-leaved forbs and grasses, 45 of these were annuals, 169 were perennials, and nine were biennials. Although there were 46 different tree and shrub species, they were always a minute proportion of total plant cover, rarely totaling greater than five percent of an individual quadrat area. Of the 240 species found, 43 were non-native to the region.

Most data are presented by treatment through all sites. However, there were nominal differences occurring among these areas (Table 14). Trace Creek and St. Francis River had species richness values of 170 and 146, with 19 and 17 percent of these being exotic, respectively. Their FQI's were both near 30.0, and each had a slight increase when removing exotic species from the equation. Mean conservatism was 2.3 for Trace Creek and 2.4 for St. Francis River, with a similar small increase when accounting for exotics. The Roubidoux Creek site was considerably different than the other sites. Total species richness was 106 with 29 percent being exotic, FQI was 18.0 and increased to 22.1 when removing the exotics, and mean conservatism was 1.8 and increased to 2.6 without the exotics.

Table 14. Floristic comparison of study areas during July and August of 2006 and 2007, using site averages species richness, percent exotic, floristic quality index, and mean conservatism values.

Parameter	------------------------------------Site------------------------------------		
	Roubidoux Creek	St. Francis River	Trace Creek
Total Species Richness	106	146	170
Native Species Richness	75	121	137
Percent Exotic	29	17	19
Floristic Quality Index	18.0	29.6	30.0
Floristic Quality Index (natives only)	22.1	32.8	33.7
Mean Conservatism	1.8	2.5	2.3
Mean Conservatism (natives only)	2.6	3.0	2.9

Community Physiognomy and Structure

For the herbicide-only treatments during the first growing season, the Poast Plus® treatment had over a four-fold decrease in foliar coverage of grasses compared to the Roundup®-only treatment (Figure 8 and Table 15). Of the cover-crops, the redtop sod established well, obtaining a third of the coverage by the first year and half the coverage by the second year. The clover, a cool-season plant, did not become established as well as the redtop, comprising about a quarter of all vegetation the first year, and much less the following year. Finally, the Virginia wild rye germinated poorly during the first year and had very low coverage during year two. As expected, treatment differences for total foliar cover did occur during the first growing season following treatment establishment, but by the second growing season, competing vegetation densities were similar. In the first year, the Poast Plus® treatment was significantly lower in total foliar coverage than all treatments, with the exception of clover, which also had reletively low coverages. Amount of competing vegetation was similar among the Roundup®-only, rye, and redtop treatments for both years.

For foliar coverage of vegetation by height class, there appear to be differences in the first year, but not the second, which is similar to the above results (Figure 9). Specifically, in year one the Poast Plus® treatment had shorter vertical competition in comparison to the Roundup®-only treatment, where vegetation often exceeded two meters in height. All other comparisons by treatment and year appeared to be similar.

In both years, the majority of foliar cover consisted of perennials for the herbicide-only and redtop treatments (Figure 10). Annual species were more common in the clover and rye treatments, and biennials were always substantially fewer than annuals and perennials. In general, perennial vegetation cover was more prevalent the second year than the first.

With the exception of the redtop treatment, broad-leaved forbs always provided the most cover (Figure 11). As previously noted, grasses were more common in the Roundup®-only and redtop treatment in comparison to the others. Woody vines had substantially higher coverage in the herbicide-only treatments. Finally, trees, shrubs and sedges were basically lacking throughout.

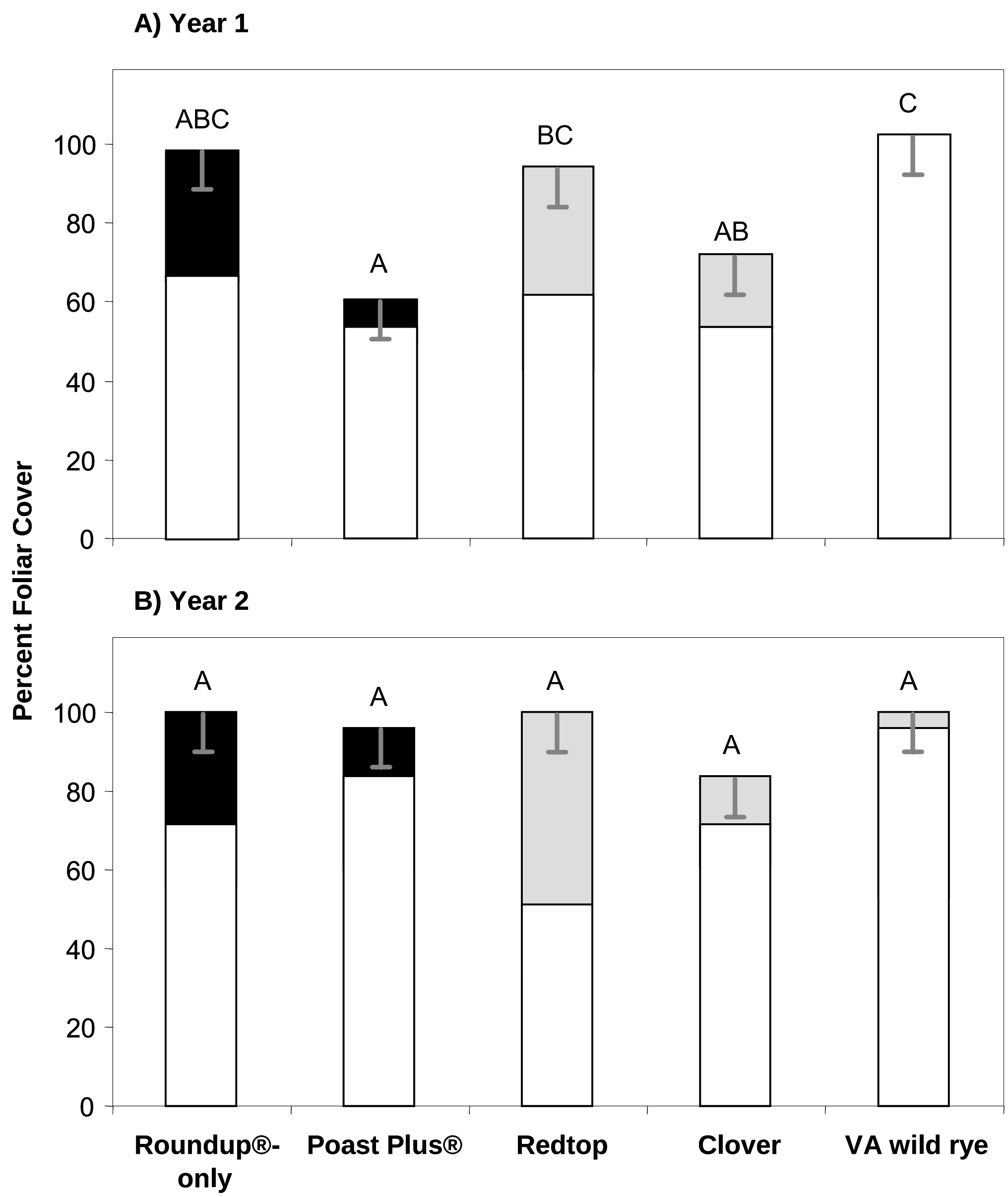

Figure 8. Mean ground flora foliar coverage with standard error bars by treatment, for A) the first growing season and B) the second growing season. Filled portion of the bars indicates the proportion of “target” vegetation for each treatment relative to resident vegetation. Grayed portions of bars show the percentage of cover-crops, while blackened portions show the percentage of grass species for the herbicide-only treatments. Letters indicate significant differences among treatments (α = 0.05).

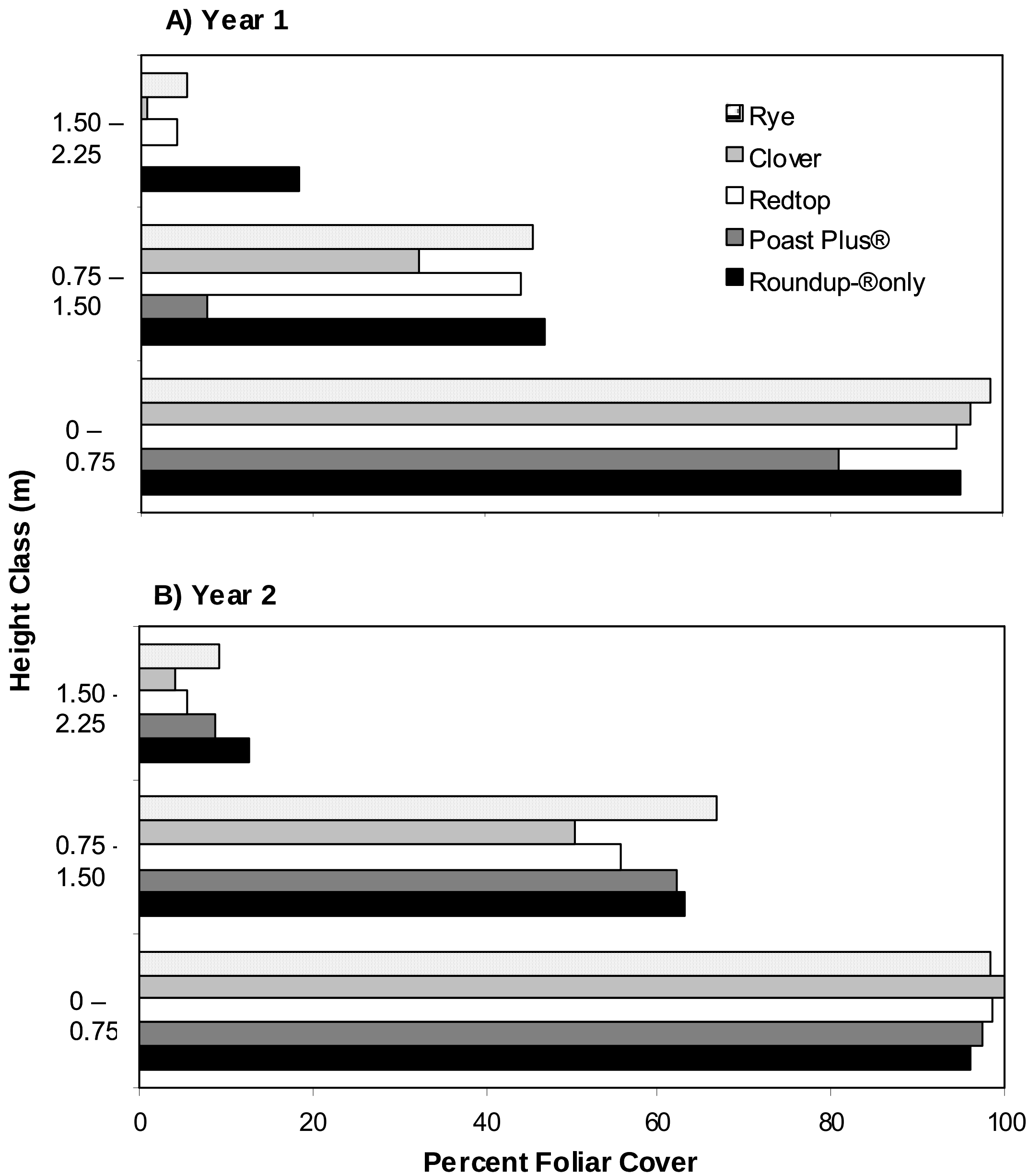

Figure 9. Foliar coverage by treatment of all competing vegetation at three 0.75 m vertical strata for A) the first growing season and B) the second growing season following establishment.

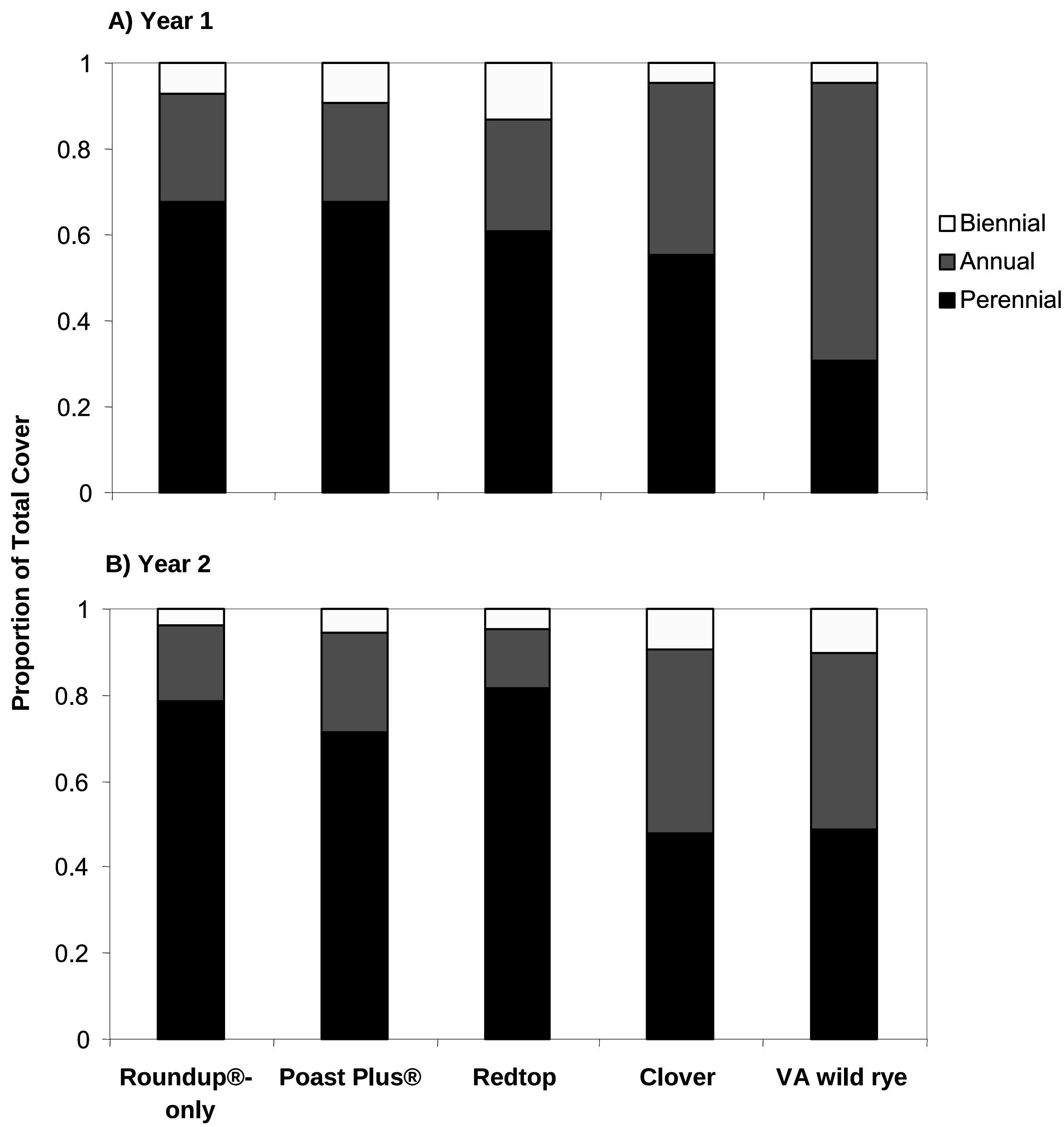

Figure 10. Proportion of total foliar coverage by plant reproductive strategies, comparing annual vs. perennial vs. biennial/unknown for A) the first growing season and B) the second growing season.

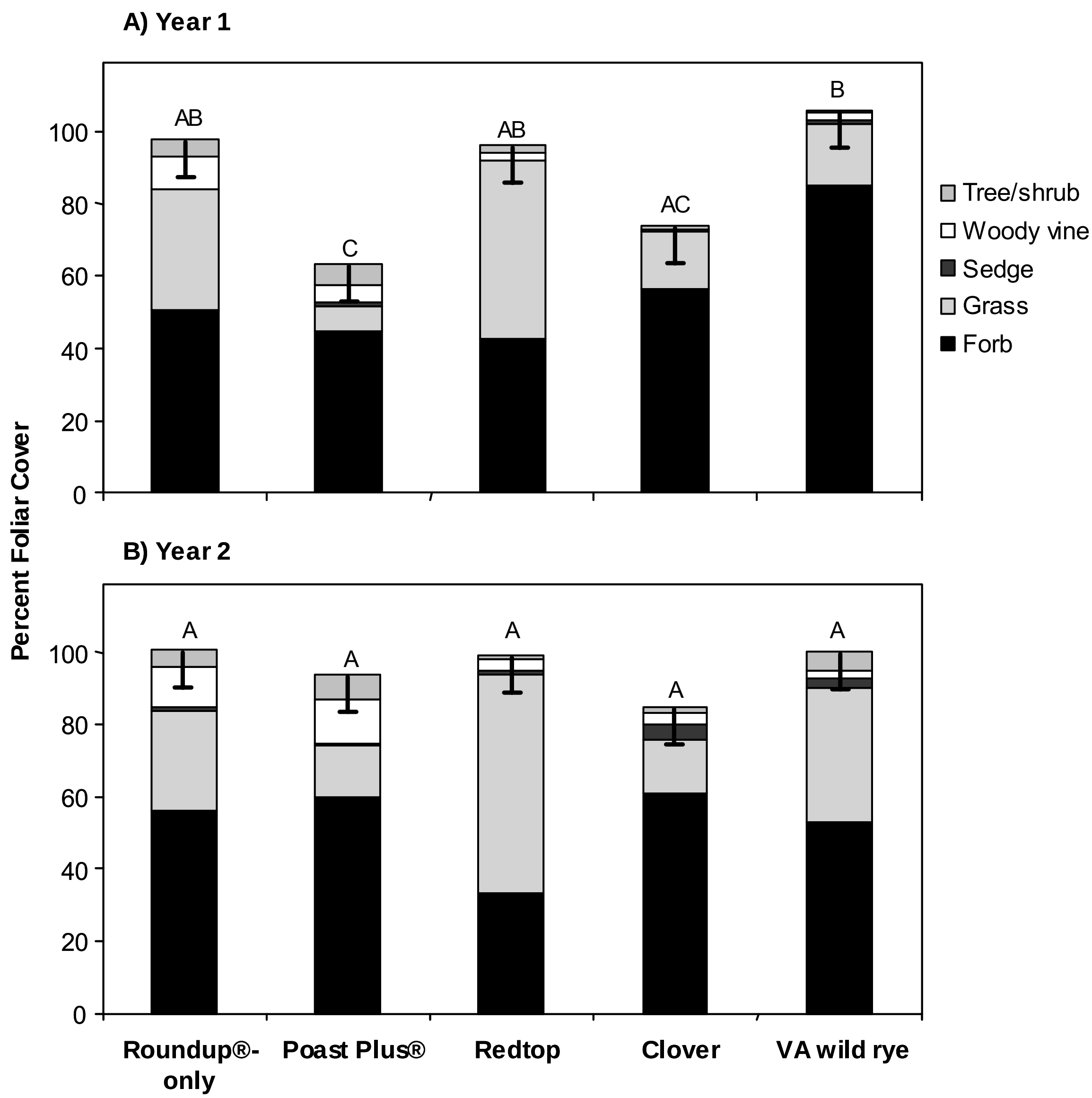

Figure 11. Proportion of total foliar coverage with standard error bars separated by physiognomic taxa group, for A) the first growing season and B) the second growing season. Letters above bars indicate statistical differences using Fisher's least significant difference for mean separations (α = 0.05).

Table 15. Analysis of variance relating treatment and year to total foliar coverage.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	8	1.45	0.3037
Year	1	2	1.00	0.4224
Year * Treatment	4	8	6.96	0.0102

Community Diversity

There were no statistical differences in the Shannon-Wiener index by treatment, year, or treatment by year (Tables 16 and 18). Treatments ranged from 0.52 for the redtop in year two, to 0.80 for Poast Plus®, also in year two. Most Shannon-Wiener values were nearly identical between years and maximum values were all near 2.00. For the Simpson's diversity index, there were only nominal treatment and year differences, with the herbicide-only treatments recording greater values than the cover-crops, and year 1 being greater than year 2 (Tables 17 and 18). However, there was a significant treatment by year interaction. By year two, the Simpson's index for redtop was significantly lower than in year one. In addition, by the second year, redtop was less diverse than clover and both herbicide-only treatments.

Table 16. Shannon-Wiener diversity indices with standard error (SE) by treatment and year. Uppercase letters indicate differences between years and lowercase letters indicate differences among treatments (α = 0.05).

Treatment Type	Treatment	Shannon-Wiener Index ----------year 1------------		----------year 2------------	
		H' ± SE	H'_{max}	H' ± SE	H'_{max}
Herbicide-only	Roundup®-only	0.78 ± 0.07 A a	2.03	0.75 ± 0.07 A a	2.08
	Poast Plus®	0.75 ± 0.07 A a	2.00	0.80 ± 0.07 A a	2.10
Cover-crops	Redtop	0.71 ± 0.07 A a	2.01	0.52 ± 0.07 A a	2.00
	Clover	0.71 ± 0.07 A a	1.97	0.73 ± 0.07 A a	2.11
	VA wild rye	0.65 ± 0.07 A a	2.17	0.65 ± 0.07 A a	2.06
	All	0.72 ± 0.04 A	2.25	0.69 ± 0.04 A	2.30

Table 17. Simpson's diversity indices with standard error (SE) by treatment and year. Uppercase letters indicate differences between years and lowercase letters indicate differences among treatments (α = 0.05).

Treatment Type	Treatment	Simpson's Diversity Index ± SE ---------------------year----------------------	
		1	2
Herbicide-only	Roundup®-only	0.74 ± 0.04 A a	0.73 ± 0.05 A a
	Poast Plus®	0.73 ± 0.04 A a	0.76 ± 0.05 A a
Cover-crops	Redtop	0.69 ± 0.04 A a	0.50 ± 0.06 B b
	Clover	0.70 ± 0.04 A a	0.70 ± 0.05 A a
	VA wild rye	0.67 ± 0.04 A a	0.65 ± 0.06 A ab
	All	0.71 ± 0.03 A	0.67 ± 0.03 A

Table 18. Analysis of variance relating treatment and year to the Shannon-Wiener and Simpson's Diversity Indices for the ground flora.

Effect	Num DF	Den DF	F Value	Pr > F
Shannon-Wiener Index:				
Treatment	4	8	1.42	0.3103
Year	1	10	0.98	0.3453
Year * Treatment	4	10	2.06	0.1619
Simpson's Diversity Index:				
Treatment	4	13	2.76	0.0724
Year	1	20	3.33	0.0830
Year * Treatment	4	20	4.47	0.0096

For the second-year data, the rank-abundance curves show the redtop treatment having the steepest initial slopes, indicating a lack of community evenness (Figure 12). The Poast Plus® and Roundup®-only treatments had the most even curves, while the clover and rye treatments were intermediate.

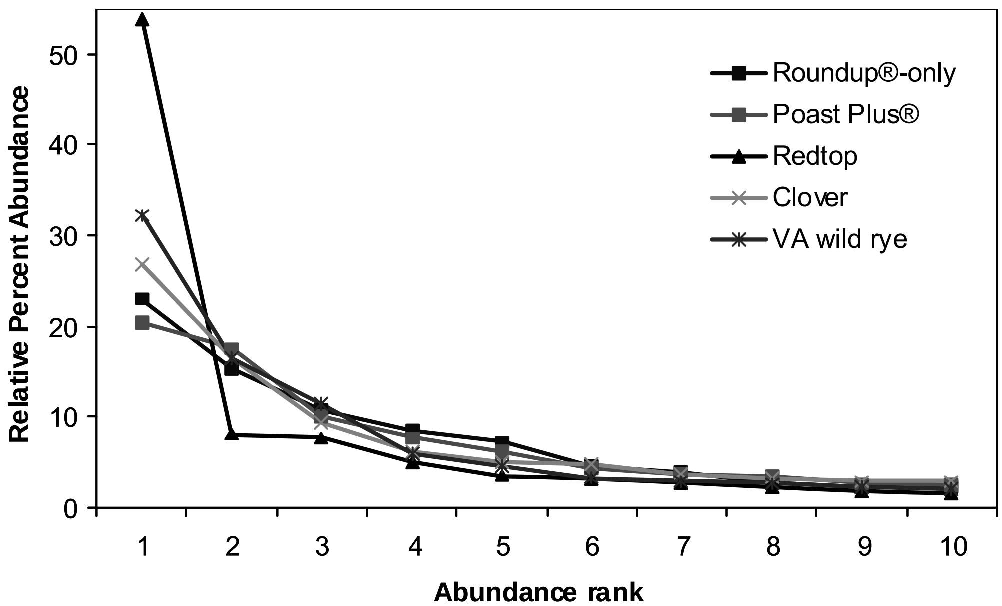

Figure 12. The ten highest ranking species at each site and treatment averaged together, with each line being an overall rank-abundance curve for each vegetation management treatment.

Exotic Species Abundance

Percent cover of exotic species was similar in year one but changed in year two (Figure 13 and Table 19). There was no overall treatment or year effect, but there was a significant treatment by year interaction. Both the redtop and rye cover-crops were different among years, with redtop having less exotic cover (25 to 11 percent), and rye having more exotic cover (15 to 43 percent) by the second year. Similarly, in year two, the rye cover-crop had significantly more exotic cover than the redtop. All other treatments were similar. However, it is noteworthy that in the first year following treatment establishment, the herbicide application targeted for the exotic grasses (Poast Plus®) had 15 percent fewer exotic species cover than the Roundup®-only.

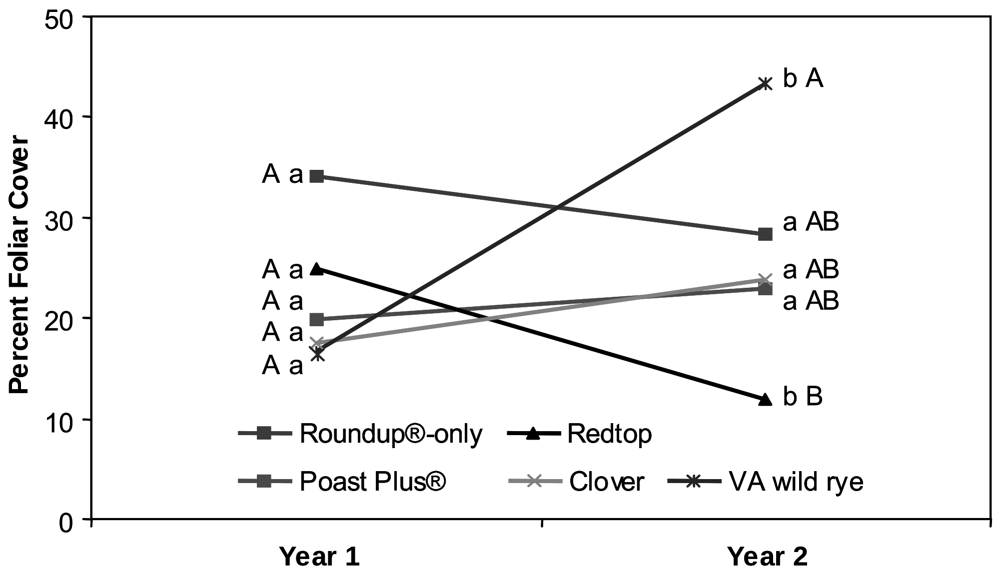

Figure 13. Percent of total foliar coverage for exotic species. Letters indicate significant differences within years, asterisks (*) indicate differences among years ($\alpha = 0.05$).

Table 19. Analysis of variance relating treatment and year to foliar coverage.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	8	0.84	0.5375
Year	1	10	0.83	0.3836
Year * Treatment	4	10	4.60	0.0243

Floristic Quality

Floristic quality indices differed by treatment and year, and there was no treatment by year interaction (Tables 20 and 21). In both years, the Poast Plus® treatment was higher than all the cover-crops, and Roundup®-only was higher than all the cover-crops with the exception of clover. Overall, year one was significantly greater than year two and although there was no interaction, all treatments nominally had greater FQI's following the second year.

Table 20. Floristic quality index and standard error (SE) by treatment and year. Uppercase letters indicate differences between years and lowercase letters indicate differences among treatments.

Treatment Type	Treatment	Floristic Quality Index ± SE ---year--- 1	 2
Herbicide-only	Roundup®-only	5.05 ± 0.93 A ab	5.55 ± 1.29 A ab
	Poast Plus®	5.01 ± 0.91 A a	5.70 ± 1.29 A a
Cover-crop	Redtop	3.30 ± 0.94 A c	4.02 ± 1.21 A c
	Clover	3.85 ± 0.93 A bc	4.69 ± 1.23 A bc
	VA wild rye	3.44 ± 1.03 A c	4.68 ± 0.00 A c
	All	4.13 ± 0.93 A	4.93 ± 0.93 B

Table 21. Analysis of variance relating treatment and year to floristic quality index.

Effect	Num DF	Den DF	F Value	Pr > F
Treatment	4	9	5.26	0.0201
Year	1	10	7.89	0.0185
Year * Treatment	3	10	0.81	0.5158

Discussion

Early stages of afforestation projects are important, and will ultimately affect restoration success. Even within the first growing season, there can be significant differences in seedling growth depending on the type of vegetation management conducted. Steele et al. (2008) found that well-established redtop and clover cover-crops provided good survival and notably better shoot growth of newly planted seedlings compared to herbicide-only treatments (Table 22). However, in addition to seedling survival and growth, such afforestation projects often include additional resource management objectives, such as restoration of the native ground flora.

Table 22. First-year seedling survival and shoot growth of thirteen bottomland species planted at three bottomland sites in the Missouri Ozarks, adapted from Steele et al. (2008). Letters indicate significant differences among treatments ($\alpha = 0.05$).

Treatment Type	Treatment	Survival (%)	Shoot Growth (cm)
Herbicide-only	Roundup®-only	86 ab	3.9 a
	Poast Plus®	89 a	5.0 ab
Cover-crop	Redtop	91 a	9.7 c
	Clover	88 ab	8.7 c
	VA wild rye	83 b	7.7 bc

The data presented in this study provide a good indication of the type of plant community composition and structure to be expected in the early stages of an afforestation project. Unless annual vegetation management is conducted after the initial year, similar densities of vegetation will likely capture the site regardless of management conducted in previous years. In general, the majority of the vegetation cover was perennial forbs and grasses, with very little sedges or woody vegetation. At all sites, the tall fescue was virtually eliminated with the Roundup® site preparation. Without the successful control of this species, it is likely that the ground flora would have suffered.

Floristic composition differed considerably among sites. Although each site is located in different ecological subsections, the Trace Creek and St. Francis River sites are only 50 km apart and had similar vegetation. Conversely, Roubidoux Creek is located greater than 160 km from the other sites in a more commercially-developed watershed and had a very different flora, recording more exotics, lower species richness, lower FQI, and lower mean conservatism. These differences likely reflect a combination of varying site histories (e.g., length of cultivation, intensity of agricultural management, amount of soil erosion, etc.), differences in adjoining habitat characteristics, biological legacies, and overall watershed characteristics (e.g., prevalence of flooding, development within watershed). Therefore, in addition to basic objectives, vegetation management decisions should strongly consider locational differences in the condition of the ground flora.

Native species richness was surprisingly high considering that the study sites are old fields. In comparison, a similar study located at two Missouri River bottomland sites in central Missouri, Dey et al. (2001) found only 101 species, over half of which were exotics. Regardless of the degraded nature of these old fields, with the exception of redtop, Shannon-Wiener and Simpson's diversity indices for this study indicate a relatively diverse distribution of ground flora composition. Unfortunately, there is little additional published material for comparison of these indices in bottomland afforestation sites.

The prescribed treatments varied greatly in their establishment success. With very little work, the redtop sod was established well at two of the three sites. This was consistent with our expectations based upon other published work using redtop in bottomland tree plantings in Missouri (Dey et al. 2004). In addition, our data show that redtop can effectively compete with noxious exotic species, such as sericea lespedeza (*Lespedeza cuneata* (Dumont) G. Don), tall fescue, and Johnson grass (*Sorghum halepense* (L.) Pers.), and does not greatly suppress tree growth. Redtop grass also provides an advantage to managers in that it can be easily removed following tree canopy establishment. However, redtop also reduces the diversity of resident ground flora, persistence of native vegetation, natural tree regeneration, and lowers overall floristic quality.

The large white clover germinated uniformly at all sites and often responded similarly to the redtop. However, it seemed to quickly lose vigor at the first sign of summer droughts, a common occurrence in southern Missouri. In addition, white clover is a cool-season plant, and it may have been underrepresented in our data due to the time-of-year botany data were collected (i.e., mid-summer). In comparison to redtop, a stand of clover requires more maintenance and will likely only last a few years before re-planting may become necessary (Van Sambeek et al. 2007, Van Sambeek et al. 2003). Stevenson and Laidlaw (1985) also found that droughty conditions adversely affect development and persistence of stands of white clover, which suggests that using this species may not be suited to many Ozark bottomlands. As a result, the use of clover may not be feasible for some managers that cannot afford the time and effort for maintenance of a cover-crop. Regardless, white clover has been used with success in many other Midwestern tree plantings and has the added benefit of being a nitrogen-fixing plant, and thus, can improve soil nutrient conditions for seedling success (Van Sambeek et al. 2003, Smith and Valenzuela 2002, Pederson 1995).

The Virginia wild rye established poorly at all sites, which resulted in elevated competing vegetation coverage consisting of a nearly all resident, old-field vegetation. Additionally, nearly half of all competing vegetation was from exotic species and by the second year, this treatment had low FQI. The exact reasoning of this failure is unknown, but likely contributors include poor planting methodology (e.g., burying seed), poor seed quality, or inadequate seed source. Nevertheless, several managers in Missouri have verbally reported successful establishment of Virginia wild rye in tree plantings, although its effect on the establishment and growth of trees remains relatively unstudied.

Lastly, for the herbicide-only treatments, levels of competing vegetation were significantly lower using Poast Plus® during the first year. Not only were grass species (most of which were exotic) nearly four times lower in the Poast Plus® treatment, but competing vegetation was shorter and total foliar coverage were lower as well. By the second year, grass coverage doubled in the Poast Plus® treatments (but remained half that of Roundup®-only) and there were no differences in total foliar cover. This periodic effect suggests that in order to control competing vegetation with herbicides, management should occur in subsequent growing seasons. Overall, selectively removing unwanted vegetation with herbicides may result in a more diverse ground flora with greater community evenness, can remove noxious weeds, and depending on site characteristics, can sustain a greater diversity of native bottomland flora.

Conclusions

It is becoming increasingly common for foresters and other land managers to manage resources with more of an ecosystem perspective (Gilliam 2007) that includes multiple resource management objectives. Accordingly, goals often include the desire to conserve, restore, and manage for a variety of biota and ecosystem processes within a management area (Ehrenfeld and Toth 1997). An understanding of the ground flora can help accomplish these multiple-use objectives. For example, in highly degraded areas that have lost most native bottomland species and have a preponderance of exotics, it might be preferred to manage the initial stages of a tree planting with a cover-crop, until light conditions provided by the canopy provide a better condition for the restoration of bottomland forest ground flora. Conversely, where there is a high likelihood of native vegetation recovery, it may be advantageous to not disturb soil conditions and selectively remove unwanted vegetation with herbicides.

The plant communities studied here are in an early-successional state, and are comprised mainly of native ruderal species. Consequently, indices comparing vegetation in these restoration plantings are low relative to intact natural communities. However, some of the species that are persisting, although at a low density, can be considered biological legacies of regional natural communities, and represent real conservation value. By using herbicides to remove fescue, and subsequent management of other unwanted weeds, desirable native species may likely be secured. However, if there is a likelihood of successive outbreaks of noxious invasives and their subsequent spread, land managers may want to consider the use of a perennial cover-crop like redtop which can be easily established, all while providing optimal tree growth.

CHAPTER IV

BALANCING VARYING LAND MANAGEMENT OBJECTIVES

Due to the historic large-scale degradation of floodplains in Missouri, restoration and management of riparian corridors is a top conservation priority throughout the region. Land managers actively working improve riparian management are from both the public and private sector. Examples of stakeholders include local communities, farmers, outdoor enthusiasts, wastewater specialists, conservation organizations, and many state and federal agencies. Although each of these stakeholders have vested interests that vary widely, the one remaining constant is that stream systems and their watersheds do not stop at jurisdictional boundaries and are equally important to all individuals.

Similar to the diverse array of publics having interest in the conservation of floodplains, there is also variation in those charged with their management. In Missouri, managers can include private landowners, the Missouri Department of Conservation, Natural Resources Conservation Service, USDA Forest Service, US Fish and Wildlife Service, National Park Service, Army Corps of Engineers, The Nature Conservancy, and Ducks Unlimited, among others. This variety of land managers can result in very different specific management goals and objectives. Some examples may include: commercial timber production, wildlife habitat management, wildlife food production, restoration of native ecosystems, improvement of floodwater storage, nutrient filtration and water quality, restriction of soil erosion, control of streambank erosion, improvement of aquatic habitat, and provision of safe and sustainable grazing practices for cattle.

To accomplish these goals in bottomlands, one of the most common techniques used is the planting of native hardwood tree species suitable to the site conditions of particular floodplains, and managing vegetation in a way that promotes seedling survival and growth. Unfortunately, there has been very little research or documented successes we can rely on to conduct this work. In addition, many stakeholders, especially private landowners, may not have the money, training, or tools available to successfully restore bottomland hardwoods. Therefore, it is important for researchers and managers to work to together to identify and solve these problems so that management guidelines can be developed for this work to be successful.

It was the original goal of this research to begin to answer questions that pertain to a variety of multiple-use objectives. Of the various vegetation management treatments, it was found that successful establishment of a cover-crop of white clover or redtop grass only nominally promoted better seedling growth compared to using herbicides only, and that these treatments had little influence on seedling survival. Competing vegetation densities were not greatly affected by vegetation management treatment type and all that were evaluated here appeared to provide sufficient light conditions for optimal growth of most species. According to the results of this study, tree species selection was the most important determinant of initial plantation success. For the prescribed management treatments in this study, natural tree regeneration was adequate only in herbicide-only treatments, and decreased rapidly with distance from the adjacent intact forest edge. In addition, natural regeneration only occurred for the light-seeded species that had seed sources directly adjacent to the particular planting site; and regeneration of hardmast and softmast species was limited. Composition and diversity of ground flora differed considerably among sites which strongly influenced restoration potential. Regardless of these initial site conditions, the herbicide-only treatments promoted greater ground flora diversity and richness, and promoted more native bottomland species than did the cover-crop treatments. However, successful establishment of a cover-crop significantly reduced the amount of exotic plant cover, which can be a major concern in these highly degraded ecosystems. Overall, many of the herbaceous species found were native bottomland forbs and grasses, some of which are quite conservative. Although most of these species did not persist in great number, they are legacies of native Ozark bottomland forests, and represent an indication that restoration of these once vast ecosystems may be attainable.

Regardless of varying land management objectives, all managers have goals of promoting sustainable land management, preventing excess soil runoff, improving the quality of our water, and providing a sustainable future for Missouri's plants, wildlife, and people. It is likely that results reported here will change in coming years. However, as a final note, it is important to remember that initial stages of this type of restoration effort can have important long-term consequences for the growth and development of riparian forests.

CHAPTER V

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Appendix A. Plant species encountered at three riparian afforestation sites in the Missouri Ozarks. C = Coefficient of Conservatism (Ladd 1993), N = native, E = exotic, U = unknown, A = annual, P = perennial, B = biennial, wvine = woody vine, hvine = herbaceous vine. Latin nomenclature is from Yatskievych (1999, 2006) or Steyermark (1963).

Scientific Name	Common Name	Family	C	Physiognomy		
Acalypha virginica L.	Virginia copperleaf	Euphorbiaceae	2	N	A	FORB
Acer negundo L.	box elder	Aceraceae	1	N	P	TREE
Acer rubrum L.	red maple	Aceraceae	6	N	P	TREE
Acer saccharinum L.	silver maple	Aceraceae	1	N	P	TREE
Acer saccharum Marshall	sugar maple	Aceraceae	5	N	P	TREE
Achillea millefolium L.	common yarrow	Asteraceae	4	N	P	FORB
Agertina altissima (L.) R.M. King & H. Rob.	white snakeroot	Asteraceae	2	N	P	FORB
Agrostis gigantea Roth	redtop	Poaceae	0	E	P	GRASS
Agrostis hyemalis (Walter) Britton, Sterns & Poggenb.	hairgrass	Poaceae	3	N	P	GRASS
Allium vineale L.	field garlic	Liliaceae	0	E	P	FORB
Ambrosia artemisiifolia L.	common ragweed	Asteraceae	0	N	A	FORB
Ambrosia bidentata Michx.	southern ragweed	Asteraceae	0	N	A	FORB
Ambrosia trifida L.	giant ragweed	Asteraceae	0	N	A	FORB
Ampelopsis cordata Michx.	raccoon grape	Vitaceae	4	N	P	WVINE
Amphicarpa bracteata (L.) Fern.	hog peanut	Fabaceae	4	N	P	HVINE
Andropogon gerardii Vitman	big bluestem	Poaceae	5	N	P	GRASS
Andropogon virginicus L.	broomsedge	Poaceae	2	N	P	GRASS
Apocynum cannabinum L.	Indian hemp	Apocynaceae	3	N	P	FORB
Asclepias syriaca L.	common milkweed	Asclepiadaceae	0	N	P	FORB
Avena fatua L. var. *sativa* (L.) Hausskn.	oats	Poaceae	0	E	A	GRASS
Barbarea vulgaris R. Br.	yellow rocket	Brassicaceae	0	E	P	FORB
Bidens frondosa L.	beggar-ticks	Asteraceae	2	N	A	FORB
Bidens aristosa (Michx.) Britton	tickseed sunflower	Asteraceae	1	N	A/B	FORB
Blephilia ciliata (L.) Benth. f.	Ohio horse mint	Lamiaceae	5	N	P	FORB
Brassica nigra (L.) W.D.J. Koch	black mustard	Brassicaceae	0	E	A	FORB
Bromus secalinus L.	rye brome	Poaceae	0	E	A	GRASS

Scientific Name	Common Name	Family	C	Physiognomy		
Bromus sp. L.	brome	Poaceae	*	E	A	GRASS
Calystegia sepium (L.) R. Br.	hedge bindweed	Convolvulaceae	1	N	P	HVINE
Campanula americana L.	tall bellflower	Campanulaceae	4	N	A	FORB
Campsis radicans (L.) Seem.	trumpet creeper	Bignoniaceae	3	N	P	WVINE
Carduus nutans L.	musk thistle	Asteraceae	0	E	B	FORB
Carex amphibola Steud.	gray sedge	Cyperaceae	3	N	P	SEDGE
Carex frankii Kunth	Frank's sedge	Cyperaceae	5	N	P	SEDGE
Carex glaucodea Tuck.	blue sedge	Cyperaceae	4	N	P	SEDGE
Carex spp. L.	sedge	Cyperaceae	*	N	P	SEDGE
Carpinus caroliniana Walter	musclewood	Betulaceae	6	N	A	TREE
Carya illinoensis (Wang.) K. Koch	pecan	Juglandaceae	6	N	P	TREE
Carya laciniosa (Michx.) Loud.	shellbark hickory	Juglandaceae	6	N	P	TREE
Carya spp. Nutt.	hickory	Juglandaceae	*	N	P	TREE
Celtis occidentalis L.	hackberry	Ulmaceae	4	N	P	TREE
Cercis canadensis L.	eastern redbud	Fabaceae	3	N	P	TREE
Chamaecrista nictitans (L.) Moench	small partridge pea	Fabaceae	2	N	A	FORB
Chasmanthium latifolium (Michx.) H.O.	river oats	Poaceae	4	N	P	GRASS
Chenopodium album L.	lamb's quarters	Chenopodiaceae	0	E	A	FORB
Cirsium altissimum (L.) Spreng.	tall thistle	Asteraceae	4	N	B/P	FORB
Cirsium discolor (Muhl. ex Willd.) Spreng.	field thistle	Asteraceae	3	N	B/P	FORB
Commelina erecta L.	day-flower	Commelinaceae	4	N	P	FORB
Conium maculatum L.	poison hemlock	Apiaceae	0	E	B	FORB
Conoclinium coelestinum (L.) DC.	mist-flower	Asteraceae	4	N	P	FORB
Conyza canadensis (L.) Cronquist	horseweed	Asteraceae	0	N	A	FORB
Coreopsis pubescens Elliot	star tickseed	Asteraceae	5	N	P	FORB
Coronilla varia L.	crown vetch	Fabaceae	0	E	P	FORB
Croton capitatus Michx.	wooly croton	Euphorbiaceae	0	N	A	FORB
Croton glandulosus L.	sand croton	Euphorbiaceae	1	N	A	FORB
Croton monanthogynus Michx.	one-seeded croton	Euphorbiaceae	2	N	A	FORB
Cuscuta spp. L.	dodder	Convolvulaceae	*	N	A	FORB
Cyperus echinatus (L.) A.W. Wood	globe flatsedge	Cyperaceae	3	N	P	SEDGE

Scientific Name	Common Name	Family	C	Physiognomy		
Cyperus spp. L.	umbrella sedge	Cyperaceae	*	N	U	SEDGE
Cyperus strigosus L.	false nutgrass	Cyperaceae	1	N	P	SEDGE
Dactylis glomerata L.	orchard grass	Poaceae	0	E	P	GRASS
Daucus carota L.	Queen Anne's lace	Apiaceae	0	E	B	FORB
Desmodium canescens (L.) DC. f.	hoary tick trefoil	Fabaceae	3	N	P	FORB
Desmodium laevigatum (Nutt.) DC.	smooth tick trefoil	Fabaceae	7	N	P	FORB
Desmodium paniculatum (L.) DC.	panicled tick trefoil	Fabaceae	3	N	P	FORB
Dianthus armeria L.	Deptford pink	Caryophyllaceae	0	E	A/B	FORB
Digitaria ischaemum (Shreb.) Schreb. ex Muhl.	smooth crab grass	Poaceae	0	E	A	GRASS
Digitaria sanguinalis (L.) Scop.	hairy crab grass	Poaceae	0	E	P	GRASS
Diodia teres Walt.	rough buttonweed	Rubiaceae	2	N	A	FORB
Diodia virginiana L.	large buttonweed	Rubiaceae	5	N	P	FORB
Dioscorea villosa L.	wild yam	Dioscoreaceae	5	N	P	HVINE
Diospyros virginiana L.	persimmon	Ebenaceae	3	N	P	TREE
Elaeagnus umbellata Thunb.	autumn olive	Elaeagnaceae	0	E	P	SHRUB
Elephantopus carolinianus Raeusch.	elephant's foot	Asteraceae	3	N	P	FORB
Elymus virginicus L.	Virginia wild rye	Poaceae	4	N	P	GRASS
Erechtites hieracifolius (L.) Raf. ex DC.	fireweed	Asteraceae	2	N	A	FORB
Erigeron annuus (L.) Pers.	daisy fleabane	Asteraceae	1	N	A	FORB
Eupatorium altissimum L.	tall boneset	Asteraceae	3	N	P	FORB
Eupatorium perfoliatum L.	common boneset	Asteraceae	5	N	P	FORB
Eupatorium serotinum Michx.	late boneset	Asteraceae	1	N	P	FORB
Eupatorium spp. L.	boneset	Asteraceae	*	N	P	FORB
Euphorbia corollata L.	flowering spurge	Euphorbiaceae	3	N	P	FORB
Euphorbia cyathophora Murray	painted spurge	Euphorbiaceae	4	N	A	FORB
Euphorbia dentata Michx.	toothed spurge	Euphorbiaceae	0	N	A	FORB
Euphorbia maculata L.	prostrate spurge	Euphorbiaceae	0	N	A	FORB
Euphorbia spp. L.	spurge	Euphorbiaceae	*	N	U	FORB
Festuca arundinacea Schreb.	tall fescue	Poaceae	0	E	P	GRASS
Fraxinus americana L. var. *americana*	white ash	Oleaceae	3	N	P	TREE
Fraxinus pennsylvanica var. *subintegerrima* (Vahl.) Fern.	green ash	Oleaceae	2	N	P	TREE

Scientific Name	Common Name	Family	C	Physiognomy		
Froelichia gracilis (Hook.) Moq.	small cottonweed	Amaranthaceae	3	N	A	FORB
Galium concinnum T. & G.	shining bedstraw	Rubiaceae	4	N	P	FORB
Galium obtusum Bigel.	wild madder	Rubiaceae	5	N	P	FORB
Galium spp. L.	bedstraw	Rubiaceae	*	N	U	FORB
Galium triflorum Michx.	sweet-scented bedstraw	Rubiaceae	4	N	P	FORB
Geum canadense Jacq.	white avens	Rosaceae	2	N	P	FORB
Gleditsia triacanthos L.	honey locust	Fabaceae	2	N	P	TREE
Glycine max (L.) Merr.	soy bean	Fabaceae	0	E	A	FORB
Helenium autumnale L.	sneezeweed	Asteraceae	5	N	P	FORB
Helenium flexuosum Raf.	purple sneezeweed	Asteraceae	3	N	P	FORB
Helianthus grosseserratus M. Martens	sawtooth sunflower	Asteraceae	4	N	P	FORB
Helianthus hirsutus Raf.	bristly sunflower	Asteraceae	4	N	P	FORB
Hypericum mutilum L.	dwarf St. John's wort	Clusiaceae	4	N	P	FORB
Hypericum punctatum Lam.	spotted St. John's wort	Clusiaceae	3	N	P	FORB
Ipomoea hederacea Jacq.	red morning-glory	Convolvulaceae	0	E	A	FORB
Ipomoea pandurata (L.) G. Mey.	wild potato vine	Convolvulaceae	2	N	P	HVINE
Iva annua L.	marsh elder	Asteraceae	0	N	A	FORB
Juglans nigra L.	black walnut	Juglandaceae	4	N	P	TREE
Juncus tenuis Willd.	path rush	Juncaceae	0	N	P	FORB
Justicia americana (L.) Vahl	water willow	Acanthaceae	5	N	P	FORB
Kummerowia stipulacea [Maxim.] Makino	Korean lespedeza	Fabaceae	0	E	A	FORB
Lactuca sp. L.	wild lettuce	Asteraceae	*	U	U	U
Leersia virginica Willd.	white grass	Poaceae	4	N	P	GRASS
Lepidium virginicum L.	pepper grass	Brassicaceae	0	N	A/B	FORB
Lespedeza cuneata (Dumont) G. Don	sericea lespedeza	Fabaceae	0	E	P	FORB
Lespedeza striata (Thunb.) H. & A.	Japanese lespedeza	Fabaceae	0	E	A	FORB
Leucanthemum vulgare Lam.	ox-eye daisy	Asteraceae	0	E	P	FORB
Lippia lanceolata Michx.	fog fruit	Verbenaceae	3	N	P	FORB
Liquidambar stryraciflua L.	sweet gum	Hamamelidaceae	6	N	P	TREE
Lobelia inflata L.	Indian tobacco	Campanulaceae	3	N	A	FORB
Lonicera japonica Thunb. ex Murray	Japanese honeysuckle	Caprifoliaceae	0	E	P	WVINE

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Ludwigia alternifolia L.	seedbox	Onagraceae	4	N	P	FORB
Medicago lupulina L.	black medic	Fabaceae	0	E	A	FORB
Melilotus sp. Mill.	sweet clover	Fabaceae	*	E	B	FORB
Mirabilis nyctaginea (Michx.) Mac M.	wild four-o'clock	Nyctaginaceae	0	N	P	FORB
Morus rubra L.	red mulberry	Moraceae	4	N	P	TREE
Muhlenbergia schreberi J.F. Gmel.	nimblewill	Poaceae	0	N	P	GRASS
Oenothera biennis L.	evening primrose	Onagraceae	0	N	B	FORB
Oenothera laciniata Hill	rgd. evening primrose	Onagraceae	1	N	A	FORB
Oxalis stricta L.	yellow wood sorrel	Oxalidaceae	0	N	P	FORB
Panicum acuminatum Sw.	panic grass	Poaceae	3	N	P	GRASS
Panicum boscii Poir.	Bosc's panic grass	Poaceae	5	N	P	GRASS
Panicum clandestinum L.	deer tongue grass	Poaceae	4	N	P	GRASS
Panicum dichotomum L.	forked panic grass	Poaceae	6	N	P	GRASS
Panicum rigidulum Bosc ex Nees	redtop panic grass	Poaceae	3	N	P	GRASS
Panicum spp. L.	panic grass	Poaceae	*	N	P	GRASS
Panicum virgatum L.	switch grass	Poaceae	4	N	P	GRASS
Parthenocissus quinquefolia (L.) Planch.	Virginia creeper	Vitaceae	3	N	P	WVINE
Paspalum laeve Michx.	field paspalum	Poaceae	2	N	P	GRASS
Paspalum setaceum Michx. var. *muhlenbergii* (Nash) D.J. Banks	hairy lens grass	Poaceae	3	N	P	GRASS
Perilla frutescens (L.) Britt.	beafsteak plant	Lamiaceae	0	E	A	FORB
Physalis heterophylla Nees	clammy ground cherry	Solanaceae	3	N	P	FORB
Physalis longifolia Nutt.	ground cherry	Solanaceae	2	N	P	FORB
Physalis pubescens L.	downy ground cherry	Solanaceae	4	N	A	FORB
Phytolacca americana L.	pokeweed	Phytolaccaceae	2	N	P	FORB
Plantago lanceolata L.	English plantain	Plantaginaceae	0	E	A	FORB
Plantago rugelii Dcne.	rugel plantain	Plantaginaceae	0	N	A	FORB
Plantago virginica L.	dwarf plantain	Plantaginaceae	1	N	A	FORB
Platanus occidentalis L.	American sycamore	Platanaceae	3	N	P	TREE
Poa compressa L.	Canada bluegrass	Poaceae	0	E	P	GRASS
Poa pratensis L.	Kentucky bluegrass	Poaceae	0	E	P	GRASS
Polygonum coccineum Muhl.	water smartweed	Polygonaceae	5	N	P	FORB

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Polygonum hydropiperoides Michx.	wild water pepper	Polygonaceae	4	N	P	FORB
Polygonum spp. L.	smartweed	Polygonaceae	*	U	U	FORB
Populus deltoides Marsh.	eastern cottonwood	Salicaceae	2	N	P	TREE
Potentilla simplex Michx.	common cinquefoil	Rosaceae	3	N	P	FORB
Potentilla recta L.	sulphur cinquefoil	Rosaceae	0	E	P	FORB
Prunus americana Marsh.	wild plum	Rosaceae	4	N	P	TREE
Prunus serotina Ehrh.	black cherry	Rosaceae	2	N	P	TREE
Prunella vulgaris L. var. *lanceolata*	self-heal	Lamiaceae	1	N	P	FORB
Pyrrhopappus carolinianus (Walter) DC.	false dandelion	Asteraceae	0	N	A/B	FORB
Quercus alba L.	white oak	Fagaceae	4	N	P	TREE
Quercus bicolor Willd.	swamp white oak	Fagaceae	7	N	P	TREE
Quercus imbricaria Michx.	shingle oak	Fagaceae	3	N	P	TREE
Quercus macrocarpa Michx.	bur oak	Fagaceae	4	N	P	TREE
Quercus muehlenbergii Engelm.	chinkapin oak	Fagaceae	4	N	P	TREE
Quercus palustris Muenchh.	pin oak	Fagaceae	4	N	P	TREE
Quercus phellos L.	willow oak	Fagaceae	7	N	P	TREE
Quercus rubra L.	northern red oak	Fagaceae	5	N	P	TREE
Quercus shummardii Buckl.	Shumard oak	Fagaceae	6	N	P	TREE
Quercus spp. L.	oak	Fagaceae	*	N	P	TREE
Quercus velutina Lam.	black oak	Fagaceae	4	N	P	TREE
Rhus copallinum L.	winged sumac	Anacardiaceae	2	N	P	SHRUB
Rosa multiflora Thunb.	multiflora rose	Rosaceae	0	E	P	SHRUB
Rubus flagellaris Willd.	common dewberry	Rosaceae	2	N	P	SHRUB
Rubus occidentalis L.	black raspberry	Rosaceae	3	N	P	SHRUB
Rubus pensilvanicus Poir.	highbush blackberry	Rosaceae	2	N	P	SHRUB
Rubus spp. L.	bramble	Rosaceae	0	N	P	SHRUB
Rubus trivialis Michx.	southern dewberry	Rosaceae	2	N	P	SHRUB
Rudbeckia hirta L.	black-eyed Susan	Asteraceae	1	N	P	FORB
Rudbeckia laciniata L.	wild goldenglow	Asteraceae	3	N	P	FORB
Rudbeckia triloba L.	brown-eyed Susan	Asteraceae	4	N	P	FORB
Ruellia strepens L.	wild petunia	Acanthaceae	3	N	P	FORB

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Rumex acetosella L.	red sorrel	Polygonaceae	0	E	P	FORB
Rumex crispus L.	curly dock	Polygonaceae	0	E	P	FORB
Salix spp. L.	willow	Salicaceae	*	N	P	SHRUB
Salvia lyrata L.	cancer weed	Lamiaceae	4	N	P	FORB
Samolus parviflorus Raf.	water pimpernel	Primulaceae	5	N	P	FORB
Sassafras albidum (Nutt.) Nees	sassafras	Lauraceae	2	N	P	TREE
Setaria faberi R.A.W. Herrm.	giant foxtail	Poaceae	0	E	A	GRASS
Setaria glauca (L.) P. Beauv.	yellow foxtail	Poaceae	0	E	A	GRASS
Silene latifolia Poir.	white campion	Caryophyllaceae	0	E	B	FORB
Sisyrinchium bermudiana L. em. Fernald	pointed blue-eyed grass	Iridaceae	5	N	P	FORB
Smilax bona-nox L.	saw greenbriar	Liliaceae	3	N	P	WVINE
Smilax glauca Walt.	cat greenbriar	Liliaceae	5	N	P	WVINE
Smilax spp. L.	greenbriar	Liliaceae	*	N	P	U
Solanum carolinense L.	horse nettle	Solanaceae	0	N	P	FORB
Solanum ptycanum Dunal	black nightshade	Solanaceae	1	N	A	FORB
Solidago altissima L.	tall goldenrod	Asteraceae	1	N	P	FORB
Solidago giantea Aiton	late goldenrod	Asteraceae	4	N	P	FORB
Solidago rugosa Mill.	rough-leaved goldenrod	Asteraceae	5	N	P	FORB
Solidago spp. L.	goldenrod	Asteraceae	*	N	P	FORB
Solidago ulmifolia Muhl. ex Willd.	elm-leaved goldenrod	Asteraceae	4	N	P	FORB
Sorghum halepense (L.) Pers.	Johnson grass	Poaceae	0	E	P	GRASS
Sporabolus spp. R. Br.	dropseed	Poaceae	*	N	P	GRASS
Strophostyles leiosperma (T. & G.) Piper	small wild bean	Fabaceae	2	N	A	FORB
Strophostyles spp. Ell.	wild bean	Fabaceae	0	N	U	FORB
Symphyotrichum cordifolium (L.) G.L. Nesom	blue wood aster	Asteraceae	7	N	P	FORB
Symphyotrichum lateriflorum (L.) A. Love & D. Love	white woodland aster	Asteraceae	3	N	P	FORB
Symphoricarpos orbiculatus Moench.	coralberry	Caprifoliaceae	1	N	P	SHRUB
Symphyotrichum pilosum (Willd.) G.L. Nesom	white heath aster	Asteraceae	0	N	P	FORB
Symphyotrichum praealtum (Poir.) G.L. Nesom	willow-leaved aster	Asteraceae	7	N	P	FORB
Symphyotrichum spp. Nees	aster	Asteraceae	*	N	P	FORB
Tanacetum vulgare L.	common tansy	Asteraceae	0	E	P	FORB

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Taraxacum officinale F.H. Wigg.	common dandelion	Asteraceae	0	E	P	FORB
Teucrium canadense L.	germander	Lamiaceae	2	N	P	FORB
Toxicodendron radicans (L.) Kuntze	poison ivy	Anacardiaceae	1	N	P	WVINE
Tridens flavus (L.) Hitchc.	purpletop	Poaceae	1	N	P	GRASS
Trifolium pratense L.	red clover	Fabaceae	0	E	B	FORB
Trifolium repens L.	white clover	Fabaceae	0	E	P	FORB
Triticum aestivum L.	winter wheat	Poaceae	0	E	A	GRASS
Ulmus alata Michx.	winged elm	Ulmaceae	4	N	P	TREE
Ulmus rubra Muhl.	slippery elm	Ulmaceae	3	N	P	TREE
Ulmus spp. L.	elm	Ulmaceae	*	N	P	TREE
Verbesina alternifolia (L.) Britton ex Kearney	wingstem	Asteraceae	4	N	P	FORB
Verbascum blattaria L.	moth mullein	Scrophulariaceae	0	E	B	FORB
Verbascum thapsus L.	common mullein	Scrophulariaceae	0	E	B	FORB
Verbena urticifolia L.	white vervain	Verbenaceae	4	N	P	FORB
Vernonia baldwinii Torr.	western ironweed	Asteraceae	2	N	P	FORB
Vicia spp. L.	vetch	Fabaceae	*	E	U	U
Viola missouriensis Greene	Missouri violet	Violaceae	4	N	P	FORB
Vitis spp. L.	grape	Vitaceae	*	N	P	WVINE
Vitis vulpina L.	winter grape	Vitaceae	5	N	P	WVINE
Xanthium strumarium L.	cocklebur	Asteraceae	0	E	A	FORB
Poaceae sp.	UNK	Poaceae	*	U	U	GRASS
Lamiaceae sp.	UNK	Lamiaceae	*	U	U	U