ASSESSING THE COSTS AND BENEFITS OF NATIVE PLANT SPECIES FOR ELECTRIC TRANSMISSION LINE RIGHT-OF-WAY REVEGETATION WITHIN THE TENNESSEE VALLEY AUTHORITY POWER SERVICE AREA

By

Joseph R. Turk

Jennifer M. Boyd
Associate Professor of Biological and Environmental Sciences
(Chair)

Neslihan Alp
Dean of the College of Engineering and Computer Science
(Committee Member)

Adam J. Dattilo
Graduate Faculty Member of Biological and Environmental Sciences
(Committee Member)

ASSESSING THE COSTS AND BENEFITS OF NATIVE PLANT SPECIES FOR ELECTRIC TRANSMISSION LINE RIGHT-OF-WAY REVEGETATION WITHIN THE TENNESSEE VALLEY AUTHORITY POWER SERVICE AREA

By

Joseph R. Turk

A Thesis Submitted to the Faculty of the University of Tennessee at Chattanooga in Partial Fulfillment of the Requirements of the Degree of Master of Science: Environmental Science

The University of Tennessee at
Chattanooga, Tennessee

May 2015

ABSTRACT

The safe operation of electric transmission lines necessitates the suppression of tall, woody vegetation on associated rights-of-way (ROWs). Native warm season grasses (NWSG) are more expensive for ROW revegetation compared to typical exotic cool season grasses (ECSG), but they may alter the successional trajectory such that long-term maintenance costs are reduced. I conducted a cost-benefit analysis to determine if ROW revegetation with NWSG is cost effective compared to ECSG. I synthesized cost information obtained from the Tennessee Valley Authority regarding ROW planting and maintenance and data collected from a feasibility study of ROWs planted with NWSG. Revegetation with NWSG was found to be 6% more expensive than ECSG. The degree of woody suppression to make NWSG a worthwhile investment was found to be 12-21% using a break-even analysis. Despite the initial greater expense of NWSG, associated potential maintenance savings and indirect ecological, environmental, social, and economic benefits favor their use.

DEDICATION

This work is dedicated to April and Lilly Turk, my wife and daughter, whose love, support, and patience made all of this possible.

ACKNOWLEDGEMENTS

First, I would like to thank my committee who helped guide me through the process of writing my thesis. Dr. Jennifer Boyd, my committee chair, provided guidance and editorial support that was crucial to my success. Dr. Nelsihan Alp provided technical advice and encouragement whenever called upon. Adam Dattilo, my friend and colleague, helped keep me on course every time I started to stray. I would also like to thank Dr. Jose Barbosa and Dr. Joey Shaw for furthering my education in botany and for providing well-reasoned advice. I would like to thank the staff at Oak Ridge National Laboratory and Gallatin Fossil Plant for cooperating with my study. To my management at TVA I am deeply indebted for funding my education and my research. I would like to give special thanks to my former managers Skip Markham and Keith Elder for encouraging my research and helping to remove barriers to its fulfillment. My coworkers at TVA were an integral part of this work. Ryan Vincent, Sam Benefield, Justin Lindsey, and John Kizer all helped monitor my research sites. Robby Wilson, Jodie Branum, Denny Brown, Jordan Sikkema, and Britney Killian all helped support my work. Allen Medearis provided project data without fail. Jack Payne, Mickey Gray, and Clem Peters provided construction field support and imparted lessons about agriculture and engineering that no school can teach. Michael Nance and Jason Regg provided a steady supply of information on right-of-way maintenance. Finally, I would like to thank the people of Roundstone Native Seed in Upton, KY. John Seymour’s life experience was key to helping me arrange my experiment and the training he provided in field identification of grass seedlings was critical to my data collection. Jeremy Hamlington never failed to answer questions in a timely and professional manner. Mark Sidebottom delivered a quality planting that went above my expectations. I owe all of these individuals a debt of gratitude that cannot be expressed in words.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

OLD-FIELD SUCCESSION: MILESTONES, MODELS, AND MECHANISMS

1.0 Introduction

The questions "Why does plant community structure change?" and "How do plant communities respond to disturbance?" have been asked by naturalists, biologists, and ecologists at least since the mid nineteenth century (Dureau de la Malle 1825, Thoreau 1860). The dynamic nature of plant communities became a major subject within the field of plant ecological research and theory just before the turn of the twentieth century (Warming 1895, Cowles 1899c, b, a). The knowledge gained over nearly 200 years of research has done more than answer purely academic questions. It has provided land managers with the information they need to make informed decisions on a variety of issues including erosion control, wildlife conservation, wildfire control, grazing, agriculture, silviculture, and vegetation management (Barrington 1929, Daubenmire 1940, Egler 1949, Byrd 1956, Ellison 1960, Penfound 1964, Niering and Goodwin 1974, Smeins et al. 1976, Voorhees and Cassel 1980, Hull and Scott 1982, Kindschy 1986, Swanton et al. 1993, Jason et al. 2008, Schlossberg and King 2009, García-Palacios et al. 2011, Olson et al. 2011, Pierson et al. 2011).

The concept of ecological succession was originally introduced to describe the establishment of vegetation and the development of soils on previously barren areas such as sand dunes, glacial tills, and volcanic islands. Later, the concept of succession was expanded to include the recovery of plant communities from any ecological disturbance (i.e., an event that removes all or part of a biological community), natural or anthropogenic. Old-field studies are a common tool to describe succession after the abandonment of agriculture. These studies have provided a wealth of data explaining how and why plant communities are dynamic. Given that most old-field plant communities do not reach a point where the community structure only changes in response to disturbance within the span of one researcher's lifetime, most old-field studies utilize chronosequences. These studies are conducted by cataloguing the flora of sites with varying times since abandonment within the same region. However, long-term old-field studies at Hutcheson Memorial Forest in New Jersey and Cedar Creek Ecosystem Research Science Reserve in Minnesota have helped to elucidate the floristic transition from cropland to a stable community (Foster and Tilman 2000, Pickett et al. 2001).

Utility rights of way (ROWs) are similar to old-fields in many ways. Like old-fields, succession on utility rights of way (ROWs) begins with removal of natural vegetation and disturbance of the topsoil. ROWs and old-fields have similar histories in that the native plant community is removed, introduced plants are established, and disturbance of soil and the plant community present ends. Following the end of disturbance, colonization by native forbs and grasses occurs on both habitats. However, there are noteworthy differences between old-fields and ROWs. Unlike old-fields, ROWs are narrow strips often flanked by surrounding natural areas with a high ratio of edge habitat per unit area whereas old-fields may cover several hectares with a lower ratio of edge habitat per unit area. In areas where natural forests occur, this typically results in faster tree establishment because of reduced seed dispersal distances and increased propagules from edge habitat. In this way, succession on ROWs often resembles the succession resulting from small forest fires or windthrow. Furthermore, old-fields are typically abandoned indefinitely whereas ROWs are maintained by mechanical or chemical management of encroaching woody plants on a regular basis. This creates a condition that resembles continued disturbance from herbivory. However, old-field studies can provide a good analogue to the stages of succession on ROWs in numerous aforementioned ways.

An understanding of the multiple factors influential to succession can inform the successful revegetation of anthropogenically disturbed areas. The construction and maintenance of utility ROWs presents both short and long-term vegetation management challenges. Initially, successful vegetation establishment following the cessation of land disturbance is needed for erosion control. Eventually, the continued suppression of tall vegetation is crucial for the safe and reliable access and operation of the lines. Only two long-term studies have looked at succession and the response to vegetation maintenance on ROWs (Bramble and Byrnes 1983, Niering 1987). Given that these two study ROWs are relatively close together, one being in Pennsylvania and one being in Connecticut, we must use the knowledge gained through other succession studies to understand succession on ROWs in other parts of North America in order to formulate management strategies applicable to specific regions. In this chapter, I review the history of research of plant succession with specific focus on old-field systems in the Southeast, characteristic plant species and community types of southeastern old-fields, the processes that drive transitions from one successional stage to the next, and contemporary applications of old-field succession research including its relevance to the management of utility ROWs.

1.1 Primary and Secondary Succession

Ecological succession refers to generally predictable changes in the composition and structure of plant communities through time. Ecologists categorize succession into two types, primary or secondary, based on the initiating event. Primary succession begins with the colonization of previously barren areas, such as rock outcrops and sand dunes, often by lichens and mosses. Through time, weathering of substrate and an accumulation of organic matter creates soil for subsequent plant species. Secondary succession occurs after a disturbance that removes part of an existing community. The specific sequence of plant communities in any given location is influenced primarily by its climate and edaphic conditions. The scale of disturbance may range from local, such as a tree falling in a forest, to landscape-level, such as deforestation for development. In the temperate deciduous forests of the southeastern U.S., common regional disturbances that trigger secondary succession include fire, silviculture, wind throw, and land-clearing by humans.

In terms of secondary succession triggered by anthropogenic disturbances, the return of forests to land previously cleared for agriculture but later abandoned is especially well studied. Though agricultural abandonment in the eastern U.S. coincided largely with the second industrial revolution (ca. 1900), no single factor has been attributed to this phenomenon. However, urbanization, strip mining, the Soil Bank program, and low productivity soils have all been noted as contributing factors (Hart 1968). From 1900 through the 1960s, the transition of lands to forest from agricultural use was especially prevalent in Appalachia, the Southeast, and the northeastern U.S. (Ramankutty et al. 2010). When the time of abandonment is known from historical records, old-field systems have provided ecologists with a unique opportunity to study entire successional sequences or seres, which can comprise 100 or more years, by observing individual old-fields that represent different times since abandonment (Oosting 1942, Keever 1950, Bazzaz 1968, Keever 1979).

A common model that is used to generalize secondary succession in the southeastern U.S. consists of three major stages: 1) Early succession begins with the cessation of disturbance and lasts 5-10 years. The dominant plants are initially annual weeds such as ragweed (*Ambrosia* spp.) and horseweed (*Conyza* spp.), progressing within a few years to perennial grasses and forbs such as broom sedge (*Andropogon virginicus*) and goldenrods (*Solidago* spp.; Oosting 1942). 2) Middle succession occurs when wind and bird disseminated woody species including shade-intolerant shrubs, such as brambles (*Rubus* spp.), and trees, primarily pines (*Pinus* spp.) encroach upon the perennial community (Oosting 1942). 3) Late succession begins with canopy dominance by mature pines. Eventually the pines are largely replaced by more shade-tolerant deciduous tree species such as oaks (*Quercus* spp.) and hickories (*Carya* spp.), which develop into a mature forest (Oosting 1942). While these stages have been historically described in the context of old-fields, they may be observed following abandonment of most anthropogenically disturbed areas including ROWs.

1.2 Foundational Research in Succession

The seeds of succession as a major discipline within plant ecology were sown by the French naturalist and geographer Adolphe Dureau de la Malle who described the succession of plants in cut over forests (1825). The term succession was later used to describe change within plant communities by Henry David Thoreau in his explanation of shift in dominance from pine to oak in the forests of Massachusetts (1860). More than three decades later, Eugene Warming began developing his concept of plant communities after observing the flora of Denmark's coastal habitats. Warming's most important work *Plantesamfund* inspired a generation of scientists to take up the relatively new discipline of ecology. One of the leaders of this new field was Henry Chandler Cowles, who resurrected the term "succession" to describe what would come to be known as primary succession on the dunes of Lake Michigan. Cowles also brought the term "climax" into use to describe a plant community with stable composition until further disturbance. In contemporary ecological parlance this is called a steady state community. One of Cowles most celebrated students, William Skinner Cooper, further perpetuated the concept of a climax community with his work describing primary and secondary succession of the plant community of Isle Royale on Lake Superior. Around the same time Frederic Clements proposed the idea of plant communities as a "super organism" with the climax community as the final stage of development, an idea that would shape much of the ecological thinking of the twentieth century. A contemporary of Clements, Henry Gleason, looked back to Cowles work and saw succession as a series of random process with community similarities being the result of environmental conditions.

The earliest studies of succession in the late nineteenth and early twentieth century focused primarily on observational descriptions of community composition through time. The ideas posited by the first generation of investigators inspired subsequent observational studies throughout much of the twentieth century with the body of knowledge being expanded primarily through contributions from different ecosystem types and following distinct types of disturbance (see Chrysler 1905, Harvey 1908, Clifton Durant 1910, Roland 1914, Shantz 1917, Ewing 1924, Gates 1926, Geisler 1926, Cain 1928, Wells 1928, Barrington 1929, Campbell 1929, Larsen 1929, Stallard 1929, Aikman 1930, Adamson 1931, Woodbury 1933, Kittredge 1934, Huberman 1935, Wilson 1935, Hanson and Whitman 1937, Whitfield and Anderson 1938, Daubenmire 1940, Booth 1941, Oosting 1942, Bard 1952, Byrd 1956, Dix 1957, Quarterman 1957, Wells 1961, Grelen 1962, Hosner and Leon 1963, Levering 1968, Peterson 1968, Herman and See 1973). In the latter part of the twentieth century, however, investigators began to synthesize the work of their predecessors in multiple systems and following various disturbance types toward understanding the mechanisms influential to the transitions from one successional stage to the next. Table 1.1 below summarizes influential contributions toward increasing such understanding. While not exclusively focused on old-field systems, knowledge of these works will provide context to the processes and mechanisms influential in old-field succession.

Table 1.1 Influential Literature on Succession

Author	Title	Date	Summary
J. E. B. Warming	Plantesamfund	1895	Plants belong to communities and the community structure is in response to environment.(Anker 2011)
H. C. Cowles	The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan. Parts I-III	1899	Plant succession is the mechanism for plant community development. (Cowles 1899c, b, a)
W. S. Cooper	The Climax Forest of Isle Royale, Lake Superior, and Its Development. Parts I-III	1913	The successional stages beginning with primary succession and leading to a climax community are described including post disturbance secondary succession. (Cooper 1913a, b, c)
F. E. Clements	Plant Succession: An Analysis of the Development of Vegetation	1916	Vegetation assemblages are predictable and act as parts of a super organism growing and developing toward a stable climax community. (Clements 1916)
H. A. Gleason	The Individualistic Concept of the Plant Association	1926	Vegetation assemblages are stochastic. Common plant associations are the result of similar habitat needs not interdependence. (Gleason 1926)
H. J. Oosting	An Ecological Analysis of the Plant Communities of Piedmont, North Carolina	1942	The stages of succession in the Piedmont of North Carolina are annual weeds, perennial bunch grasses, pines, and finally oak/hickory climax. (Oosting 1942)
C. Keever	Causes of Succession on Old-fields of the Piedmont, North Carolina	1950	The stages of succession in the Piedmont of North Carolina are explained in terms of the life histories of the plants involved. (Keever 1950)
R. H. Whittaker	A Consideration of Climax Theory: The Climax as a Population and Pattern	1953	The composition of the climax community is a function of the biotic and abiotic environment as well as chance dispersal events. Similar climax communities are found in similar environments. (Whittaker 1953)
F. E. Egler	Vegetation Science Concepts I. Initial Floristic Composition, a Factor in Old-Field Vegetation Development	1954	All of the propagules of future plant communities are present at or immediately after abandonment of old-fields. They are released when anthropogenic disturbance ends. (Egler 1954b)
F. A. Bazzaz	Succession on Abandoned Fields in the Shawnee Hills, Southern Illinois	1968	Similar to Oosting's findings, the stages and causes of succession were recorded for the Shawnee Hills of southern Illinois. (Bazzaz 1968)
J. H. Connell and R. O. Slayter	Mechanisms of Succession in Natural Communities and Their Role in Community Stability and Organization	1977	Tolerance, Inhibition, and Facilitation were proposed as the three main models for plant succession. (Connell and Slatyer 1977)
G. D. Tilman	The Resource-Ratio Hypothesis of Plant Succession	1985	Limiting resources are allocated based on individual plant's ability to compete. On poor soils plants that better competitors either by their physiology or their life history will be favored.(Tilman 1985)

Clearly, the total available literature on ecological succession is extremely rich. A full text search of “succession” within the ecology and botany disciplines of the JSTOR database from 1890 to 2014 yields over 40,000 results. However, adding “old-field” to a title search yields just 89 results. Some of this relatively small number of results may be explained by inconsistencies of terminology by investigators; for example, in “Forest Growth on Abandoned Agricultural Land” the author describes the establishment and structure of various tree communities found on old-fields throughout the northeastern U.S. but never specifically mentions succession (Buttrick 1917).

These results, however, demonstrate that successional studies that focus on old-fields in particular are rather limited in contrast with the commonness of these systems. Using various search terms, 478 studies in the lower 48 states of the U.S. were found to contain original research on secondary succession relevant to old-field and ROW succession. Political boundaries were used as a matter of convenience to capture studies most applicable to the southeastern U.S., where my study sites are located. These papers were categorized by state, successional stage, and subject to show general spatial and temporal trends in secondary successional research. Figure 1.1 shows the distribution of succession research as a function of time. Likewise, Figure 1.1 shows the distribution of old-fields succession research by state. While succession research is seen in every region of the contiguous U.S., these figures show a bias in old-field succession research toward the eastern states. Secondary succession studies in western states tend to focus more on rangeland grazing and fire ecology.

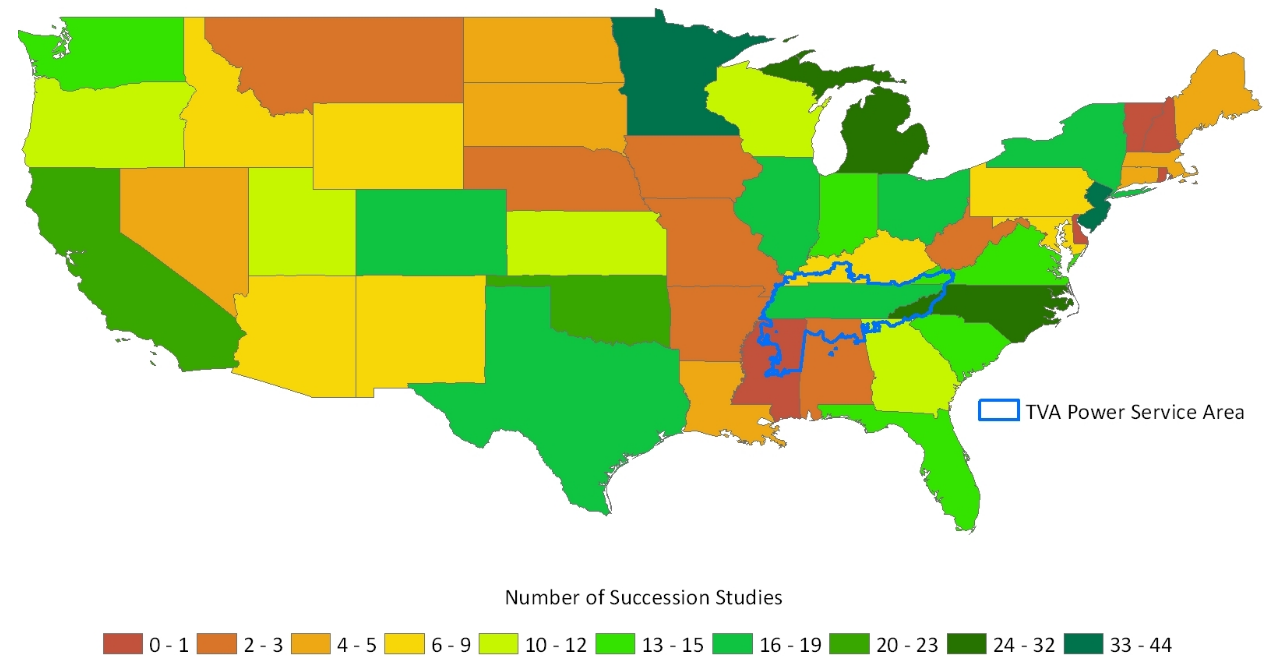

Figure 1.1 Geographic Distribution of Succession Studies

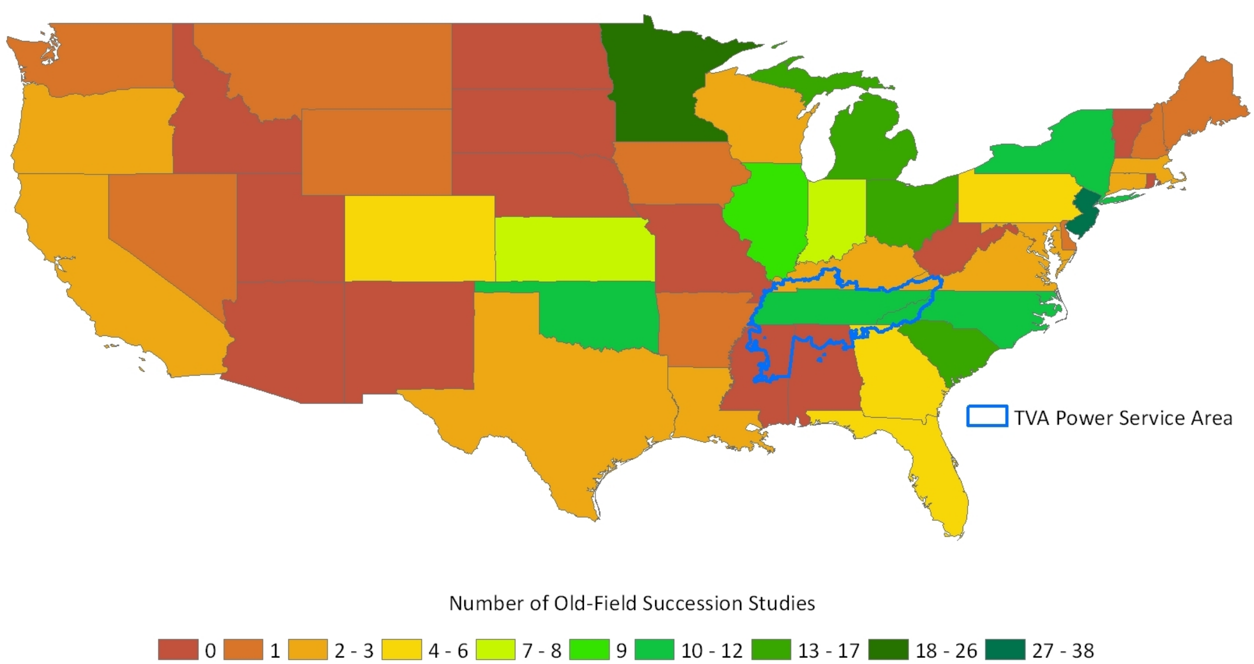

Figure 1.2 Geographic Distribution of Old-Field Succession Studies

1.3 Process Models

The focus of many old-field investigations is on the path toward a stable (i.e., climax) community. Since utility line ROWs by their nature undergo disturbance at regular intervals, the successional changes through the establishment of woody species are sufficient to explain influential conditions and processes. A convenient way of describing the interactions seen during succession is to categorize them by process model. One of the most influential works on the causes of succession was Connell and Slatyer's 1977 paper describing succession in terms of three models: inhibition, tolerance, and facilitation. The inhibition model states that early colonizers prevent the establishment of subsequent colonizers. As such, new species only establish when a disturbance creates a gap that can be exploited (Connell and Slatyer 1977). The tolerance model states that two or more species can coexist as long as they can tolerate their environmental conditions. For succession to occur one species must develop a competitive advantage over its neighbors (Connell and Slatyer 1977). The facilitation model states that early colonizers alter the environment in such a way to make establishment of subsequent colonizers possible (Connell and Slatyer 1977). The following sections describe these models in relation to old-field succession

1.3.1 Inhibition

Inhibition can occur through either direct mechanisms as in the production of allelopathic chemicals or indirectly through competition for resources (Connell and Slatyer 1977). In her work on old-fields in the Piedmont, Keever (1950) described the allelopathic effects of *C. canadensis* on later successional plants. Other research has shown an allelopathic effect from many other early successional species. *Helianthus annuus, Digitaria sanguinalis, Ambrosia psilostachya, and Andropogon virginicus* have all been shown to have allelopathic effects on other old-field invaders (Wilson and Rice 1968, Parenti and Rice 1969, Neill and Rice 1971, Rice 1972). The allelopathic mechanism of *A. virginicus* is especially interesting. Rice (1972) found that in addition to directly inhibiting the growth or germination of other plants its root and shoot extracts inhibit both free living and symbiotic nitrogen fixing bacteria, thus keeping the overall fertility of the soil low and discouraging invasion from species with a greater nitrogen dependence.

1.3.2 Tolerance

Though Connell and Slatyer (1977) explicitly described the tolerance model, the concept can be found in hypotheses from prior investigators. For example, Egler's "Initial Floristic Hypothesis" posits that all of the propagules for future plant communities are present at or shortly after the cessation of disturbance (Egler 1954b). For this to be true, slow-growing perennial species must be able to tolerate unfavorable conditions and competition from fast-growing annual species until they become large enough to dominate the community (Everett and Ward 1984). The "Initial Floristic Hypothesis" largely has been rejected as a model for succession in a general sense (Buell et al. 1971). However, the idea that two or more species can coexist until one exhibits a competitive advantage is the core of Connell and Slatyer's tolerance model.

Many researchers have sought to test the tolerance model in a controlled setting. One such example is a greenhouse experiment conducted to test suppression based versus tolerance based competition between invasive exotic grasses and native grasses found in the oak savannas of British Columbia. The findings showed that under low nutrients and infrequent disturbance the exotic grasses were dominant. Alternately, under increased nutrients and frequent disturbance native species became dominant. Thus, dominance by the exotic grasses was explained by the interaction of the tolerance based competitive strategy, nutrient availability, and site history. In species removal experiments, it has been shown that second year dominant species become established regardless of the presence of first year invaders (Hils and Vankat 1982, Armesto and Pickett 1986). This is consistent with Keever's work showing the season of abandonment and the invading species' seed physiology plays the primary role in early succession. Thus, tolerance has largely been accepted as a successional mechanism as plant assemblages transition through the first few years of succession.

1.3.3 Facilitation

Like the tolerance model, the facilitation model has its roots in some of the classic works on succession. Clement's idea of succession as an organized, predictable mechanism is dependent on what Egler termed "Relay Floristics". This idea states that each stage of succession prepares the site for subsequent waves of invasion. While the successional models discussed above are the most widely recognized contributors to the earliest stages of succession facilitation processes are at play near the end of early succession. A meta-analysis of 539 articles on plant succession in terrestrial ecosystems yielded 2080 cases of facilitation responses, with 330 of those cases affiliated with temperate ecosystems (Bonanomi et al. 2011). Species of shrubs, trees, and herbaceous perennials all were found to act as significant nurse species in temperate ecosystems, with tree species followed by herbaceous perennials being the most important beneficiaries (Bonanomi et al. 2011). Among temperate ecosystems, the strongest facilitation response was found in the encroachment of shrubs into grassland habitats, with the most common facilitation mechanisms being changed microclimate, soil fertility improvement, associational refuge, reduced interspecific competition, and soil biotic condition improvement (Bonanomi et al. 2011). These data indicate that the transition from one successional phase to the next is heavily influenced by facilitation.

Nucleation, succession based on facilitation radiating out from an early pioneer, was first proposed by Yarranton and Morrison in 1974 by studying the vegetation around *Juniperus virginiana* on the sand dunes of Grand Bend, Ontario. They found that *J. virginiana* modified the surrounding environment through an improvement in soil from accumulation of litter and microclimate modification.

Later successional species were better able to establish around *J. virginiana* than in open areas (Yarranton and Morrison 1974). In old-fields nucleation occurs both because of improvements in the microhabitat and because increases in structural complexity increases the richness of animal species that disseminate seeds. This was shown by McDonnell and Stiles who found a greater number of seeds in older fields with greater complexity, at the edge of old-fields, and under simulated trees in old-fields lacking structural complexity (McDonnell and Stiles 1983).

1.3.4 Limitations of Successional Models

The inhibition, facilitation, and tolerance models represent extreme conditions on the continuum of succession and only attempt to predict net effect (Connell et al. 1987). Given the reality that field conditions rarely reflect the idealized models as proposed by Connell and Slatyer, other mechanisms also must be considered to understand individual species interactions (Pickett et al. 1987). The model at play for site specific interactions may be based on richness, abundance, resource availability, or other environmental factors (Walker and Chapin 1987, Maggi et al. 2011). Nevertheless, the inhibition, facilitation, and tolerance models are useful when considering the transition from herbaceous dominance to woody dominance in old-fields and ROWs.

1.4 Influential Mechanisms

To explain succession at smaller spatial scales, several important ecological mechanisms should be considered. While innumerable variables may be interacting in any given site, soil nutrient availability, competitive ability, herbivory, and colonization often are cited as important factors that contribute to a specific sere.

1.4.1 Soil Nutrient Availability

Within the context of revegetation efforts as an early step to restoration, an understanding of how soil nutrient availability affects succession can be especially important. This is because it is standard practice within agriculture and construction site revegetation to amend soils to promote fast plant establishment and growth. Old-field studies conducted shortly after abandonment provide good information about the role of soil fertility in succession because of residual fertilizers. For example, in a study of primary production on abandoned agricultural fields at the Savanna River Plant in Aiken, SC, Odum attributed an early peak in productivity during the first year following abandonment to residual fertilizer from the previous crops (Odum 1960). As such, soil nutrient amendments could be an important management consideration for the establishment of herbaceous vegetation on ROWs.

Soil nutrient availability also could influence the encroachment of woody plants on ROWs since it has been observed that woody invaders sometimes establish in the first year after abandonment only to become dominant many years later (Egler 1954b). It also has been shown that fertilizer enrichment generally speeds succession, which could be detrimental for ROWs by reducing the time until woody encroachment occurs (Collins and Wein 1998). An associated reduction in species richness during the herbaceous/grass stage also could increase the need for active management since systems with greater species richness are more resistant to change (Maggi et al. 2011). By using soil amendments to promote fast establishment of ground cover at the expense of accelerating woody encroachment, these scenarios could inadvertently increase management time and costs. This potentially detrimental fertilization effect could be mitigated to some extent by pioneer species such as *Ambrosia artemisiifolia*, which has been shown to uptake available nitrogen then slowly release it from its residue in subsequent years (Foster et al. 1980, Vitousek 1983). This slow release of nitrogen favors native warm season grasses over early woody invaders as they have been shown to out-compete exotic weedy species at low to intermediate concentrations of nitrogen (Honu et al. 2006, Priest and Epstein 2011).

1.4.2 Resource Competition

Just as the availability of nutrients can be an important influence to succession, so can interspecific competition among co-occurring plants for nutrients and other resources. In his resource-ratio hypothesis, Tillman proposed that every species is the best competitor under the right conditions. When two or more limiting resources change, competitive ability dictates that the community structure should change (Tilman 1985). This is consistent with the findings of Allison and Weltzin (2007), who attempted to construct a competitive hierarchy with four common old-field plants, *Dactylis glomerata, Festuca elatior*(also known as *Lolium arundinaceum*) *, Trifolium pratense, and Plantago lanceolata*. They found that competitive hierarchies could not be established based on one environmental gradient, suggesting that the interaction of competition for different resources is responsible for one species' inhibition of others (Allison and Weltzin 2007). Likewise, Kosola and Gross found that first year colonizers of old-fields were not able to compete with later invaders because of a combination of above- and below-ground competition. While first year colonizers like *Achillea millefolium* and *Ambrosia artemisiifolia* produce large quantities of seed, such pioneer species rarely persist beyond the second year after abandonment. Kosola and Gross showed that second year invaders were better able to compete for nitrogen. This allows them to produce more vegetative growth above-ground, which can shade weaker competitors, and to produce better root systems, which enhances their relatively ability to compete for below-ground resources (Kosola and Gross 1999).

1.4.3 Herbivory

While interspecific inhibition drives much of the successional change in old-fields, the interaction of competition and herbivory also can exert an important influence on succession. Apparent competition, first described by Holt, is the inhibitory effect of two coexisting species based not on competition for resources or allelopathy but because of external pressures from predators (1977).

Evidence for the interaction of competition and herbivory has been shown by numerous investigators. By using insecticides to exclude insect herbivores, Carson and Root found significant top-down effects on biomass and plant dominance in old-fields three years after abandonment (1999). Suwa and Louda attempted to explain why the exotic *Cirsium vulgare* does not spread and become invasive in the tall grass prairie as it tend to do in other habitats. They clearly showed that the effects of interspecific competition with *Cirsium altissimum* combined with the effects of herbivory acted to inhibit C. *vulgare* (Suwa and Louda 2012). Likewise, simulations based on field data show that without herbivory *Solidago altissima* and *Solanum carolinense* coexist, but with herbivory *S. carolinense* is inhibited by *S. altissima* (Kim et al. 2013). Furthermore, rodent herbivory on tree seedlings has been shown to give a competitive advantage to grasses in old-fields (Ostfeld and Canham 1993, Ostfeld et al. 1997). Broadly speaking, the competitive advantages of one plant species over another conferred by herbivores closely parallel the effects of selective herbicide treatments used by many utilities on ROWs.

1.4.4 Propagule Pressure and Colonization Success

Major factors governing the establishment of vegetation on old-fields and ROWs are season and scale of disturbance, seed size and dispersal method, and distance to seed source. Keever showed that similar patterns of early invasion occurred in old-fields in the Piedmont of North Carolina and in Lancaster County, PA (Keever 1950, 1979). There was substantial overlap in the species present in the two areas. While each site had species not found in the other, functionally the two suites of species were nearly identical. The early invading species all have wind dispersed seeds and were primarily annuals. In the Piedmont of North Carolina, the dominant plant species in the first year of abandonment was found to be *Conyza canadensis*. This was explained by the fact that *C. canadensis* seeds mature and are ready to germinate in the late summer when most agricultural plots are tilled (Keever 1950). Other early successional species do not germinate immediately after abandonment because they require a period of cold stratification to germinate and because *C. canadensis* root residue has an allopathic effect on plant growth and survival (Keever 1950). *Symphyotrichum pilosus* becomes dominant in the second year after abandonment, but is out-competed by *Andropogon virginicus* in the third year after abandonment (Keever 1950). The delayed dominance of *A. virginicus* until the third year after abandonment was explained by limited dispersal ability and the proximity of adult plants to the abandoned fields (Keever 1950, 1979).

The relationship between seed source proximity and species dominance described by Keever is supported by more recent work. In a study of succession on abandoned mine sites in Florida it was shown that seed source proximity is the best predictor of later successional species. Furthermore, the study showed that an absence of climax species near the site of disturbance can slow successional processes (McClanahan 1986). Other studies have sought to elucidate the interaction of the level of disturbance, the fertility of the soil, and the availability of seed as variables in successional trajectory. Gibson et al. found that in Illinois old-fields seed availability had the greatest impact on community structure on a regional scale, whereas level of disturbance and fertility played a more important role at a local scale (Gibson et al. 2005).

As shown in Table 1.2, the first woody species observed during succession are primarily dispersed by birds or mammals (endozoochory) or by wind (anemochory). More specifically, the first woody species are wind dispersed and these are then are replaced by animal dispersed species later in succession. Wind dispersed species tend to have a random distribution and establish themselves on bare soil whereas bird dispersed species tend to aggregate and can be found growing with herbaceous cover. (Foster and Gross 1999)

Table 1.2 Summary of Pioneer Woody Invasion

Reference	State	Pioneer Tree Genus	Years Since Abandonment	Dispersal Mechanism
(Bard 1952)	NJ	*Prunus*	1	Endozoochory
		Pyrus	1	Endozoochory
		Sassafras	5	Endozoochory
		Acer	2	Anemochory
(Bazzaz 1968)	IL	*Sassafras*	1	Endozoochory
		Juniperus	4	Endozoochory
		Diospyros	1	Endozoochory
		Ulmus	4	Anemochory
(Byrd 1956)	VA	*Diospyros*	2	Endozoochory
		Liriodendron	2	Anemochory
		Liquidambar	2	Anemochory
		Pinus	3	Anemochory
(Drew 1942)	MO	*Sassafras*	1	Endozoochory
		Diospyros	1	Endozoochory
		Quercus	1	Seed Cache
		Carya	1	Seed Cache
(McQuilkin 1940)	NC	*Pinus*	1	Anemochory
(Oosting 1942)	NC	*Pinus*	3	Anemochory
(Quarterman 1957)	TN	*Juniperus*	1	Endozoochory
		Prunus	1	Endozoochory
		Ulmus	1	Anemochory
		Celtis	1	Anemochory
		Plantanus	1	Anemochory
		Acer	1	Anemochory

In the Piedmont of North Carolina, *Pinus* spp. (pines) have been shown to be more successful than other wind dispersed woody invaders because their seeds and seedlings are well adapted to old-fields, they bare seeds early, and there is typically a large pool of adult trees to spread seed (Bormann 1953). It also has been shown that woody species with heavy seeds have an advantage of greater energy stores, but are limited in dispersal, whereas small seeds are limited by energy stores but compensate by greater dispersal ability and greater numbers of seed (McEuen and Curran 2004). Table 1.3 shows the dispersal ability of common wind dispersed species.

Table 1.3 Dispersal Distance of Wind Dispersed Trees

Species	Dispersal Distance (m)	Reference
Acer saccharum	100	(Burns and Honkala 1990b)
Fraxinus americana	140	(Williams and Hanks 1976)
Liquidambar styraciflua	61	(Burns and Honkala 1990b)
Liriodendron tulipifera	183	(Burns and Honkala 1990b)
Ulmus americana	91	(Burns and Honkala 1990b)
Pi nus taeda	91	(Fowells 1965)
Pinus virginiana	30	(Burns and Honkala 1990a)
Pinus echinata	40	(Burns and Honkala 1990b)

Based on the data above, ROWs less than 200m in width and flanked by forest have a higher potential for invasion by wind dispersed trees than large old-fields of many hectares with similar edge habitat. This key difference between ROWs and old-fields creates the potential for accelerated succession.

1.5 Contemporary Applications of Successional Studies

The many theoretical concepts described in studies of succession, both broad and those specific to old-field systems, can be applied toward the land management of systems characterized by large-scale clearing of natural vegetation and disturbance but not removal of soil. Rangeland managers are often concerned with post grazing recovery time and community structure. Using the principles described above it has been shown that recovery to the previous plant community can take more than 25 years (Penfound 1964, Potter and Krenetsky 1967, Anderson and Holte 1981, Jeffries and Klopatek 1987, Samuel and Hart 1994). Other studies have shown that the long-term community structure may be permanently altered as a result of grazing (Pieper 1968, West et al. 1984, Wood and Blackburn 1984, Gibson et al. 1987, Green and Kauffman 1995). Succession concepts also have been utilized by the forestry industry to better understand the effect of clear-cutting. Investigators have found that clear-cuts without subsequent replanting may result in a long-term shift in canopy dominance (Abrams and

Nowacki 1992). Others have shown that clear-cuts are analogous to natural disturbance causing an increase in species richness and diversity (Greenberg et al. 1995, Elliott et al. 2002). Of particular concern are the successional pathways that lead to the growth of trees on utility ROWs. In many ways, ROWs behave like old-fields in that they are cleared and left undisturbed for long periods between maintenance cycles. However, ROWs are heavily influenced by adjacent forests due to a relatively proportion of edge habitat and as such often behave like anthropogenically or naturally disturbed forests in early succession. Likewise, maintenance treatments on ROWs often alter successional pathways similar to grazing disturbance. Other industries have applied the principles of succession to the various stages of their land disturbance. As with most utility providers, the Tennessee Valley Authority (TVA) historically has used mechanical removal methods and herbicides to control incompatible vegetation on their ROWs. However, the TVA recently has begun to explore alternative methods for controlling succession in order to reduce operations and maintenance costs and improve relationships with the general public.

CHAPTER 2

REVEGETATION AND MANAGEMENT OF SUCCESSION ON ROWS

2.1 Description of Electric Transmission Line ROWs

Utility right-of-ways (ROWs) are strips of privately owned on which utilities have purchased easements for the operation and maintenance of electric transmission lines. Typical transmission ROWs are 23-90 meters (75-300 feet) in width depending on their voltage and configuration (Ballard 2009). Approximately 716,000 kilometers (445,000 miles) of electric transmission lines traverse the U.S.A. and Canada to form a power grid governed by the North American Electric Reliability Council (North American Electric Reliability Corporation 2009). As of 2011, an additional 48,000 kilometers (30,000 miles) of transmission lines were under construction or planned to be constructed by the year 2019 (North American Electric Reliability Corporation 2011). These transmission lines deliver high voltage electricity (69 kV and above) from electric power generation sites to local power stations.

Created by an act of Congress in 1933, The Tennessee Valley Authority (TVA) is the largest public power provider in the U.S. (Tennessee Valley Authority 2012). The TVA power service area includes parts of 7 southeastern states contiguous to Tennessee and serves over 9 million residents (Tennessee Valley Authority 2012). TVA owns and operates approximately 26,500 kilometers (16,500 miles) of transmission lines within its power service area. This amounts to almost 100,000 hectares (250,000 acres) of ROWs that must be maintained (TVA unpublished data). Within the TVA region, these lines traverse a mosaic of land use types including agricultural, commercial, industrial, residential, silviculture, and stable wooded and wetland communities (Sparry 2002).

The mechanisms of succession described in Chapter 1 are typical of old-fields where anthropogenic disturbance has permanently halted. Transmission line ROWs share many characteristics with old-fields, but they are unique in the study of succession because in early stages they are completely denuded and typically planted with introduced grasses after which they are disturbed every two to three years to prevent trees from growing tall enough to create unsafe conditions for the operation of the lines above. The focus of this chapter is on strategies for managing vegetation on these lands from initial planting through long-term management of succession to create stable plant communities.

2.2 The Construction of Transmission Lines

Vegetation management of ROWs begins with post-construction revegetation for erosion control. Environmental regulations driven by the Clean Water Act and the need to terminate construction activities have traditionally dictated the species mixes and methods used for restoration. This section describes these methods and the rational for the traditional revegetation approach.

2.2.1 Construction Environmental Requirements

The control of erosion and the prevention of sediment escape are the major goals of environmental regulation on construction sites. State and local issuing authorities receive their regulatory authority from the Environmental Protection Administration as directed by the Clean Water Act (CWA). In 1972, the CWA became law with the goal of eliminating water pollution and making the nation’s waters fishable and swimmable (1972). In 1987, the CWA was amended to regulate sediment generated by runoff from construction sites as a pollutant (1972). In 2003 final rules regulating construction sites greater than 0.40 hectares (1 acre) were written by the Environmental Protection Agency (EPA) (Environmental Protection Agency 2003). As such, construction sites are regulated by the

National Pollution Discharge Elimination System (NPDES). Under this system, states and densely populated cities and counties are granted permit writing authority by the EPA for construction activities in their jurisdiction (Franklin 2010). Prior to the start of construction, the land disturbing entity is required to file a Stormwater Prevention Pollution Plan (SWPPP) and a Notice of Intent (NOI) with the appropriate regulatory agency. After a brief review of the plan, the regulator grants a Notice of Coverage (NOC) permitting the start of land disturbance. The rules set forth by the NPDES restrict the discharge of sediment from construction sites. While specific requirements vary, all state and local permitting authorities have a basic set of requirements including: erosion and sediment shall controls be installed prior to land disturbance; frequent documented self-inspections shall be conducted during land-disturbing construction activities; and the site must be stabilized by vegetation at 70-85% density (depending on the state) distributed evenly across the site or by other permanent means when land disturbing activities have ended (J.R. Turk Construction Stormwater Notice of Intent Requirements for the TVA Power Service Area-Unpublished). Self-inspections are required until vegetation has been established at a density as required by the terms and conditions of the permit (J.R. Turk Construction Stormwater Notice of Intent Requirements for the TVA Power Service Area-Unpublished). When the site is stabilized, the land disturbing entity may file a Notice of Termination to end permit coverage and self inspections (J.R. Turk Construction Stormwater Notice of Intent Requirements for the TVA Power Service Area-Unpublished).

On projects where soils are poor and resources for vegetation establishment are limited, inspections are often conducted for several months after construction has been completed with multiple revegetation efforts. In extreme cases, TVA has conducted inspections on for up to 1 year after the end of construction. These frequent revegetation efforts and extended self inspections come at a time when most of the budgeted funds for the project have been spent, placing a significant financial strain on the permit holding entity.

2.2.2 Transmission Line Construction Sequencing

To comply with the rules outlined above, TVA has broken the construction of its electric transmission lines into three phases: initial clearing, line construction, and final restoration (J. R. Turk TVA Standard SWPPP Template-Unpublished). During the initial clearing phase, all wooded areas on the ROW are cleared and grubbed (trees and stumps are removed), erosion and sediment controls are installed, and access roads are constructed. After this phase, the site is largely devoid of living plants. Temporary vegetative stabilization by annual or perennial grasses may be established at the end of this phase depending on the time of year and the line construction schedule. During line construction, transmission line support structures are erected and conductor and overhead ground wire are pulled from the line source to its delivery point. Grading and excavation are done in this phase for the installation of the structures and for the safe operation of construction equipment. During the final phase, permanent vegetation is established and all temporary erosion and sediment controls are removed.

To facilitate permit termination, revegetation species mixes and planting methods have been devised based on quick establishment. As a result of clearing, grubbing and recontouring activities, most of the topsoil is homogenized with the subsoil and the soils are compacted. Prior to planting, a seed bed is created using a disk harrow in much the same manner that agricultural fields are tilled. The disk harrow has the benefit of reducing soil compaction and eliminating competition from temporary cover crops and annual weeds. However, disking further homogenizes the upper organic soil horizons with the deeper mineral soils forming a largely mineral soil and gravel seed bed. To mitigate the effects of losing the upper soil, strata lime and fertilizers are applied to raise the pH and correct nutrient deficiencies. Traditionally, exotic, cool season, turf-forming grasses mixed with exotic legumes inoculated with nitrogen-fixing bacteria are broadcast at or above the upper end of the recommended seeding rate. Revegetation species are selected on the basis of commercial availability and climate.

After seeding, the site is covered in straw or hay mulch to prevent erosion and hold moisture for the seedlings. (Muncy et al. 2012)

Successful seeding often results in a dense vegetative cover in 30-60 days. This approach, however, has several shortcomings: First, the species used may only be established when daytime high temperatures are between 15 and 29° C (60-85° F). In the TVA region, this means that site restoration only can be accomplished from mid-March to late May and from late September to early November (Turk 2014). These narrow planting windows often do not coincide with the end of earth disturbing activities, which means that restoration must be deferred until the next appropriate planting season. Second, the species used prefer a pH of about 5.8 to 6.5 with high fertility soils (Turk 2014). This often results in high applications of soil amendments that may be lost to runoff or biochemical process before they are available to the restoration species (Turk 2014). Finally, high planting rates coupled with naturally low-fertility soils often lead to high plant density initially with high mortality in the long-term (Turk 2014).

2.3 Vegetation Management for Transmission Lines

A key goal of ROW vegetation management is to ensure the safe, reliable operation of transmission lines by suspension of succession on ROWs. Prior to the mid-1940s, vegetation management on transmission line ROWs consisted of hand-cutting or mowing objectionable species every three to five years. This resulted in substantial resprouting and ultimately increased ROW maintenance costs. With the advent of chlorophenox and sulfamate-based herbicides after World War II, a shift toward chemical control of woody species on ROWs began. Early on, most spraying techniques were nonselective with the goal of eliminating all woody plants on the ROW. This was shown to create unstable plant communities (Egler 1949). In the 1950s, ecologists began to take notice of the overuse of herbicides on ROWs and suggested alternative approaches. Instead of using broadcast spraying, selective spraying techniques were suggested with the hope of creating stable plant communities (Egler 1954a, Niering 1958).

By the 1990s, enough data were available to show that herbicide treatments are more effective at controlling the woody stem count on transmission line ROWs than mowing or hand-cutting (Johnstone 1990, Luken 1991, Luken et al. 1991). Other data have shown that selective stem/foliar sprays are the most cost effective herbicide technique for vegetation management and that herbicide treatment sets back the succession process (Nowak et al. 1992, Luken et al. 1994, Yahner and Hutnik 2004).

An event on August 14, 2003 at approximately 2 PM EDT prompted the electric utility industry to more seriously consider the management of vegetation on ROWs. At this time, the most widespread blackout in North American history began after a 345-kV transmission line owned by First Energy in Ohio tripped after arcing over to a tree that had grown too tall under an energized line. This began a cascade of line-to-tree faults that eventually would blackout much of the northeastern United States and parts of southeastern Canada affecting 50 million people. Through the course of the ensuing investigation, it was found that First Energy had not adequately maintained the vegetation on their ROWs. As a result, Congress wrote language in the Energy Policy Act of 2005 giving the Federal Electric Reliability Council (FERC) regulatory authority over the reliability of the nation's transmission system. Since 2005, FERC has promulgated regulations providing national standards for vegetation management on transmission line ROWs. (Mcloughlin 2007) The following subsections describe the current vegetation management strategies employed by TVA and their ecological basis.

2.3.1 TVA's Transmission Vegetation Management Approach

FERC requires that all bulk power transmission lines (defined as 200 kV and above) be inspected once per calendar year with no more than 18 months between inspections (Federal Energy Regulatory

Commission 2014). In compliance with this regulation, TVA conducts annual aerial inspections on all of its transmission lines and annual ground inspections of lines 200 kV and above. Areas that show potential for vegetation encroachment are recorded for future maintenance. TVA manages the vegetation on its ROWs in two zones. Directly below the wires, grasses, forbs, and shrubs are allowed to remain and tall-growing vegetation is removed. On either side of the wire zone, border zones with taller growing vegetation are allowed. Traditionally, TVA has viewed vegetation over 4.5 meters (15 feet) tall as incompatible with the safe operation of the transmission system. However, tall-growing vegetation may be assessed on a site specific basis by ROW maintenance personnel. Typical wire zone maintenance intervals are 2 years for lines 200 kV and above and 3 years for lines below 200 kV. Trees in the border zones are managed on a 5-year cycle (J. T. Regg personal communication 12/4/2014). Mowing, hand clearing, or herbicides may be used for the control of vegetation depending on site topography and the species that need control. However, mechanical methods are discouraged because of the risk of resprouting (Tennessee Valley Authority 2013). These methods are typical of most North American utilities and have been developed based on more than 60 years of research and practical experience.

2.3.2 The Ecological Basis for Managing Succession

In 1953, two long-term ROW research areas were established independently at Pennsylvania Game Lands 33 and the Connecticut Arboretum. The goals of the Pennsylvania study were to determine the effectiveness of various herbicide treatments and to determine the effect of herbicide treatments on wildlife (Bramble and Byrnes 1967). The Connecticut study was conducted to demonstrate the use of selective herbicide treatments with the hope of showing indiscriminant herbicide spraying had been unnecessarily destructive. In addition to these two long-term studies, several other shorter-term studies sought to describe the plant community structure on ROWs after years of management.

The State Game Lands 33 Research and Demonstration Project began in 1953 after Pennsylvania Electric Company constructed a new 230 kV transmission line in the previous year. Two miles of the line crossing Pennsylvania State Game Lands 33 were set up as a research and demonstration area in cooperation with the Pennsylvania Game Commission, Pennsylvania State University's School of Forestry and Conservation, DuPont, Amchem, and Asplundh Tree Expert Company (Orr 2008). Table 2.1 summarizes the six initial treatments with follow-up sprays using the same methods plus two subsequent treatments.

Table 2.1 Summary of State Game Lands 33 ROW Maintenance Treatments

Treatment	Date	Herbicide	Concentration	Carrier	Rate (gal/ac)
A-Hand Cut	As needed	-	-	-	-
B-Broadcast	June 1953	2,4-D plus 2,4,5-T	4 lbs. aehg[1]	Water	460
C-Semi-basal	June 1953	2,4-D plus 2,4,5-T	6 lbs. aehg	Water plus Fuel Oil	345
D-Summer Basal	June 1953	2,4-D plus 2,4,5-T	12 lbs. aehg	Fuel Oil	140
E-Winter Basal	February 1954	2,4,5-T 2	12 lbs. aehg	Fuel Oil	137
F-Broadcast	June 1953	Ammonium sulfamate	0.75 lbs./gallon	Water	415
Follow Up B-D, C-D, D-D, F-D	June 1954	2,4-D plus 2,4,5-T	16 lbs. aehg	Fuel Oil	32
Follow Up E-D	June 1956	2,4-D plus 2,4,5-T	16 lbs. aehg	Fuel Oil	32
G-Selective Basal and Stump	June/July 1966	2,4-D plus 2,4,5-T	16 lbs. aehg	Fuel Oil	25
H-Stem/foliage	June/July 1966	2,4-D plus 2,4,5-T	4 lbs. aihg[2]	Water	206

1-acid equivalent per 100 gallons
2-active ingredient per 100 gallons
(Bramble and Byrnes 1967, Bramble and Byrnes 1976)

Based on the findings of these experiments, Bramble and Byrnes (1976) suggest a simple model for managed succession on ROWs. Given no maintenance, a ROW will tend to return to its previously forested state. In areas where vegetation is managed by mechanical cutting of tree saplings, the result is greater tree stem count and a suppressed herbaceous and shrub community (Bramble et al. 1991). Broadcast sprayed herbicides results in a grass-sedge community with few tree sprouts. Selective basal spraying initially results in communities dominated by forest understory shrubs (Bramble and Byrnes 1976). However with selective maintenance, both broadcast sprayed areas and selective basal sprayed areas can converge in a mosaic of forest understory shrubs, shrubs requiring full sun, grasses, and herbs (Bramble and Byrnes 1983). Such communities with dense stem counts of plants that reproduce vegetatively via rhizomes have some resistance to tree invasion, thus subsequent herbicide treatments are less intense (Bramble et al. 1991).

The Connecticut Arboretum Right-of-way Demonstration Area was initiated in response to public concern over the widespread use of broadcast herbicides on ROWs. The goal of the demonstration was to show that selective spraying could be an effective method of controlling tree invasion on ROWs. In 1953, a 457 m (1,500 ft.) segment of Connecticut Power Company's transmission line ROW was set aside for selective spraying. In 1957, another 610 m (2,000 ft.) long segment was set aside. Together, these two segments amounted to 4 ha (10 ac) of ROW (Niering and Goodwin 1974). The broadcast spray treatment was equal parts 2,4-D and 2,4,5-T in water. Additionally, old-field shrub communities in the Arboretum were set aside for observation of succession and potential community stability in 1967. Table 2.2 summarizes the initial treatments.

Table 2.2 Summary of Connecticut Arboretum ROW Demonstration Area Maintenance Treatments

Plot	Date	Location	Treatment	Concentration	% Killed
A	December 1953	Wire Border	Dormant Basal	1:20	90 (small sprouts only)
B	December 1953	Wire Border	Dormant Basal	1:20	90 (small sprouts only)
C	January 1954	Wire Border	Dormant Basal	1:20	90 (small sprouts only)
D	February 1954	Wire Border	Dormant Basal	1:20	100
E	April 1954	Under Wire	Spring Basal	1:40	Ineffective
F	September 1954	Under Wires	Broadcast	1:100	90-100 (Top kill only)
G	September 1954	Wire Border	Stem Foliar	1:100	53
H	December 1954	Wire Border	Dormant Basal	1:30	78
I	January 1955	Wire Border	Dormant Basal	1:30	78
K	February 1955	Under Wire	Dormant Stem	1:20	100 (5% resurge)
L	February 1955	Wire Border	Dormant Basal	1:20	>90
M	February 1955	Wire Border	Dormant Basal	1:20	100
N	April 1955	Under Wire	Electrocution	8000 Volts	Ineffective

(Niering 1957)

Much like the Pennsylvania study, selective herbicide treatments were shown to favor a shrub/grass/herb community after 20 years of observation. Previously forested areas formed a shrub/fern/grassland community. Old-fields on the ROW added to the study in 1957 formed a grassland/shrub community. In areas with high shrub density, little or no tree invasion occurred. This was also the case for monoculture patches of *Schizachyrium scoparium* (Niering and Goodwin 1974).

In addition to these long-term studies, several other studies have attempted to elucidate the succession of plants on managed ROWs. These studies are primarily *post hoc* studies of existing ROWs after years of management. When considering the validity of these studies it is important to note that the results of selective spray techniques are contingent upon proper identification of incompatible species by the applicators (Nationalgrid 2010). While the specific herbicide and cutting treatments differ, a general trend of response is evident. Specifically, indiscriminant spraying favors early successional herbaceous communities, selective spraying of tall woody vegetation favors shrub/grass communities, and cutting increases woody stem count. Table 2.3 summarizes these studies.

Table 2.3 Summary of *Post Hoc* ROW Maintenance Studies

Reference	No. of Plots (No. of ROWs)	State/ Provence	Year(s) of Treatment	Treatment	Results
(Stalter 1972)	3 (1)	RI	1963-1965	Selective vs. Control	Stump treatment and selective sprays favored some species of shrubs and eliminated most tree species.
(Johnston and Bramble 1981)	N/A (20)	NY	1961-1976	Broadcast vs. Selective	Broadcast sprays favor herbaceous plant communities.
(Luken et al. 1991)	60 (20)	KY	N/A	Manual cutting/ Mowing	Stem counts were increased by frequent cutting.
(Geier et al. 1992)	19 (3)	AB	1985-1988	Selective vs. Control	Selective sprays lead to higher diversity communities with relative stability.
(Meilleur et al. 1994)	360 (1)	QC	1978-1987	Selective and Manual cutting	Selective sprays favor shrub communities. High density shrubs suppress invasion. Low shrub density may facilitate invasion.
(Canham et al. 1998)	64 (16)	NY	N/A	Selective and Manual cutting	Selective sprays favor shrub communities through light competition.
(Abrahamson 1999)	58 (21)	NY	1975-1990	Selective and Manual cutting	Targeting tall trees with herbicide favors shrubs and small trees. Hand cutting tall trees increases the tree stem density 10 fold.
(Mercier et al. 2001)	175 (1)	QC	1978-1984 1987-1996	Herbicide Mowing	Acidic sites were more likely to exhibit high tree invasion. Vegetation gaps left by over spraying herbicides created favorable habitat for tree invasion. Hydric sites showed good resistance to invasion.
(Wagner et al. 2014)	27 (1)	CT/MA/NH	N/A	Herbicide and Mowing	ROWs have higher plant species richness than surrounding forests. This is the result of a combination of increased light and disturbance from mowing, herbicides, access roads, etc.

By targeting tall woody vegetation ROW managers are giving lower growing species a competitive advantage. Essentially, the selective spray management strategy creates an apparent competition condition as described by Holt. In a traditional apparent competition scenario, herbivores create a condition where one plant has a competitive advantage because neighboring species are more susceptible to herbivory (Holt 1977). In the case of selective spraying, humans create a condition where low growing vegetation has a competitive advantage because we exclude it from spraying. This creates the potential for a stable community when the shrub layer becomes dense enough to out-compete early successional trees. However, when shrub density is low or when there are breaks in the shrub canopy due to disturbance trees can easily emerge (Mercier et al. 2001).

While there is clearly a body of evidence to show that selective spraying is an effective technique for maintaining a stable low-stature plant community, caution should be observed in extrapolating these results in all areas. As described previously, the majority of the research in vegetation management has occurred in northeastern North America. Wright and Fridley showed that successional rates are dependent on latitude. Southern sites have exhibit generally faster rates of successional change due to their relatively long growing season (Wright and Fridley 2010). Furthermore, the suite of species found in northeastern North America is different from that found in other regions of the continent. Those species that are found throughout North America may occupy a different niche depending on latitude and physiographic province. Despite these differences, a useful common conclusion that can be drawn from the studies noted above is that a dense overstory can suppress the growth of tree seedlings.

2.4 Natural Plant Community Stability

Aside from shrub communities maintained through herbicide treatments, other plant communities dominated by grasses and herbs have shown stability. As previously noted, *Schizachyrium scoparium* communities were found to resist woody invasion in early experiments. In the long-term Pennsylvania research, communities dominated by introduced cool season grasses, by native warm season grasses, and by herbs were all found to be resistant (Bramble et al. 1990). In the Pacific Northwest, communities dominated by herbs were found to be more resistant to invasion than shrub dominated communities (Shatford et al. 2003).

Several studies have sought to describe the mechanisms that lead to community stability. At Cedar Creek, MN, *Andropogon gerardii* and *Schizachyrium scoparium* were shown to alter the nitrogen cycle and thus contribute to prairie stability by locking nitrogen in their leaf litter. With nitrogen limited *A. gerardii* and *S. scoparium* are able to out compete other plants and become dominant members of the community (Wedin and Tilman 1992). In New York's Hudson Valley, a study excluded herbivores to examine competition and facilitation in woody seedling growth on a gradient from herb and grass dominated cover to shrub dominated cover in old-fields and ROWs. Plots planted with seedlings were either left intact or cleared to eliminate above-ground competition. Growth and survival were measured for two growing seasons. Above-ground biomass was measured at the end of the second growing season. In shrub/grass meadows tree suppression was found under favorable weather conditions while facilitation was observed under drought conditions (Berkowitz et al. 1995). A second study from the same site found that early successional herbaceous communities in productive areas were the most easily invaded by trees. In contrast, communities dominated by *S. scoparium* had relatively high levels of tree seedling herbivory and showed good resistance to woody invasion (Hill et al. 1995). Data from the State Game Lands 33 project showed that a herb/grass community consisting of *Solidago* species, *Dennstaedtia punctilobula*, and *Danthonia spic*ata was resistant to tree invasion (Bramble et al. 1996).

The study found that the majority of tree seeds were consumed by granivores (Bramble et al. 1996). Those that were not eaten and were not dormant could not establish because of the thick mat of roots from the herbaceous layer (Bramble et al. 1996). Furthermore, soil moisture and aspect have been shown to influence diversity and richness on ROWs indicating that competition alone is not responsible for the composition of plant communities on ROWs (Cameron et al. 1997). While the research described above show sight specific mechanisms for community composition on a landscape scale, stability is most likely determined by complex interactions of these and other unknown mechanisms.

2.5 Initial Planting to Suppress Woody Invasion

It has been suggested that vegetation used for post construction erosion control also should be selected on the basis of invasion resistance (Arner 1960, Richards and Goodland 1973, Gillespie 1978, Brown 1995, De Blois et al. 2002, 2004). While limited data is available describing the invasion resistance of plantings on electric transmission ROWs, a few related studies describe woody invasion of areas with similar vegetation management strategies. Highway ROWs, landfill closure caps, and restored mines are all heavily disturbed areas where vegetation establishment and persistence is a crucial management goal. Much like transmission ROWs, these areas have traditionally been revegetated using exotic cool season grasses and forbs. However, with growing concerns that commonly used species have the potential to become invasive exotic pests, there is increasing interest in using native vegetation for site stabilization (Harper-Lore 1999).

Prior to the regulation of construction stormwater as a pollutant by the Clean Water Act, little emphasis was placed on revegetation of transmission lines in previously forested areas (C. F. Peters, personal communication, May 9, 2013). In the 1970s, Ontario Hydro began investigating the use of *Phleum pretense*, *Phalaris arundinacea*, *and Bromus inermis* as cover crops with the potential to resist invasion. Anecdotal evidence showed a decrease in woody stem count in seeded ROWs as compared to unseeded ROWs (Gillespie 1978). A more rigorous study begun in Ontario during the spring of 1989 tested the inhibitory effect of *Dactylis glomerata, Festuca rubra, Lotus corniculatus,* and a *mixture of Coronilla varia* and *Lolium multiflorum* on 1-year-old transplants of *Fraxinus pennsylvanica, Acer saccharum,* and *Populus* x *canadensis*. After five years, *D. glomerata* was found to reduce forb biomass by 70% and survival of *F. pennsylvanica* and *P. canadensis* was reduced by up to 75% (Brown 1995). In a study of bird abundance on reclaimed strip mines in Indiana, it was reported that *Lolium arundinaceum* (also known as *Festuca elatior*) and *Bromus inermis* made up 64% of the canopy cover several decades after reclamation. The persistence of *L. arundinaceum* may be explained partially by advantages imparted by the endophytic fungus *Neotyphodium coenophialum*. In an example of apparent competition, the endophyte makes *L. arundinaceum* unpalatable to herbivores. Instead of eating young shoots of the grass, *Microtus* spp*.* (voles) consume young tree seedlings. In an experiment conducted at the University Of Indiana Botany Experimental Field in Bloomington, IN, the presence of the endophyte increased tree seedling predation by 65% over controls.

Invasive species have increasingly become a problem for land managers (Simberloff 2001). As a result Executive Order 13112 was signed in 1999 with the goals of limiting the spread of invasive species and promoting the restoration of native species on federal lands (Clinton 1999). Armed with information and regulations, mine reclamation managers have begun to see native grasses and forbs as an attractive alternative to exotic grasses (Richards et al. 1998). A strip mine in Illinois that was restored with prairie species in the 1970 showed stability at the community level; however, the dominant grass *Panicum virgatum* was found to slowly replace *Sorghastrum nutans* after 15 years of growth (Corbett et al. 1996). Contrary to these findings, a study of iron mine tailing stabilization using *P. virgatum* found that this species had a facilitative effect on early successional trees. Specifically, the authors found *Panicum virgatum* improved the soil, captured wind born tree seeds, and acted as a nurse crop for young tree seedlings (Choi and Wali 1995). These contradictory results may be explained by site-specific conditions.

Despite the lack of clear evidence showing that native grasses can impede woody succession, interest in their use for revegetation remains high. In 1999 the Federal Highway Administration produced a report detailing techniques and resources for restoring roadside ROWs with native vegetation (Harper-Lore 1999). A study conducted outside of Austin, TX, compared the establishment of native warm season grasses to Texas Department of Transportation typical roadside restoration seed mix containing primarily introduced grasses. The researchers found that native grasses established faster in more sever climatic conditions than the conventional mix (Tinsley et al. 2006). Likewise, a landfill closure cap on the Savanah River site near Aiken, SC found that native grasses typical of local old-fields could be successfully established while showing the potential for tree invasion resistance (Kwit and Collins 2008). Other projects have focused on the environmental and ecological benefits of native grass plantings. The most widespread of these is the Unites States Department of Agriculture's (USDA) Conservation Reserve Program (CRP). The CRP is a nationwide program that began with the Food Security Act of 1985 with the goal of converting environmentally sensitive farm land into native grasslands to reduce non-point source pollution and improve wildlife habitat (Farm Service Agency 2014). Within Tennessee, projects such as the Catoosa Wildlife Management Area Oak Savanna Restoration and the Native Grass Community Management Plan for the Oak Ridge Reservation have sought restore native grassland communities for the benefit of the general public (Ryon et al. 2006, Vander Yacht 2013). The coupling of potential direct benefits such as improved revegetation performance with known indirect social, ecological, and environmental benefits is a key focus of my research.

CHAPTER 3

A COSTS-BENEFITS ANALYSIS OF NATIVE PLANT SPECIES FOR RIGHT-OF-WAY REVEGETATION

3.0 Introduction

Transmission lines are the arteries of electrical transport for the North American electrical energy system, traversing approximately 716,000 km (445,000 mi). These lines, defined as those transmitting 69 kV and above, form an electrical grid that delivers energy from electrical generation sites to local substations. As a result of economic growth and the need for a stable, reliable electric grid, an additional 48,000 km (30,000 mi) of transmission lines were under construction or planned to be constructed by the between 2011 and 2019 (North American Electric Reliability Corporation 2011).

In addition to their vital role to North America's energy infrastructure, transmission lines also have been shown to have ecological values. For example, transmission line ROWs have been demonstrated to serve as a refuge for prairie plant species in southeastern North America (Davis et al. 2002). The flora of transmission line ROWs also have been recognized as an important resource for pollinators (Wojcik and Buchmann 2012). Likewise, transmission lines have been shown to be habitat for shrubland birds, reptiles, amphibians, and small mammals (Johnson et al. 1979, Yahner et al. 2001, King and Byers 2002).

While transmission line ROWs play an important role in the ecology of environments heavily disturbed by human influence, some of the life forms on of transmission lines can be problematic. Given the danger of arcing between transmission lines and tall vegetation, the elimination of trees on transmission line rights-of-way (ROWs) is a key element of maintaining the national electric grid. Traditionally, ROW vegetation maintenance and post construction ROW revegetation were managed by two separate organizations at TVA. Little consideration was given to the long-term effects of ROW revegetation species selection. Recent organizational changes at TVA have placed revegetation and vegetation maintenance within the same work group. This provides an opportunity to take an ecologically sound approach to ROW revegetation. Native warm season grasses (NWSG) are prairie remnant species often found on ROWs throughout the Southeast. Based on a review of available literature, NWSG have the potential of to slow succession and reduce woody invasion (Hill et al. 1995, Bramble et al. 1996, Corbett et al. 1996, Kwit and Collins 2008). This makes use of NWSG for post-construction revegetation of transmission line ROWs an attractive option with the potential for long-term maintenance cost savings.

In response to declining revenues from overall slow economic growth, the Tennessee Valley Authority (TVA) began a major effort to reduce its operating and maintenance expenses in 2011 (Tennessee Valley Authority 2014c). In support of this effort, the TVA's Transmission Power Systems, as the organization responsible for constructing and maintaining the TVA's electric transmission system, and the TVA's Environment organization, as the organization responsible for maintaining compliance with environmental regulations, organized five pilot projects in the summer of 2014 to determine the feasibility of planting NWSG on recently disturbed electric transmission line ROWs. Three of these projects were chosen for qualitative study and only provided a pass/fail measure of success. Two of these projects were selected for quantitative study with the intention of long-term monitoring because of their size, their close proximity to conventional grass plantings, and their location on federally owned land. To help determine the direct and indirect benefits of planting NWSG relative to their additional initial cost, I conducted a combined study of field trials and cost-benefit analyses. Given that the economic benefits of NWSG on TVA's ROWs may not be realized for several years, it is impossible to assign them a monetary value based on data from a simple feasibility study. Rather, this work compares the actual initial cost difference between exotic, cool season grass (ECSG) and NWSG to their estimated direct and indirect benefits.

3.1 Methods

Cost-Benefit Analysis (CBA) is a technique typically applied to economic decision making that is often used by industry and government when deciding between two or more options (Hanley and Spash 1993). In simple terms, the costs and benefits of each alternative are quantified with the option that has the greatest benefit relative to its cost deemed to be the best. As early as 1808, CBA was used in the U.S. for the consideration of alternatives on infrastructure and environmental projects (Hanley and Spash 1993). Today, CBA may be used in a variety of applications from assessing preschool programs to major infrastructure projects (Barnett 1996, Vickerman 2007). This method is often used when setting environmental policy with costs calculated as the capital necessary to implement a regulation and benefits estimated either by valuation of the public health savings of a particular alternative or by conducting willingness to pay surveys for an environmental service (Kahneman and Knetsch 1992, Revesz 1999). CBA has limitations when considering environmental problems because they often attempt to monetize the benefits and costs of environmental services using public opinion surveys. However, they remain a common tool used for decision making (Ackerman and Heinzerling 2002).

As the name implies, cost benefit analysis (CBA) requires an estimation of the costs and benefits of the alternatives considered. Key data required for the cost side of my analysis were the time necessary for vegetation to meet the conditions of state construction stormwater regulations, the failure rate of revegetation efforts, and the costs of equipment and materials necessary for implementation. These data were acquired for both NWSG and ECSG through a combination of field trials, examination of historical data, and surveys of industry professionals. To find the expected maximum and minimum number of days from planting to permit termination for NWSG, I combined regional weather data with the minimum germination rates calculated from the two plantings selected for long-term study. The planting success rate for NWSG was obtained by surveying NWSG revegetation professionals and supported by combined data from the plantings used for qualitative study with data from the plantings used for quantitative study. For ECSG I found the number of days from planting to permit closure and the planting success rate by reviewing TVA's archived construction schedules from 2012 to 2014. These parameters were verified by surveying industry professionals. I obtained cost data for NWSG and ECSG through TVA from a combination of actual expenses provided by TVA contractors, national statistical data, and vendor quotes.

For the benefit side of my analysis, I calculated break even cost savings considering the cost difference between NWSG and ECSG as an initial investment. The results of this analysis can be used to guide future decision making. Direct benefits were estimated to show the potential for cost savings given a modest initial investment. Indirect benefits were estimated from a review of literature on similar projects, but no attempt to monetize these benefits was made.

3.1.1 Feasibility Study

3.1.1.1 Study Site Descriptions

Five planned TVA transmission line corridor sites for an initial NWSG feasibility study were chosen during fall 2013 and spring 2014. The number, size, and location of sites were based on landowner cooperation, construction schedules, and construction budget. Details of these sites are shown in Table 3.1 below. Since the Hillsboro and Waynesboro sites were on privately owned property and TVA's easement rights do not restrict private landowner's use of their property, these sites were rejected for quantitative study because landowners may choose to develop or disturb their property at any point in the future, invalidating data from long-term study. The remaining three sites were located on federally owned property in Cherokee National Forest in Polk County, TN, Oak Ridge National Laboratory (ORNL) in Roane County, TN, and at Gallatin Fossil Plant (GAF) in Sumner County, TN. The Cherokee National Forest site consisted of narrow construction access roads and was rejected for qualitative study because of its size and a lack of adjacent conventional plantings for comparison. The

ORNL and GAF sites were accepted for qualitative study because they were adequately large enough plant both NWSG and ECSG adjacent to one another and because federal ownership helps to ensure that they will be available for study in the future.

Table 3.1 NWSG Feasibility Study Sites

Site	Latitude	Longitude	NWSG Planting Area (ha)	NWSG Planting Area (ac)	Physiographic Provence	Data Acquired
Waynesboro	35.33152	-87.75549	0.40	1	Highland Rim	Pass/Fail
Hillsboro	35.41689	-86.01481	2.02	5	Highland Rim	Pass/Fail
Cherokee	35.17841	-84.57590	0.28	0.7	Blue Ridge	Pass/Fail
GAF	36.31142	-86.40164	0.89	2.2	Nashville Basin	Plant Density
ORNL	35.93425	-84.32034	1.34	3.3	Ridge and Valley	Plant Density

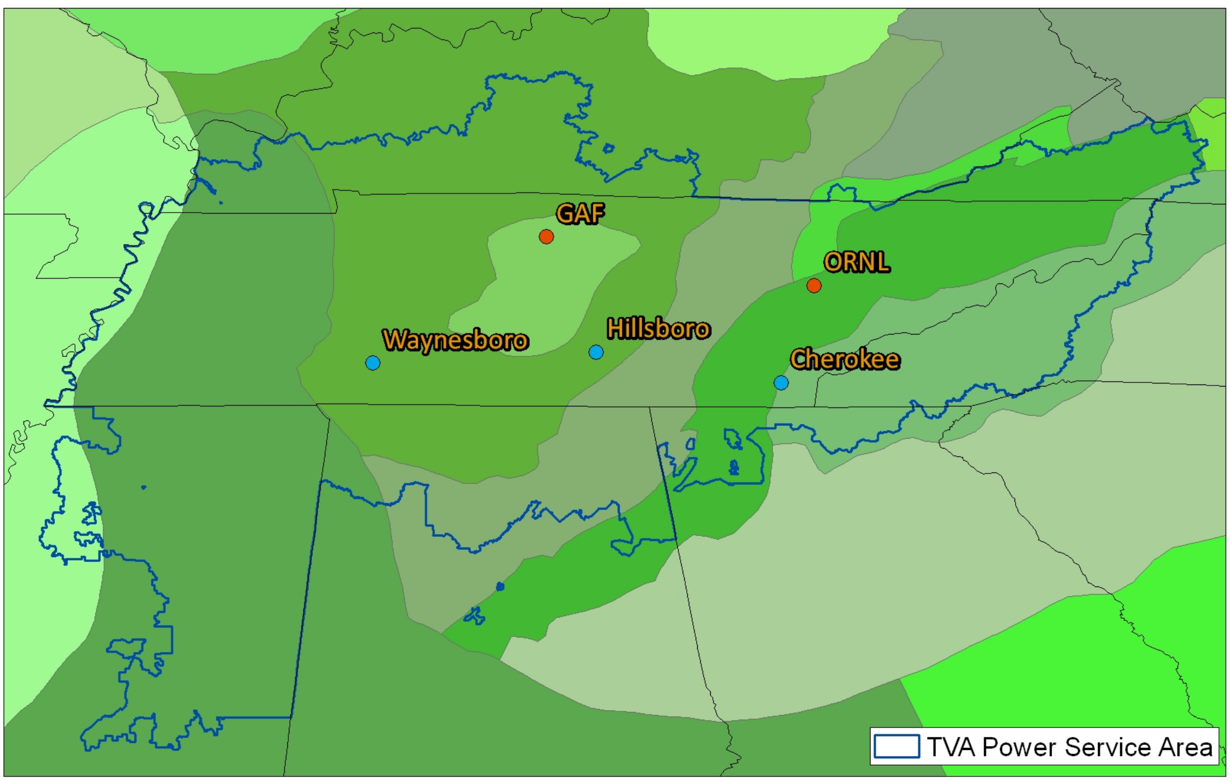

Figure 3.1Feasibility Study Site Locations

The Oak Ridge National Laboratory site lies on a transmission line corridor on the southeastern aspect of a ridgeline roughly paralleling Bethel Valley Road. The transmission line alignment has a northeasterly orientation, running from Tennessee State Route 95 to TVA's Bethel Valley Substation. Figure 3.2 shows the alignment and surrounding area. The project area is in the Ridge and Valley Physiographic Provence. While soil reports are not available for the specific location, field investigation by of a nearby site by GEOServices LLC (Knoxville, TN) and laboratory analyses of soil samples I collected along the ROW by the University of Tennessee Institute of Agriculture Soil, Plant, and Pest Center (Nashville, TN) show that the soil strata consist of 102-356 mm (4-14 in.) of topsoil with underlying lean and fat clay residual soils with varying amounts of chert fragments (GEOServices LLC 2013). This is consistent with the band of Fullerton, Dewey, and Waynesboro soil types found to the northeast and southwest of ORNL along the same ridgeline. The soils are moderately well drained and are derived from Cambrian and Ordovician limestones, dolomites, shales, and silty sandstones (DeSelm et al. 1969). Extensive faulting and folding from geologic forces has resulted in sharp dipping of the rock strata yielding parallel ridges of rock resistant to weathering and valleys of softer limestone and shale (DeSelm et al. 1969). The topography of the project area consists of flat benches, rolling hills, and steep slopes up to 20% in grade. The climate is typical of eastern Tennessee with adequate precipitation for vegetation in all seasons (DeSelm et al. 1969). The forests are typical of the temperate deciduous forest and are dominated by *Quercus* and *Carya* with *Pinus* and *Juniperus* interspersed (DeSelm et al. 1969).

The Gallatin Fossil Plant site lies between the plant to the north and Old Hickory Reservoir of the Cumberland River to the south. The transmission line corridor extends from the main transmission line corridor originating from at plant's main switchyard to the plant's newly constructed emission control facility switchyard. Figure 3.3 shows the alignment and surrounding area. The topography of the project area is generally flat with a few short, rolling hills. The climate of Sumner County is typical of central Tennessee with adequate precipitation for vegetation in all seasons (Prater 1997). The project area is in the Nashville Basin Physiographic Provence. The soils of this area clayey and are derived from decomposed limestone and alluvium (Prater 1997). The soils in the immediate project area are described as Udorthents indicating that the area has previously been disturbed with the original soil strata excavated, filled, or homogenized such that the origin of the soil cannot be generally described (Prater 1997). The forest in the project area is dominated by *Pinus taeda* approximately 20 m (65 ft.) in height with an understory of *Ligustrum sinense*. The presence of Udorthents and a *Pinus* dominanted canopy indicates that the site was heavily disturbed 50-75 years ago. This is consistent with the initial construction of the plant which took place between 1953 and 1959 (Wren 2013).

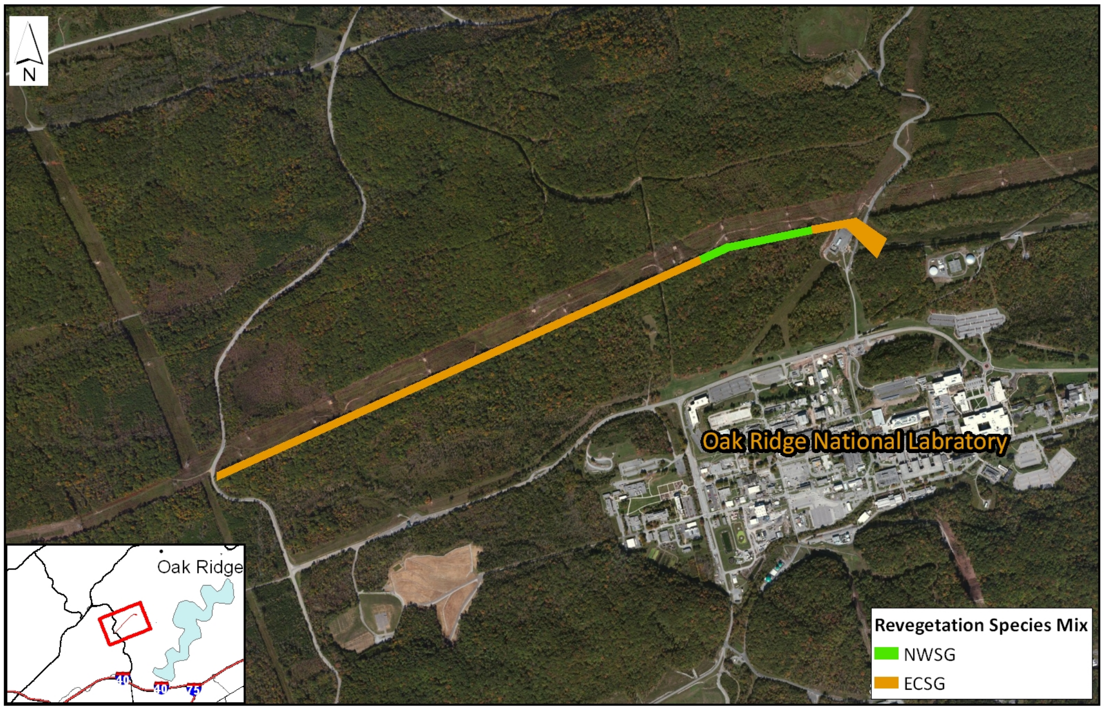

Figure 3.2 ORNL Revegetation Area

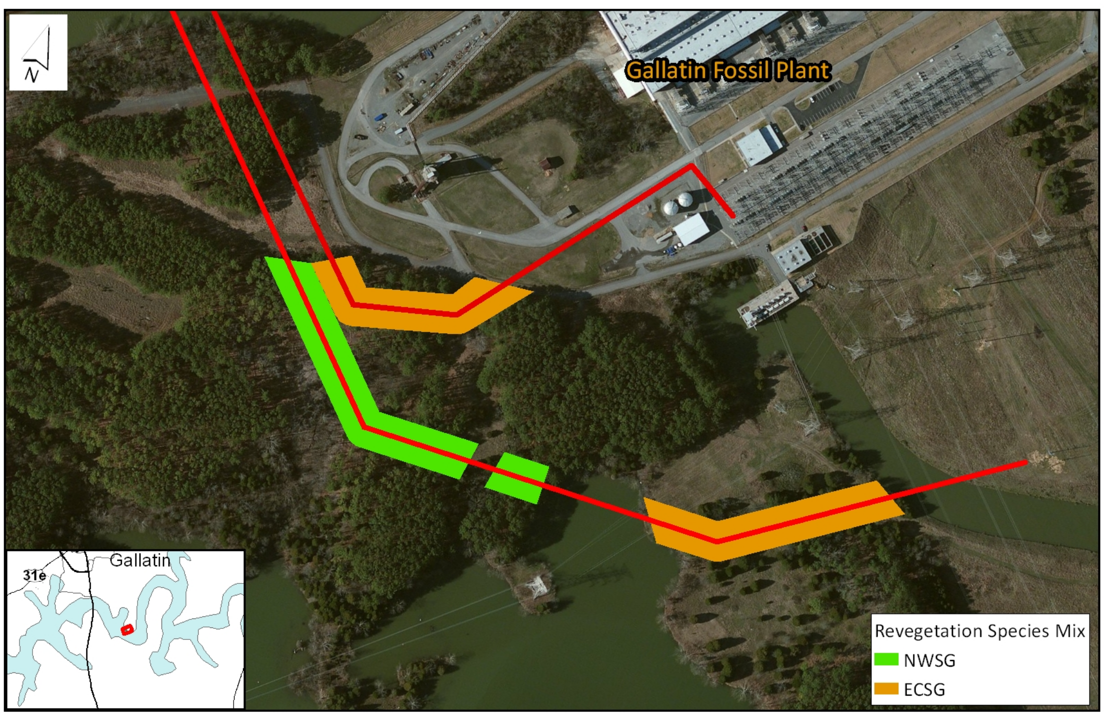

Figure 3.3 GAF Revegetation Area

3.1.1.2 Planting

For ECSG plantings, the planting procedure, grass mix, and soil amendments were all specified by TVA's standard revegetation specification (Muncy et al. 2012). As is standard practice, seed and soil amendments for ESCG plantings were obtained by the revegetation contractor with no retention of records for seed source or amendment manufacturer. ECSG species were selected on the basis of availability and their adaptability to the soils and climate of the TVA power service area. *Lolium arundinaceum* (tall fescue) and *Dactylis glomerata* (orchard grass) were chosen for their suitability to upland, mesic sites; *Agrostis gigantea* (redtop grass) was added to the mix for its suitability to mesic to partially hydric lowlands; *Trifolium repens* (white Dutch clover) was used to add nitrogen to the soil; and the annual *Avena sativa* (oats) was used for quick soil stabilization for erosion control. Exotic warm season grasses are not typically considered for ROW revegetation because the TVA power service area lies just above the northern extent of most commercially available exotic warm season species. Seed was purchased as bulk seed meaning that the non-viable seed, inert matter, and foreign seed were not accounted for in the planting. The specified seed mix and broadcast rate are shown in Table 3.2. ESCG were planted at GAF and ORNL on 17 April 2014 and 27 March 2014 respectively by Crisp and Crisp Inc. of Robbinsville, NC a clearing, restoration, and erosion control contractor used extensively by TVA. The planting procedure consisted of removing large roots or rocks from the planting area followed by one pass by a bog disk harrow to prepare the seed bed. After seed bed preparation, the seed was broadcast with 6-12-12 N-P-K fertilizer at approximately 11,200 kg/ha (1000 lb/ac). Lime was added at a rate of 44, 840 kg/ha (2 tons/ac) to lower the pH of the soil to a level suitable for growing grass. This rate was determined by standard practice, not by laboratory analysis and recommendation. After broadcasting seed and fertilizer, wheat straw was applied to 75% uniform density.

Table 3.2 ECSG Revegetation Seed Mix

Perennial Grasses		Rate (kg/ha)	Rate (lbs./ac)
Lolium arundinaceum	Tall Fescue	22.4	20
Dactylis glomerata	Orchard Grass	22.4	20
Agrostis gigantea	Red Top	6.7	6
Forbs			
Trifolium repens	White Clover	4.5	4
Annual Nurse Crops			
Avena sativa	Spring Oats	5.6	50

Native, warm season grasses were planted at GAF and ORNL on 3 May 2014 and 4 May 2014 respectively by Roundstone Native Seed LLC of Upton, KY, a native seed vendor and restoration contractor that serves the Southeast and Midwest. The NWSG mix was applied in a similar fashion to the ECSG. Unlike the ECSG planting, the seed bed was prepared by one pass of a bog disk harrow followed by a second pass with a finish disk harrow. The seed bed was then compacted using a cultipacker to remove any large clumps of soil. This provided a firm, even seed bed which is contrasted with the rough, uneven seed bed used for planting ECSG. After cultipacking the seed mix shown in Table 3.3 was broadcast followed by a second pass with the cultipacker to ensure good seed to soil contact. Seed was purchased as pure live seed (PLS) meaning that the non-viable seed, inert matter, and foreign seed were accounted for in the planting. No soil amendments were added to modify soil nutrients or pH. Following the broadcast seeding wheat straw was applied to 75% uniform coverage. The NWSG mix was designed by Roundstone Native Seed LLC in cooperation with TVA. Species were selected based on price, historical presence in the TVA power service area, and their potential to suppress woody species. All perennial grasses except *Elymus virginicus* are warm season grasses. The annual forbs *Cassia fascuculata* (partridge pea) and *Bidens aristosa* (showy tickseed) and the biennial *Rudbeckia hirta* (black eyed susan), were added to the grass mix for quick establishment and erosion control. The annual forb *Desmanthus illinoensis* (Illinois bundle flower) was included in the mix to fix nitrogen and for its value for wildlife. The annuals *Lolium multiflorum* (annual rye) and *Panicum ramosum* (brown top millet) were used for quick soil stabilization for erosion control. This mix is similar to those utilized for Conservation Reserve Program (CRP) plantings.

Table 3.3 NWSG Revegetation Seed Mix

Perennial Grasses		PLS Seeding Rate (kg/ha)	PLS Seeding Rate (lbs./ac)
Panicum virgatum	Switchgrass	56	5
Schizachyrium scoparium	Little Bluestem	25.2	2.25
Elymus virginicus	Virginia Wild Rye	25.2	2.25
Andropogon gerardii	Big Bluestem	11.2	1
Sorghastrum nutans	Indian Grass	11.2	1
Panicum anceps	Fall Panicum	8.4	0.75
Tridens flavus	Purple Top	8.4	0.75
Forbs			
Cassia fascuculata	Partridge Pea	7	0.625
Bidens aristosa	Showy Tickseed	4.2	0.375
Rudbeckia hirta	Blackeyed Susan	3.5	0.3125
Desmanthus illinoensis	Illinois Bundleflower	2.8	0.25
Annual Nurse Crops			
Panicum ramosum	Brown Top Millet	56	5
Lolium multiflorum	Annual Rye Grass	44.8	4

3.1.2 Data Acquisition

3.1.2.1 Weather Data

Since site rainfall, temperature, wind, and humidity can all affect the performance of seedlings weather data was collected to help explain variation in the two sites. For each site, daily rainfall data were acquired from automated rain gauges owned and read by TVA. At GAF an onsite rain gauge was used. At ORNL a rain gauge at Melton Hill Dam, approximately 5.6 km from the project site, was used. Temperature, humidity, and wind data for the duration of the trial were acquired via www.weatherunderground.com (accessed 18 January 2015) for Nashville International Airport for GAF and from McGhee Tyson Airport for ORNL. Historical rainfall data from 1 May 2004 to 31 July 2014 were acquired for Bowling Green, KY, Bristol, TN, Chattanooga, TN, Columbus, MS, Huntsville, AL, Knoxville, TN, Nashville, TN, and Knoxville, TN from the National Oceanic and Atmospheric Administration National Climatic Data Center database (retrieved 22 January 2015) for use in calculating the average return period for rainfall events of 20 mm (0.80 in) or greater for the TVA power service area. These data were used to calculate the expected number of days to coverage per state regulations.

3.1.2.2 Seed Mix Germination Laboratory Testing

For NWSG, seed test data was supplied by the seed vendor. Seed tests were undertaken in accordance with Association of Official Seed Analysts (AOSA) standards. After holding the seeds in a germination medium for 14 days the number of dead seeds, germinated seeds, and dormant seeds were counted (Association of Official Seed Analysts 1993). For species with very low or very high dormancy, the seed viability was tested using tetrazolium chloride (TZ) per AOSA standards. For these species the live seeds were assumed to be either completely dormant or to have complete germination. Since each species in the seed mix had a different germination percentage a weighted average germination percentage was calculated for the mix.

3.1.2.3 Field Planting Evaluation

Most state construction stormwater regulations specify that the site must be stabilized with 70% vegetation coverage. Standard practice for the assessment of ECSG is to estimate visually the planting density giving a qualitative measure of planting success. This methodology is used in the field by both state regulators and TVA construction stormwater inspectors because the goal of the planting is to stabilize the soil and prevent erosion loss. This approach is only possible because of the high planting rates for ECSG. Since NWSG have a much lower planting rate a quantitative measure of planting density is necessary. Since none of the states in the TVA power service area dictate a quantitative technique for measuring revegetation plant density a technique from agricultural research was adapted. The perennial plant density of the NWSG plots at GAF and ORNL was determined by using a modified frequency grid as suggested by Vogel and Masters (2001). Specifically, a 5 x 5 grid consisting of wires on 406 mm (6") centers was placed on the ground. The number of cells containing NWSG was recorded and divided by the total number of cells (25) to determine the density within the grid (Vogel and Masters 2001). Forbs were excluded from the counts since state stormwater regulations specify permanent cover must be by perennial vegetation. In consideration of this, *D. illinoensis* would have been included in the counts, but its close similarity to *C. fascuculata* at the seedling stage made accurate identification impossible. Given that *C. fascuculata* was a minor component of the seed mix, this is not thought to have skewed the results. NWSG seedlings were identified by carefully uprooting the seedling and examining the empty seed coat which was still attached to the roots. At GAF, a minimum of seven measurements were taken monthly between 1 June 2014 and 31 September 2014. The procedure for selecting data collection locations was adapted from TVA recommendations for soil sampling (TVA unpublished). Data collection locations were determined by taking an initial measurement adjacent to the site access, turning a random angle between 0 degrees and 180 degrees, and then stepping off a random distance between 0 and 20 paces as determined with a random number generator. This procedure was followed after each measurement to determine the next sampling location. The density within each grid measurement was averaged for each month. This was assumed to be the perennial plant density of NWSG for the site. At ORNL germination was not homogeneous, which complicated the ability to randomize data collection locations. Instead, planting density was recorded only in areas where germination occurred. In these small areas, data collection locations were selected that were representative of each area. Observations were made monthly from June to September. In August, observations were made, but no data were collected because there was no change from the previous month. While the germination success of the Waynesboro, Hillsboro, and Cherokee sites was not measured quantitatively, they were observed throughout the growing season and qualitative observations of planting success were made on a pass/fail basis. These data were used in determining the overall feasibility of NWSG plantings. The success rate of the feasibility trials was determined based on the 70% coverage criterion described above. Each of the five sites was assessed qualitatively as pass or fail. Sites that required follow up plantings were deemed a failure.

3.1.2.4 Expected Time for NWSG to Meet Permit Requirements

Since the number of days from NWSG planting to 70% perennial cover was only determined for one planting an expected range for this quantity was calculated using the change in plant density over time. Given that the seed at each site was broadcast at a uniform distribution and the soils and topography at each site were generally homogeneous the rate of change in plant density was used as an analogue for the germination rate. This made it possible to compare field germination with laboratory seed test results. The rate of change in plant density for each site was calculated from the data collected as described above. For conservatism, the minimum of rate from the plantings at GAF and ORNL was used as the minimum field rate of change in plant density. The maximum possible rate of change in plant density was assumed to be the weighted average rate from laboratory testing. The maximum and minimum rates were used to calculate the maximum and minimum number of days from initial germination to vegetation density per state regulations. Since germination generally will not occur until the seed has been thoroughly wetted, the number of days calculated from the minimum germination rate above was added to the average return period for 20 mm (0.80 in) or greater rainfall as described above. Typical industry practice dictates that seed bed preparation and planting cannot occur when the soil is saturated. Generally, planting occurs at four or more days after rainfall of 20 mm (0.80 in) or more. Deducting this time from the sum of the average return period for 20 mm (0.80 in) or greater rainfall and the number of days calculated from germination to permit closure gave the expected maximum number of days from planting to permit closure. Assuming rainfall greater than 20 mm (0.80 in) immediately after planting and the maximum possible germination rate gave the expected minimum number of days from planting to permit closure. Figure 3.4 shows these methods in flowchart form.

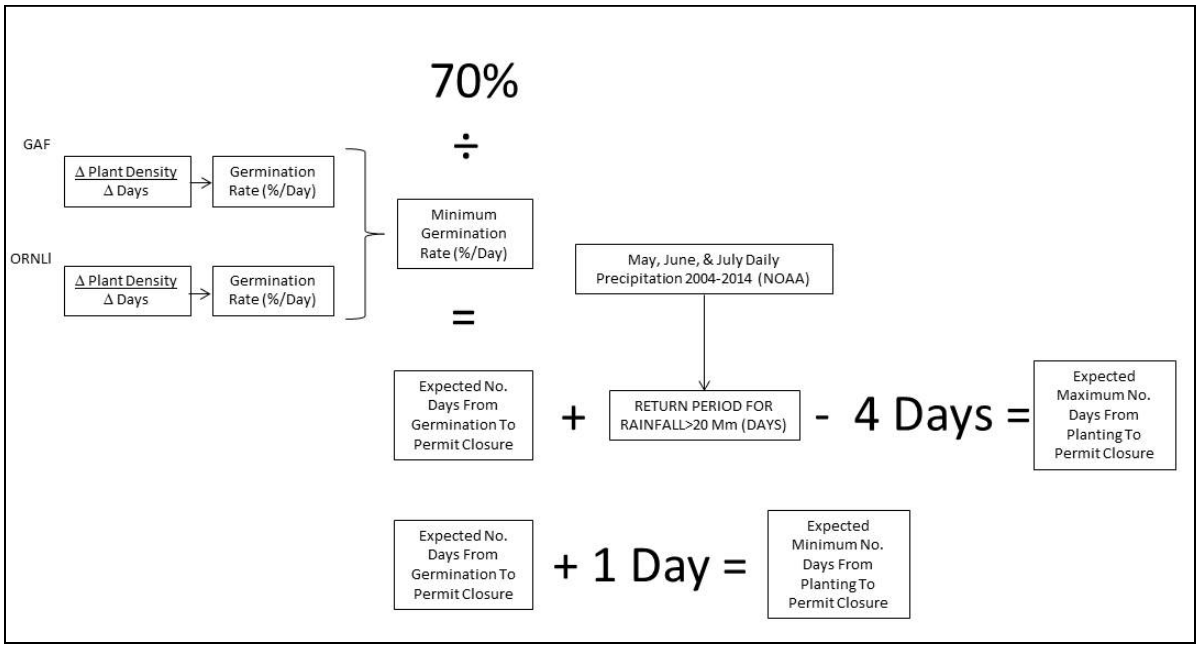

Figure 3.4 Calculation Steps for Determining the Expected Time to Reach 70% Vegetation Coverage

3.1.2.5 TVA Historical Project Data

A review of all TVA transmission line construction projects completed between February 2012 and December 2014 was conducted to determine the average area of disturbance, the average duration from revegetation to construction stormwater permit closure, the average number of post revegetation construction stormwater inspections, and the average failure rate of spring/summer revegetation efforts. Since state stormwater regulations require construction stormwater permitting for sites with greater than 0.40 ha (1 ac) of disturbance, only these projects have records tracking when the revegetation effort is successful. Thus, only projects with greater than 0.4 ha (1 ac) of disturbance were considered for review. Projects with delays not related to revegetation were removed from the data set. These included project delays from construction sequencing, material delivery, property owner damage claim resolution, and re-engineering to meet customer requests.

Project disturbed area was determined by reviewing construction stormwater permit applications. Revegetation planting dates and permit closure dates were acquired from TVA's archived construction schedules. Because this research focuses on comparing NWSG with ECSG planted in the late spring, these plantings were divided into spring/summer plantings and fall/winter plantings. Because each of the seven states within TVA's power service area have different requirements for post revegetation inspections and TVA's construction projects are not uniformly distributed among the seven states, a weighted average number of inspections per project per month was calculated by multiplying each state's required number of inspections by the number of projects within each state then dividing the summation of inspections by the number of projects within the data set.

3.1.2.6 Stand Establishment Duration and Failure Rate

Ideally, ECSG revegetation success would be determined by reviewing the invoices from revegetation contractors for each of the 46 projects discussed above; however, such data were not available because TVA's cost tracking archives were found to be incomplete. Instead, revegetation failures were assumed to be projects where the permit closure date for the project was in a different growing season than the revegetation finish date. This assumption was made because TVA's schedule tracking process records the date that the revegetation activity begins and ends, but does not track any follow up revegetation work necessary to satisfy state stormwater regulations. The average failure rate was calculated by dividing the number of projects with planting failures by the total number of projects where revegetation was attempted. The duration from revegetation to construction stormwater permit closure was calculated by counting the number of days from the revegetation planting end date to the permit closure date. For comparison with NWSG plantings, the average number of days to permit closure was calculated by averaging the number of days for successful plantings. Given that permit closure is based on planting density, the average number of days to permit closure was assumed to be equal to the average number of days to establish vegetation at 70% uniform coverage per state stormwater regulations.

3.1.2.7 Survey Methods

Many project specific variables can affect the success rate of revegetation efforts. For the NWSG feasibility trials undertaken by TVA in the summer of 2014, the success rate could be taken as the number of successful plantings divided by the total number of plantings. However, with only five plantings, the validity of this success rate is suspect. To confirm the success rate of ECSG plantings and NWSG plantings, a survey of revegetation professionals was conducted to determine the success rate of spring/summer grass plantings, and the establishment duration for spring/summer grass plantings.

Forty-two individuals were sent the survey via email. The surveyed group was recruited from individuals known by the author to have five or more years of experience in ROW revegetation with ECSG and by NWSG revegetation contractors recommended by Roundstone Native Seed LLC of Upton, KY. Participants were asked for the information described in Figure 3.5. Question 1 was used to segregate responses between individuals with experience with NWSG from those with experience with ECSG. For questions 2 and 3, responses were quantified using the median of each range, the maximum value, or the minimum value. Question 4 was used to determine if planting success is more a function of variables within the control of the revegetation professional or variables outside of the control of the revegetation professional.

1) Select which grass list best describes your typical revegetation mix.

[ ] Tall Fescue, Orchard Grass, Bermuda Grass, Clover
[ ] Switchgrass, Big Bluestem, Little Bluestem, Indian Grass, Partridge Pea

2) What percentage of projects require follow up seeding after the initial site restoration and revegetation effort?

[ ] Less than 10%
[ ] 10-20%
[ ] 20-30%
[ ] 30-40%
[ ] 40-50%
[ ] Greater than 50%

3) For sites that need follow up seeding, what percentage of the original area typically needs to be re-seeded?

[ ] Less than 10%
[ ] 10-20%
[ ] 20-30%
[ ] 30-40%
[ ] 40-50%
[ ] Greater than 50%

4) In your opinion, what is the most important factor in revegetation success?

[ ] Rainfall
[ ] Planting date
[ ] Soil
[ ] Terrain
[ ] Contractor experience

Figure 3.5 Survey Questions Presented to Revegetation Professionals

3.1.2.8 Cost Data

To complete the CBA, all cost data had to be converted into a common unit. The major costs considered were planting equipment, materials, and post revegetation construction stormwater inspections. TVA writes its revegetation contracts as “turn-key” projects with the costs of materials and equipment combined into a cost per unit area. To decouple these costs, market prices for ECSG seed, fertilizer, and lime were acquired from the USDA National Agricultural Statistical Service Quick Stats database and confirmed by quotes from three large seed vendors in the TVA power service area. These material costs were deducted from the average contract revegetation costs per unit area for TVA’s three most commonly utilized revegetation to give the average equipment cost. NWSG seed cost was based on actual seed cost from seed supplied by Roundstone Native Seed LLC of Upton, KY and confirmed with quotes from three other large seed vendors in the TVA power service area. Additional equipment costs per unit area for NWSG were based on actual equipment costs from Roundstone Native Seed LLC (Upton, KY). These costs are consistent with equipment cost rates from TVA’s revegetation contractors. Because equipment and material rates were calculated in terms of dollars per unit area, construction stormwater inspections were converted to this unit using the average cost per inspection from TVA’s estimating system, the average number of inspections per month after revegetation, the average number of days from revegetation to permit closure, and the average disturbed area for the projects completed between 2012 and 2014. This resulted in inspection cost per unit area per day. For ECSG this figure multiplied by the average number of days from revegetation to permit closure was used as the inspection cost per unit area. For NWSG the inspection cost per unit area per day was multiplied by the actual number of days from planting to 70% perennial plant coverage was used as the inspection cost per unit area. Figure 3.6 shows the calculation steps to determine the cost of inspections per unit area. Equipment, material, and inspection costs for NWSG and ECSG revegetation were totaled then multiplied by a replanting cost factor to account for different failure rates for NWSG and ECSG. The replanting cost factor was calculated as one plus the product of the average failure percentage and the average replanted percentage. Figure 3.7 shows the calculation steps described above.

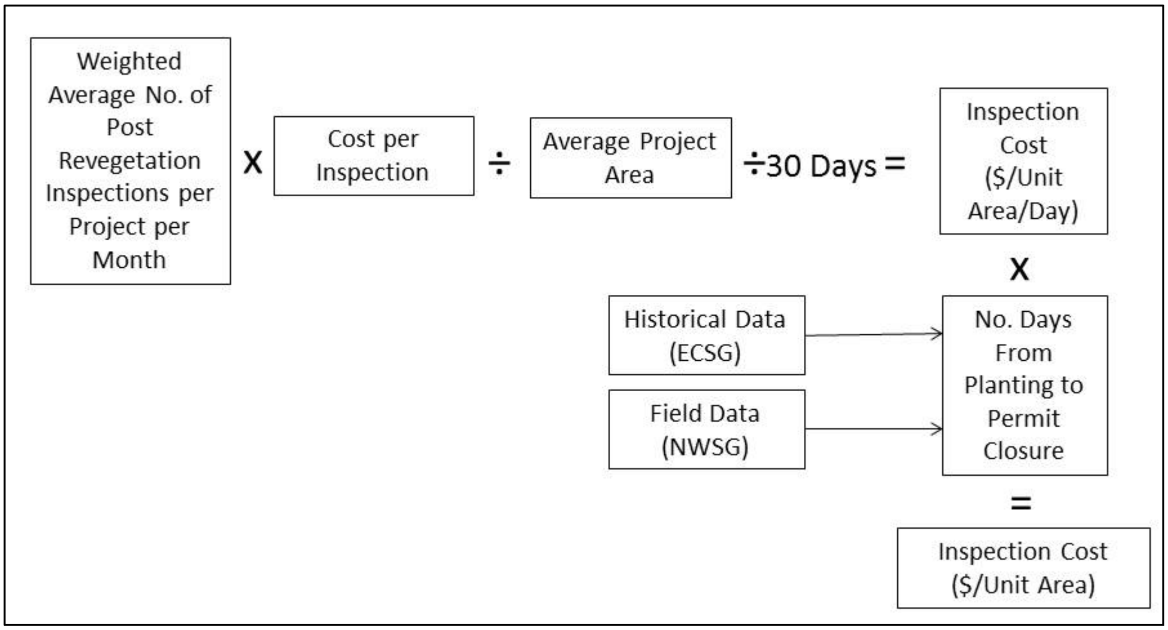

Figure 3.6 Calculation Steps for Determining the Cost of Construction Stormwater Inspections

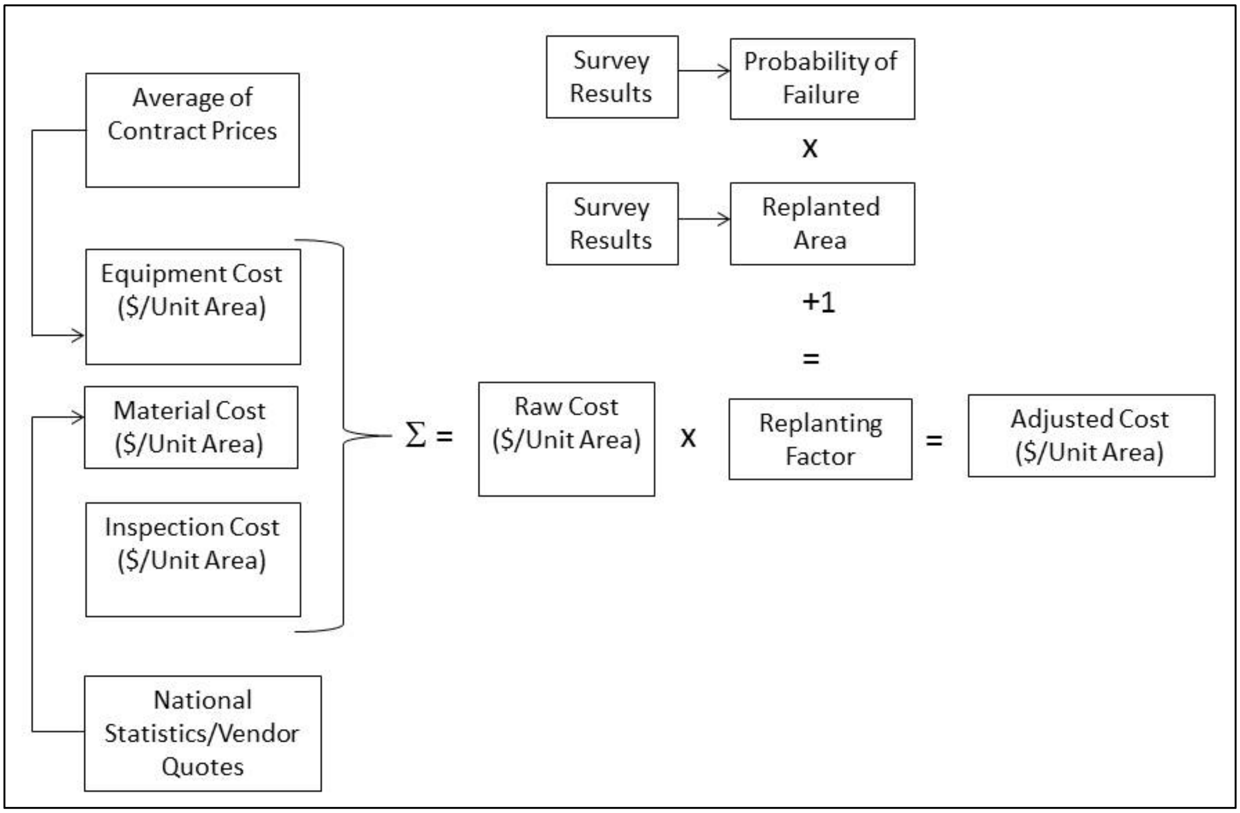

Figure 3.7 Calculation Steps for Determining Adjusted Planting Cost

3.1.2.9 Break-Even Analysis

Direct benefits were considered as the economic benefits directly affecting the long-term maintenance of TVA's transmission system. Because these benefits cannot be quantified without further study, a series of calculations was conducted to determine the annual cost savings necessary for the initial investment to be equal to that of the additional cost associated with planting NWSG. Calculations were conducted using the "PMT" function of Microsoft Excel (Redmond, WA). This function calculates the payments for an annuity based on the number of payments, the interest rate, and the present value of the investment. Annual payments during a payback period of 12 years were assumed. This time was based on the assumption that woody species would become a maintenance concern if they first appear one to five years after planting (McQuilkin 1940, Drew 1942, Oosting 1942, Bard 1952, Byrd 1956, Quarterman 1957, Bazzaz 1968). Twelve years also coincides with six maintenance cycles on for TVA's transmission lines above 200 kV and four maintenance cycles for TVA's transmission lines below 200 kV. Given the complexity involved in determining TVA's internal rate or return, interest rates of 2.875 % and 5% annual percentage yield (APY) were assumed based on TVA bond rates. The lower rate was based on TVA's current bond rate (Tennessee Valley Authority 2014b). The higher rate is an estimated rate based on past bond rates when TVA experienced peak demand (Tennessee Valley Authority 2007). The present value field was set to the adjusted additional cost of NWSG. The annual cost savings were divided by the annual maintenance cost to determine a maintenance reduction percentage necessary for NWSG plantings to break even within 12 years. Maintenance cost per unit area was provided by TVA's ROW Services organization. Because the failure rate for NWSG was based on qualitative data from a small survey sample, a sensitivity analysis was conducted to determine what failure rate for NWSG would make the planting cost of NWSG equal the planting cost of ECSG and what failure rate would make maintenance cost reduction unrealistic. Figure 3.8 shows the calculation steps described above.

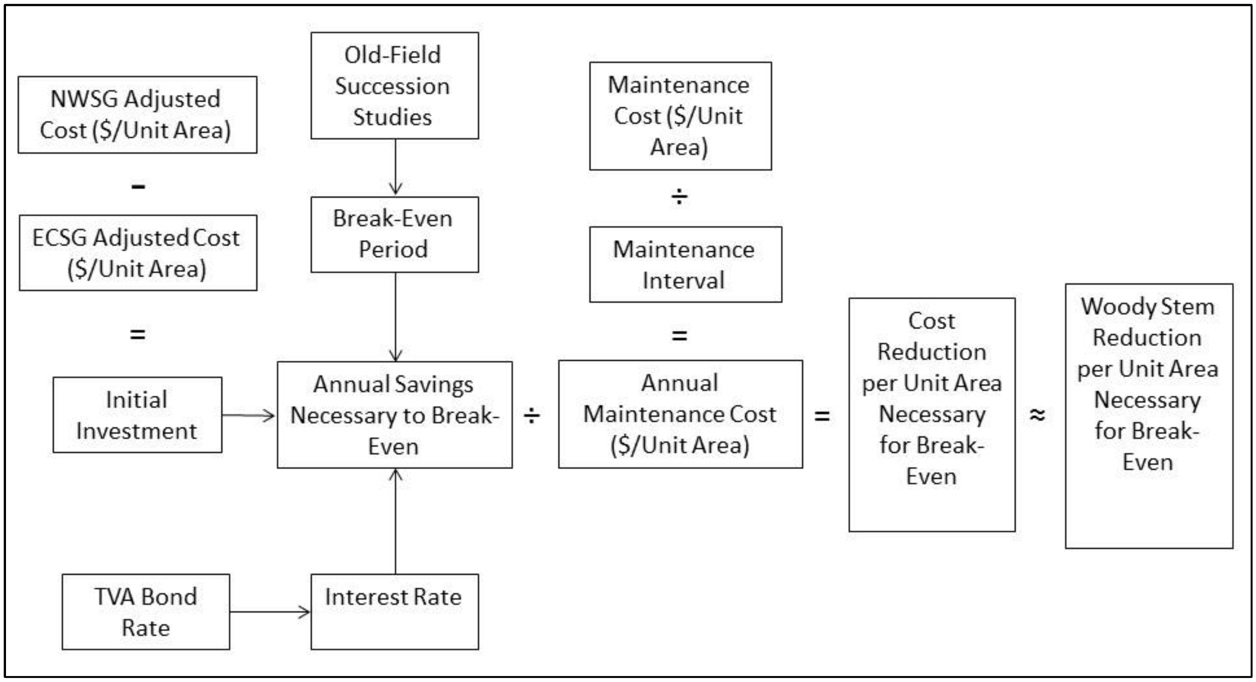

Figure 3.8 Calculation Steps to Determine the Degree of Woody Stem Reduction to Break-Even

3.1.2.10 Potential Direct Benefit Analysis

The direct benefits of NWSG would be seen over the lifetime of the transmission line. To estimate the potential long-term cost savings, the future value of the initial investment was calculated. Using the "FV" function of Microsoft Excel, the future value was calculated assuming that maintenance cost reductions would persist throughout the life of the transmission line. This calculation was only conducted at a 5% rate of return for the greater than 200 kV transmission lines because those lines showed the greatest opportunity for cost savings because their maintenance interval is two years.

3.1.2.11 Indirect Benefit Assessment

Indirect benefits are assumed to be those benefits that have ecological, environmental, social, or economic implications not directly related to TVA's economic interest. While these benefits cannot be assessed quantitatively within the scope of this research they can be assessed qualitatively. To this end, a review of available literature was conducted to find benefits within the categories above on similar projects.

3.2 Results

3.2.1 Feasibility Trials

Of the five sites planted, GAF, Waynesboro, and Cherokee had successful NWSG plantings. At the Hillsboro site approximately 70% of the area planted failed. At the ORNL site NWSG was successfully established in some areas but at a density less than the 70% requirement. Other areas at ORNL had significantly less cover. Collectively, the overall failure rate of NWSG plantings was 40%.

3.2.2 Weather Data

A review of rainfall data from 2004 to 2014 for sites within the TVA power service are yielded a 14 day return period for rainfall over 20 mm (0.80 in) in the months of May, June, and July. Weather stations used in this analysis are shown with their average rainfall return periods in Table 3.4. Daily rainfall and cumulative rainfall for GAF and ORNL are shown in Figures 3.10 and 3.11. Other weather data for GAF and ORNL show similar conditions at each site with slightly more favorable conditions for seedling growth at ORNL.

Table 3.4 Return Period for Summer Rainfall ≥20 mm for Cities in the TVA Power Service Area

Weather Station	Average Days Between Rainfall ≥20 mm 2004-2014 (May-July)
Bowling Green, KY	14
Bristol, TN	12
Chattanooga, TN	15
Columbus, MS	11
Huntsville, AL	15
Knoxville, TN	18
Memphis, TN	13
Nashville, TN	15

3.2.3 Laboratory Seed Test Results

Seed germination test results for perennial grasses are shown in Table 3.5 with the weighted average germination rate at 14 days and the average germination per day.

Table 3.5 Laboratory Germination Results of NWSG

Species	PLS Seed Rate (kg/ha)	PLS Seed Rate (lb./ac)	% Dormant	% Germination	% Live Seed	Mass Live Seed Germinated at 14 Days (kg)
Panicum virgatum	5.604	5.000	60	18	78	1.0
Schizachyrium scoparium	2.522	2.250	76	8	84	0.2
Elymus virginicus	2.522	2.250	36	60	96	1.5
Andropogon gerardii	1.121	1.000	9	72	81	0.8
Sorghastrum nutans	1.121	1.000	6	82	88	0.9
Panicum anceps	0.841	0.750	83	0	83	0.0
Tridens flavus	0.841	0.750	90	0	90	0.0
Total Mass Specified	14.60 (kg/ha)	13.00 (lb/ac)	Mass Germinated at 14 Days			4.4 (kg)
			Weighted Average Germination at 14 Days			30%
			Germination rate			2.2%/day

3.2.4 Field Germination Results

Using the frequency grid method plant densities were recorded for GAF and ORNL the rate of change of these measurements were taken as an analogue for germination rate. As shown in Figures 3.10 and 3.11, maximum germination rate was observed at 31 days post-planting for GAF and 67 days post-planting for ORNL. It should be noted that at ORNL successful germination was only recorded on flat to rolling terrain. On steep slopes little to no germination was observed. Given the inherent variability of field trials the field NWSG plant density rate of change was expected to be slower than the laboratory germination rate results above. At GAF a germination rate of 1.3 % germination per day was calculated by adjusting the germination start date by 11 days. This start date corresponds to the date of the first rainfall post planting. Similarly at ORNL a germination rate of 1.8 % germination per day was calculated by adjusting the germination start date of the planting by 39 days. This corresponds to the second major rain event post planting. The lower of these two rates was taken as the minimum germination rate for this species mix. It is recognized, however, given different weather or site-specific variables, that the minimum rate for this mix could be as low as 0.8% per day to achieve 70% coverage within 90 days. As shown in Figures 3.9 and 3.10, rainfall had a major impact on the rate of germination.

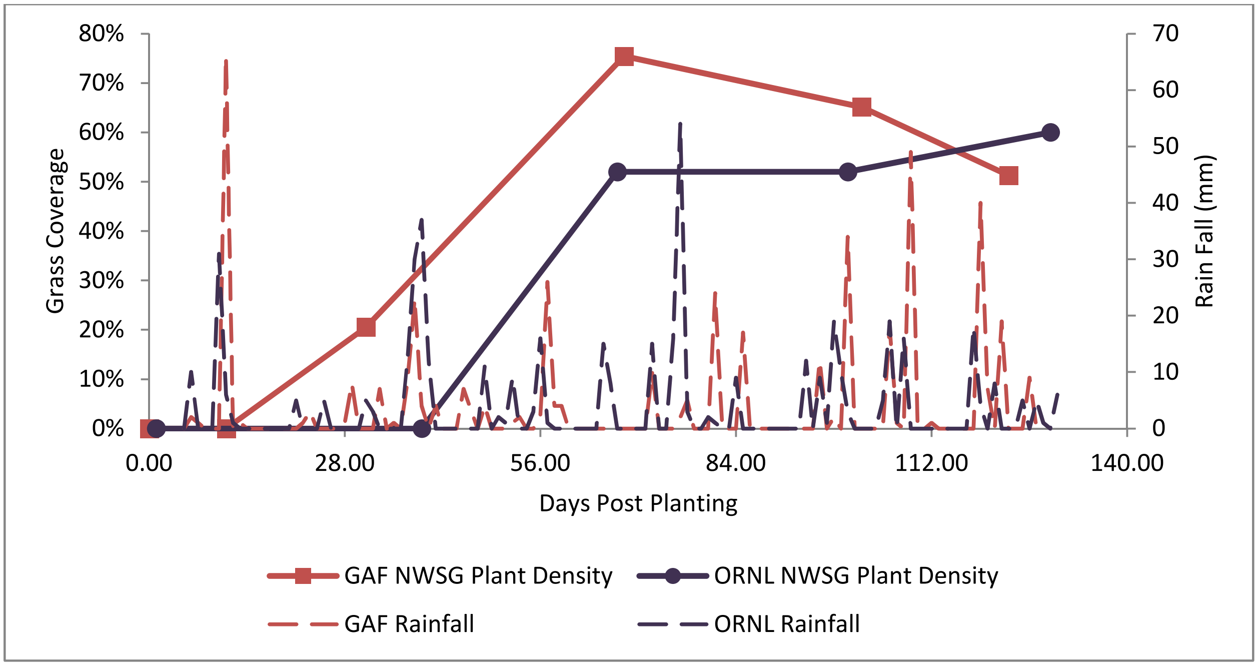

Figure 3.9 Change in NWSG Coverage with Daily Rainfall

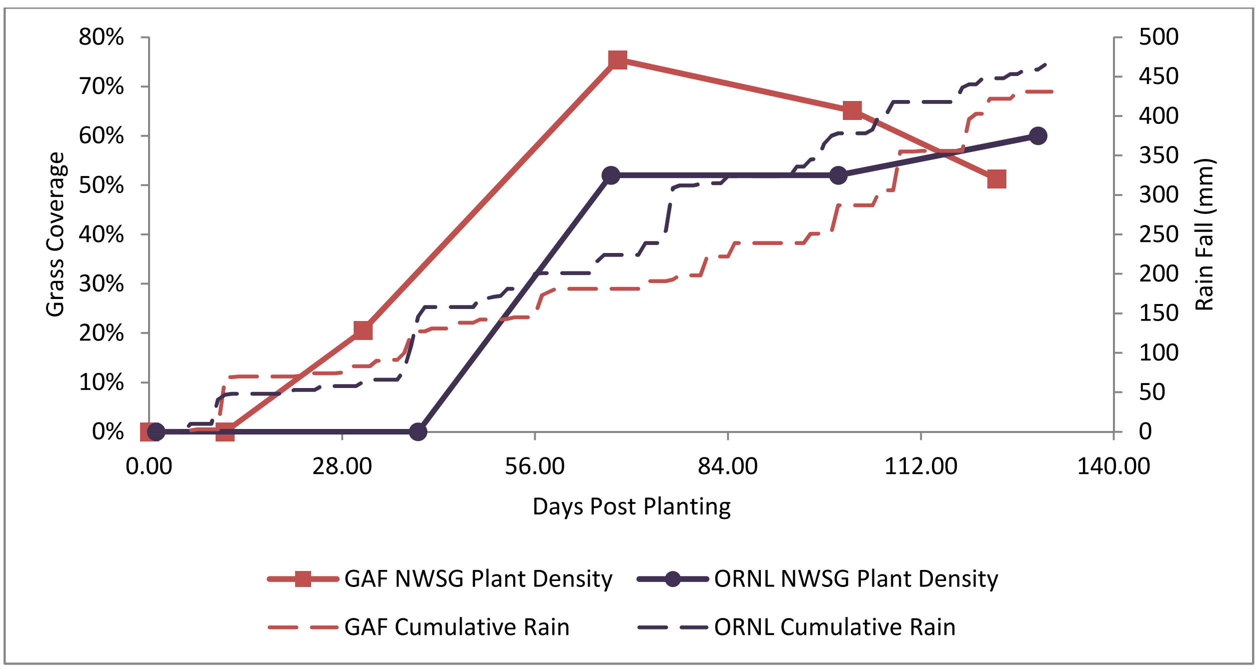

Figure 3.10 Change in NWSG Coverage with Cumulative Rainfall

3.2.5 Estimated Duration from Planting to Permit Termination for NWSG

Using the minimum germination rate of 1.3% per day the maximum number of days from initial germination to 70% coverage was calculated as 54 days. Assuming planting four days after a 20 mm (0.80 in) or greater rainfall event gives a maximum expected time from planting to 70% coverage of 64 days. Similarly, the minimum number of days from planting to 70% coverage was calculated as 55 days assuming that planting one day prior to a 20 mm (0.8 in) or greater rainfall event.

3.2.6 Historical Project Data Analysis

A review of TVA's archived construction schedules from 2012 to 2014 provided the revegetation end date and the construction stormwater permit termination date for 50 projects. Four of these projects were removed from schedule analysis because they were known to have significant delays not related to revegetation. Of this set of 46 projects, 30 had revegetation activities ending in the spring/summer planting season and 16 had revegetation activities ending in the fall planting season. Of the spring/summer plantings, the average time necessary for vegetation to reach 70% coverage with successful plantings was 60 days. The failure rate for these plantings was 28%. These results are similar to fall/winter plantings which required 67 days for vegetation establishment with a 25% failure rate. Figure 3.11 below shows the frequency distribution for the days to vegetation establishment of spring/summer and fall/winter plantings.

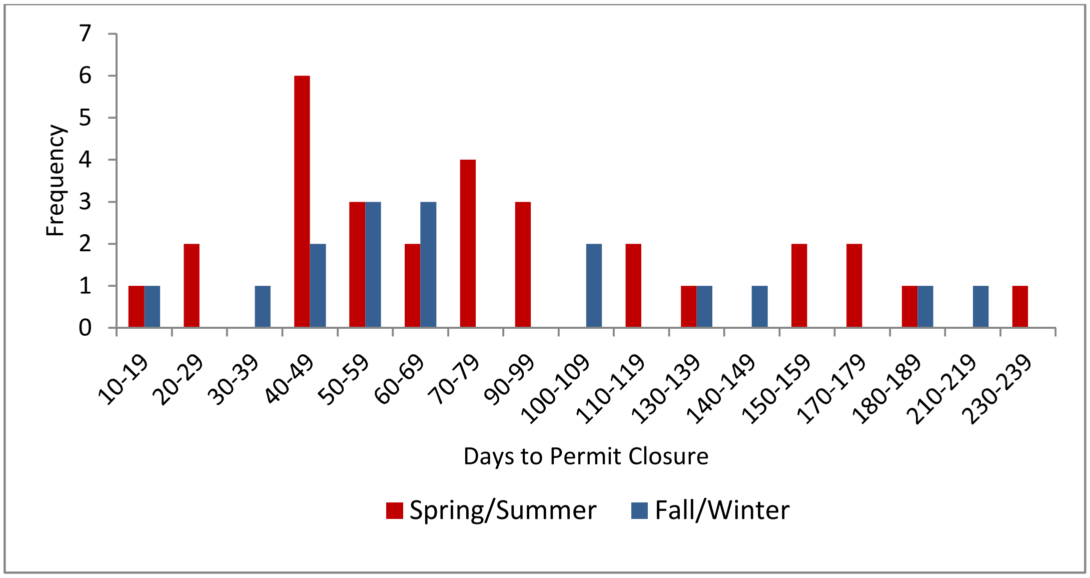

Figure 3.11 Distribution of Days Post Revegetation to Stormwater Permit Closure

3.2.7 Survey of Revegetation Professionals

Nine professionals with experience planting ESCG and six professionals with experience planting NWSG responded to surveys. Responses indicated that 22% of spring/summer ECSG plantings required follow up seeding with 16% of the original area be replanted, while 14% of spring/summer NWSG plantings required follow up seeding with 32% of the original area be replanted. On average, responses indicated that ECSG establish in 48 days, which is 20% faster than the average based on actual project data. However, 48 days is consistent with the mode of the data shown in Figure 3.11. The survey indicates that NWSG establish in 74 days, which is consistent with the findings above. Furthermore, respondents indicated that factors within the control of the revegetation professional were more important to the success of the planting than site-specific factors.

3.2.8 Cost Data Findings

The cost of NWSG was found to be only slightly higher than ECSG. The additional cost of seed and equipment for NWSG was offset by not using soil amendments. Cost data for post-revegetation inspections are shown in Table 3.6. Cost data for NWSG and ECSG plantings are shown in Table 3.7.

Table 3.6 Cost of Post Revegetation Construction Stormwater Inspections

	SI	English
Average Inspections/Project/mo	2.5	2.5
Cost per Inspection	$1,000	$1,000
Average Inspection Cost/mo	$2,500	$2,500
Average Project Area	10.5 ha	26.0 ac
Inspection Cost/Unit Area/mo	$237.60/ha/mo	$96.15/ac/mo
Inspection Cost/Unit Area/Day	$7.92/ha/day	$3.21/ac/day

Table 3.7 Total Cost of Revegetation

		ECSG		NWSG	
Equipment	Standard Equipment	$3,459.44/ha	$1,400.00/ac	$3,459.44/ha	$1,400.00/ac
	Finish Disk (1 pass)			$222.39/ha	$90.00/ac
	Cultipacker (2 passes)			$444.78/ha	$180.00/ac
Materials	Seed	$160.62/ha	$65.00/ac	$536.21/ha	$217.00/ac
	Fertilizer	$536.21/ha	$217.00/ac		
	Lime	$343.47/ha	$139.00/ac		
Inspections	Days to Establishment	60	60	68	68
	Daily Inspection Cost	$7.92/ha/day	$3.21/ha/day	$7.92/ha/day	$3.21/ha/day
	Cost of Inspections	$475.20/ha	$192.31/ac	$539.24	$218.28
Cost of Planting (Equipment + Materials + Inspections)		$4,974.94/ha	$2,013.31/ac	$5,169.70/ha	$2,092.13/ac
	Probability of Replanting	0.22	0.22	0.14	0.14
	Area Replanted	0.16	0.16	0.32	0.32
	Replanting Cost Factor	1.04	1.04	1.04	1.04
	Adjusted Cost of Planting	$5,150.06/ha	$2,084.18/ac	$5,401.30/ha	$2,185.86/ac
	Initial Investment (NWSG Cost-ECSG Cost)	$284.43/ha		$115.12/ac	

3.2.9 Break-Even Results

Using the above cost difference as an initial investment for a net present value calculation with a break-even period of 12 years, maintenance cost reductions between 12% and 21%, depending on voltage and interest rate assumptions, were found to be necessary for NWSG to be cost neutral. This is shown below in Table 3.8.

Table 3.8 Break-Even Cost Reduction

	<200 kV		>200 kV	
Assumed Break-even Period (yrs.)	12	12	12	12
Interest Rate (APY)	2.875%	5.000%	2.875%	5.000%
Initial Investment	-$284.43/ha	-$284.43/ha	-$284.43/ha	-$284.43/ha
Annual Savings Necessary for Break-even	$28.36/ha	$32.09/ha	$28.36/ha	$32.09/ha
Cost per Maintenance Cycle	$457.14/ha	$457.14/ha	$457.14/ha	$457.14/ha
Years Between Maintenance Cycles	3	3	2	2
Annual Maintenance Cost	$152.38/ha	$152.38/ha	$228.57/ha	$228.57/ha
% Cost Reduction for Break-even	19%	21%	12%	14%
	<200 kV		>200 kV	
Assumed Break-even Period (yrs.)	12	12	12	12
Interest Rate (APY)	2.875%	5.000%	2.875%	5.000%
Initial Investment	-$115.12/ac	-$115.12/ac	-$115.12/ac	-$115.12/ac
Annual Savings Necessary for Break-even	$11.48/ac	$12.99/ac	$11.48/ac	$12.99/ac
Cost per Maintenance Cycle	$185.00/ac	$185.00/ac	$185.00/ac	$185.00/ac
Years Between Maintenance Cycles	3	3	2	2
Annual Maintenance Cost	$61.67/ac	$61.67/ac	$92.50/ac	$92.50/ac
% Cost Reduction for Break-even	19%	21%	12%	14%

Given that the probability of failure and the percentage of area requiring replanting are based on limited data, a sensitivity analysis of these parameters was conducted. Figures 3.12 and 3.13 show cost reductions necessary across a range of replanting cost factors. A replanting cost factor of 1.13 would result from a 40% failure rate with 32% of the original planting requiring replanting. This is considered a worst-case scenario, and not likely given a large sample and average rainfall. The lower end of the replanting cost factor range is mathematically possible, but not likely in the field. Survey results suggest that the replanting cost factor is between 1.02 and 1.06. The probability of failure is determined by a combination of site-specific factors, the quality of the planting, and the timing of the planting (Seymour et al. 2008). Both survey groups agree that contractor experience is an important factor in revegetation success. These data indicate that factors within the control of revegetation professionals may improve the break-even cost reduction.

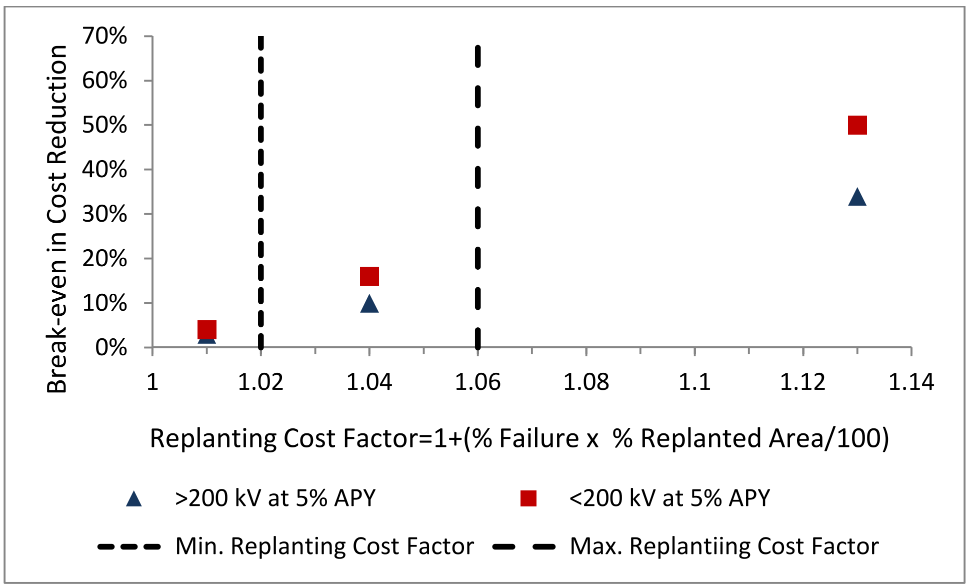

Figure 3.12 Maintenance Cost Reduction vs. Replanting Cost Factor at 5% APY

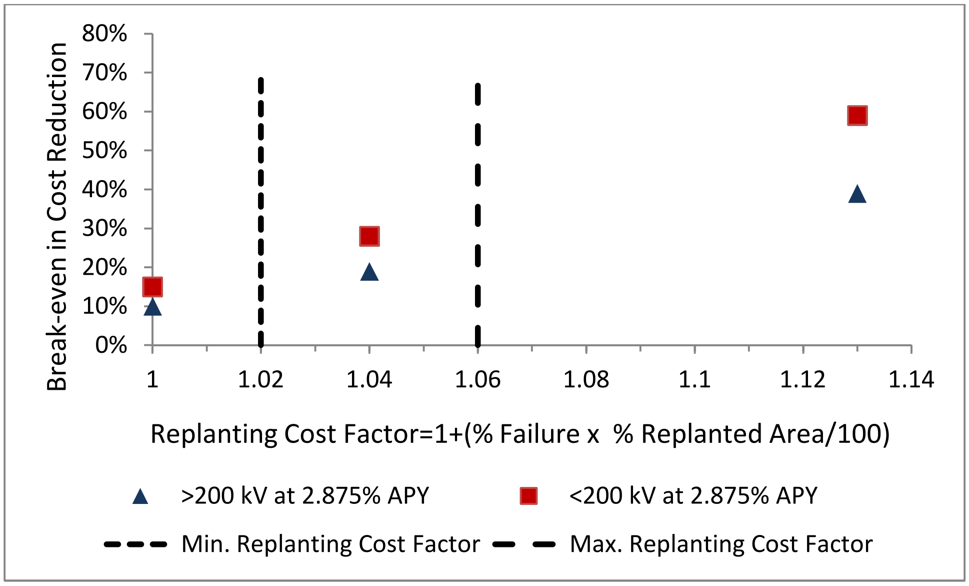

Figure 3.13 Maintenance Cost Reduction vs. Replanting Cost Factor at 2.875% APY

3.2.10 Potential Long-Term Benefit Results

Based on their design criteria and TVA's recent cycle of transmission system upgrades, transmission lines are assumed to have a 40-50 year lifespan (Association 2007, Khandelwal and Pachori 2013). Assuming that NWSG reduces woody invasion by 12% to break-even on the initial investment in 12 years, maintenance costs could be reduced for the remaining 38-years of a 50 year lifespan for the transmission line facility. At a 5% rate of return over this period, the cost savings in reduced maintenance be approximately $3,000/ha ($1,200/ac).

3.2.11 Indirect Benefits of Native Restoration

A review of literature shows numerous potential ecological, environmental, social, and economic benefits for planting ROWs with NWSG. While these benefits do not have a direct economic effect on short-term or long-term costs their indirect effects on TVA's ability to negotiate with landowners and stakeholders when siting, constructing, and maintaining transmission lines should be considered. These indirect benefits are shown in Table 3.9.

Table 3.9 Indirect Benefits of NWSG

Benefit Category	Benefit Sub-Category	Benefit Observed	Potential Implications for ROW Restoration	References
Ecological	Biodiversity	Native plantings increase local biodiversity.	ROWs can become a sink for locally rare prairie species.	(Dunn et al. 1993, King and Savidge 1995, McCoy et al. 2001)
	Invasive Species	Linear disturbance can provide a pathway for invasive species.	At a minimum, native plantings eliminate intentionally introduced, potentially invasive species. Native plantings may suppress invasion.	(D'Antonio and Meyerson 2002, Barney 2006, Waldner 2008)
Environmental	Carbon Sequestration	NWSGs have been shown to sequester carbon at a greater rate and at greater depths as compared to introduced cool season grasses.	ROWs planted in NWSGs may be used to offset the carbon generated by the burning of fossil fuels at TVA.	(Gebhart et al. 1994, Kindscher and Tieszen 1998, Corre et al. 1999, Post and Kwon 2000, Liebig et al. 2005, Liebig et al. 2008, Qian et al. 2010, Hartman et al. 2011, Agostini et al. 2015)
	Sediment and Nutrient Reduction	NWSGs have been shown to reduce nonpoint source pollution from sediment and nutrients more effectively than introduced cool season grasses.	NWSGs better fulfill the intent of the CWA.	(Lee et al. 1998, Blanco-Canqui et al. 2004)
Social		Loss of aesthetic value and loss of wildlife habitat are major complaints of the public at large and affected property owners when transmission lines are sited.	Education about the ecological and environmental benefits of NWSGs may mitigate objections to new transmission lines.	(Furby et al. 1988, Priestley and Evans 1996, Soini et al. 2011)
Economic		NWSG plantings provide outdoor recreation activities such as hunting and wildlife viewing.	Increased recreation opportunities may provide an economic benefit to local communities and property owners.	(Young and Osborn 1990, Feather et al. 1999, Sullivan et al. 2004)

3.3 Discussion

3.3.1 NWSG vs. ECSG Establishment

It is widely believed that NWSG are inappropriate for erosion control plantings because of their slow time to maturity (Washburn et al. 2000). In Tennessee, it has been shown that NWSGs may take more than two years to mature (Keyser et al. 2012). The time for a NWSG stand to mature should not be confused with the time necessary to achieve erosion control. In contrast to the previous argument, my findings indicate that the time necessary to establish NWSG for erosion control is about the same as for ECSG. Another major criticism of NWSG is that the plantings often fail (Harper et al. 2002). However, my results suggest that NWSG can be successfully established with proper planting technique and adequate rainfall.

At GAF, both the ECSG and NWSG performed well until rainfall frequency and intensity dropped in August. While NWSG showed moderate decline after this point, the ECSG showed a sharp decline, with patches of predominantly *T. flavus* between large bare areas typically characterizing spring planted ECSG by the end the growing season. The NWSG failures that TVA experienced in 2014 are not without cause. At Hillsboro, NWSG were planted after two attempts at revegetation with ESCG failed. After planting with NWSG, approximately 40% of the planted area was successfully revegetated. The remainder of the site has failed to grow even naturally occurring early successional vegetation. It is hypothesized that the site's hydraulics and soil are interacting to prevent the establishment of vegetation. This has been confirmed by local residents and landscapers. At ORNL, in areas where the soil's moisture holding capacity was adequate ECSG out-performed NWSG. In areas where the soil was predominantly clay and chert fragments, NWSG and ECSG performed about the same with low germination success. A nearby off ROW planting of NWSG on the slopes surrounding TVA's Bethel Valley Substation was a complete success. Within days after planting the ORNL ROW a flock of wild turkeys (*Meleagris gallopavo*) were observed browsing the seed bed. Because construction work was ongoing at the Bethel Valley Substation no turkeys were observed. Wild turkeys were not observed browsing the portion of the ORNL site planted with ECSG. This is not surprising since it has been shown that birds prefer not to consume *Lolium arundinaceum* seed due to the presence of a fungal endophyte (Madej and Clay 1991, Barnes et al. 1995, Conover and Messmer 1996a, b). It is hypothesized that a combination of lack of rain infiltration due to steep slopes and low soil organic content and granivory by wild turkeys lead to the failure of the ORNL planting. NWSG were established at greater than 50% density in several areas at ORNL. While this is a failure in terms of the 70% threshold, it has been shown that *P. virgatum* and *A. gerardii* established as low as 25% in their first growing season produce successful plantings for wildlife in their second year, and plots established at greater than 40% in their first growing season produce plots adequate for bioenergy production in their second year (Vogel 1987, Masters 1997, Vogel and Masters 2001, Schmer et al. 2006).

3.3.2 NWSG vs. ECSG Initial Revegetation Cost Comparison

My findings suggest that the use of NWSG for revegetation of transmission line ROWs would cost approximately $280 more than ECSG on a per hectare basis ($115 on a per acre basis). Given that annually TVA averages about 280 ha (690 ac) of disturbance on permitted transmission line construction projects, the increase in annual revegetation expense would be approximately $80,000. However, the actual increase in annual revegetation expense would be far less than this because TVA's transmission lines traverse a mosaic of previously disturbed land use including farms, residential and commercial areas. On these areas, landowner preference dictates the species used for revegetation with the typical practice being replacement of vegetation with the same grass species originally present. Given these considerations, NWSG would be most appropriate on federal property as dictated by Executive Order 13112, in areas wooded prior to ROW clearing, or where the property owner requests that revegetation be accomplished with native species (Clinton 1999). Such is often the case with public land managed as wilderness or private land managed for wildlife viewing or hunting. Based on current land use in the TVA service area and transmission line siting practices, it is estimated that less than 50% of TVA's ROW revegetation would meet these criteria (C. E. Columber personal communication 2/13/15). Planting season places a further limitation on site applicability for NWSG. While NWSG can be planted in the fall, germination will not occur until the following spring. As such, NWSG show their best value for ROW revegetation when planted in the warm season. Based on past projects, roughly half of TVA's revegetation activities will fall in this timeframe. This means that about 25% of TVA's ROW revegetation efforts would be viable candidates for NWSG. Thus, the expected additional annual cost increase from using NWSG would be approximately $20,000 or 0.0001% of TVA's 2015 capital budget for its transmission system (Tennessee Valley Authority 2014a).

3.3.3 Direct Benefits Analysis

Based on TVA's system for assessing ROWs for vegetation management, invasion by woody species is directly correlated to the maintenance cost. Thus, the cost reduction scenarios shown above can be considered as woody stem count reductions. Positive results would be most evident on lines greater than 200 kV because the maintenance interval is shorter. Given the worst case probability of failure, the woody stem count reduction at 12 years would have to be between 19% and 27% for transmission lines greater than 200 kV, which is most likely not a realistic goal. However, given a more moderate probability of failure, the woody stem count reduction can be between 12% and 14% and still break even in 12 years. After the break-even period, the long-term effects of NWSG could provide substantial cost savings to TVA. These assumptions of long-term cost savings, however, should be further verified with medium-term (10-15 years) studies of succession on ROWs planted in NWSG. No studies were found that looked at NWSG/tree interactions at the high seed rate used for ROW plantings.

However, some authors have warned against using NWSG for strip mine reclamation because they have the potential to outcompete desirable woody species (Ashby et al. 1989, Rizza et al. 2007).

3.3.4 Indirect Benefits of Native Restoration

While the direct benefits of NWSG are speculative, there is ample literature to show their indirect benefits. Ecologically, NWSG plantings have the potential to provide habitat for a variety of grassland species and reduce the spread of invasive species (Dunn et al. 1993, King and Savidge 1995, McCoy et al. 2001, D'Antonio and Meyerson 2002, Barney 2006, Waldner 2008). This has the potential to mitigate landowner disputes over the loss of use of their property. This is a major issue faced during transmission line construction. Many landowners consider transmission lines to be a blemish on their property (Furby et al. 1988, Priestley and Evans 1996), while others are concerned with the loss of woodland habitat associated with transmission lines (Soini et al. 2011). Transmission line construction and ROW personnel spend considerable time negotiating with these landowners to ensure the timely completion of transmission line construction projects. By providing NWSG as an alternative revegetation practice, landowners could gain the ecological benefits of NWSG which could lead to improved hunting and wildlife viewing opportunities (Young and Osborn 1990, Feather et al. 1999, Sullivan et al. 2004).

The Conservation Reserve Program (CRP) was initiated by the U.S. Department of Agriculture in 1985 with the goal of reducing nonpoint source water pollution by converting marginal farmland into native grassland (Young and Osborn 1990). NWSG make up many of the CRP plantings. Follow up studies of areas planted in NWSG show improved soil stability and water quality (Allan et al. 1999). NWSG have been shown to be more effective at removing sediment and nutrients from runoff than ECSG (Lee et al. 1998). Adoption of NWSG for use in riparian buffer zones on ROWs could have a positive effect on nonpoint source pollution.

With the growing body of knowledge on greenhouse gasses and the likely hood of carbon regulations growing, reduction of carbon emissions has become a major consideration throughout the utility industry (Hoffman 2004). NWSG have been shown to sequester carbon more effectively than ECSG (Gebhart et al. 1994, Kindscher and Tieszen 1998, Corre et al. 1999, Post and Kwon 2000, Liebig et al. 2005, Liebig et al. 2008, Qian et al. 2010, Hartman et al. 2011, Agostini et al. 2015). While NWSG on ROWs may only sequester a fraction of TVA's carbon output, this could become a consideration if a carbon tax becomes a reality.

ROW revegetation with NWSG is expected to increase cost per unit area by approximately 6% over ECSG. As species mixes are improved and TVA gains more experience NWSG planting success will likely be improved in the future, whereas ECSG planting techniques are well established. Failure rates of NWSG and ECSG may eventually reach unity further reducing the cost difference. While the direct long-term benefits are unknown at this time, my results show that the additional cost can be recouped with a modest reduction in woody invasion over two to three maintenance cycles. The indirect benefits of NWSG have the potential to improve cooperation with stakeholders and improve TVA's image as an environmental steward. Based on these findings NWSG clearly have a place in ROW revegetation.

CHAPTER 4

Conclusions and Recommendations

4.1 Grasslands in the Southeastern U.S.

It is often assumed that prior to European colonization eastern North America was a contiguous forest starting at the Atlantic Ocean and extending to the Great Plains (Bakeless 1961). While southeastern North America is considered to be part of the Temperate Deciduous Forest Biome dominated by *Quercus* and *Carya* (oak and hickory) forests (Greller 1988), it is now understood that there were once widespread prairie, barren, and savanna habitats throughout eastern North America that were maintained through intentional burning by Native Americans (Denevan 1992, Williams 2000, Kimmerer and Lake 2001). This presence of grassland habitat was documented by early explorers in the Tennessee Valley Authority's (TVA) power service area (Hawkins 1797, Steiner 1799, Michaux 1802). Worldwide, nearly half of grassland habitats have been lost due to human disturbances (Hoekstra et al. 2005). Depending on specific habitat type, 0.001% to 10% of the pre-colonization grasslands in southeastern North America exist today (Noss 2012). ROWs have been shown to act as refuges for many of the grassland plants that have been displaced by human disturbance (Borowske and Heitlinger 1981, Davis et al. 2002). By replacing exotic ROW revegetation species with NWSG, ROWs could become important conservation areas.

4.2 Future NWSG Planting Recommendations

Based on my findings, I recommend that NWSG be planted on ROWs. The focus of these plantings should be on transmission lines 200 kV and greater since my analysis shows that these lines have greatest potential for maintenance cost reduction. In support of this, TVA's ROW revegetation specifications should be updated to reflect the planting methods previously described in this thesis and TVA's revegetation personnel and contractors should be trained in proper seed bed preparation and planting time selection to optimize NWSG success rate. Additionally, NWSG restoration should be included as a line item in TVA's ROW revegetation contracts to account for additional equipment costs and the elimination of soil amendments. I also suggest that NWSG seed mixes should be improved by the inclusion of more early successional forbs such as *Heliopsis helianthoides* (false sunflower), *Echinacea purpurea* (purple coneflower), *Solidago* species (goldenrods), *Asclepias* species (milkweeds), and *Ambrosia artemisiifolia* (ragweed). The addition of these species could raise the seed mix cost by as much as 10%, but this could be offset by improving the probability of success and the value of ROWs to wildlife conservation and overall aesthetics. The addition of other grass species possibly beneficial to the NWSG mix also should be explored. For example, *Bouteloua curtipendula* (side oats grama) should be investigated because of its fast germination rate (Wasser 1982, Simanton and Jordan 1986, Jordan and Haferkamp 1989). The known stability of *Danthonia spicata* (poverty grass) on Appalachian balds and its tolerance of dry upland habitat may make this species useful to revegetation efforts despite its relatively high cost (Sullivan and Pittillo 1988). In areas where providing grazing habitat for game animals such as white-tailed deer (*Odocoileus virginianus*) and eastern cotton tailed rabbit (*Sylvilagus floridanus*) is important, *Tripsacum dactyloides* (eastern gamagrass) should be considered for its high forage value (Ball et al. 2007). Future plantings containing these and other potentially beneficial species should be tracked closely to monitor their time to construction stormwater permit closure and costs.

4.3 Future Research Recommendations

My research provides the basis for a NWSG revegetation program on transmission line ROWs. However, there are many questions that cannot be answered within the limited scope of my thesis. For example, the germination rate under field conditions directly relates to the time necessary to terminate construction stormwater permits and is an extremely difficult variable to predict. Using my methods, this germination rate can be estimated from the change in plant density over time as a proxy, but this requires investing significant time and resources with no guarantee of success. Using controlled-environment growth chambers in a laboratory setting would allow for testing of the germination rates of individual species' under a variety of expected and extreme conditions such as those predicted as a result of climate change. Such data would aid in future NWSG mix designs and selection of planting dates. As another potential limitation, the key assumption of my work is that NWSG planted at a high seeding rate can compete with woody species, which in concert with vegetation maintenance may change the trajectory of succession to create a stable grassland on the ROW. To validate this assumption, monitoring of NWSG plots should take place for the next 10 to 15 years. In addition, while there is an existing literature on wildlife use of conservation plantings and ROWs separately, little previous research has integrated these concepts by investigating wildlife use of conservation plantings on ROWs. Given that ROWs are linear corridors traversing a mosaic of land-use types, wildlife use of ROWs planted with NWSG may be different than typical conservation plantings. Studying the wildlife use of NWSG plantings would both confirm some of my proposed indirect benefits and aid in species selection for future plantings. Finally, once NWSG plantings on ROWs are well established (i.e., after the second or third growing season), ROW stakeholders, including TVA transmission line maintenance personnel, TVA ROW vegetation managers, and public and private landowners, should be surveyed to determine if NWSG are an effective tool in mitigating negative opinions of transmission lines among the general public.

REFFERENCES

1972. Clean Water Act. 33 U.S.C. 1251 (2002).

Abrahamson, L. P. N., C. A.; Raynal, D. J.; Leopold, D. J.; Cameron, D. S.; Van Ord, A. 1999. Rights-of-Way Stability: A 15-year Appraisal of Plant Dynamics on Electric Power Rights-of-Way in New York State. EPRI, ESEERCO, Palo Alto, CA.

Abrams, M. D., and G. J. Nowacki. 1992. Historical Variation in Fire, Oak Recruitment, and Post-Logging Accelerated Succession in Central Pennsylvania. Bulletin of the Torrey Botanical Club **119**:19-28.

Ackerman, F., and L. Heinzerling. 2002. Pricing the priceless: Cost-benefit analysis of environmental protection. University of Pennsylvania Law Review:1553-1584.

Agostini, F., A. S. Gregory, and G. M. Richter. 2015. Carbon Sequestration by Perennial Energy Crops: Is the Jury Still Out? BioEnergy Research:1-24.

Allan, D. L., A. M.J., D. F. Bezdicek, M. Flock, J. C. Gardner, and D. R. Huggins. 1999. Conservation Reserve Program effects on soil quality indicators. Journal of Soil and Water Conservation **54**.

Allison, M. F., and J. F. Weltzin. 2007. Competitive Hierarchy for Four Common Old-Field Plant Species Depends on Resource Identity and Availability. Journal of the Torrey Botanical Society **134**:166-176.

Anderson, J. E., and K. E. Holte. 1981. Vegetation Development over 25 Years without Grazing on Sagebrush-Dominated Rangeland in Southeastern Idaho. Journal of Range Management **34**:25-29.

Anker, P. 2011. Plant Community, Plantesamfund. Pages 325-331 Ecology Revisited. Springer.

Armesto, J. J., and S. T. A. Pickett. 1986. Removal Experiments to Test Mechanisms of Plant Succession in Oldfields. Vegetatio **66**:85-93.

Arner, D. H. 1960. Effects of rights of way techniques on vegetation. Transactions of the North American Wildlife and Natural Resource Confrence:378-386.

Ashby, W. C., K. P. Hannigan, and D. A. Kost. 1989. Coal mine reclamation with grasses and legumes in southern Illinois. Journal of Soil and Water Conservation **44**:79-83.

Association, N. F. P. 2007. National Electrical Code 2008. NationalFireProtectionAssoc.

Association of Official Seed Analysts. 1993. Rules for testing seeds. J. Seed Technol **16**:1-112.

Bakeless, J. E. 1961. The eyes of discovery: the pageant of North America as seen by the first explorers. Dover Publications.

Ball, D., C. Hoveland, and G. Lacefield. 2007. Southern forages, modern concept for forage crop management. IPIN: Norcross.

Ballard, D. B., Bob; Becket, Thomas; Dille, Patric; Lukkarila, Charles; McCall, Charles; Metro, Patti; Ruggeri, Eric; Shambrock, Aaron; Turner, David; Twitty, John. 2009. Design Manual For High Voltage Transmission Lines. USDA, Washington, DC.

Bard, G. E. 1952. Secondary Succession on the Piedmont of New Jersey. Ecological Monographs **22**:195-215.

Barnes, T. G., L. A. Madison, J. D. Sole, and M. J. Lacki. 1995. An assessment of habitat quality for northern bobwhite in tall fescue-dominated fields. Wildlife Society Bulletin:231-237.

Barnett, W. S. 1996. Lives in the Balance: Age-27 Benefit-Cost Analysis of the High/Scope Perry Preschool Program. Monographs of the High/Scope Educational Research Foundation, Number Eleven. ERIC.

Barney, J. N. 2006. North American history of two invasive plant species: phytogeographic distribution, dispersal vectors, and multiple introductions. Biological Invasions **8**:703-717.

Barrington, M. 1929. Forest Succession and Silviculture in Southern New England. Ecology **10**:257-258.

Bazzaz, F. A. 1968. Succession on Abandoned Fields in the Shawnee Hills, Southern Illinois. Ecology **49**:924-936.

Berkowitz, A. R., C. D. Canham, and V. R. Kelly. 1995. Competition vs. Facilitation of Tree Seedling Growth and Survival in Early Successional Communities. Ecology **76**:1156-1168.

Blanco-Canqui, H., C. Gantzer, S. Anderson, E. Alberts, and A. Thompson. 2004. Grass barrier and vegetative filter strip effectiveness in reducing runoff, sediment, nitrogen, and phosphorus loss. Soil Science Society of America Journal **68**:1670-1678.

Bonanomi, G., G. Incerti, and S. Mazzoleni. 2011. Assessing occurrence, specificity, and mechanisms of plant facilitation in terrestrial ecosystems. Plant Ecology **212**:1777-1790.

Bormann, F. H. 1953. Factors Determining the Role of Loblolly Pine and Sweetgum in Early Old-Field Succession in the Piedmont of North Carolina. Ecological Monographs **23**:339-358.

Borowske, J. R., and M. E. Heitlinger. 1981. Survey of native prairie on railroad rights-of-way in Minnesota. Transp. Res. Rec.(Washington) **822**:22-26.

Bramble, W., and W. Byrnes. 1976. Development of a stable, low plant cover on a utility right-of-way. Pages 167-176 *in* Proceedings of the first national symposium on environmental concerns in rights-of-way management. Mississippi State University, Mississippi State. Mississippi State Universit, Mississippi State University, Mississippi.

Bramble, W., and W. Byrnes. 1983. Thirty years of research on development of plant cover on an electric transmission right-of-way. Journal of Arboriculture **9**:67-74.

Bramble, W., W. Byrnes, and R. Hutnik. 1990. Resistance of plant cover types to tree seedling invasion on an electric transmission right-of-way. Journal of Arboriculture **16**:130-135.

Bramble, W., W. Byrnes, R. Hutnik, and S. Liscinsky. 1991. Prediction of cover type on rights-of-way after maintenance treatments. J. Arboric **17**:38-43.

Bramble, W., W. F. Byrnes, F. J. Hutnik, and S. Liscinsky. 1996. Interference Factors Responsible for Resistance of Forb-Grass Cover Types to Tree Invasion on an Electric Utility Right-of-Way. Journal of Arboriculture **22**:99.

Bramble, W. C., and W. R. Byrnes. 1967. Ecological Aspects of Brush Control: A Long Term Study on a Utility Right of Way. Purdue University Agricultural Experiment Station.

Brown, D. 1995. The impact of species introduced to control tree invasion on the vegetation of an electrical utility right-of-way. Canadian journal of botany **73**:1217-1228.

Buell, M. F., H. F. Buell, and J. A. Small. 1971. Invasion of Trees in Secondary Succession on the New Jersey Piedmont. Bulletin of the Torrey Botanical Club **98**:67-74.

Burns, R., and B. Honkala. 1990a. Silvics of North America, Vol. 1, Conifers. Washington DC: USDA Forest Service Agriculture Handbook 654.

Burns, R., and B. Honkala. 1990b. Silvics of North America. Vol. 2. Hardwoods. USDA Forest Service, Washington, DC. Agriculture Handbook **654**.

Buttrick, P. L. 1917. Forest Growth on Abandoned Agricultural Land. The Scientific Monthly **5**:80-91.

Byrd, M. A. 1956. Relation of Ecological Succession to Farm Game in Cumberland County in the Virginia Piedmont. The Journal of Wildlife Management **20**:188-195.

Cameron, D. S., D. J. Leopold, and D. J. Raynal. 1997. Effect of landscape position on plant diversity and richness on electric transmission rights-of-way in New York State. Canadian journal of botany **75**:242-251.

Canham, C., J. Hill, A. Berkowitz, and R. Ostfeld. 1998. Ecological perspectives on tree invasion in rights-of-way: quantifying variation among communities in resistance to tree invasion. Pages 81-86 *in* Fifth International Symposium on Environmental Concerns in Right-of-way Management. Montréal: Vice présidence Environnement Hydro-Québec.

Carson, W. P., and R. B. Root. 1999. Top-down Effects of Insect Herbivores during Early Succession: Influence on Biomass and Plant Dominance. Oecologia **121**:260-272.

Choi, Y. D., and M. K. Wali. 1995. The Role of Panicum virgatum (Switch Grass) in the Revegetation of Iron-Mine Tailings in Northern New York. Restoration Ecology **3**:123-132.

Clements, F. E. 1916. Plant Succession: An Analysis of the Development of Vegetation. Carnegie Institution of Washington, Washington.

Clinton, W. J. 1999. Executive Order 13112.*in* T. W. House, editor. Federal Register, Washington, DC.

Collins, B., and G. Wein. 1998. Soil Resource Heterogeneity Effects on Early Succession. Oikos **82**:238-245.

Connell, J. H., I. R. Noble, and R. O. Slatyer. 1987. On the Mechanisms Producing Successional Change. Oikos **50**:136-137.

Connell, J. H., and R. O. Slatyer. 1977. Mechanisms of Succession in Natural Communities and Their Role in Community Stability and Organization. The American Naturalist **111**:1119-1144.

Conover, M. R., and T. A. Messmer. 1996a. Consequences for captive Zebra Finches of consuming tall fescue seeds infected with the endophytic fungus Acremonium coenophialum. The Auk:492-495.

Conover, M. R., and T. A. Messmer. 1996b. Feeding preferences and changes in mass of Canada geese grazing endophyte-infected tall fescue. Condor:859-862.

Cooper, W. S. 1913a. The Climax Forest of Isle Royale, Lake Superior, and Its Development. I. Botanical Gazette **55**:1-44.

Cooper, W. S. 1913b. The Climax Forest of Isle Royale, Lake Superior, and Its Development. II. Botanical Gazette **55**:115-140.

Cooper, W. S. 1913c. The Climax Forest of Isle Royale, Lake Superior, and Its Development. III. Botanical Gazette **55**:189-235.

Corbett, E. A., R. C. Anderson, and C. S. Rodgers. 1996. Prairie Revegetation of a Strip Mine in Illinois: Fifteen Years after Establishment. Restoration Ecology **4**:346-354.

Corre, M., R. Schnabel, and J. Shaffer. 1999. Evaluation of soil organic carbon under forests, cool-season and warm-season grasses in the northeastern US. Soil Biology and Biochemistry **31**:1531-1539.

Cowles, H. C. 1899a. The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan (Concluded). Botanical Gazette **27**:361-391.

Cowles, H. C. 1899b. The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan (Continued). Botanical Gazette **27**:281-308.

Cowles, H. C. 1899c. The Ecological Relations of the Vegetation on the Sand Dunes of Lake Michigan. Part I.-Geographical Relations of the Dune Floras. Botanical Gazette **27**:95-117.

D'Antonio, C., and L. A. Meyerson. 2002. Exotic plant species as problems and solutions in ecological restoration: a synthesis. Restoration Ecology **10**:703-713.

Daubenmire, R. F. 1940. Plant Succession Due to Overgrazing in the Agropyron Bunchgrass Prairie of Southeastern Washington. Ecology **21**:55-64.

Davis, J. E., Jr., C. McRae, B. L. Estep, L. S. Barden, and J. F. Matthews. 2002. Vascular Flora of Piedmont Prairies: Evidence from Several Prairie Remnants. Castanea **67**:1-12.

De Blois, S., J. Brisson, and A. Bouchard. 2002. Selecting Herbaceous Plant Covers to Control Tree Invasion in Rights-of-Way. Pages 103-110 *in* Proceedings of the Seventh International Symposium on Environmental Concerns in Rights-of-Way Management. JW Goodrich-Mahoney et al., eds. Elsevier Science Ltd.

De Blois, S., J. Brisson, and A. Bouchard. 2004. Herbaceous covers to control tree invasion in rights-of-way: ecological concepts and applications. Environmental Management **33**:606-619.

Denevan, W. M. 1992. The pristine myth: the landscape of the Americas in 1492. Annals of the Association of American Geographers **82**:369-385.

DeSelm, H., P. Whitford, and J. Olson. 1969. The barrens of the Oak Ridge area, Tennessee. American Midland Naturalist:315-330.

Drew, W. B. 1942. The revegetation of abandoned crop land in the Cedar Creek area, Boone and Callaway counties, Missouri. Univ. of Mo. Ag. Exp. Sta. Bull **344**:51.

Dunn, C. P., F. Stearns, G. R. Guntenspergen, and D. M. Sharpe. 1993. Ecological benefits of the conservation reserve program. Conservation Biology **7**:132-139.

Dureau de la Malle, A. 1825. Memoire sur l'alternance ou sur ce problem: la succession alternative dans la reproduction des especes vegetales vivant en society, est-elle une loi generale de la nature? . Annales des sciences naturelles **15**:353-381.

Egler, F. E. 1949. Right of Way Maintenance by Plant-community Management. Aton Forest.

Egler, F. E. 1954a. Vegetation management for rights-of-way and roadsides.

Egler, F. E. 1954b. Vegetation Science Concepts I. Initial Floristic Composition, a Factor in Old-Field Vegetation Development. Vegetatio **4**:412-417.

Elliott, K. J., S. L. Hitchcock, and L. Krueger. 2002. Vegetation Response to Large Scale Disturbance in a Southern Appalachian Forest: Hurricane Opal and Salvage Logging. Journal of the Torrey Botanical Society **129**:48-59.

Ellison, L. 1960. Influence of Grazing on Plant Succession of Rangelands. Botanical Review **26**:1-78.

Environmental Protection Agency. 2003. NPDES General Permit for Storm Water Discharges From Construction Activities.*in* E. P. Agency, editor. 40, Chapter 1, Subchapter D.

Everett, R. L., and K. Ward. 1984. Early plant succession on pinyon-juniper controlled burns. Northwest Science **58**:57-68.

Farm Service Agency. 2014. Conservation Fact Sheet.*in* U. S. D. o. A. F. S. Agency, editor. USDA, Whashington DC.

Feather, P., D. Hellerstein, and L. Hansen. 1999. Economic valuation of environmental benefits and the targeting of conservation programs. Agricultural Economics Report.

Federal Energy Regulatory Commission. 2014. Transmission Vegetation Management.*in* F. E. R. Comission, editor. FAC-003, Washington D.C.

Foster, B. L., and K. L. Gross. 1999. Temporal and Spatial Patterns of Woody Plant Establishment in Michigan Old Fields. American Midland Naturalist **142**:229-243.

Foster, B. L., and D. Tilman. 2000. Dynamic and Static Views of Succession: Testing the Descriptive Power of the Chronosequence Approach. Plant Ecology **146**:1-10.

Foster, M. M., P. M. Vitousek, and P. A. Randolph. 1980. The Effects of Ragweed (Ambrosia artemisiifolia L.) on Nutrient Cycling in a 1st-year Old-field. American Midland Naturalist **103**:106-113.

Fowells, H. A. 1965. Silvics of forest trees of the United States. Agric. Handb. US Dep. Agric.

Franklin, D. S., T.; Lake, D.; Scherer, J. E.; Forrest, C. L.; Berntsen, E.; Hildebrand, J.; Bordenave, P.; King, T.; Chase, M.; Harding, M. 2010. Certified Professional in Erosion and Sediment Control Exam Review Study Guide. EnviroCert International, Inc., Marion, NC.

Furby, L., P. Slovic, B. Fischhoff, and R. Gregory. 1988. Public perceptions of electric power transmission lines. Journal of Environmental Psychology **8**:19-43.

García-Palacios, P., M. A. Bowker, F. T. Maestre, S. Soliveres, F. Valladares, J. Papadopoulos, and A. Escudero. 2011. Ecosystem development in roadside grasslands: biotic control, plant—soil interactions, and dispersal limitations. Ecological Applications **21**:2806-2821.

Gebhart, D. L., H. B. Johnson, H. Mayeux, and H. Polley. 1994. The CRP increases soil organic carbon. Journal of Soil and Water Conservation **49**:488-492.

Geier, R. L., S. Guggenmoos, and N. Theissen. 1992. Ecological aspects of herbicide usage on power line rights-of-way. Journal of Arboriculture **18**:209.

GEOServices LLC. 2013. Report of Geotechnical Exploration TVA Substation Expansion – Oak Ridge, Tennessee. Knoxville, TN.

Gibson, C. W. D., H. C. Dawkins, V. K. Brown, and M. Jepsen. 1987. Spring Grazing by Sheep: Effects on Seasonal Changes during Early Old Field Succession. Vegetatio **70**:33-43.

Gibson, D. J., B. A. Middleton, K. Foster, Y. A. K. Honu, E. W. Hoyer, and M. Mathis. 2005. Species Frequency Dynamics in an Old-Field Succession: Effects of Disturbance, Fertilization and Scale. Journal of Vegetation Science **16**:415-422.

Gillespie, E. D. 1978. Cover crops as a control for woody growth on electrical transmission rights-of-way. Reclamation Review **1**:31-33.

Gleason, H. A. 1926. The Individualistic Concept of the Plant Association. Bulletin of the Torrey Botanical Club **53**:7-26.

Green, D. M., and J. B. Kauffman. 1995. Succession and Livestock Grazing in a Northeastern Oregon Riparian Ecosystem. Journal of Range Management **48**:307-313.

Greenberg, C. H., D. G. Neary, L. D. Harris, and S. P. Linda. 1995. Vegetation Recovery Following High-intensity Wildfire and Silvicultural Treatments in Sand Pine Scrub. American Midland Naturalist **133**:149-163.

Greller, A. M. 1988. Chapter 10 Deciduous Forests.*in* M. G. B. a. W. D. Billings, editor. North American Terrestrial Vegetation. Cambridge University Press, New York.

Hanley, N., and C. L. Spash. 1993. Cost-Benefit Analysis and The Environment. Edward Elgar Cheltenham.

Harper-Lore, B. 1999. Roadside Use of Native Plants. Washington, DC: USDOT, Federal Highway Administration Pub. FHWA–EP–99–014.

Harper, C. A., G. D. Morgan, and C. E. Dixon. 2002. Establishing native warm-season grasses using conventional and no-till technology with various applications of Plateau herbicide.*in* Proceedings 3rd Eastern Native Grass Symposium.

Hart, J. F. 1968. Loss and Abandonment of Cleared Farm Land in the Eastern United States. Annals of the Association of American Geographers **58**:417-440.

Hartman, J. C., J. B. Nippert, R. A. Orozco, and C. J. Springer. 2011. Potential ecological impacts of switchgrass (Panicum virgatum L.) biofuel cultivation in the Central Great Plains, USA. Biomass and Bioenergy **35**:3415-3421.

Hawkins, B., editor. 1797. Journal of Benjamin Hawkins. The Watauga Press, Johnson City, TN.

Hill, J. D., C. D. Canham, and D. M. Wood. 1995. Patterns and causes of resistance to tree invasion in rights-of-way. Ecological Applications:459-470.

Hils, M. H., and J. L. Vankat. 1982. Species Removals From a First-Year Old-Field Plant Community. Ecology **63**:705-711.

Hoekstra, J. M., T. M. Boucher, T. H. Ricketts, and C. Roberts. 2005. Confronting a biome crisis: global disparities of habitat loss and protection. Ecology Letters **8**:23-29.

Hoffman, A. J. 2004. Climate change strategy: The business logic behind voluntary greenhouse gas reductions. Ross School of Business Paper.

Holt, R. D. 1977. Predation, apparent competition, and the structure of prey communities. Theoretical population biology **12**:197-229.

Honu, Y. A. K., D. J. Gibson, and B. A. Middleton. 2006. Response of Tridens flavus (L.) A. S. Hitchc. to Soil Nutrients and Disturbance in an Early Successional Old Field. Journal of the Torrey Botanical Society **133**:421-428.

Hull, J. C., and R. C. Scott. 1982. Plant Succession on Debris Avalanches of Nelson County, Virginia. Castanea **47**:158-176.

Jason, D. B., M. J. Chamberlain, and J. P. Geaghan. 2008. Effects of Understory Vegetation Management on Brood Habitat for Northern Bobwhites. The Journal of Wildlife Management **72**:1361-1368.

Jeffries, D. L., and J. M. Klopatek. 1987. Effects of Grazing on the Vegetation of the Blackbrush Association. Journal of Range Management **40**:390-392.

Johnson, W. C., R. K. Schreiber, and R. L. Burgess. 1979. Diversity of small mammals in a powerline right-of-way and adjacent forest in east Tennessee. American Midland Naturalist:231-235.

Johnston, P. A., and W. C. Bramble. 1981. Vegetation distribution associated with right-of-way habitats in New York. Pages 441-445 *in* Proceedings of Second Symposium on Environ-menal Concerns in Rights-of-Way Management (ed. RE Tillman).

Johnstone, R. 1990. Vegetation management: mowing to spraying. Journal of Arboriculture **16**:186-189.

Jordan, G. L., and M. R. Haferkamp. 1989. Temperature responses and calculated heat units for germination of several range grasses and shrubs. Journal of Range Management:41-45.

Kahneman, D., and J. L. Knetsch. 1992. Valuing public goods: the purchase of moral satisfaction. Journal of environmental economics and management **22**:57-70.

Keever, C. 1950. Causes of Succession on Old Fields of the Piedmont, North Carolina. Ecological Monographs **20**:229-250.

Keever, C. 1979. Mechanisms of Plant Succession on Old Fields of Lancaster County, Pennsylvania. Bulletin of the Torrey Botanical Club **106**:299-308.

Keyser, P., C. Harper, G. Bates, J. Waller, and E. Doxon. 2012. SP731-B Establishing Native Warm-Season Grasses for Livestock Forage in the Mid-South.

Khandelwal, P., and A. Pachori. 2013. Variation of Life Cycle Cost of Overhead Transmission Line and Underground Transmission Cable. International Journal of Enhanced Research in Science Technology & Engineering **2**:55-64.

Kim, T. N., N. Underwood, and B. D. Inouye. 2013. Insect herbivores change the outcome of plant competition through both inter- and intraspecific processes. Ecology **94**:1753-1763.

Kimmerer, R. W., and F. K. Lake. 2001. The role of indigenous burning in land management. Journal of Forestry **99**:36-41.

Kindscher, K., and L. L. Tieszen. 1998. Floristic and Soil Organic Matter Changes after Five and Thirty-Five Years of Native Tallgrass Prairie Restoration. Restoration Ecology **6**:181-196.

Kindschy, R. R. 1986. Rangeland Vegetative Succession: Implications to Wildlife. Rangelands **8**:157-159.

King, D. I., and B. E. Byers. 2002. An evaluation of powerline rights-of-way as habitat for early-successional shrubland birds. Wildlife Society Bulletin:868-874.

King, J. W., and J. A. Savidge. 1995. Effects of the Conservation Reserve Program on wildlife in southeast Nebraska. Wildlife Society Bulletin:377-385.

Kosola, K. R., and K. L. Gross. 1999. Resource Competition and Suppression of Plants Colonizing Early Successional Old Fields. Oecologia **118**:69-75.

Kwit, C., and B. Collins. 2008. Native grasses as a management alternative on vegetated closure caps. Environmental Management **41**:929-936.

Lee, K., T. Isenhart, R. Schultz, and S. Mickelson. 1998. Nutrient and sediment removal by switchgrass and cool-season grass filter strips in Central Iowa, USA. Agroforestry Systems **44**:121-132.

Liebig, M., H. Johnson, J. Hanson, and A. Frank. 2005. Soil carbon under switchgrass stands and cultivated cropland. Biomass and Bioenergy **28**:347-354.

Liebig, M. A., M. R. Schmer, K. P. Vogel, and R. B. Mitchell. 2008. Soil carbon storage by switchgrass grown for bioenergy. BioEnergy Research **1**:215-222.

Luken, J. O. 1991. Managing power-line corridor vegetation. Journal of Arboriculture **17**:318-322.

Luken, J. O., S. W. Beiting, S. K. Kareth, R. L. Kumler, J. H. Liu, and C. A. Seither. 1994. Target and nontarget discrimination of herbicides applied to vegetation in a power-line corridor. Environmental Management **18**:251-255.

Luken, J. O., A. C. Hinton, and D. G. Baker. 1991. Assessment of frequent cutting as a plant-community management technique in power-line corridors. Environmental Management **15**:381-388.

Madej, C. W., and K. Clay. 1991. Avian seed preference and weight loss experiments: the effect of fungal endophyte-infected tall fescue seeds. Oecologia **88**:296-302.

Maggi, E., I. Bertocci, S. Vaselli, and L. Benedetti-Cecchi. 2011. Connell and Slatyer's models of succession in the biodiversity era. Ecology **92**:1399-1406.

Masters, R. A. 1997. Influence of seeding rate on big bluestem establishment with herbicides. Agronomy journal **89**:947-951.

McClanahan, T. R. 1986. The Effect of a Seed Source on Primary Succession in a Forest Ecosystem. Vegetatio **65**:175-178.

McCoy, T. D., M. R. Ryan, L. W. B. Jr, and E. W. Kurzejeski. 2001. Grassland Bird Conservation: CP1 vs. CP2 Plantings in Conservation Reserve Program Fields in Missouri. American Midland Naturalist **145**:1-17.

McDonnell, M. J., and E. W. Stiles. 1983. The Structural Complexity of Old Field Vegetation and the Recruitment of Bird-Dispersed Plant Species. Oecologia **56**:109-116.

McEuen, A. B., and L. M. Curran. 2004. Seed Dispersal and Recruitment Limitation across Spatial Scales in Temperate Forest Fragments. Ecology **85**:507-518.

Mcloughlin, K. T. K., D. 2007. Electric Transmission Right-of-Way Post-Blackout Vegetation Management Strategies. EPRI.

McQuilkin, W. E. 1940. The Natural Establishment of Pine in Abandoned Fields in the Piedmont Plateau Region. Ecology **21**:135-147.

Meilleur, A., H. Véronneau, and A. Bouchard. 1994. Shrub communities as inhibitors of plant succession in southern Quebec. Environmental Management **18**:907-921.

Mercier, C., J. Brison, and A. Bouchard. 2001. Demographic Analysis of Tree Colonization in a20-Year-Old Right-of-Way. Environmental Management **28**:777-787.

Michaux, F. A. 1802. Travels to the Westward of the Allegheny Mountains in the States of Ohio. Kentucky, and Tennessee, in the Year **95**.

Muncy, J. A., A. Bowen, J. Branum, C. Chandler, A. Dattilo, B. Dimick, S., C. H. Gaither, T. Liskey, J. Melton, C. Minghini, P. Pearman, K., and J. T. Smithson, E. Willard, R. Wilson. 2012. A Guide for Environmental Protection and Best Management Practices for Tennessee Valley Authority Transmission Construction and Maintenance Activities.*in* T. V. Authority, editor. Tennessee Valley Authority, Chattanooga, TN.

Nationalgrid. 2010. TRANSMISSION RIGHT-OF-WAY MANAGEMENT PROGRAM. Waltham, MA.

Neill, R. L., and E. L. Rice. 1971. Possible Role of Ambrosia psilostachya on Pattern and Succession in Old-Fields. American Midland Naturalist **86**:344-357.

Niering, W. A. 1957. The Connecticut Arboretum right-of-way demonstration area progress report. Pages 203-208 Northeast Weed Control Confrence.

Niering, W. A. 1958. Principles of Sound Right-of-Way Vegetation Management. Economic Botany **12**:140-144.

Niering, W. A. 1987. Vegetation Dynamics (Succession and Climax) in Relation to Plant Community Management. Conservation Biology **1**:287-295.

Niering, W. A., and R. H. Goodwin. 1974. Creation of Relatively Stable Shrublands with Herbicides: Arresting "Succession" on Rights-of-Way and Pastureland. Ecology **55**:784-795.

North American Electric Reliability Corporation. 2009. Long-Term Reliability Assessment 2009-2018. North American Electric Reliability Corporation, Princton, NJ.

North American Electric Reliability Corporation. 2011. Long-Term Reliability Assessment 2011. North American Electric Reliability Corporation, Princton, NJ.

Noss, R. F. 2012. Forgotten grasslands of the South: natural history and conservation. Island Press.

Nowak, C. A., L. P. Abrahamson, E. F. Neuhauser, C. G. Foreback, H. D. Freed, S. B. Shaheen, and C. H. Stevens. 1992. Cost Effective Vegetation Management on a Recently Cleared Electric Transmission Line Right-of-Way. Weed Technology **6**:828-837.

Odum, E. P. 1960. Organic Production and Turnover in Old Field Succession. Ecology **41**:34-49.

Olson, E., L. S. Kenefic, C. D. Alison, and J. C. Brissette. 2011. Nonnative invasive plants in the Penobscot Experimental Forest in Maine, USA: Influence of site, silviculture, and land use history. Journal of the Torrey Botanical Society **138**:453-464.

Oosting, H. J. 1942. An Ecological Analysis of the Plant Communities of Piedmont, North Carolina. American Midland Naturalist **28**:1-126.

Orr, J. W. 2008. State Game Lands 33 Research and Demonstration Area: 55 Years of Integrated Vegetation Management at Work. Electric Energy T&D **July/August**:31-33.

Ostfeld, R. S., and C. D. Canham. 1993. Effects of Meadow Vole Population Density on Tree Seedling Survival in Old Fields. Ecology **74**:1792-1801.

Ostfeld, R. S., R. H. Manson, and C. D. Canham. 1997. Effects of Rodents on Survival of Tree Seeds and Seedlings Invading Old Fields. Ecology **78**:1531-1542.

Parenti, R. L., and E. L. Rice. 1969. Inhibitional Effects of Digitaria sanguinalis and Possible Role in Old-Field Succession. Bulletin of the Torrey Botanical Club **96**:70-78.

Penfound, W. T. 1964. The Relation of Grazing to Plant Succession in the Tall Grass Prairie. Journal of Range Management **17**:256-260.

Pickett, S. T. A., M. L. Cadenasso, and S. Bartha. 2001. Implications from the Buell-Small Succession Study for Vegetation Restoration. Applied Vegetation Science **4**:41-52.

Pickett, S. T. A., S. L. Collins, and J. J. Armesto. 1987. Models, Mechanisms and Pathways of Succession. Botanical Review **53**:335-371.

Pieper, R. D. 1968. Comparison of Vegetation on Grazed and Ungrazed Pinyon-Juniper Grassland Sites in Southcentral New Mexico. Journal of Range Management **21**:51-53.

Pierson, F. B., C. J. Williams, S. P. Hardegree, M. A. Weltz, J. J. Stone, and P. E. Clark. 2011. Fire, Plant Invasions, and Erosion Events on Western Rangelands. Rangeland Ecology & Management **64**:439-449.

Post, W. M., and K. C. Kwon. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology **6**:317-327.

Potter, L. D., and J. C. Krenetsky. 1967. Plant Succession with Released Grazing on New Mexico Range Lands. Journal of Range Management **20**:145-151.

Prater, J. L. O. L. N. M. M. S. M. B. B. J. A. T. P. D. D. 1997. Soil survey of Sumner County, Tennessee.*in* N. R. C. S. US Department of Agriculture, editor.

Priest, A., and H. Epstein. 2011. Native Grass Restoration in Virginia Old Fields. Castanea **76**:149-156.

Priestley, T., and G. W. Evans. 1996. Resident perceptions of a nearby electric transmission line. Journal of Environmental Psychology **16**:65-74.

Qian, Y., R. F. Follett, and J. M. Kimble. 2010. Soil organic carbon input from urban turfgrasses. Soil Science Society of America Journal **74**:366-371.

Quarterman, E. 1957. Early Plant Succession on Abandoned Cropland in the Central Basin of Tennessee. Ecology **38**:300-309.

Ramankutty, N., E. Heller, and J. Rhemtulla. 2010. Prevailing Myths About Agricultural Abandonment and Forest Regrowth in the United States. Annals of the Association of American Geographers **100**:502-512.

Revesz, R. L. 1999. Environmental regulation, cost-benefit analysis, and the discounting of human lives. Columbia Law Review:941-1017.

Rice, E. L. 1972. Allelopathic Effects of Andropogon virginicus and its Persistence in Old Fields. American Journal of Botany **59**:752-755.

Richards, N., and R. Goodland. 1973. Old field vegetation as an inhibitor of tree vegetation. Pages 78-88 *in* Proceedings of the Colloquium Biotic Management Along Power Transmission Rights of Way.

Richards, R. T., J. C. Chambers, and C. Ross. 1998. Use of native plants on federal lands: policy and practice. Journal of Range Management:625-632.

Rizza, J., J. Franklin, and D. Buckley. 2007. The influence of different ground cover treatments on the growth and survival of tree seedlings on remined sites in eastern Tennessee. Barnhisel RI (ed) **30**:2-7.

Ryon, M. G., P. D. Parr, and K. Cohen. 2006. Native Grass Community Management Plan for the Oak Ridge Reservation.

Samuel, M. J., and R. H. Hart. 1994. Sixty-One Years of Secondary Succession on Rangelands of the Wyoming High Plains. Journal of Range Management **47**:184-191.

Schlossberg, S., and D. I. King. 2009. Postlogging Succession and Habitat Usage of Shrubland Birds. The Journal of Wildlife Management **73**:226-231.

Schmer, M. R., K. P. Vogel, R. B. Mitchell, L. E. Moser, K. M. Eskridge, and R. K. Perrin. 2006. Establishment stand thresholds for switchgrass grown as a bioenergy crop. Crop Science **46**:157-161.

Seymour, R., J. Seymour, and C. Blackford. 2008. Six Basic Elements for a Successful Native Grass and Forb Establishment. Roundstone Native Seed LLC, Upton, KY.

Shatford, J., D. Hibbs, and L. Norris. 2003. Identifying Plant Communities Resistant to Conifer Establishment Along Utility Rights-of-Way in Washington and Oregon, US. Journal of Arboriculture **29**:172-176.

Simanton, J. R., and G. L. Jordan. 1986. Early root and shoot elongation of selected warm-season perennial grasses. Journal of Range Management:63-67.

Simberloff, D. 2001. Biological invasions--How are they affecting us, and what can we do about them? Western North American Naturalist **61**:308-315.

Smeins, F. E., T. W. Taylor, and L. B. Merrill. 1976. Vegetation of a 25-Year Exclosure on the Edwards Plateau, Texas. Journal of Range Management **29**:24-29.

Soini, K., E. Pouta, M. Salmiovirta, M. Uusitalo, and T. Kivinen. 2011. Local residents' perceptions of energy landscape: the case of transmission lines. Land Use Policy **28**:294-305.

Sparry, R. E. 2002. Transmission Line Standards Siting and Environmental Review Process Description Of Siting Process.*in* T. E. T. T. S. E. Design, editor. Tennessee Valley Authority, Chattanooga, TN.

Stalter, R. 1972. The Revegetation of a Rhode Island Right-of-Way, Exeter, Rhode Island. Castanea **37**:77-83.

Steiner, A. a. d. S., Frederick C., editor. 1799. Report of the Journey of the Bretheren Abraham Steiner and Frederic C. de Schweintz to the Cherokees and the Cumverland Settelements. The Watauga Press, Johnson City, TN.

Sullivan, J. H., and J. D. Pittillo. 1988. Succession of Woody Plants into a High Elevation Grassy Bald of the Balsam Mountains. Castanea **53**:245-251.

Sullivan, P., D. Hellerstein, L. Hansen, R. Johansson, S. Koenig, R. N. Lubowski, W. D. McBride, D. A. McGranahan, M. J. Roberts, and S. J. Vogel. 2004. The conservation reserve program: economic implications for rural America. USDA-ERS Agricultural Economic Report.

Suwa, T., and S. M. Louda. 2012. Combined effects of plant competition and insect herbivory hinder invasiveness of an introduced thistle. Oecologia **169**:467-476.

Swanton, C. J., D. R. Clements, and D. A. Derksen. 1993. Weed Succession under Conservation Tillage: A Hierarchical Framework for Research and Management. Weed Technology **7**:286-297.

Tennessee Valley Authority. 2007. Offering Circular. Tennessee Valley Authority, Knoxville, TN.

Tennessee Valley Authority. 2012. TVA Fact Book.

Tennessee Valley Authority. 2013. Right of Way Vegetation Management Guidelines.*in* T. V. A. E.-E. Delivery, editor. Tennessee Valley Authority, Chattanooga, TN.

Tennessee Valley Authority. 2014a. Budget Proposal and Management Agenda For the Fiscal Year Ending September 30, 2015. Tennessee Valley Authority, Knoxville, TN.

Tennessee Valley Authority. 2014b. Offering Circular. Tennessee Valley Authority, Knoxville, TN.

Tennessee Valley Authority. 2014c. Unites States Securities and Exchange Commission form 10-K. Tennessee Valley Authority, Knoxville, TN.

Thoreau, H. D. 1860. The succession of forest trees. Wm. White Printer, Boston, MA.

Tilman, D. 1985. The Resource-Ratio Hypothesis of Plant Succession. The American Naturalist **125**:827-852.

Tinsley, M. J., M. T. Simmons, and S. Windhager. 2006. The establishment success of native versus non-native herbaceous seed mixes on a revegetated roadside in Central Texas. Ecological Engineering **26**:231-240.

Turk, J. R. 2014. Challenging the Status Quo: How TVA is Updating Its Vegetative Best Management Practices. International Erosion Controll Association Environmental Connection. IECA, Nashville, TN.

Vander Yacht, A. L. 2013. Vegetation Response to Oak Savanna and Woodland Restoration in the Mid-South USA.

Vickerman, R. 2007. Cost-benefit analysis and large-scale infrastructure projects: state of the art and challenges. ENVIRONMENT AND PLANNING B PLANNING AND DESIGN **34**:598.

Vitousek, P. 1983. Nitrogen Turnover in a Ragweed-dominated 1st-year Old Field in Southern Indiana. American Midland Naturalist **110**:46-53.

Vogel, K. P. 1987. Seeding rates for establishing big bluestem and switchgrass with preemergence atrazine applications. Agronomy journal **79**:509-512.

Vogel, K. P., and R. A. Masters. 2001. Frequency grid: A simple tool for measuring grassland establishment. Journal of Range Management:653-655.

Voorhees, L. D., and J. F. Cassel. 1980. Highway Right-of-Way: Mowing versus Succession as Related to Duck Nesting. The Journal of Wildlife Management **44**:155-163.

Wagner, D. L., K. J. Metzler, S. A. Leicht-Young, and G. Motzkin. 2014. Vegetation composition along a New England transmission line corridor and its implications for other trophic levels. Forest Ecology and Management **327**:231-239.

Waldner, L. S. 2008. The kudzu connection: Exploring the link between land use and invasive species. Land Use Policy **25**:399-409.

Walker, L. R., and F. S. Chapin, III. 1987. Interactions among Processes Controlling Successional Change. Oikos **50**:131-135.

Warming, J. E. B. 1895. Plantesamfund. Grundtræk Af Den Økologiske Plantegeografi.

Washburn, B. E., T. G. Barnes, and J. D. Sole. 2000. Improving northern bobwhite habitat by converting tall fescue fields to native warm-season grasses. Wildlife Society Bulletin:97-104.

Wasser, C. H. 1982. Ecology and culture of selected species useful in revegetating disturbed lands in the West. Fish and Wildlife Service, US Department of the Interior.

Wedin, D. A., and D. Tilman. 1992. Nitrogen cycling, plant competition, and the stability of tallgrass prairie. Pages 5-8 *in* Proceedings of the Twelfth North AmericanPrairie Conference: Recapturing a Vanishing Heritage.

West, N. E., F. D. Provenza, P. S. Johnson, and M. K. Owens. 1984. Vegetation Change after 13 Years of Livestock Grazing Exclusion on Sagebrush Semidesert in West Central Utah. Journal of Range Management **37**:262-264.

Whittaker, R. H. 1953. A Consideration of Climax Theory: The Climax as a Population and Pattern. Ecological Monographs **23**:41-78.

Williams, G. W. 2000. Introduction to aboriginal fire use in North America. Fire Management **60**:8.

Williams, R. D., and S. H. Hanks. 1976. Hardwood nurseryman's guide. Agriculture Handbook, US Department of Agriculture.

Wilson, R. E., and E. L. Rice. 1968. Allelopathy as Expressed by Helianthus annuus and Its Role in Old-Field Succession. Bulletin of the Torrey Botanical Club **95**:432-448.

Wojcik, V. A., and S. Buchmann. 2012. POLLINATOR CONSERVATION AND MANAGEMENT ON ELECTRICAL TRANSMISSION AND ROADSIDE RIGHTS-OF-WAY: A REVIEW. Journal of Pollination Ecology **7**.

Wood, M. K., and W. H. Blackburn. 1984. Vegetation and Soil Responses to Cattle Grazing Systems in the Texas Rolling Plains. Journal of Range Management **37**:303-308.

Wren, C. R. 2013. Final Environmental Assessment: Installation of Emission Control Equipment and Associated Facilities at Gallatin Fossil Plant.*in* T. V. Authority, editor., Chattanooga, TN.

Wright, J. P., and J. Fridley, D. . 2010. Biogeographic synthesis of secondary succession rates in eastern North America. Journal of Biogeography **37**:1584-1596.

Yahner, R. H., W. C. Bramble, and W. R. Byrnes. 2001. Response of amphibian and reptile populations to vegetation maintenance of an electric transmission line right-of-way. Journal of Arboriculture **27**:215-221.

Yahner, R. H., and R. J. Hutnik. 2004. Integrated Vegetation Management on an Electric Transmission Right-of-Way in Pennsylvania, US. Journal of Arboriculture **30**:295-300.

Yarranton, G. A., and R. G. Morrison. 1974. Spatial Dynamics of a Primary Succession: Nucleation. Journal of Ecology **62**:417-428.

Young, C. E., and C. T. Osborn. 1990. Costs and benefits of the Conservation Reserve Program. Journal of Soil and Water Conservation **45**:370-373.

VITA

Joseph R. Turk is a native of Somerville, Alabama. He graduated from A. P. Brewer High School in 1997. After high school he attended the University of Alabama in Huntsville where he studied civil engineering and was awarded a Bachelor of Science in Engineering, graduating *cum laude* in May 2003. He then attended Vanderbilt University in Nashville, Tennessee where he studied construction management and advanced structural engineering under the guidance of Dr. Sanjiv Gokhale and was a Graduate Teaching Assistant for material science labs. He was awarded a Master of Engineering in May 2005, graduating *cum laude*. While pursuing his studies at Vanderbilt, Mr. Turk was employed as a civil engineer with the Tennessee Department of Transportation. In 2006 Mr. Turk began his career with the Tennessee Valley Authority (TVA) as a civil engineer in transmission line design. After being promoted to senior engineer he began working as an environmental engineer supporting transmission line construction. He now works as an instrumentation engineer in TVA's Dam Safety organization. While working for TVA Mr. Turk began pursuing further graduate studies at the University of Tennessee at Chattanooga in 2008. He completed his thesis under the guidance of Dr. Jennifer Boyd, graduating with a Master of Science in Environmental Science in May 2015. Mr. Turk is a Certified Professional in Erosion and Sediment Control and holds stormwater certifications from several states. He spoke at the Tennessee Academy of Science annual meeting in 2012, at the International Erosion and Sediment Control Environmental Connection Conference in Nashville, Tennessee in 2014, and has given numerous lectures and trainings in erosion and sediment control for TVA. Mr. Turk is a resident of Hixson, Tennessee where he lives with his wife April Turk and their daughter Lilly Turk.