An assessment of early-stage forest restoration outcomes and the instruments used to evaluate ecosystem recovery

by

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Abstract

Ecological restoration projects are considered successful when identified goals are achieved and the ecosystem progresses along a predicted successional trajectory. My study examined the progress of early-stage forest restoration projects within the Regional Municipality of Waterloo to determine the variables that affect early successional trajectories. The study was undertaken to gain further insight into the most appropriate methods to use in the evaluation of restoration outcomes and to provide some useful recommendations for restoration ecologists and practitioners.

Between April-October 2005 and April 2006, data were collected using a stratified random sampling technique and the wandering-quarter method to evaluate herbaceous vegetation, regenerating woody vegetation and mature trees at 7 forest restoration sites within the Regional Municipality of Waterloo. The Regional Municipality of Waterloo was selected as the study area because it has restoration projects established in forested ecosystems and the Region is typical of southern Ontario, i.e., forest ecosystems have been disturbed by urban and agricultural activities and require ecological restoration.

A nested Analysis of Variance was used to test the responses of various herbaceous and woody vegetation parameters to the restoration site, restoration technique nested within the restoration site, and transects nested within the restoration technique. Site location, restoration technique, and restoration transect all appear to significantly affect restoration progress for some structural metrics. Species diversity (measured by the Shannon-Wiener Index) was significantly affected by the restoration site ($p<0.01$) and transect nested within the restoration technique ($p<0.01$). For some sites, differences in diversity among transects are expected to diminish as restoration proceeds and natural succession progresses. For heavily degraded sites, however, that exhibit low native plant species diversity may require a more intensive restoration strategy to improve local conditions. Density was significantly affected by the restoration site ($p<0.001$) and the restoration technique nested within the site ($p<0.01$). Sites without a closed forest canopy had higher densities of plants for all sampling guilds. The percentage of native species was significantly affected by the restoration site ($p<0.01$) and the restoration technique nested with the site ($p<0.05$). Sites that were restored from degraded forest conditions, rather than from old fields, exhibited significantly higher percentages of native plants for all sampling guilds.

Generally, sites with high species diversity, a high percentage of native species, and high density indicated that ecological restoration was progressing on the predicted successional trajectories and should lead to a successful restoration as time goes on. Results indicate that 4 out of 7 restoration sites are progressing as expected, i.e., towards the predetermined restoration goal. The remaining 3 restoration sites may recover over time, but will most likely require additional restoration measures to achieve a desirable long-term outcome. At early-stages, structural measures appear to be useful indicators for evaluating the progress of restoration. In order for a restoring ecosystem to follow along an expected trajectory, formative evaluation must occur throughout the process to ensure that positive outcomes are achieved along the way. The study concludes that evaluating the progress of forest restoration projects at an early stage could greatly improve the long-term success of restoration outcomes by offering opportunities for mid-course correction and to learn from past mistakes.

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Chapter 1

Introduction

Many habitats are threatened worldwide and it is often necessary to expend considerable efforts in decontaminating and rehabilitating degraded ecosystems. The incentives for the initial development of the field of restoration ecology included the need to prevent or halt land degradation and a desire to improve the aesthetics and amenity of industrial landscapes (Adam 2001). Today, restoration efforts vary greatly in terms of motivating factors, goals, approach, and scale. Restoration ecology begins with the premise that "something is missing" and that the ecosystem and more broadly the landscape that it occupies will benefit if the missing pieces or processes are restored (SER 2004). Specific species, ecological functions, communities, and landscapes alike have acted as restoration project endpoints (Anand & Desrochers 2004; Lake 2001).

Forested ecosystems, comprising approximately half of Canada's landmass at 402.1 million hectares, are important in moderating climate, purifying air and water, stabilizing soil and providing sanctuary for wildlife (NRC 2005). Canadian forests, however, currently face the serious challenges of environmental degradation and global climate change. In particular, forest cover in parts of southwestern Ontario, Canada is now at less than 5% because of intensive agricultural and urban land use (McLachlan & Bazely 2003). Prior to European settlement, forest cover has been estimated at 95%, lowering to approximately 60% in 1840 (Riley & Mohr 1994). Environmental degradation results in a decline in the productive or regenerative capacity of an ecosystem. Although ecosystems can degrade naturally, numerous anthropogenic activities have played a significant role in increasing the rate of forest degradation, alteration and removal. Forest planting, ecosystem restoration and the natural expansion of forests have managed to reduce some of the local and regional effects that result from deforestation (FAO 2005). Based on the altered state of the Earth's ecosystems and the inherently dynamic nature of ecosystems, newly established and regenerating forest ecosystems will most likely not be exact replicas of those that stood prior to human impact after European settlement.

Recovery plans and techniques used in the practice of restoration ecology have been improved and continue to progress through trial and error and by knowledge gained from ecological studies (Perrow & Davy 2002; SER 2004). Aspects considered important in the majority of forest restoration techniques encountered include: (1) the use of native plant species; (2) the use of site-adapted species; (3) the inclusion of natural processes in restoration plans; (4) the inclusion of remnant patches of forest in restoration plans; and (5) the application of continuous forest management. Use of the terminology ‘recovery’, perhaps, leads to unrealistic expectations as to what may be achievable (Lake 2001). The science and practice of restoration ecology must recognize that ecosystems are inherently complex and that restoration projects are observer dependent, thus making exact ecological interpretation and replication impossible (Waltner-Toews et al. 2003; White & Walker 1997). In the context of restoration ecology, complexity refers to the number of variables present and the nature of dynamics within the restoring ecosystem. It has been projected that as ecological knowledge increases, the science of restoration will become more effective and efficient in guiding all types of restoration projects.

One of the challenges for restoration ecologists is to determine what the reconstructed ecosystem should look like. Historically, ‘success’ was judged in terms of establishing vegetation cover and was achieved through a mix of empiricism and the application of advanced ecological science (Adam 2001). The goals of contemporary restoration projects have largely remained the re-creation of an exact ecological representation (Perrow & Davy 2002). This is called a reference site or target ecosystem (SER 2004). In addition to defining restoration goals, information provided by the reference site can be used to determine the restoration potential of a site and evaluate the success of restoration efforts (White & Walker 1997). Restoration projects must have clearly defined goals to direct restoration plans and inform monitoring strategies (Lake 2001; Michener 1997). Without a clearly defined goal, the information collected through monitoring will not hold any useful meaning (Busch & Trexler 2003; Vos et al. 2000).

Ecosystems undergoing the process of restoration must be assessed relative to their pre-restoration condition, designated goals and current ecosystem conditions. The literature predominantly suggests that restoration project objectives be evaluated on the basis of success criteria (e.g., SER 2004). These criteria can be learned and extracted from historical, existing or fabricated reference ecosystems (Hobbs & Norton 1996). Reference ecosystems should generally reflect the compositional and structural attributes that have developed following natural disturbances, where the most useful reference ecosystems are those that represent the associated range of natural variability of an ecosystem (Goebel et al. 2005; Ruiz-Jaén & Aide 2005a). Restoration sites and their reference ecosystems should be close to the restoration project, exposed to similar natural disturbances and occur within the same life zone (Martin et al. 2005; SER 2004; Hobbs & Harris 2001). Appropriately selected reference ecosystems can effectively act as endpoints for evaluating restoration project outcomes.

Discrepancy exists surrounding the way in which restoration outcomes should be assessed. The recommended use of a reference ecosystem to guide the assessment process along a restoration trajectory for evaluating restoration outcomes was most predominant in the literature, where restoration projects are thought to be complete when groups of species are established in abundances and proportions similar to those in natural communities such that natural processes can occur (e.g., Allison 2002; Howell & Jordan 1991). Moreover, the inclusion of various parameters in restoration assessment frameworks has been widely debated (Hughes et al. 2005; Jansson et al. 2005; Martin et al. 2005; Palmer et al. 2005; Ruiz-Jaén & Aide 2005a; Choi 2004; Palmer et al. 1997; Hobbs & Norton 1996). Some argue the importance of including functional attributes, while others are satisfied with structural assessments alone. It is not known which aspects of community structure and ecosystem processes are restorable for most ecosystems, yet this information is crucial for evaluating the achievement of successful restoration (Martin et al. 2005). It is obvious that further research is required to fully understand processes of recovery following disturbance and the intervention of restoration in order to adequately evaluate restoration outcomes.

Given the complexity of natural and restoring ecosystems, how can thresholds be identified and how can restoration outcomes be evaluated? Restoration projects are considered successful when identified goals are achieved and the ecosystem is in a new equilibrium state or progressing along an acceptable restoration trajectory. Measures of ecosystem structure and function that are considered important from a scientific or other point of view must be used to identify and define restoration project goals. Reference ecosystems, selected according to ecosystem structure and function, provide an opportunity to define goals in a realistic fashion. In this way, an assessment of restoration progress then becomes the distance in ecosystem state space between degraded and reference sites (Hobbs & Norton 2004).

Structure may not always be the best indicator but it is often more pragmatic, i.e., easier and cheaper, to measure than most ecosystem functions (Ruiz-Jaén & Aide 2005b; Reay & Norton 1999). Nonetheless, there is evidence that structural indicators like increased species diversity may not always indicate the implicitly or explicitly assumed improvement in ecosystem function (e.g., Salomon et al. 2005). Despite the need for long-term measures of functional indicators, structural measures, such as species diversity and percentage of native species, are appropriate indicators of early ecological restoration progress. At early stages of forest restoration, the survival and expansion of planted vegetation is a good indication that the restoration strategy is working (Wilkins et al. 2003). If the planted vegetation has died or is not doing well, further intervention will obviously be required. Generally, sites with high species diversity, a high percentage of native species, and high density are considered to be progressing on the predicted successional trajectory and should lead to a successful restoration as time goes on. Assessing whether the planted vegetation is alive, determining how well the vegetation is doing and if their populations have expanded, and evaluating whether there is a high percentage of native species will conceivably help to fill in the gap of knowledge on early-stage forest restoration outcomes and provide opportunities for the midcourse correction of restoration projects.

Evaluating the similarity among restoration projects and identified reference ecosystems requires accurate and repetitive measurements. Since the ecosystem structure and function, and abiotic components of even a small area are far too complex to be comprehensively measured and quantified, suitable measurements have to be identified and relied upon (Duelli & Obrist 2003). There is no single measurement for evaluating restoration outcomes and thus the selection of parameters is dependent on the type of restoration project being assessed. Choices of parameters are guided by human perceptions of ecological appropriateness and a value system based on personal and/or professional motivation. Common goals of ecological restoration projects are to replicate the community structure (e.g., species composition and diversity) and ecosystem function found in remnant sites (Martin et al. 2005; Palmer et al. 2005). Thus, structural and functional ecosystem attributes often form the basis of restoration evaluative frameworks. In cases where ecosystems are altered and degraded beyond the vegetation, parameters dealing with affected soils, topography, drainage, etc. must be selected and applied prior to further restoration efforts.

Monitoring is essential to managing resource systems that are characterized by unpredictability (Busch & Trexler 2003). Although the response and impact of restoration activities are highly unpredictable, monitoring plans have only recently become a recognized component of restoration plans (i.e., within the last 20 years) (Michener 1997). Documentation and analysis of past restoration experience is crucial for furthering both the science and practice of restoration (Jansson et al. 2005; Palmer et al. 2005). Cooperation must be fostered among ecologists and practitioners in order to maximize the effectiveness and efficiency of both restoration and monitoring strategies (Clewell & Rieger 1997). Effectiveness, with respect to restoration ecology, refers to the ability of various techniques to produce expected changes within the restoring ecosystem. Efficiency refers to the length of time and amount of resources required to reproduce expected effects or the target ecosystem. Improved effectiveness and efficiency of restoration strategies are important, as the need and urgency to restore degraded and endangered environments continues to increase (Lake 2001).

Coincident with the development of restoration techniques, the processes used to evaluate restoration success have also become more sophisticated and insightful (Busch & Trexler 2003; Vos et al. 2000). However, numerous limitations of evaluation strategies currently used to assess restoration efforts have been identified, including:

1) The exclusion of a conceptual framework (Busch & Trexler 2003; NRC 2000; Palmer et al. 1997);
2) The lack of agreed upon success criteria (Jansson et al. 2005; Palmer et al. 2005; Hobbs 2003; Hobbs & Norton 1996);
3) The reliance on environmental indicators to determine restoration success (Anand & Desrochers 2004; Brydges 2001; Dale & Beyeler 2001; NRC 2000);
4) The lack of monitoring and monitoring documentation (Thompson & Thompson 2004; Clewell & Rieger 1997; Michener 1997); and
5) The deficiency of communication and cooperation between and among restoration ecologists and practitioners (Hobbs 2003; Lake 2001; Clewell & Rieger 1997; Palmer et al. 1997).

This information indicates that current evaluative frameworks employed in restoration strategies are insufficient and could be improved. For the relationship between project design and implementation, and restoration progress to be revealed, monitoring techniques and the involvement of scientists and practitioners must be reevaluated. This study identifies the strengths and limitations of the assessment practices used to evaluate restoration project outcomes, provide some suggestions for improvement, and hypothesize how improved monitoring might have an impact on restoration success.

It has been proposed that restoration success should be based on the restoration of three main ecosystem attributes, which are: (1) the proportion of native species and vegetation structure; (2) ecosystem processes (e.g., net primary productivity and nutrient cycling); and (3) species diversity at all spatial scales (Martin et al. 2005; Ruiz-Jaén & Aide 2005a; Bradshaw 1996; Hobbs & Norton 1996). These attributes have been identified as essential components for the long-term persistence of an ecosystem (Ruiz-Jaén & Aide 2005b) and are thus important to include in an evaluative restoration framework. Despite the call for extensive evaluative frameworks, where other components of the ecosystem are measured and evaluated, most forest restoration projects have focused on the recovery of vegetation to assess restoration success. This type of assessment is judged appropriate because the goals of conservation and restoration have usually been defined in terms of well-documented vegetation types (Hughes et al. 2005), although it provides a limited evaluation of overall ecological integrity.

According to Parks Canada (2006), ecological integrity is “a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes.” To assess the integrity of a restoring ecosystem, measures of ecosystem process must be included in the evaluative framework. However, at early stages of restoration assessment, measures of ecosystem process and function are often omitted in exchange for more-depth analyses of vegetation structure (Hughes et al. 2005; Ruiz-Jaén & Aide 2005b; Hobbs & Norton 1996). Initial stages of recovery along a restoration trajectory are most often characterized by the rapid re-colonization and re-development of vegetation structure. Many ecosystem processes and functions recover further along the restoration trajectory, once suitable conditions become available to support their re-establishment (Shepherd & Debinski 2005; Zedler & Callaway 1999; Jackson et al. 1995; Hobbs 1993). Strong correlations have been found between the recovery of vegetation composition and functions for some ecosystems (Stanturf et al. 2001; Higgs 1997). Moreover, there is a general lack of understanding of how ecosystems function (Kreman 2005; Mouillot et al. 2005; Hobbs & Norton 1996).

Early-stage restoration outcomes are most often evaluated using measures of vegetation structure, rather than process or function, based on their ease of measurement and extent of ecological understanding. Structural metrics, such as species diversity, plant density, and the percentage of native species are useful in determining the response of the restoration site to the restoration technique at early stages. For example, if planted species have not survived and/or expanded over the first few years of restoration, further intervention will most likely be required. Although imperfect, early assessments of structure provide useful insight into the initial stages of ecosystem recovery and the future development of ecosystem processes.

For the current study, the progress of early-stage forest restoration projects was evaluated at 7 sites in the Regional Municipality of Waterloo, based on vegetation structure and diversity measures. Data were collected, analyzed and interpreted for each restoration site and the reference ecosystem to determine how restoration is progressing in each case. The study provides an indication of the variables that contribute to restoration success or failure at an early stage of restoration. Significant differences were found among the restoration sites in response to restoration site, restoration technique, and restoration transect within the restoration site. Knowing that much can be learned from early-stage restoration evaluation, it is hoped that this information will motivate those who are planning to evaluate implemented projects to begin the evaluation process immediately, and not only in the long-term (i.e., in 20 years). The evaluation of early-stage restoration outcomes is useful for determining which restoration techniques provide the most effective and efficient results and for predicting future restoration outcomes. Numerous authors have decried the lack of early-stage restoration evaluation and have alluded to the usefulness of viewing restoration as a continuum where restoration goals can be measured throughout the management process (Haynes 2004; Reay & Norton 1999; Stanturf et al. 1999; Clewell & Rieger 1997; Majer 1989).

Restoration projects should be evaluated over the short-term as well as the long-term to increase the possibility of achieving lasting restoration success. Insight into future restoration outcomes can be gained from earlier ones by using ecological theories that are relevant to ecosystem recovery. Determining restoration outcomes at different stages along the restoration trajectory will help to reduce the frequency of failed restoration projects by improving the usefulness of the tools used to facilitate restoration. The study opines that the evaluation of early-stage outcomes is important and relevant to progressing restoration ecology as a scientific field and contributor to ecology theory.

A contribution has been made to maintaining the impetus in the process of developing a set of guidelines that will help scientists and practitioners identify ecologically successful forest restoration outcomes. And, this work should encourage more robust assessment of ecological restoration projects in forests and elsewhere. Whether over the short-term or long-term, the evaluation of restoration outcomes provides opportunities to learn and improve restoration techniques, approaches and theories. These opportunities are required to further the understanding of the processes involved with ecosystem recovery.

The purpose of the present study was to evaluate restoration project outcomes and examine the effectiveness of the assessment tools currently used to evaluate progress in restoration ecology. These areas of interest were addressed by the following research questions: *What are the outcomes of early-stage forest restoration projects based on the assessment strategies advocated by restoration ecology? What factors appear to play the greatest role in achieving successful restoration outcomes? And, how successful are the instruments of evaluation in determining the recovery of desired ecosystems at early stages of the restoration process?* The study was undertaken to gain further insight into the most appropriate methods to use in the evaluation of restoration outcomes. In particular, the goals of the project were to provide a critique of the evaluative techniques most strongly advocated by the literature and to provide some useful recommendations for restoration ecologists and practitioners alike. It is hoped that this study will build upon previous work completed in the area of evaluative frameworks for restoration projects and provide insight into areas of needed future research.

The scope of the present study was limited to the forested regions of the Regional Municipality of Waterloo, which is located at the edge of two forest regions: the Carolinian zone and the Great Lakes-St. Lawrence Forest region. Moreover, the study sites were limited to young forest restoration projects that were completed using some form of active restoration. The fieldwork methods were limited to vegetation structure and diversity. Lastly, the scope of the project has been limited to the ecological realm; however, several of the recommendations made involve many of the social, political and philosophical issues that are associated with restoration ecology. This report begins with a review of the relevant literature, followed by an outline of the methodology used, an explanation of the field study sites, a presentation of the results, a discussion section, recommendations and conclusions.

Chapter 2

Literature Review

2.1 Introduction

The literature review aimed to address the following framework questions: (1) What is the meaning of progress in restoration ecology? (2) What ways of assessing restoration outcomes are advocated in the literature? and (3) How effective are these techniques in evaluating long-term restoration outcomes? The database used to collect information on these topics was predominantly the Web of Science. The search terms used included: restoration success, restoration evaluation, restoration outcomes, restoration goals, indicators/bio-indicators, ecological integrity, ecological monitoring, reference ecosystems, vegetation dynamics, succession, and ecological assembly rules. Literary searches were restricted to the English language, and journal articles that were published in 1990 or onwards. The year 1990 was used as a cut-off because a preliminary review of the literature indicated that the study of evaluative frameworks for restoration projects began around this time. Using these terms and restrictions, 141 papers were retrieved. Reasons for not including certain retrieved papers included irrelevance to the topic and the degree of technicality and/or specificity of the article (e.g., exceedingly technical or specific papers were omitted because they did not contribute to the questions at hand). The major themes reviewed in the literature were the motivations for restoration ecology, the science and practice of restoration ecology, ecological filters and the filtering process, the goals of restoration projects, the evaluation of restoration projects, and the role of ecological monitoring in restoration project evaluation. The aim of the literature review was to identify the general perspectives and approaches used by restoration ecology researchers and practitioners in pursuit of evaluating restoration outcomes over the long-term.

2.2 Restoration ecology as a scientific framework and the practice of ecological restoration

“Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (SER 2004). Therefore, any management activity that accelerates expected change can be considered a restoration effort. The ideal of restoration ecology is to re-establish a completely functioning and self-sustaining system (Jackson et al. 1995). It has been recommended that restoration measures take advantage of natural vegetation succession resulting from remnant patches, which often provide valuable sources of local biodiversity (Sayer et al. 2004). However, it should not be assumed that indirect benefits will result from non-manipulated components of the ecosystem (McLachlan & Bazely 2003). In this respect, active restoration measures that accelerate ecological change through optimizing site availability, species availability and species performance should be sought (Pickett et al. 1987). Active ecological restoration is a process fundamental to recovering the structure and function of degraded landscapes that are necessary for achieving self-sustaining ecosystems (e.g., Box 1996).

Restoration ecology has been recognized as an opportunity to test and advance ecological theories in the field, either by bringing new focus to existing ecological theory or by fostering novel ecological ideas (Young et al. 2005; Choi 2004; Bradshaw 1993). Scientific triumphs have been achieved through the paradigm of restoration ecology. For example, recent advances in plant community ecology have been strongly linked with issues in restoration ecology (Young et al. 2005). However, the classification of restoration ecology as a science has been questioned for the following conceptual and logistical reasons: (1) the general lack of understanding of ecosystem structure and function; (2) the challenge of identifying which factors are important in ecosystem development; (3) the difficulty of spatial and temporal replication in a restoration context; (4) the use of large areas to be restored at a great expense; (5) the requirement of collaboration among and between restoration ecologists and practitioners; (6) the difficulty of design and implementation control in an ecological setting; and (7) the need for a reference or specific restoration goal (Wolters et al. 2005; Allen et al. 1997; Clewell & Rieger 1997; Michener 1997). Although most of these examples are not unique to restoration ecology, data that could be extremely useful from both an applied and a theory-based ecological perspective are often not collected as a result (Michener 1997). Palmer et al. (2005) state that, for restoration to progress as a science, there is a need for widely supported standards and criteria that motivate restoration practitioners to assess and report on the methods used. The use of long-term studies, large-scale comparative studies, space-for-time substitutions, modelling, and focused-experiment analytical tools have been recommended as methods to advance restoration ecology as a science (Stanturf et al. 2001; Michener 1997).

2.3 Motivations for restoration ecology

Inappropriate land use practices, pollutants, exploitation and overpopulation have led to simplified ecosystems and degraded environmental quality (Brooks et al. 2002). Many habitats are now threatened worldwide; thus, it is often necessary to expend considerable efforts in decontaminating and rehabilitating degraded ecosystems and resources. Concern for the diminishing amount of natural area, habitat heterogeneity, indigenous biodiversity, and small population sizes has led to a tremendous increase in interest in restoration as a technique for reversing habitat degradation (Reay & Norton 1999; Yates & Hobbs 1997; Hobbs & Norton 1996; Bradshaw 1983). The incentives for the initial development of the field of restoration ecology included the need to prevent or halt land degradation and a desire to improve the aesthetics and amenity of industrial landscapes (Adam 2001). Most restoration projects begin with the premise that "something is missing" and that the ecosystem, and more broadly the landscape that it occupies, will benefit if the missing pieces or processes are restored (SER 2004). However, recent restoration efforts have varied greatly in terms of their motivating factors, goals, approach, and scale.

As the need and urgency to restore degraded and endangered environments continues to rise, improved effectiveness and efficiency of restoration strategies becomes increasingly important. With respect to restoration, effectiveness refers to the ability of various techniques to produce expected changes within the restoring ecosystem, whereas efficiency refers to the length of time and amount of resources required to reproduce expected effects or the target ecosystem. Restoration is thought to be a practical option in circumstances where intervention enables the resulting system to develop considerably faster than if left to natural processes (Reay & Norton 1999). Although there are still many practical problems associated with restoration, these efforts have begun to play a key role in counteracting anthropogenic and natural ecosystem degradation and have been considered a new paradigm for biological conservation (Choi 2004; SER 2004; Reay & Norton 1999). Restoration efforts should, however, seek to further conservation efforts rather than serve as an alternative for conservation – conservation prior to degradation should remain the greater priority (Palmer et al. 2005; MacMahon & Holl 2001).

2.4 Ecological filters and the filtering process

Restoration outcomes are the product of a number of different abiotic, biotic and social filters, which influence and guide the trajectory along which the restoring ecosystem follows (Hobbs & Norton 2004; see Figure 1). Environmental filters are mechanisms and conditions capable of reducing the size of the potential species pool (Fattorini & Halle 2004). Starting conditions, the order of species arrival or introduction, and type and timing of disturbance or management influence the structure and function of restored community assemblages (Hobbs & Norton 2004). Moreover, unanticipated environmental variation can alter the progression of the restoration project at any time (SER 2004). Environmental filters not only determine the resistance to restoration but also determine the necessary steps for overcoming that resistance (Hobbs & Norton 2004). By furthering the understanding of these filtering variables, it may become possible to identify those that are likely to play an important role in determining restoration outcomes.

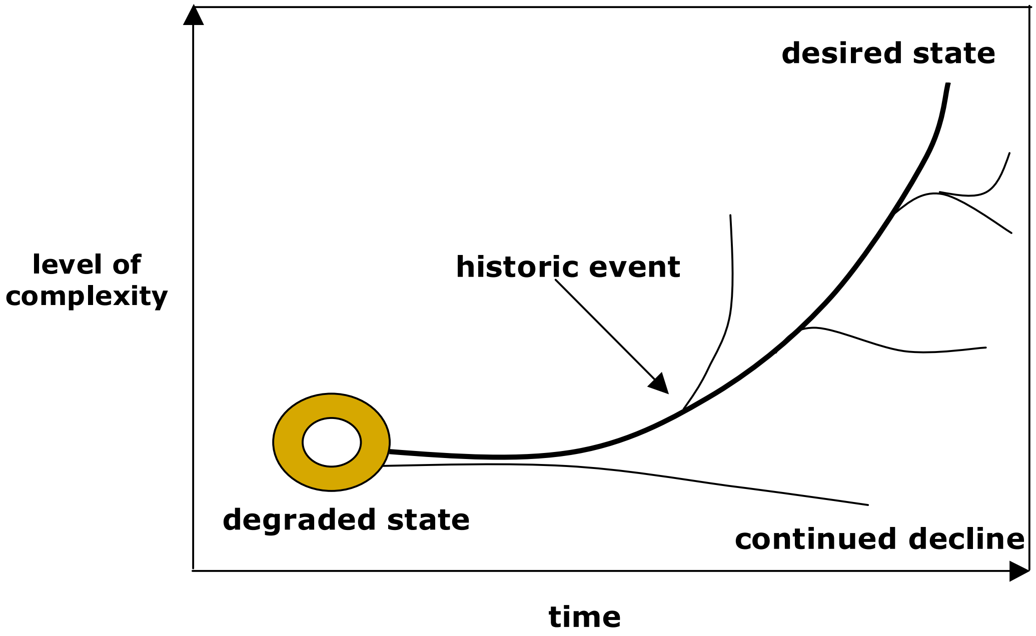


Figure 1. An illustration of the effects of the filtering process on the restoration trajectory and progress toward restoration success (modified from Hobbs & Mooney 1993).

Following a disturbance, a restoration site is able to return to its former state only by replicating the exact combination of filtering effects that created the pre-existing ecosystem. Although it is theoretically possible to achieve a complete or exact ecosystem restoration, this theoretical possibility is challenged by the inherent complex and dynamic nature of ecosystems that have the propensity to exist in multiple different states. Therefore, the goals of restoration projects must reflect the ability of restoration and natural process to force the system over any threshold (i.e., any hindrance to the assembly process that is capable of preventing successful restoration) that may be present and how inflexibly the return to a particular state will be accepted (Hobbs & Norton 2004). This suggests that restoration project objectives and success criteria aimed at achieving a precise restoration endpoint may not be appropriate in most cases.

The dynamic nature of environmental filters acting on species reassembly following a disturbance makes it highly unlikely that the exact combination of the reference ecosystem can be re-created (Aronson et al. 1995). The existence of alternative ecosystem states and ecosystem trajectories are important concepts for restoration ecology, particularly for the goals that are set for specific restoration projects. How stringently the return to a particular state is demanded must be related to the knowledge and ability to force the system over any thresholds that may be present (Hobbs & Norton 2004). Ecological filters represent the thresholds placed on the assembly process and thus limit the achievement of successful restoration outcomes.

2.5 Restoration goals

Considerable debate remains around the definition of restoration end-points (e.g., Ormerod 2003), although it has been clearly established that restoration goals must be selected in order to guide project implementation and assessment (Wolters et al. 2005; Hobbs 2003; Ehrenfeld 2000; Palmer et al. 1997; Aronson & LeFloc'h 1996; Hobbs & Norton 1996). In most cases, restoration projects do have ecological goals, yet most fail to clearly enunciate them (Hobbs 2003; Lake 2001). Restoration goals should be explicit and meaningful, realistic and achievable, and decided upon in an iterative and ecologically, economically, socially, and morally acceptable fashion (Hobbs 2003; Hobbs & Harris 2001; Higgs 1997; Hobbs & Norton 1996). Restoration goals have ranged from measurable ecological outcomes (Hobbs 2003) to aesthetic ones (Allison 2002; Lake 2001). Setting the wrong goals has been identified as one of the causes of restoration failure (Bakker et al. 2000). Restoration goals must be set in a variety of contexts and should therefore be developed appropriately for each project, relative to the scope and motivation for the restoration effort (Ehrenfeld 2000).

Restoration objectives are required for both management and monitoring in order to enable the measurement of restoration outcomes, provide a means for ensuring that ecological goals are achieved, and to increase knowledge of the ecological processes involved in restoration (Box 1996). To date, the most effective way to achieve positive restoration outcomes is to define the goal of the restoration process, be it a habitat, vegetation type, or biological community. However, few scientific guidelines currently exist for undertaking restoration programs, making it difficult to set specific objectives (Palmer et al. 2005; Yates & Hobbs 1997). In each case, the appropriate restoration strategy is location-specific, ultimately depending on the level of degradation and the goals of individual projects (Aide et al. 2000).

The goals of contemporary restoration projects have largely remained the exact ecological re-creation of a predetermined historic or indigenous ecosystem (Perrow & Davy 2002). Goals may be set using information from undamaged reference areas, reliable historical data, or an idealized state or scenario (Lake 2001). Goals may be set at various ecological levels: species, populations, ecosystems or landscapes, and ecological processes are most commonly used to develop restoration goals (Lake 2001; Ehrenfeld 2000). The ultimate goal of restoration is to create a self-supporting ecosystem that is resilient to perturbation without further assistance (Ruiz-Jaén & Aide 2005a; SER 2004). If the purpose of restoration is to recreate a self-supporting ecosystem then the restoration of ecological integrity becomes an important management goal (Rohde et al. 2001; Kay 1994); however, there is much debate over how ecological integrity and resilience can be quantified and measured accurately.

Ideally, restoration efforts will initiate the recovery of damaged ecosystems along a desired trajectory towards a condition similar to a reference system that is believed to represent an advanced stage of ecological development (Anand & Desrochers 2004; SER 2004). Data collected from restoring ecosystems can be compared with those from reference sites to estimate the level of restoration success using resemblance functions (e.g., coefficient of community, indices of percent similarity) (Westman 1991). If possible, reference sites should be close in environmental conditions and geographical position, have similar exposure to natural disturbances, low-level direct human influence, and minimal fragmentation effects (Ruiz-Jaén & Aide 2005a; White & Walker 1997). Reference sites do not have to be in pristine condition but may simply be in good condition and typical of relatively undamaged sites in the region (Lake 2001). Restoration ecologists use reference information to define realistic restoration goals, determine the restoration potential of sites, and evaluate the success of restoration efforts (Yates & Hobbs 1997; Aronson et al. 1995).

The two most common forms of reference information are contemporary data from sites that are good analogs of the site to be restored, and historical data collected from the site to be restored (Wolters et al. 2005; Allison 2002; White & Walker 1997). Contemporary remnant references have been criticised for the following reasons: (1) remnant ecosystems are often small in size and isolated from other patches, which could have led to species loss (Allison 2002); (2) restoration may start on a different substrate or different elevation than the reference (Thom 2000); and (3) variation occurs among reference sites (Ruiz-Jaén & Aide 2005b; Clewell & Rieger 1997). Complete restoration of pre-disturbance conditions is not realistic because it is rarely possible to determine what historic or prehistoric ecosystems looked like or how they functioned (Choi 2004; Lake 2001; Zedler & Callaway 1999). Moreover, some types of ecological damage may be irreversible (Hobbs & Norton 1996; Jackson et al. 1995; Aronson et al. 1993). Since historical references often fail to provide complete ecological databases and ecologically relevant contemporary reference sites are often not available, the use of multiple references has been suggested as a way to further our understanding of ecological variation in restoration contexts (Ruiz-Jaén & Aide 2005b; White & Walker 1997; Pickett & Parker 1994).

The achievement of restoration goals may take more than 100 years. Therefore, it is necessary to determine whether the recovering ecosystem is following the desired trajectory throughout the restoration process (Lake 2001; Westman 1991). Both natural and anthropogenic disturbances can lead an ecosystem along a trajectory towards an endpoint that does not resemble the pre-disturbance community (Wilkinson et al. 2005). Ecosystem processes in particular can be quite sensitive to the timing of particular perturbations. Depending on the timing and strength of interacting forces, a range of alternative meta-stable states may be achieved. Current theory on non-equilibrium communities, thresholds of irreversibility and ecological resilience suggest that restoration goals should aim to re-establish the temporal and spatial diversity inherent in natural ecosystems (Wilkinson et al. 2005; Lake 2001; Westman 1991).

Since our knowledge of ecosystems and their development is limited, restoration goals must be pragmatically set (Zedler 1996). The degree of certainty that can be attached to any restoration objective will always be limited by our understanding of ecological components and the interaction of natural and management processes (Box 1996). This uncertainty questions the setting of clear goals and criteria for success, which are often set using the assumption of a predictable restoration trajectory rather than a chaotic and unpredictable one (Choi 2004).

2.6 Restoration project evaluation

The evaluation of restoration projects has been widely researched (Anand & Desrochers 2004; Hobbs 2003; Stanturf et al. 2001) and many researchers have long argued the importance of evaluation for promoting restoration ecology as a field of scientific study (e.g., Lake 2001; Hobbs & Norton 1996; Bradshaw 1993). The lack of agreed upon criteria for judging restoration outcomes has hampered the progress made by the science and practice of restoration (Jansson et al. 2005; Palmer et al. 2005). It is imperative that the field of restoration ecology identify and accept a set of criteria for defining and assessing ecologically successful restoration projects in order to provide the incentive for practitioners to assess and report restoration outcomes.

Restoration project outcomes can be evaluated in many different ways. However, forest restoration projects connote 'ecological' and must be judged on whether the restoration is an ecological success (Palmer et al. 2005). Ecological success must be distinguished from other types of improvement, such as participant success or learning success (Palmer et al. 2005). Participant success includes improvements in aesthetics, recreation and economic benefits while learning success includes improvements in restoration methods, management and science. The most effective restoration is capable of achieving and maintaining ecological, stakeholder, and learning success simultaneously over time.

Determining how to assess the outcome of a restoration project is one of the most important challenges facing restoration ecologists, yet restoration practitioners and scientists alike remain ill-prepared to quantitatively evaluate restoration success (Michener 1997). Debates continue over what constitutes a reference ecosystem and what attributes are most appropriate to assess restoration outcomes (Palmer et al. 2005; Wolters et al. 2005; Hobbs & Harris 2001; Stanturf et al. 2001; Michener 1997; Palmer et al. 1997; White & Walker 1997). In order to measure success, restoration goals must be discerned, pre-restoration conditions must be assessed, and changes in condition must be detected over time (Hobbs 2003). The preparation of effective and easily measured success criteria and monitoring protocols prior to project implementation is crucial to evaluation (Ruiz-Jaén & Aide 2005b; Hobbs & Harris 2001; Clewell & Rieger 1997; Bradshaw 1983). Few criteria have been established (Hobbs & Norton 1996), despite the discourse on requirements for restoration success and the need to establish clear goals to guide restoration project implementation and evaluation. The purpose of evaluating restoration success is to maximize learning and to allow for mid-course corrections; therefore, measuring success must also account for the possibility of measuring failure.

Ecological understanding can be increased by: (1) collecting long-term monitoring data using standardized methods and keeping detailed records of restoration protocols; (2) consulting with scientists and practitioners in early stages of restoration planning to maximize the opportunity to learn from restoration efforts; and (3) capitalizing on existing restoration efforts and enhancing collaborations among academic researchers and management practitioners (Holl et al. 2003). Monitoring, consultation and collaboration offer enormous potential to improve understanding of dynamic ecosystem processes in general and restoration success in particular.

Restoration ecologists often rely on theoretical models to speculate on how a damaged ecological system can be led along a trajectory to a desired state (Anand & Desrocher 2004; Anand 2000; Carpenter et al. 1999), but succession does not necessarily follow a so-called Clementsian pathway (Clement 1916; see Figures 2 and 3). Due to the unpredictable nature of ecosystems, it has been suggested that a confined region rather than a point become the goal for restoration projects (Anand & Desrochers 2004) and that restoration be promoted as a program rather than discrete beginning and ending points (Clewell & Rieger 1997). Restoration success can be viewed as a continuum beginning with the successful establishment of the initial planting through to the successful establishment of self-sustaining and functional attributes. For longer-term goals to be met, initial stages must be established successfully; however, later stages of the restoration continuum are usually set as the goals of the project (Haynes 2004; Reay & Norton 1999).

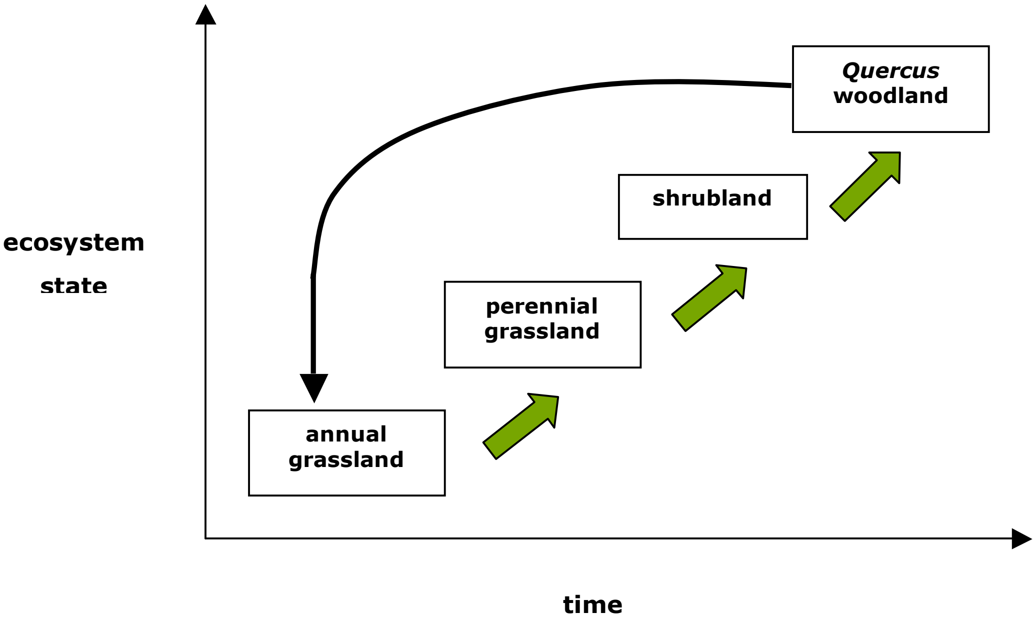


Figure 2. An illustration of the deterministic "climax" model of succession, where ecosystems proceed along a predictable successional trajectory, from one stage to another (modified from Temperton et al. 2004).

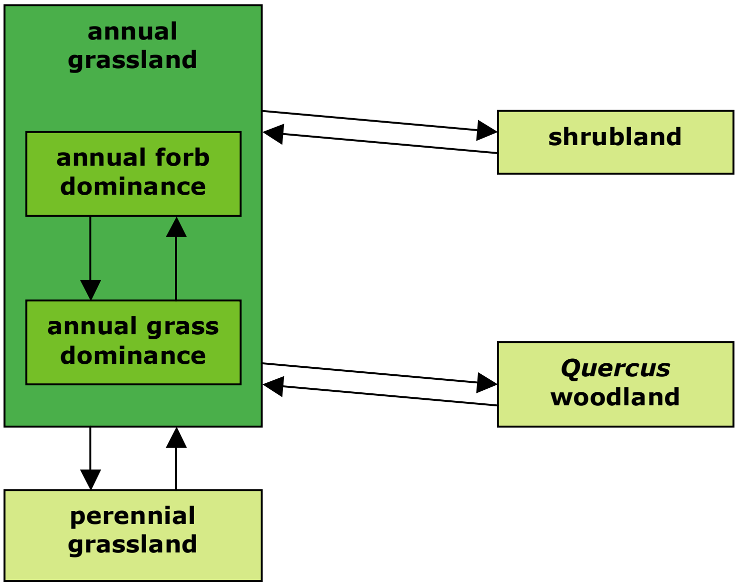


Figure 3. An illustration of an alternative stable states model, where ecosystems are viewed as dynamic and susceptible to human interference. Outcomes are unpredictable and in a state of flux (modified from Temperton et al. 2004).

Recognition of a restoration continuum and the factors that indicate whether or not a system has crossed particular thresholds would improve the methods used to assess restoration outcomes (Hughes et al. 2005; Reay & Norton 1999; Yates & Hobbs 1997). Evaluation of restoration success can be achieved with greater ease by describing restoration success in the context of a continuum where assessments of whether conditions are suitable at the various stages of restoration can be made. The continuum model offers a broader context for restoration by avoiding the specification of a precise endpoint for restoration and allowing restoration practitioners to be prescriptive and flexible in setting restoration goals (Haynes 2004; Stanturf et al. 1999). Since the long-term success of any forest restoration project cannot be determined for many years, the continuum model offers an important guide for evaluating short-term restoration outcomes throughout the management process.

Most often, restoration ecologists look to successional traits (Odum 1969) to select attributes for judging restoration success. The Society of Ecological Restoration International (SER) (2004) produced a primer on ecosystem attributes that should be considered when evaluating restoration success. They suggest that a restored ecosystem should have the following attributes: (1) similar diversity and community structure in comparison with reference sites; (2) presence of indigenous species; (3) presence of functional groups necessary for long-term stability; (4) capacity of physical environment to sustain reproducing populations; (5) normal functioning; (6) integration with the landscape; (7) elimination of potential threats; (8) resilience to natural disturbances; and (9) self-sustainability. Other general qualitative lists for use in developing site-specific and quantitative criteria for success have been provided by Ewel (1987), Aronson et al. (1993), Aronson & LeFloc'h (1996), Hobbs & Norton (1996), Jansson et al. 2005; Palmer et al. (2005), and Ruiz-Jaén & Aide (2005a). Few studies have the financial resources to monitor all possible ecosystem attributes, many of which require detailed and long-term studies (Holl & Howarth 2000; Clewell & Rieger 1997). The selection of which variables to assess and which to ignore requires pragmatism and value judgment by the evaluator (SER 2004). Ruiz-Jaén and Aide (2005a) recommend that future restoration projects include at least two variables within the general attributes of diversity (e.g., richness, abundance), vegetation structure (e.g., vegetation cover), and ecological processes (e.g., nutrient cycling), and at least two reference ecosystems to adequately capture the variation that exists in ecosystems.

Many problems associated with evaluating restoration success have been identified in the literature. These include: (1) the lack of accurate records; (2) the deficiency of communication and cooperation between and among restoration ecologists and practitioners; (3) the small size of restoration sites and reference ecosystems; (4) spatial habitat arrangement; (5) the availability and accessibility of indigenous species; (6) misunderstood ecology; (7) unclear restoration objectives; (8) the resistance to new methods; (9) past land uses; and (10) the financial cost associated with monitoring (Wolters et al. 2005; Choi 2004; Noss 2004; Allison 2002; Lake 2001; Stanturf et al. 2001; Clewell & Rieger 1997; Palmer et al. 1997; Pickett & Parker 1994). Past restoration projects have been unsuccessful mainly due to the setting of unrealistic goals, and social, economic and political constraints (Choi 2004). When setting restoration goals it is important to recognize that some sites may never fully recover their historical character and ecological functions due to irreversible damage, inadequate restoration strategies, or both (Stanturf et al. 2001; Zedler & Callaway 1999).

2.6.1 Evaluation of Ecosystem Structure or Ecosystem Function?

Most forest restoration projects have focused on the recovery of vegetation to assess restoration success. Nevertheless, if the goal of the restoration project is to create an ecosystem that is self-supporting and resilient to perturbation, we also need information on the recovery of other trophic levels and ecosystem processes (Ruiz-Jaén & Aide 2005a). It has been proposed that restoration success should be based on the restoration of three main ecosystem attributes, which are: (1) vegetation structure and composition; (2) ecosystem processes (e.g., net primary productivity and nutrient cycling); and (3) species diversity at all spatial scales (Martin et al. 2005; Ruiz-Jaén & Aide 2005a; Ryder & Miller 2005; Bradshaw 1996; Hobbs & Norton 1996). Measures of vegetation structure and composition, and species diversity provide information on habitat suitability, ecosystem productivity, susceptibility to invasions, ecosystem resilience, and the prediction of successional pathways (McLachlan & Bazely 2003; Bash & Ryan 2002; Anand 2000). Measures of ecosystem processes provide information on nutrient cycling and biogeochemical cycles necessary for the long-term stability of ecosystems (Brooks et al. 2002; Stanturf et al. 2001; Reay & Norton 1999). These attributes have been identified as essential components for the long-term persistence of an ecosystem (Ruiz-Jaén & Aide 2005a) and are thus important to include in an evaluative restoration framework.

When evaluating restorations, structure is measured in relation to a reference ecosystem. Rather than all possible species, a certain diversity or assemblage of species is sought. Goals of restoration projects are, therefore, often structural and evaluative frameworks most often focus on community structural measurements, such as density, composition, and diversity. It has been argued that goals and evaluative frameworks alike should, at least in part, focus on ecosystem functions, as it has been conceded that structure is not always the best indicator (e.g., Zedler & Callaway 1999). Why study structure as an indicator? First of all, structure is generally easier and cheaper to measure. Restoration projects generally are not evaluated and since structural measures are more easily measured than functional ones (Bash & Ryan 2002; Michener 1997), these measures are often chosen pragmatically on the basis that some evaluation is better than no evaluation.

Structural metrics are good early indicators of restoration progress because ecosystem structure is thought to restore before ecosystem function (Haynes 2004; McLachlan & Bazely 2003; Wilkins et al. 2003). Therefore, evaluating the survival and expansion of restoration plantings, measuring species diversity, density, and percentage of native plants provides an indication that the structural aspects of a forested ecosystem are or are not recovering as predicted. Since early successional restoration projects are at greatest risk of invasion (Anand 2000; Hobbs & Norton 1996), structural measures can also help to avoid future threats by providing indications of low density, diversity, and percentage of native plants. Also, biodiversity tends to be higher in states of flux (Salomon et al. 2005). Restoration sites are, by definition, in a state of flux. If restoration sites have high native diversity (not diversity dominated by non-native weeds) these ecosystems are thought to be progressing well, especially in relation to the reference ecosystem.

There is a correlation between structure and some functional attributes (Wilkins et al. 2003; Reay & Norton 1999). This is especially relevant in the context of restoration ecology, where structure is guided towards a specified endpoint or target area. If the same structure is restored, it is likely that the associated functions will also eventuate (Wilkins et al. 2003). Rather than measuring ecosystem functions directly, as some studies have (e.g., Zedler & Callaway 1999), most forest-based restoration projects seek to draw inferences about functions from compositional and structural data (Wilkins et al. 2003; Reay & Norton 1999).

Forest succession has been studied for centuries (e.g., Clements 1916; Odum 1969; Pickett et al. 1987) and although not all mysteries on this front have been solved, structural measures are perhaps more useful indicators at early stages of succession because it is roughly known how the restoration will progress. At an early stage, functional measures may be restoring simultaneously; however, these measures are thought to fluctuate immensely during the onset of restoration (Yeates & Lee 1999; Keddy & Drummond 1996). There is a general lack of understanding of how ecosystems function (Kreman 2005; Mouillot et al. 2005). If not much is known about soil, for example, how can restoration ecologists be expected to predict restoration outcomes in changing environments if conclusions have not yet been drawn for healthy ones? Moreover, what attributes are restorable for ecosystems are not known (Martin et al. 2005). The study of ecosystem functions is in its infancy, and to attempt their measurement in the context of assessing early-stage restoration outcomes would be difficult at best.

2.7 The role of monitoring in the evaluation process

Monitoring is a key process for assessing the progress of restoration projects relative to their pre-set goals and for adjusting necessary procedures along a desired restoration trajectory and given time period (Davis et al. 2004; Nakamura 2002; Bakker et al. 2000; Reay & Norton 1999; Zedler & Callaway 1999; Hobbs & Norton 1996; Kondolf 1996; Berger 1991). The absence of monitoring not only decreases the effectiveness of the restoration, but also provides little evidence of success or failure to refine a methodology or encourage restoration in other regions (Davis et al. 2004). Monitoring allows for the evaluation of success and provides important feedback upon which management of the site can be adapted if necessary (Bash & Ryan 2002; Box 1996). Long-term monitoring is essential because ecosystem development in a vastly altered environment is often extremely slow (Wali 1999). If monitoring programs are restricted to relatively short time periods, a distorted sense of potential equilibrium conditions and/or restoration success could be produced (Choi 2004; Davis et al. 2004; Korb et al. 2002).

Past and future restoration schemes can contribute to further ecological understanding, provided that key parameters and processes are being monitored (Wolters et al. 2005). With this in mind, restoration projects should be carried out using scientific methods that include testing, monitoring, and adjusting the model used for predicting and controlling ecosystem development (Pickett & Parker 1994). Monitoring programs are thought to play an important role in revealing trends and predicting the outcomes of restoration projects (Bash & Ryan 2002; White & Walker 1997), yet monitoring programs have long been criticized for their incompleteness and inappropriate focus (Brydges 2001; Michener 1997). Progress in the science and practice of restoration has been hampered by the lack of appropriate monitoring and reporting on successes and failures. Without well-accepted criteria that are ultimately supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes (Palmer et al. 2005; Michener 1997).

At present, despite pleas to report long-term responses to restoration efforts, most projects are never monitored post-restoration (Zedler 2000), and in cases where evaluation has occurred, the data collected are not necessarily appropriate to the project objective or the site (Aronson et al. 1995).

Bash and Ryan (2002) constructed a list of barriers that discourage restoration outcomes from being monitored. In decreasing frequency, these barriers included: lack of funding, lack of time, lack of personnel and training, perception that monitoring is not important, lack of political interest, lack of institutional support, absence of appropriate survey methods, and lack of volunteers to monitor. Restoration projects are, however, routinely subjected to informal evaluation by land owners, restoration consultants, and resources managers. Here, answers to broad questions (e.g., what was done? did it work? how well did it work? can it be done more inexpensively?) are given based on little to no scientific input (Michener 1997). Since most restoration projects are either inadequately monitored or not monitored at all, there exists little opportunity to evaluate and learn from the restoration methods used.

Monitoring plans have only become a recognized component of restoration plans within the last 20 years (Michener 1997). Monitoring is the repetition of measurements over time for the purpose of quantifying change, providing information about plant populations, communities, processes, and management techniques (Busch & Trexler 2003). Since monitoring is often the tool used to define success in restoration projects and provides the justification for restoration treatment alterations, choosing monitoring parameters that are compatible with the goals of the restoration project is crucial to the evaluation of any ecological restoration project (Korb et al. 2002). According to Lake (2001), monitoring parameters should consider the state of the inputs, the restoration manipulation, and the ecological responses. Bash and Ryan (2002) suggest that defining an appropriate time frame for monitoring, providing incentives for monitoring, and ensuring adequate funding are all prerequisites for achieving successful monitoring outcomes.

Without a clearly defined goal, the information collected through monitoring will not hold any meaning (Bush & Trexler 2003). Therefore, parameters that are chosen for inclusion in a monitoring program must provide useful information relevant to the goals (Hobbs 2003). As aforementioned, realistic restoration assessment requires long-term monitoring. However, everything cannot be measured and salient patterns and processes often cannot be defined in a complex and changing ecosystem (Duelli & Obrist 2003; Boyle et al. 2001; Michener 1997).

Part of the debate on how to define success focuses on the question of whether the aim should be the restoration of the structure of an ecosystem or its functioning. Recreating structure and composition without restoring function, or recreating function in the absence of structure and composition, fails to constitute complete restoration (Ryder & Miller 2005; Reay & Norton 1999;

Hobbs & Norton 1996; Berger 1993; Westman 1991). Ecosystem structure can be thought of as a condition at one point in time (e.g., species diversity), whereas an ecosystem function is a process that occurs over time (e.g., primary production). Based on the high amount of variability inherent in most natural communities, ecological function measures have been suggested as more appropriate indicators of change (Palmer et al. 2005; Brooks et al. 2002; Palmer et al. 1997). The focus of restoration ecology should ultimately be to restore functions in addition to structure; however, the restoration of functionality often takes longer than the restoration of the plant communities themselves (Zedler & Callaway 1999). Ideally, ecosystem processes will be restored through the re-establishment of ecosystem structure (Shepherd & Debinski 2005; Jackson et al. 1995; Hobbs 1993). Function may not follow upon the restoration of the structure (e.g., vegetation) if the site is inaccessible or if the habitat structure is not suitable (Wolters et al. 2005). The importance of evaluating functional ecosystem attributes in the assessment of restoration projects has been recognized (Shepherd & Debinski 2005); however, the choice of monitoring basic plant community measurements (e.g., species richness, species composition) have remained popular based on the ease of their measurement, the correlation between vegetation composition and structure for most functional attributes (Stanturf et al. 2001; Higgs 1997), and the general lack of understanding of how ecosystems function (Hobbs & Norton 1996).

Monitoring provides essential information related to the changing conditions of a restoration site. Evaluation builds on the information provided by monitoring programs and acts as a tool for translating monitoring data into useful information. Mitchell (2002) states that monitoring programs tend to describe changing conditions and explain cause-and-effect relationships; however, unlike evaluation processes, monitoring programs do not involve assessments of the effectiveness, efficiency or equity of the initiative at hand. In combination, monitoring and evaluation provide essential tools to assist managers in determining whether restoration projects are progressing along an expected trajectory.

2.8 Expectations for early-stage restoration outcomes

Recommendations for evaluating restoration outcomes have been made in the literature (Palmer et al. 2005; Ryder & Miller 2005; Anand & Desrocher 2004; Hobbs 2003; Lake 2001; Michener 1997; Hobbs & Norton 1996; Bradshaw 1993), and some authors have argued the importance of evaluation throughout the restoration continuum (Haynes 2004; Stanturf et al. 2001; Reay & Norton 1999; Majer 1989), including evaluation at early stages (i.e., within the first 10 years post-restoration). The central purpose of evaluating restoration outcomes is to determine restoration progress (Bash & Ryan 2002; Hobbs & Norton 1996). Appropriate parameters are selected and used to monitor ecosystem change and restoration progress is predicted based on this information, often in relation to a reference ecosystem. In particular, how can progress be detected at early stages of forest restoration? According to the literature, certain outcomes and structural measures can be expected at an early stage of forest restoration. For example:

1. Rates, densities, and trajectories vary markedly among restoration sites (Yang et al. 2005*; Moola & Vasseur 2004†);
2. High seedling densities should be achieved during early restoration stages (Haynes 2004*);
3. Plant density, woody biomass, snag volume, and coarse woody debris should be increasing at early-stages (Carleton 2003†);
4. Species regeneration should be evident within 4-6 years following a disturbance. Tree species become dominant and species diversity reaches a maximum after 10 years (Hibbs 1983*);
5. The re-colonization and establishment of indigenous biodiversity are good indicators of restoration progress (Reay & Norton 1999◦; Haynes & Moore 1988*);
6. Following disturbance, sites are often invaded by highly competitive species, such as wild red raspberry (*Rubus idaeus*), which remain abundant for a 10-year period but disappear almost completely afterwards (Archambault et al. 1998†; Ricard & Messier 1996†);
7. Restoration sites with high densities of native plant species have the ability to suppress invasive and non-native species (Murphy 2005†).

(† = Canadian study; * = USA study; ◦ = New Zealand study)

Although studies of early-stage restoration progress are still very few in number, common conclusions emerge – forest restorations require a great length of time to complete (i.e., up to 150 years; Carleton 2003; Wilkins et al. 2003) and outcomes vary considerably among sites (Yang et al. 2005; Moola & Vasseur 2004). According to the literature, early-stage forest restoration projects with high native plant diversity and density (Murphy 2005; Haynes 2004; Carleton 2003; Reay & Norton 1999; Haynes & Moore 1988), aggrading woody biomass (Carleton 2003), and detectable natural regeneration (Haynes 2004; Hibbs 1983) are progressing on the predicted successional trajectory and should lead to a successful restoration as time goes on. Progress in early-stage forest restoration is indicated first and foremost by the survival of planted individuals, and secondly by the expansion of native species populations (in terms of both diversity and plant density). Also, evidence of understorey regeneration is an important early-stage outcome of forest restoration and overall forest integrity (Duchesne et al. 2005). Suitable indicators for detecting the progress of early-stage forest restoration outcomes, therefore, include such structural measures as species diversity, plant density, and the percentage of native species.

2.9 Changes in restoration approaches

Due to the complex nature of restoration trajectories (i.e., nonlinear, unpredictable, and tending towards multiple attractors), the impact of changing initial conditions, and disturbances to the recovery pathway, a holistic view is considered necessary to understand the governing processes in restoration ecology (Anand & Desrochers 2004; Young et al. 2001; Aronson et al. 1995; Holling 1973). How, then, can a restoration endpoint be determined and evaluated? Since our ability to predict is severely limited by the complex nature of ecological systems, new methods for quantifying the success of restoration endeavors that embrace the complexity of ecological recovery trajectories and allow for anticipatory and adaptive management have been recommended (Anand & Desrochers 2004; Kay 1994). Adaptive management makes it possible to learn from past mistakes and provides the opportunity to improve our understanding of the restoration process (Hobbs 2003).

State-transition models are based on the assumption that potential alternative states exist in communities and that communities are rarely (if ever) in equilibrium. A given state is thought to persist until processes or an event causes a change in the types or groups of species in assemblage, forcing the ecosystem to reorganize (Holling 1973). State-transition models identify current and desirable ecosystem states, as well as the natural and human disturbances and management actions that cause transitions between them. These types of models can be used as a starting point for restoration programs by providing a suitable framework for organizing knowledge and identifying areas where further information is needed (Yates & Hobbs 1997). Although state-transition models have been criticized for underestimating the number of potential states due to insufficient scientific knowledge (Wilkinson et al. 2005), land managers can use these types of tools to assess the efforts needed to achieve short and long-term goals, and to assist in decision-making (Yates & Hobbs 1997).

Projecting an expected trajectory and restoration outcome is often challenged by the unpredictability of ecological communities in a complex and changing environment. A paradigm shift occurred in the field of restoration ecology, coincident with the recognition of dynamic non-equilibrium ecosystems and multiple paths to restoration (Pickett & Parker 1994). This paradigm shift challenges the sustainability of reconstructed ecosystems, and diminishes the credibility of historic and contemporary reference ecosystems as achievable goals. Choi (2004) recommends that "futuristic" restoration be undertaken where realistic and dynamic goals that assume the possibility of multiple restoration trajectories and unpredictability are set. Restoration projects are often focused on the past as most seek to undo previous human influence. This focus has been thought to obscure the goals of self-sustainment and resiliency, which are arguably more important than the replication of past conditions (Choi 2004; White & Walker 1997). This point reinforces the need for restoration projects to have clearly defined and understood goals, at least in terms of project design and desired outcomes, as well as monitoring and management programs for following the development of the ecological community of interest.

2.10 Conclusion

Success in restoration ecology is understood as the achievement of goals along a desired restoration trajectory. These goals may refer to community structure and function or an overall aesthetic impression. The importance of setting explicit criteria for restoration success at the outset of restoration implementation is crucial for guiding restoration strategies, providing guidelines for evaluating restoration outcomes, improving restoration techniques, and learning how ecosystems undergo the process of recovery. Although there is debate in the literature regarding the goals of restoration projects, it is clear that restoration ecologists have begun to recognize the importance of setting goals that go beyond historical records and contemporary reference sites. Due to inherent uncertainty and lack of scientific understanding, present methods for measuring restoration success have been insufficient. With the recognition of alternative stable states, multiple attractors and the complex and changing nature of ecosystems, multiple restoration goals should be set periodically along the desired restoration trajectory. These goals should be explicit and possible to identify using pre-defined ecological thresholds. A summary of the major themes encountered in the literature review and their supporting authors can be found in Table 1 below.

Strategies for the evaluation of restoration outcomes can include measures of diversity, vegetation structure, and/or ecological processes. Vegetation structure and diversity measurements are relatively easy to quantify and provide valuable information about the composition and structure of the restoring ecosystem, and have consequently been the most common means of measuring restoration success in the literature. These measures also provide some insight into the restoration of ecological processes, as numerous studies have found that the recovery of ecological function is linked to the restoration of community structure. During the early stages of the recovery process and where financial and human resources are limited, monitoring efforts should be focused on diversity and vegetation structure measures. Further along the restoration trajectory, monitoring programs can be broadened to include the measurement of ecological processes in order to understand the full extent of ecosystem recovery. This strategy is recommended for monitoring restoration projects and deciphering project outcomes; however, this approach to monitoring should be modified and tested as part of a broader adaptive management strategy to improve the effectiveness and efficiency of restoration efforts.

Various techniques and strategies for evaluating restoration outcomes have been suggested in the literature; however, consensus has not yet been reached. Many researchers have identified the area of restoration evaluation along with the development of effective and easily measured success criteria as a critical research need (e.g., Clewell & Rieger 1997). Once more knowledge has been gained on the topic of ecosystem recovery, it is expected that evaluative measures will subsequently be improved. Without an evaluative component built within restoration strategies, opportunities to learn and improve project effectiveness and efficiency will be significantly hindered. This study has applied the techniques most often advocated by the literature for evaluating restoration outcomes in order to gain insight into the process of restoration evaluation and identify possible areas of improvement.

Table 1. Summary of the key themes encountered in the literature review that were associated with evaluating restoration outcomes, and their supporting authors.

Themes Associated with Evaluating Restoration Outcomes	Supporting Authors
1. Setting restoration goals is important for achieving successful outcomes over the long-term	Palmer et al. 2005; Ruiz-Jaén & Aide 2005a; Wolters et al. 2005; SER 2004; Hobbs 2003; Hobbs & Harris 2001; Lake 2001; Rohde et al. 2001; Aide et al. 2000; Bakker et al. 2000; Ehrenfeld 2000; Stanturf et al. 1999; Higgs 1997; Palmer et al. 1997; Aronson & LeFloc'h 1996; Box 1996; Hobbs & Norton 1996
2. Because of a lack of scientific guidelines, it is difficult to set specific restoration objectives	Palmer et al. 2005; Anand & Desrochers 2004; Aide et al. 2000; Michener 1997; Yates & Hobbs 1997; Hobbs & Norton 1996
3. Reference information should be used to help define realistic restoration goals	Ruiz-Jaén & Aide 2005a; Wolters et al. 2005; Allison 2002; Lake 2001; White & Walker 1997; Yates & Hobbs 1997; Aronson et al. 1995; Westman 1991
4. The use of reference information has been criticized for its relevance and achievability when in the context of specific restoration projects	Ruiz-Jaén & Aide 2005b; Choi 2004; Sayer et al. 2004; Allison 2002; Lake 2001; Thom 2000; Zedler & Callaway 1999; Clewell & Rieger 1997; White & Walker 1997; Hobbs & Norton 1996; Jackson et al. 1995; Pickett & Parker 1994; Aronson et al. 1993
5. The concept of a "restoration trajectory" is useful to guide restoration goals and the process of restoration management	Wilkinson et al. 2005; Anand & Desrochers 2004; Haynes 2004; Lake 2001; Anand 2000; Carpenter et al. 1999; Reay & Norton 1999; Stanturf et al. 1999; Yates & Hobbs 1997; Westman 1991
6. Restoration goals must be set pragmatically and uncertainty must be planned for and expected	Wilkinson et al. 2005; Anand & Desrochers 2004; Choi 2004; Young et al. 2001; White & Walker 1997; Yates & Hobbs 1997; Box 1996; Zedler 1996; Aronson et al. 1995; Pickett & Parker; Holling 1973
7. Restoration project evaluation is crucial for achieving restoration goals and is important for maximizing learning opportunities	Palmer et al. 2005; Ryder & Miller 2005; Anand & Desrochers 2004; Hobbs 2003; Lake 2001; Stanturf et al. 2001; Michener 1997; Hobbs & Norton 1996; Bradshaw 1993
8. Debate exists around what aspects should be evaluated when determining restoration success	Palmer et al. 2005; Wolters et al. 2005; Hobbs 2003; Hobbs & Harris 2001; Stanturf et al. 1999; Michener 1997; Palmer et al. 1997; White & Walker 1997
9. Effective and easily measured success criteria must be developed and represents a critical research need	Ruiz-Jaén & Aide 2005b; Holl et al. 2003; Hobbs & Harris 2001; Clewell & Rieger 1997; Hobbs & Norton 1996; Bradshaw 1983
10. Main ecosystem attributes discussed in the literature for evaluative frameworks are:	
a) vegetation structure and composition	Palmer et al. 2005; Ruiz-Jaén & Aide 2005a; McLachlan & Bazely 2003; Allison 2002; Bash & Ryan 2002; Anand 2000; Stanturf et al. 1999; Hobbs & Norton 1996; Reay & Norton 1996
b) ecosystem processes	Palmer et al. 2005; Ruiz-Jaén & Aide 2005a; Ryder & Miller 2005; Shepherd & Debinski 2005; Brooks et al. 2002; Stanturf et al. 2001; Reay & Norton 1999; Zedler & Callaway 1999; Palmer et al. 1997; Jackson et al. 1995; Hobbs 1993
c) species diversity at all spatial scales	Martin et al. 2005; Ruiz-Jaén & Aide 2005a; Wolters et al. 2005; Stanturf et al. 1999; Higgs 1997; Bradshaw 1996; Hobbs & Norton 1996

Chapter 3

Fieldwork Methods

3.1 Introduction to Fieldwork Methods

Reference sites or reference ecosystems serve a dual purpose in restoration projects. They first act as a model for planning and project implementation, and later serve as templates for evaluation. The simplest form of a reference ecosystem is an actual site. An ecosystem undergoing the process of restoration can be considered successful as long as it is comparable to any of the potential states from which a reference could have developed from (SER 2004). Since a simple reference inadequately expresses the wide array of potential states expressed by healthy and/or restored ecosystems, multiple reference sites or sources of reference information have been suggested as a more realistic basis for restoration planning (Ruiz-Jaén & Aide 2005a; Pickett & Parker 1994). This study used a simple reference ecosystem accompanied by alternative sources of reference information to determine the progress of early-stage forest restoration projects. The alternative sources of reference information used in this study were: (1) ecological descriptions; (2) species lists and maps of sites prior to damage; (3) historical and recent aerial and ground-level photographs; (4) historical accounts and oral histories by persons familiar with the project site prior to damage; and (5) indications of previous physical and biotic conditions. Ideally, remnants of each restoration site would have been sampled and evaluated in addition to the simple reference, but due to time constraints and unavailability in some cases this was not possible.

It is difficult to compare the success of individual restoration techniques outside a given location without a replication of treatment-site combinations and none exist in this Region – a common problem when comparing actual restoration projects as opposed to using controlled experiments (Andrews & Broome 2006; Brewer 2005; Wilkins et al. 2003). Each restoration site is confounded with the restoration technique used. Although the restoration site is roughly equivalent to the restoration technique employed, responses to the restoration technique may be expressed in a number of different ways. How can the difference between restoration sites and techniques be distinguished? Every restoration site is unique and it is difficult (if not impossible) to de-confound the effect of a specific restoration technique versus the spatial/geographical influence. Confounding effects can be managed my determining whether or not the same restoration technique will work at two different locations at the same site. In this example, confounding effects are managed by having complete replication at two different sites. This type of deliberate experiment provides a good example of restoration site and technique effects, but where restoration projects are not part of a deliberate experiment, restoration site and technique effects cannot be de-confounded. This will remain the reality unless there is financial support and a political/research mandate and for this type of experiment to take place. What this study was able to do was pick sites that were restored around roughly the same time to de-confound temporal effects. Understandably, this study was not, however, able to untangle spatial and technique effects.

To remind readers, the following research questions were asked: (1) What are the outcomes of early-stage restoration projects based on the assessment strategies advocated by restoration ecology? (2) What factors (e.g., restoration site, restoration technique) appear to play the greatest role in achieving successful restoration outcomes? (3) How successful are the instruments of evaluation in determining the recovery of desired ecosystems at early stages of the restoration process? The purpose of this study was to evaluate restoration project outcomes and examine the effectiveness of monitoring practices currently used to evaluate restoration outcomes in order to make improvements to the approach and practice of restoration evaluation. The restoration projects selected for this study were all at a relatively early stage of restoration (i.e., less than 10 years). Therefore, this study also sheds light on what can be learned from the early stages of the restoration process and the initial processes of restoration (e.g., recovery dynamics, assembly rules).

This research is important because many habitats, particularly intact forested ones, are increasingly becoming degraded and threatened worldwide. Restoration efforts are beginning to play a key role in the mitigation and prevention of natural ecosystem degradation. Therefore, the success of restoration efforts is exceedingly important. Restoration outcomes can only improve if learning is involved in the process, whereby mistakes are built upon instead of repeated and techniques are modified to obtain more effective and efficient results.

3.2 Boundaries and Study Scope

The spatial boundaries of this study were restricted to restoration projects conducted within the Regional Municipality of Waterloo. The fieldwork component of this study was conducted in three distinct areas, which all consist or once consisted of similar forest characteristics. Perhaps more importantly, all three areas had specified a similar restoration goal prior to the onset of restoration procedures. Study areas reflecting similar vegetation patterns and sharing common restoration goals were selected for comparative purposes. This study evaluated the restoration outcomes of 3 distinct restoration areas, which include 2 sites at Foxwood Golf Course, 3 sites at Schneider's Woods, and 2 sites at Natchez Hills. The reference ecosystem used for all three restoration projects was located at Schneider's Woods in a remnant patch of upland maple beech forest.

To further define the scope of this study, the fieldwork considered the parameters of herbaceous and woody vegetation structure, composition, and diversity to compare with the reference ecosystem to evaluate early-stage restoration project outcomes. This study takes a critical look at the suggestions made by the literature for assessing restoration outcomes and provides a practical example of their strengths and weaknesses by putting these recommendations into practice. This study concludes by making suggestions for future restoration evaluation strategies and further research needs.

The study was carried out during the growing season of 2005 (i.e., from mid-April to mid-October) and the spring of 2006 (mid-April to mid-May). A second field season was conducted for herbaceous vegetation during the spring to account for the relatively high variability of spring ephemerals. A background discussion of the fieldwork methods used in this study is presented in this chapter, as well a detailed description of each field site and the reference ecosystem.

3.3 General Outline of Methodology

The fieldwork component of this study assessed the outcomes of three distinct restoration areas within the Regional Municipality of Waterloo. Evaluation techniques most strongly and most often advocated by the literature were used, which involved a comparison of each restoration site to a reference ecosystem. The parameters included in the assessment framework were evaluations of herbaceous and regenerating woody vegetation species composition, and mature trees. These parameters were chosen based on: (1) pre-determined restoration goals; (2) their suitability for evaluating the progress of relatively young restoration projects; and (3) their ease of measurement. Structural parameters were chosen over functional ones in order to gain an overview of the restoration rather than insight into a single function, where function data provides the greatest information over longer time periods, rather than as a snap shot.

The data collected from each site were compared to the reference data for similarity. Restoration sites with a species composition and structure similar to the reference site that have a high species diversity coupled with a high percentage of native species and high densities are theoretically considered to be progressing along a successful trajectory. Summary statistics were tabulated for herbaceous vegetation, regenerating woody vegetation, and mature tree data. A Shannon-Wiener Diversity Index was calculated at the quadrat, transect and site level for herbaceous data at each restoration and the reference site. Where possible, data were analyzed using SPSS v. 14.0 (SPSS Inc., Chicago, Illinois) to conduct a nested Analysis of Variance (ANOVA) to compare means and identify significant differences among the sites. Nested ANOVAs were used to test the response of the density of all species, the Shannon-Wiener Index of Diversity, and the percentage of species that are native to Waterloo Region to restoration site, restoration technique nested within restoration site, and transect nested within restoration technique. Following each nested ANOVA, post hoc contrasts using Type III sums of squares were performed to test the significance of individual comparisons within each restoration site. Data were analyzed for each sampling period (Spring, Summer, Fall in 2005; Spring 2006). Bray-Curtis Ordination was calculated for the herbaceous data collected at the site level. PC-ord™ v. 4 (MjM Software, Edinburgh, UK) was used to conduct a Cluster Analysis using the nearest neighbour technique. Simpson's Dominance Index was calculated for mature trees using the DBH for each tree species at each site.

3.4 Study Design

Forest restoration projects within the Regional Municipality of Waterloo in southern Ontario were evaluated using a monitoring framework that was implemented and carried out over one full growing season (i.e., from April to October, 2005) and a second spring field season (i.e., May, 2006) to account for the variability of spring ephemeral plant communities. The following sections provide an in depth discussion of how each field work component was carried out, including the methods used to gather data and the materials used in the study. The study included the following components: (1) a vegetation analysis of the herbaceous plants found at each site; (2) a regeneration analysis of the shrubs, seedlings and saplings found at each site; (3) a composition and dominance analysis of the mature trees found at each site; and (4) a comparison of qualitative field observations at each site. Evaluations of each forest restoration project were compared to a reference ecosystem and restoration outcomes were determined based on the level of similarity between the restoration project and reference ecosystem.

3.4.1 Assessing Herbaceous Vegetation

Plant species composition, abundance and coverage were sampled to determine biodiversity levels and plant community character of the herbaceous vegetation at each site. Herbaceous vegetation data were collected 3 different times, during the spring, summer and fall. Each time, data were collected using a stratified random sampling method. Quadrats were located along 10 different transects running parallel through each site, totalling 50, $1m^2$ quadrats per season per site, for a total of 150, $1m^2$ quadrats for each site, for a grand total of 1200, $1m^2$ quadrats. Transects were randomly located using a table of random numbers to give a distance from a designated point along the base of each site. Once each transect was located, 5 quadrats were placed using a table of random numbers and a compass. The random numbers represented the distance along each transect and marked the bottom left-hand corner of each quadrat. Within each $1m^2$ quadrat, all species were identified, relative abundance was determined (i.e., number of stems) and percent cover was estimated for each species present in order to assess species abundance and density. The native or non-native status was noted for each plant species using a species list created by Dr. Stephen Murphy for the flora of north-eastern Canada and U.S.A. (Murphy 2004). Quadrat, transect and site species lists were analyzed separately to determine the percentage of non-native species present, biodiversity levels and plant community character.

The materials used to conduct the herbaceous vegetation field component included the following: a table of random numbers, rope to delineate transects where possible, a compass to delineate transects, $1m^2$ quadrat, flagging tape, sealable plastic bags to collect and store unidentified plant species, masking tape to mark each unidentified plant, plant field guides to aid in the identification of unknown plants, and a field notebook to record data.

Following the collection of data, the Shannon-Wiener Index ($H' = - \Sigma\, p_{\mathrm{i}} \log p_{\mathrm{i}}$) was calculated to measure species diversity. The Shannon-Wiener Index characterizes the species diversity of a community by accounting for both abundance and evenness of the species present. This calculation was done using species abundance data for each quadrat, transect and site for each season. The Bray-Curtis Ordination ($I_{\mathrm{BC}} = 1 - \Sigma\, |x_i - y_i| / \Sigma\, (x_i + y_i)$) was also calculated to indicate differences in species abundances and detect differences among the various plant communities sampled and the reference ecosystem. Bray Curtis Ordination detects similarities among communities by measuring the difference between the abundances of each species present compared to the reference ecosystem. A Cluster Analysis was performed using the nearest neighbour technique to determine the similarity of the restoration sites to the reference ecosystem. Cluster Analyses are used to discover structures in data without providing an explanation or interpretation of why the structure exists.

3.4.2 Assessing Regenerating Woody Vegetation

Shrubs, seedlings and small saplings of woody species (≤ 1.5 cm DBH) were measured in the shrubs and regenerating vegetation survey. All sites were sampled once during the month of June, 2005 using 25 randomly located $2m^2$ quadrats along 5 different transects using a stratified random sampling method. The quadrats were located in a manner similar to that of the herbaceous vegetation, where a baseline was established and transects were located along the baseline using a table of random numbers. The quadrats were then located along transects using a table of random numbers and a compass. The quadrats were marked out using a pre-measured rope and plastic stakes to form a $2m^2$ enclosed area. Within each quadrat, all relevant species were identified, species abundances were tallied, coverage of each species was estimated, diameter at breast height (DBH; DBH = 1.3 m) was measured for each plant where possible. In cases where a plant had more than one stem, the DBH of all stems were measured and documented as separate stems of the same woody plant. The native or non-native status of each plant was noted to determine the percentage of native species regeneration for each site. Following data collection, Shannon-Wiener Indices were calculated for each restoration site and the reference ecosystem to measure species diversity.

The materials used to conduct the shrubs and regenerated vegetation field component included a table of random numbers, a compass, 4 plastic stakes, a 10 m rope marked off in 2 m sections, callipers to measure the DBH, sealable plastic bags and masking tape to collect and mark unknown species, plant identification books to aid in identifying unknown species, and a notebook to record collected field data.

3.4.3 Assessing Mature Trees

A wandering quarter sampling method was used to assess forest stand structure and character by surveying all standing (i.e., alive or dead) trees. The mature trees at all restoration sites and the reference ecosystem were assessed once during the month of July, 2005. Numerous measurements of woody species were made to determine forest and habitat characters. All trees were identified for each site to determine stand composition. DBH for all trees ≥ 1.5 cm were measured using either callipers or a diameter tape. Tree abundance and density were measured for each site to assess each site's regenerative ability. The native or non-native status of each tree species was noted in order to calculate the percentage of native species present. Whether the standing tree was alive or dead was also noted to calculate the percentage of living tree species.

The materials required to conduct this portion of the field work included flagging tape, measuring tape, callipers, diameter tape, tree field guides and a notebook to record field data. Following the collection of field data, the Simpson's Dominance Index ($I = \Sigma\, n_i (n_i - 1) / N(N-1)$) was calculated and the mean distance between trees was determined. The Simpson's Dominance Index estimates the probability of drawing two individuals belonging to different species at random from a community.

3.5 Procedures used to record and manage data

In order to stay organized and dependable, numerous procedures were used to record and manage the collected data. Data collection sheets were created to ensure that appropriate data were collected and recorded in all cases. These data sheets were then stored in a field notebook for future reference. Following each site visit, data were inputted into a database in Microsoft Excel™. Separate spreadsheets were created for each site and season for the herbaceous vegetation, and for each site for the shrubs and regenerated vegetation and mature trees data. These spreadsheets were later manipulated to summarize and report the important information.

When an unknown plant species was encountered in the field, the plant was sampled and masking tape was wrapped around the base. A number corresponding to the quadrat and site that the unknown plant was found in was marked on the masking tape. These samples were stored in sealable plastic bags in the refrigerator for future identification. Plant identification books were used for this purpose along with a compound microscope for many of the difficult to identify species. For example, many of the sedge species (*Carex sp.*) encountered were dissected and viewed under a compound microscope for identification purposes. Mr. Larry Lamb from the Environmental Studies Ecology Lab at the University of Waterloo was also instrumental in the plant identification process.

3.6 Methods for analyzing data

The data were organized and summary statistics were created for herbaceous vegetation, shrubs and regenerated vegetation, and mature trees. The summary statistics for herbaceous vegetation included a species list, species abundance, percent cover of each species, and percentage of native species. For regenerating woody vegetation and mature trees, the summary statistics included the same measures plus the percentage of dead vegetation. Shannon-Wiener Indices were calculated at the quadrat, transect and site level for the herbaceous vegetation. Bray-Curtis Ordinations were calculated at the site level for herbaceous vegetation only and Simpson's Dominance Indices were calculated for the mature tree data only.

The density of all species, Shannon-Wiener Index of Diversity, and the percentage of species that are native to Waterloo Region were analyzed using SPSS v. 14.0 (SPSS Inc., Chicago, Illinois) using a nested Analysis of Variance (ANOVA) and post hoc contrasts to compare means and identify significant differences among the herbaceous data. Comparisons were made at the quadrat, transect and site level for data collected using a stratified random sample. Nested ANOVAs were used to test the responses of the density of all species, the Shannon-Wiener Index of Diversity, and the percentage of species that are native to Waterloo Region to the restoration site, the restoration technique nested within the restoration site, and the transect nested within the restoration technique used. The density of all regenerating woody species, the number of species, the percentage of species native to Waterloo Region, and the percentage of dead regenerating woody vegetation were also analysed using a nested ANOVA and post hoc contrast test to identify significant differences in the response of regenerating woody vegetation to restoration site, the restoration technique nested within the restoration site, and the transect nested within the restoration technique used. A Cluster Analysis was completed using the nearest neighbourhood technique in PC-ORD™ (MjM Software Design, Edinburgh, UK) to identify herbaceous community similarities and categories among the various restoration sites sampled.

The purpose of the analysis was to identify key differences among and between the restoration sites when compared with the reference ecosystem in order to determine overall restoration progress. Following this analysis, the results were further analyzed to identify the most important influences of restoration success (i.e., distance to reference ecosystem or time since restoration endeavour). This was done by looking into the trends associated with grouped data.

3.7 Field Study Sites

3.7.1 Regional Municipality of Waterloo, Ontario

The Regional Municipality of Waterloo is located in Southern Ontario, in between the Great Lakes Ontario, Erie and Huron. Waterloo Region is made up of four rural townships – North Dumfries, Wellesley, Wilmot and Woolwich, and three urban municipalities – Cambridge, Kitchener and Waterloo (Region of Waterloo, 2006). Waterloo Region is located at the edge of two forest regions: the Carolinian zone and the Great Lakes-St. Lawrence Forest region. Being on the northern edge of the deciduous forest region, some species characteristic of the Carolinian zone can be found along the Grand River and in the southern parts of the City of Kitchener (Schmitt 1995). The combined effects of climate, landforms, soils and vegetation strongly influence the distribution of trees and other forest species. Most of Waterloo Region can be characterized as moist, fertile uplands where sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*) are the dominant tree species. Older Ontario forest stands of beech and maple have significant conservation value (especially those never cleared since European settlement) and should be managed and restored to ensure longevity (Suffling et al. 2003).

3.7.2 Restoration Sites

All of the restoration sites and the reference ecosystem were located within the Regional Municipality of Waterloo. The restoration sites are located at 3 different restoration areas: Foxwood Golf Course, Schneider's Woods, and Natchez Hills. The reference ecosystem was also located at Schneider's Woods. Figure 4 provides a Regional context for the restoration areas used in the study.

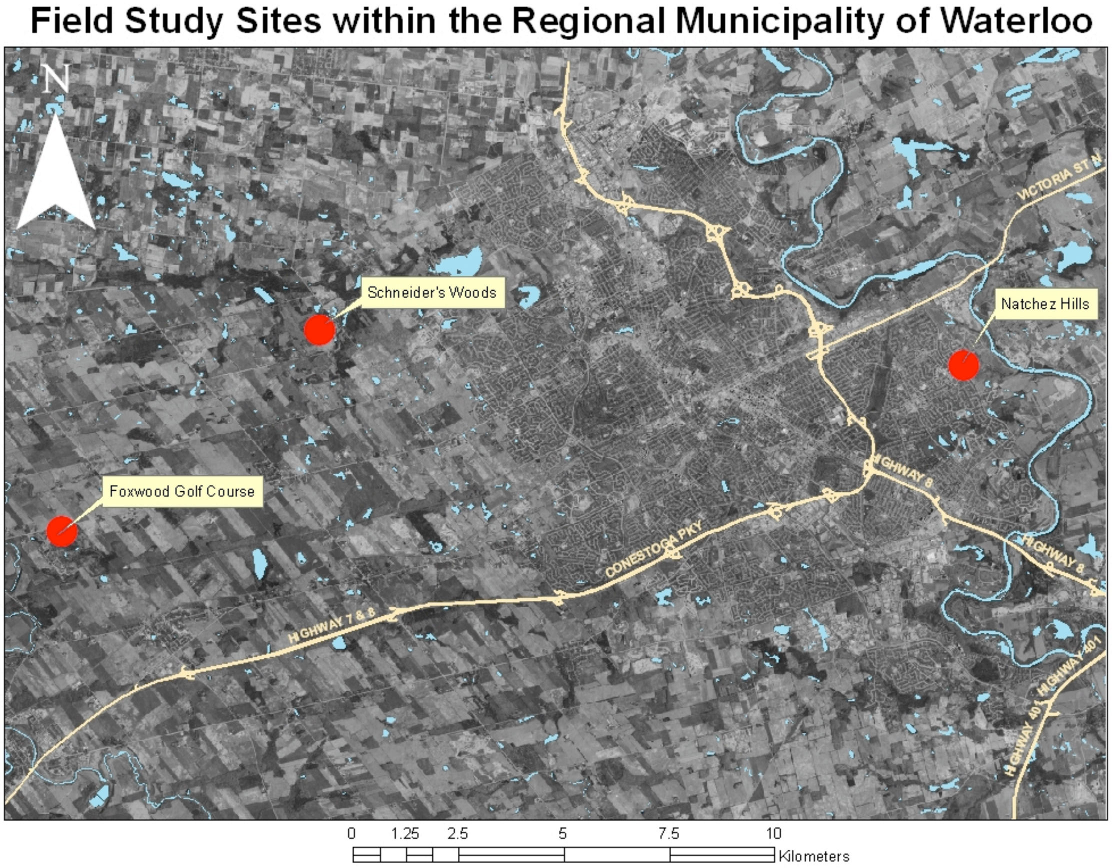


Figure 4. Regional context for the field study sites used in the study. Foxwood Golf Course and Schneider's Woods are west of Kitchener-Waterloo and Natchez Hills is east of Kitchener-Waterloo. All study areas were located within the Regional Municipality of Waterloo.

3.7.2.1 Foxwood Golf Course

2777 Erb's Road, Township of Wilmot, Regional Municipality of Waterloo

After a violation of the Tree Cutting By-Law, a Conservation Easement Agreement with the Regional Municipality of Waterloo required Foxwood Golf Course to expend considerable efforts to recreate a healthy, self-sustaining, representative natural stand of trees (Woodman 2004). The forest was previously comprised of upland, lowland, and transitional forest communities, and a graminoid marsh (Hovingh 2002). Three long strips of roughly a 20 000 m^2 area were clear-cut in an approximately east-west orientation. Figure 5 shows one of the three clear-cut strips at Foxwood Golf Course. Upland portions, which covered approximately 50 percent of the restoration area, were dominated by sugar maples (*Acer saccharum*), American beech (*Fagus grandifolia*) and white ash (*Fraxinus americana*) whereas the lowland portions, which covered approximately 25 percent of the restoration site, were dominated by eastern hemlock (*Tsuga canadensis*) and yellow birch (*Betula alleghaniensis*). The southwestern portion of the forest was comprised of an open, marshy habitat which covered approximately 25 percent of the restoration site. Upland areas appeared to have been grubbed after cutting where most of the stumps and slash were dragged into piles. This resulted in the invasion of "weedy" species such as wild red raspberry (*Rubus idaeus*) and dandelion (*Taraxacum officinale*) that favour exposed mineral soils and a subsequent loss of indigenous forest species. In the wetland areas, felled trees were not cleared and grubbing did not take place (Woodman 2004; Hovingh 2002).

Figure 5. Photograph of Site 1 at Foxwood Golf Course in March of 2005 (Photograph taken by Lefler, 2005). Wild red raspberry (*Rubus idaeus*) and other invasive species have overgrown much of the restoration site.

The restoration effort at Foxwood Golf Course involved the following:

- A survey of the sites prior to restoration and assessment of natural regeneration (April 2004);
- Planting, mulching, pruning and flagging of trees (April-May, 2004);
- Installment of metal t-post stakes around the restoration area boundaries at 10 meter intervals (August, 2004);
- Posting of signs reading "Ecological Restoration Area: Authorized Personnel Only" (August, 2004); and
- Filling in a large pit, which was excavated to burry stumps and logs following cutting (December, 2004).

Restoration efforts were carried out on the two most southerly clear-cut strips, and the northern-most strip was left as a control. Each restoration site was approximately 20 000 m^2 in area. Tree seedlings were planted to accelerate the natural succession of the clear-cuts into a young forest stand. Trees were planted using a species composition similar to what was thought to have previously existed on site prior to cutting and to the adjacent uncut areas (See Table 2). Foxwood Site 1 (FW1) lies between the restoration control and Foxwood Site 2 (FW2). Similar restoration strategies were used at both sites; however, FW2 has a larger proportion of marshy habitat than FW2. Also, more extensive grubbing and tree removal occurred at FW1 than FW2.

Table 2. Tree seedling planting schedule used in the restoration plans for Foxwood Golf Course. The forest was divided into Upland, Lowland and Transitional types at both restoration sites.

Site	Upland	Lowland	Transitional
FW1	160 sugar maple 25 American beech 25 white ash 20 basswood 5 black cherry	10 hemlock 10 yellow birch 10 black ash 3 white cedar	60 sugar maple 20 white ash 25 American beech 13 basswood 5 hemlock 7 white pine
TOTAL:	242 seedlings	33 seedlings	130 seedlings
Grand Total:			***405 seedlings***
FW2	90 sugar maple 25 white ash 10 basswood 3 hemlock 7 white pine	20 red maple 20 yellow birch 15 hemlock 2 basswood 10 black ash 3 white pine 2 white cedar	0 Trees
TOTAL:	135 seedlings	72 seedlings	0 seedlings
Grand Total:			***207 seedlings***

(Modified from Woodman, 2004)

3.7.2.2 Schneider's Woods E.S.P.A.

567 Wilmot Line, Township of Wilmot, Regional Municipality of Waterloo

Schneider's Woods is part of a recognized Environmentally Sensitive Landscape (E.S.L.), and is designated as an Environmentally Sensitive Policy Area (E.S.P.A.) and Provincially Significant Wetland (P.S.W.) in the Regional Municipality of Waterloo. The landscape at Schneider's Woods has largely been left in its natural state, as the rolling topography and extensive wetlands have made much of the property unsuitable for use in agriculture. A range of natural areas exist at Schneider's Woods, including upland and lowland forests, long-established hemlock (*Tsuga canadensis*) and planted red pine (*Pinus resinosa*) stands, wetlands, swamps, marshes, and open wet and dry meadows. Upland forests are dominated primarily by sugar maple (*Acer saccharum*) and American beech (*Fagus grandifolia*). The area has been observed to provide refuge for many significant species of plants and animals. Trails throughout the Schneider property provide excellent opportunities for recreational activities, such as bird watching, nature observation, hiking and cross-country skiing.

The Schneider family has made a number of efforts to restore some of the property's natural features through the application of practical knowledge related to the natural successional tendencies of forested ecosystems. The goal of their efforts has been regeneration and preservation. Restoration endeavors at Schneider's Woods include the following:

- Red pine (*Pinus resinosa*) plantations were evenly thinned by approximately 75% of stems to allow for the natural regeneration of indigenous understorey vegetation such as alternate-leaf dogwood (*Cornus alternifolia*), eastern chokecherry (*Prunus virginiana*), and basswood (*Tilia americana*);
- Numerous areas that were once farmed have now been left fallow in order for meadow species to regenerate and take over from non-indigenous and "weedy" species;
- Periodic controlled burns have helped numerous tall-grass prairie species to establish themselves within these types of ecosystems, along with direct seeding of certain desired species;
- Planting of native trees seedlings occurred in patches of forest or open meadow in hopes of encouraging the re-growth of upland and lowland type forests; and
- Installation of tree guards to protect some of the newly planted saplings from the impacts of herbivory by deer and rodents.

In this study, 3 different restoration areas were evaluated at Schneider's Woods. The first site was along a path in the middle of the Schneider property within a red pine plantation. This site was approximately 4 000 m^2 in area. Following European settlement, tracts of native forest were replaced with stands of red and white pine. Restoration trajectories have been further altered in these areas through changes in local abiotic conditions, such as the acidification of soils from dominant pine species. At this site, the restoration effort involved evenly thinning out the pine plantation by approximately 75% of stems to allow for the natural regeneration of native understorey trees, shrubs and herbaceous plants. The second and third sites, which were approximately 6 000 m^2 in area each, were located in a fallow field between two forested areas. The aim of this restoration effort was to create a linkage or corridor between the two established forests by planting native tree species, decreasing mowing activities and conducting controlled burns (See Figure 6). If successful, these sites have the potential to reduce fragmentation by connecting two forest patches along an approximately 2 kilometer long corridor.

Figure 6. Photograph of Sites 2 and 3 at Schneider's Woods, which are old fields that have been planted with native tree and shrub species to create a linkage between two forested areas. As seen in the picture, bull thistle (*Cirsium vulgare*) and New England aster (*Aster novae-angliae*) are two species commonly found at these restoration sites.

3.7.2.3 Natchez Hills E.S.P.A.

End of Ebydale Street, City of Kitchener, Regional Municipality of Waterloo

Natchez Hills (38.4 hectares) is a designated Environmentally Sensitive Policy Area (E.S.P.A.) in the City of Kitchener within the Regional Municipality of Waterloo. Natchez Hills has a rolling topography and is dominated by sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and ash (*Fraxinus sp.*) tree species. In the early spring of 2002, serious impacts resulting from mountain biking activities were discovered here. Referred to as "technical ecstasy", Natchez Hills was home to an intermediate-level natural mountain biking area equipped with drop-offs, bridges, jumps, large gradient hills, log rides, and teeter totters, all hand crafted by its riders (see Figure 7) (Schmitt 2002). Natchez Hills was seriously degraded by the negative impacts associated with mountain biking. Some of these negative impacts include: excavations, soil disruption and compaction, trampling of vegetation, erosion, introduction of invasive species, and damage of mature trees (McKee & Ditner 2003; Schmitt 2002). Continued vandalism and evidence of mountain biking at the site indicated that restoration efforts have been met with resistance by mountain bikers, which will seriously impede restoration efforts. Natchez Hills provides an example of the importance of mitigating disturbances prior to initiating restoration efforts.

In 2003, efforts of restoration at Natchez Hills began. A passive restoration approach was used to minimize further degradation of the site and allow the damaged ecosystem to gradually rebuild its natural structure, function, and integrity. The restoration efforts at Natchez Hills E.S.P.A. included the following:

- Mountain bike jumps, ramps, and other structures were removed to prevent further damage from mountain biking activities and relieve pressure on mature trees that played a structural role in the mountain biking props;
- Excavations were filled in to restore the site's natural topography and physical character;
- Dead trees and coarse woody debris were relocated in a natural way throughout the site to provide habitat and return nutrients to the forest ecosystem;
- Herbaceous plants and saplings were collected from Westmount Golf and Country Club and planted at Natchez Hills to encourage the regeneration of the forest understorey. Only native species and species typically found at Natchez Hills were planted;
- Seeds from Natchez Hills were collected and planted at restoration sites.
- Litter and recyclables were removed and disposed of; and
- Signs were posted to mark the restoration areas and unmarked, newly created trails were fenced off to prevent further fragmentation and degradation of the ecosystem.

Figure 7. Example of one of the many structures built at Natchez Hills E.S.P.A. for the purpose of mountain biking. The soil was heavily compacted and the forest understorey was completely destroyed (Photograph courtesy of Ditner, 2002).

Restoration plans also indicated the importance of educating mountain bikers and the general public about the effects of riding bicycles off designated mountain biking trails. The City of Kitchener is attempting to work with mountain biking enthusiasts to create a new designation of mountain biking trails to support this type of high-impact recreation. The City of Kitchener has also recognized the importance of enforcing laws stating that mountain bikers must stay on designated trails in order to prevent further degradation.

This study investigated restoration outcomes at 2 sites within Natchez Hills E.S.P.A. The first site was located along a path stretching across the side of a steep hill, and was approximately 2 000 m^2 in area. Following the removal of mountain biking structures, native herbaceous understorey species (e.g., cut-leaved toothwort (*Cardamine concentata*), wild ginger (*Asarum canadense*), and spinulose wood fern (*Dryopteris carthusiana*)) were planted and woody debris was redistributed. The second site stretched down a steep hill, which was bordered by trails on two sides, and was also approximately 2 000 m^2 in area. Ramps were deconstructed and woody debris was either redistributed or disposed of. Seedlings and herbaceous plant species were planted to encourage forest regeneration.

More extensive planting occurred at this site as it was viewed to be more severely degraded. Metal stakes and snow fences were installed to mark off the restoration area and discourage further mountain biking activities. The goal of both restoration areas was to reintegrate the degraded ecosystems within the greater forested ecosystem at Natchez Hills.

3.7.2.4 Reference site at Schneider's Woods

567 Wilmot Line, Township of Wilmot, Regional Municipality of Waterloo

A remnant patch of upland maple-beech forest was selected as the simple reference site at Schneider's Woods (see Figure 8). The area sampled within the reference ecosystem was approximately 15 000 m^2 in area. This remnant patch of forest is typical of what is thought to have once covered the Regional Municipality of Waterloo in terms of both its species composition and physical characteristics. Schneider's Woods has been designated as an E.S.L., an E.S.P.A., and a P.S.W. within the Regional Municipality of Waterloo; therefore, continued protected of the reference ecosystem has been to some extent guaranteed. The reference information gained from this remnant patch of forest was combined with alternative sources of reference information to determine the relative success of restoration project outcomes through comparison.

Figure 8. Photograph of reference site at Schneider's Woods, which represents the type of forest that is thought to have historically covered parts of the Regional Municipality of Waterloo during pre-European settlement times (Photograph taken by Lefler in October, 2005).

Chapter 4
Results

4.1 Fieldwork Results

4.1.1 Herbaceous Vegetation

4.1.1.1 Summary Statistics (Table 3)

Summary statistics were tabulated from the data collected for herbaceous vegetation at each restoration site and the reference site for each sampling season (Table 3). The summary statistics include measurements of the total number of species per restoration site, the mean number of species per quadrat, the total number of species native to Waterloo Region per restoration site, the mean number of species native to Waterloo Region per quadrat, the total percentage of native species per restoration site, and lastly the mean percentage of native species per quadrat. Results of the summary statistics are as follows (see Table 3):

- **Total number of species:** Foxwood Golf Course site 2 (FW2) had the highest, followed by Foxwood Golf Course site 1 (FW1), then Schneider's Woods site 2 (SW2) and site 3 (SW3), then Schneider's Woods site 1 (SW1), then Natchez Hills site 2 (NH2), then Natchez Hills site 1 (NH1), and lastly the reference site.
- **Number of species per quadrat:** FW1, FW2, SW2 and SW3 had the highest, followed by SW1 and NH2, then NH1, and lastly the reference site.
- **Total number of native species:** FW1 and FW2 had the highest, followed by SW1, then NH2, SW2 and SW3, then NH1, and lastly the reference site.
- **Number of native species per quadrat:** FW1 and FW2 had the highest, followed by NH2 and SW1, then SW2 and SW3, then NH1, and lastly the reference site.
- **Total percentage of native species:** the reference site and NH1 had the highest, followed by SW1, then NH2, then FW1 and FW2, and lastly SW2 and SW3.
- **Percentage of native species per quadrat:** the reference site and NH1 had the highest, followed by SW1, then NH2, then FW1 and FW2, and lastly SW2 and SW3.

These results indicate that NH1 is most similar to the reference site, then NH2 and SW1, then FW1, FW2, SW2 and SW3 in terms of the summary statistics tabulated for the herbaceous species data.

Table 3. Summary statistics ± SD for herbaceous vegetation data collected at each restoration site for each sampling season. Summary statistics include total number of species, mean number of species per quadrat, total number of native species, mean number of native species per quadrat, total percentage of native species, and mean percentage of native species per quadrat.

Site	Total # Species	Mean # Species Per Quadrat	Total # Native Species	Mean # Native Per Quadrat	Total % Native Species	Mean % Native Per Quadrat
Sp05						
FW1	76	11.10 (±4.43)	62	8.74 (±3.38)	81.58	80.74 (±11.75)
FW2	83	10.80 (±5.40)	66	8.40 (±3.91)	79.52	81.01 (±14.79)
NH1	23	4.58 (±1.46)	21	4.40 (±1.36)	91.30	96.58 (±7.84)
NH2	35	7.82 (±3.08)	29	6.52 (±2.55)	82.86	84.16 (±13.40)
SW1	57	7.24 (±3.60)	47	6.18 (±2.74)	82.46	88.19 (±12.43)
SW2	60	10.40 (±3.27)	30	4.96 (±1.91)	50.00	48.97 (±14.68)
SW3	47	10.10 (±2.16)	24	5.00 (±1.46)	51.06	50.09 (±12.69)
Ref.	24	2.84 (±1.61)	20	2.52 (±1.46)	83.33	88.84 (±20.99)
Sum05						
FW1	71	11.94 (±3.85)	56	8.68 (±2.59)	78.87	73.59 (±10.07)
FW2	85	12.66 (±4.01)	63	8.34 (±2.40)	74.12	67.55 (±11.94)
NH1	29	3.50 (±1.40)	25	3.14 (±1.36)	86.21	89.23 (±19.65)
NH2	40	6.80 (±3.02)	32	5.34 (±2.14)	80.00	81.47 (±12.95)
SW1	45	8.82 (±3.24)	36	7.48 (±2.60)	80.00	85.99 (±9.67)
SW2	59	10.48 (±2.51)	31	4.50 (±1.34)	52.54	44.18 (±13.25)
SW3	54	11.34 (±2.68)	28	5.76 (±1.72)	51.85	51.51 (±12.04)
Ref.	22	2.08 (±1.05)	20	1.96 (±1.09)	90.91	89.67 (±26.49)
Fall05						
FW1	67	10.34 (±2.65)	49	7.54 (±2.04)	73.13	73.67 (±12.65)
FW2	71	10.20 (±2.81)	55	7.40 (±2.08)	77.46	73.68 (±12.69)
NH1	26	2.64 (±1.17)	24	2.46 (±1.05)	92.31	94.87 (±11.70)
NH2	37	6.38 (±2.93)	27	5.08 (±2.59)	72.97	79.33 (±16.34)
SW1	49	7.28 (±2.88)	38	6.40 (±2.38)	77.55	89.59 (±11.12)
SW2	58	12.22 (±2.93)	30	5.58 (±1.57)	51.72	46.66 (±11.64)
SW3	61	10.70 (±2.32)	31	4.94 (±1.60)	50.82	47.24 (±16.32)
Ref.	20	2.18 (±1.00)	15	2.06 (±1.02)	75.00	90.17 (±25.96)
Sp06						
FW1	57	8.52 (±3.83)	41	6.24 (±2.87)	71.93	74.59 (±14.85)
FW2	60	6.82 (±2.65)	45	5.38 (±1.93)	75.00	81.53 (±17.45)
NH1	20	3.10 (±1.28)	17	2.86 (±1.29)	85.00	92.05 (±15.31)
NH2	30	5.82 (±2.91)	24	4.62 (±2.35)	80.00	80.60 (±18.83)
SW1	40	4.70 (±1.78)	33	4.10 (±1.49)	82.50	88.77 (±13.20)
SW2	49	10.18 (±2.01)	13	3.64 (±1.47)	26.53	35.89 (±13.67)
SW3	34	8.28 (±2.59)	9	2.64 (±0.88)	26.47	33.51 (±11.04)
Ref.	24	2.26 (±1.38)	19	2.12 (±1.10)	79.17	92.81 (±21.74)

4.1.1.2 Nested Analysis of Variance for Number of Herbaceous Species (Table 4)

A nested ANOVA was performed to test the responses of the density of all species, Shannon-Wiener Index of Diversity, and the percentage of species that are native to Waterloo Region in relation to the study site, the restoration technique used nested within the restoration site, and transect nested within the restoration technique used (Table 4 a, b, c, d). The Mean Square of x (MS), F-value (F), and P-value (P) are reported in each case. Analyses were performed using SPSS v. 14 (SPSS Inc., Chicago, Illinois). Data collected for each sampling period were analyzed independently, separating the ANOVA output into Spring, Summer and Fall Guilds 2005, and Spring Guild 2006. Any data expressed as percentages were arcsine square root transformed prior to analyses to ensure homoscedascity.

The density of all species showed a statistically significant response to the restoration site for all seasons ($p<0.001$). The Shannon-Wiener Index of Diversity had a statistically significant response to the restoration site at all seasons (Spring and Summer 2005, $p<0.01$; Fall 2005 and Spring 2006, $p<0.001$). The percentage of species that are native to Waterloo Region had a statistically significant response to the restoration site at all seasons (Spring and Summer 2005, $p<0.01$; Fall 2005 and Spring 2006, $p<0.001$).

The density of all species had a statistically significant response to the restoration technique nested within the restoration site at all seasons (Spring and Fall 2005, $p<0.01$; Summer 2005 and Spring 2006, $p<0.001$). The Shannon-Wiener Index of Diversity did not have a statistically significant response to the restoration technique nested within the restoration site at any season. The percentage of species that are native to Waterloo Region had a statistically significant response to the restoration technique nested within the restoration site at all seasons ($p<0.05$).

The density of all species and the percentage of species that are native to Waterloo Region did not have a statistically significant response to transect nested within the restoration technique for any season. The Shannon-Wiener Index of Diversity had a statistically significant response to transect nested within the restoration technique for all seasons ($p<0.01$).

Table 4. Nested ANOVAs testing responses of density of all species, Shannon-Wiener Index of Diversity, % of species that are native to Waterloo Region. Data were analyzed for each sampling period. Any data expressed as percentages were arcsine square root transformed prior to analyses to ensure homoscedascity. * = p<0.05; ** = p<0.01; *** = p<0.001.

(a) Spring Guild 2005

	Density			**Shannon-Wiener Index**			**% Native**		
	MS	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Site	43.77	29.87	***	18.97	11.25	**	24.81	15.74	**
Restoration Technique Nested Within Site	20.91	14.58	**	2.15	0.96	0.307	9.92	6.71	*
Transect Nested Within Restoration Technique	2.05	0.92	0.356	20.87	13.91	**	3.18	1.04	0.262
Error	1.13			1.28			1.49		

(b) Summer Guild 2005

	Density			**Shannon-Wiener Index**			**% Native**		
	MS	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Site	46.81	31.46	***	21.91	12.85	**	20.79	13.26	**
Restoration Technique Nested Within Site	25.42	16.71	***	3.56	1.13	0.220	9.17	7.42	*
Transect Nested Within Restoration Technique	1.56	0.68	0.420	15.87	10.94	**	2.96	0.99	0.295
Error	1.07			1.95			1.02		

(c) Fall Guild 2005

	Density			**Shannon-Wiener Index**			**% Native**		
	MS	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Site	40.19	28.71	***	22.97	13.34	***	22.45	13.00	***
Restoration Technique Nested Within Site	27.06	17.94	**	3.28	1.09	0.186	8.81	6.59	*
Transect Nested Within Restoration Technique	2.41	1.37	0.266	14.32	10.46	**	1.44	0.85	0.354
Error	1.75			1.63			1.06		

(d) Spring Guild 2006

	Density			**Shannon-Wiener Index**			**% Native**		
	MS	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Site	41.74	29.14	***	24.25	14.27	***	23.17	13.64	***
Restoration Technique Nested Within Site	26.19	17.26	***	2.57	0.84	0.274	10.04	8.36	*
Transect Nested Within Restoration Technique	2.13	0.92	0.308	15.41	10.73	**	1.72	0.96	0.322
Error	1.58			1.03			2.11		

4.1.1.3 Density of Herbaceous Plants (Tables 5, Figure 9)

The restoration site and restoration technique had a statistically significant response on the density of herbaceous plant stems (Table 4). The mean density of herbaceous stems per quadrat ± SD is reported for each site at each sampling period (Table 5 and Figure 9). Post hoc contrasts were performed with the nested ANOVA (SPSS Inc., Chicago, Illinois) to determine where significant differences exist within the herbaceous density data (Table 5). The values and contrasts are indicated in Figure 9. For all sampling seasons, the reference site and SW1 had the lowest density of stems, and were found to be significantly different from all other sites. In terms of the density of herbaceous plant stems, NH1, NH2 and SW1 were most similar to the reference site, followed by FW1, FW2, SW2 and SW3 overall.

Table 5. Mean density of herbaceous stems ± SD per quadrat for each restoration site at each sampling period, and post hoc contrasts. Completely different letters indicate that they are significantly different from each other.

Season	**Site**	**Mean Density (# stems/quadrat)**	**Constrasts**	**Season**	**Site**	**Mean Density (# stems/quadrat)**	**Contrasts**
Sp05	FW2	526.90 (±167.63)	b	***Sum05***	FW2	657.00 (±145.12)	d
	SW3	489.20 (±80.34)	b		FW1	574.00 (±77.49)	d
	SW2	476.90 (±86.88)	b		SW3	507.80 (±77.35)	c
	FW1	473.70 (±89.30)	b		SW2	457.00 (±65.21)	c
	NH1	379.00 (±199.81)	b		NH2	267.60 (±88.02)	b
	NH2	349.60 (±85.48)	b		SW1	212.50 (±85.88)	b
	SW1	197.10 (±50.26)	a		NH1	152.90 (±33.94)	a
	Ref.	121.19 (±47.33)	a		Ref.	51.10 (±11.87)	a
Fall05	FW1	606.60 (±119.99)	d	***Sp06***	SW2	644.00 (±174.17)	c
	SW2	492.00 (±88.55)	d		SW3	536.40 (±139.33)	bc
	SW3	480.50 (±63.55)	d		FW1	419.00 (±112.04)	bc
	FW2	438.20 (±157.67)	d		FW2	341.10 (±91.84)	b
	NH2	225.30 (±81.84)	c		NH2	318.90 (±159.78)	b
	SW1	192.00 (±77.09)	c		NH1	285.50 (±89.36)	b
	NH1	73.20 (±27.22)	b		Ref.	147.10 (±47.78)	a
	Ref.	28.90 (±11.04)	a		SW1	141.60 (±33.95)	a

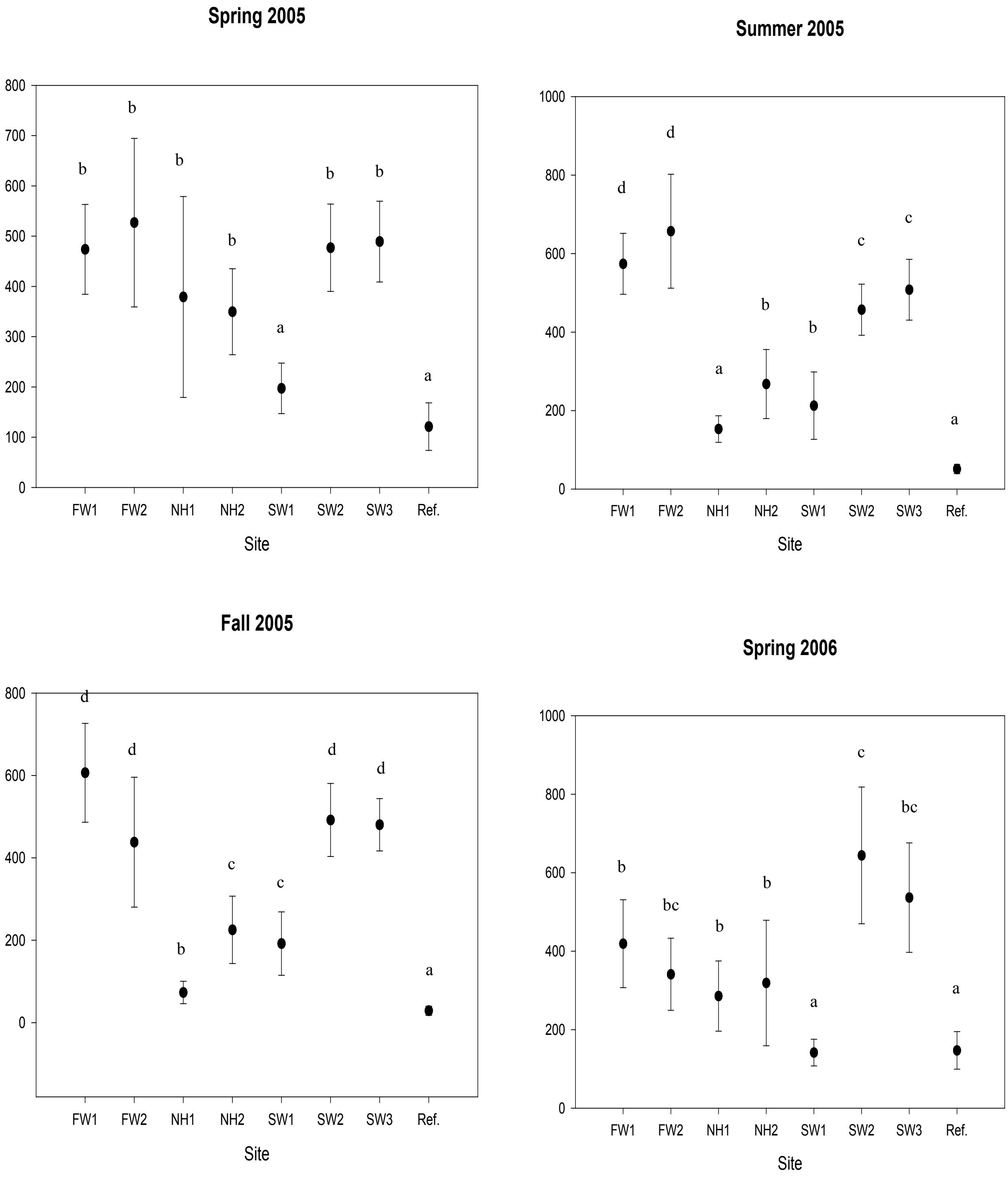


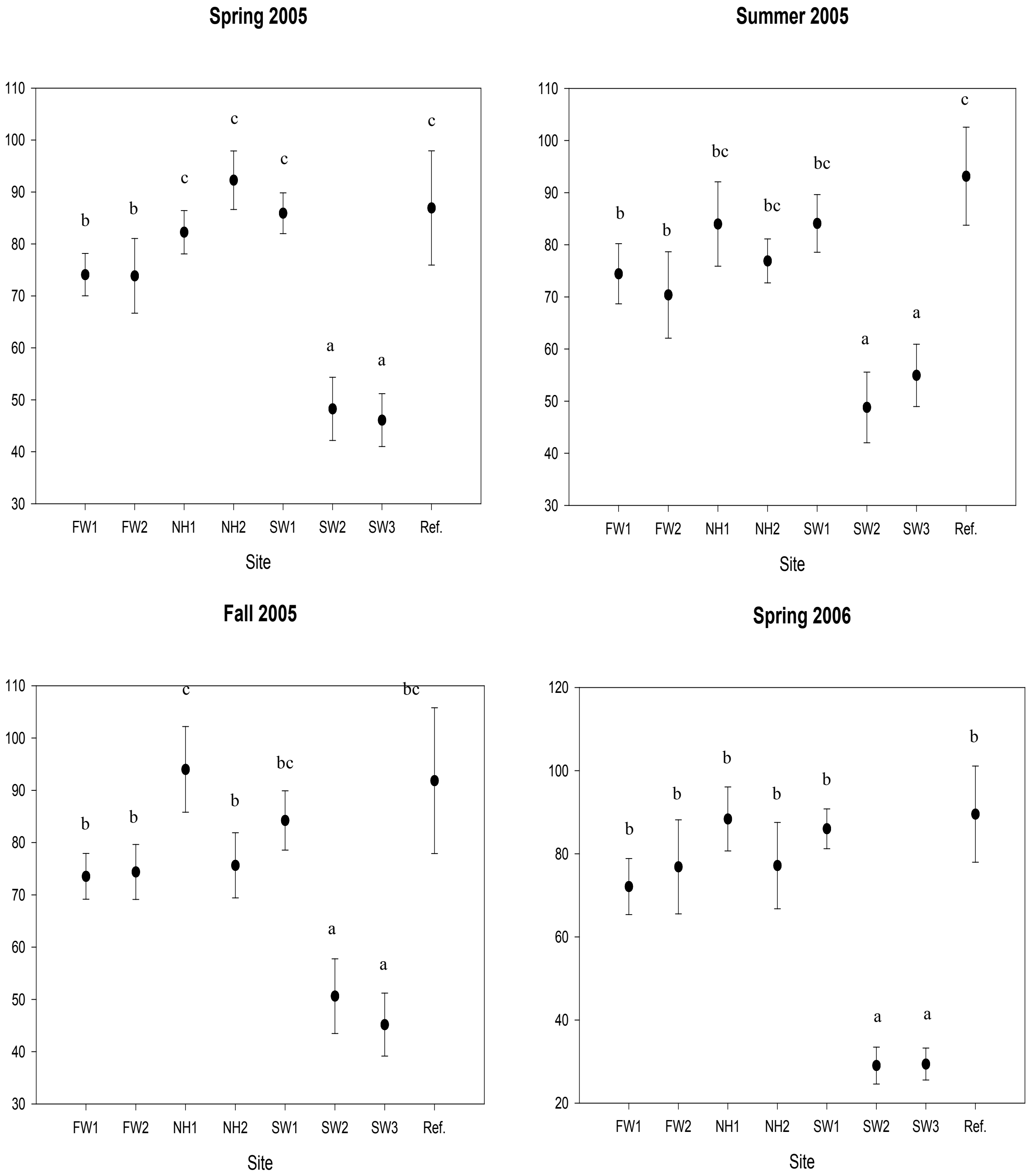
Figure 9. Mean density of herbaceous stems per quadrat and standard deviations for each site and field season. Letters above the data points represent results from post hoc contrasts. Completely different letters indicate significantly different means.

4.1.1.4 Percentage of Native Herbaceous Species (Tables 6, Figure 10)

The restoration site and restoration technique also appear to have a significant response to the percentage of species that are native to Waterloo Region (Table 4 a, b, c, d). The mean percentage of native species per quadrat ± SD is reported for each site at each sampling period (Table 6 and Figure 10). Post hoc contrasts were performed following the nested ANOVA to determine where significant differences exist within the percentage of native species data (Table 6). Overall, SW2 and SW3 appear to have a significantly lower percentage of native species than the reference site. NH1, NH2, and SW1 have similar percentages of native plants to that of the reference site, followed by FW1 and FW2.

Table 6. Mean percentage of herbaceous species native to Waterloo Region ± SD per quadrat for each site at each sampling period. Post hoc contrasts are also included, where completely different letters represent significant differences.

Season	**Site**	**Mean % Native (% native/quadrat)**	**Contrasts**	**Season**	**Site**	**Mean % Native (% native/quadrat)**	**Contrasts**
Sp05	NH1	92.27 (±5.63)	c	***Sum05***	Ref.	93.15 (±9.40)	c
	Ref.	86.92 (±10.99)	c		SW1	84.10 (±5.53)	bc
	SW1	85.91 (±3.92)	c		NH1	83.98 (±8.10)	bc
	NH2	82.26 (±4.17)	c		NH2	76.90 (±4.21)	bc
	FW1	74.09 (±4.08)	b		FW1	74.43 (±5.77)	b
	FW2	73.86 (±7.19)	b		FW2	70.37 (±8.28)	b
	SW2	48.26 (±6.08)	a		SW3	54.94 (±5.97)	a
	SW3	46.09 (±5.08)	a		SW2	48.79 (±6.77)	a
Fall05	NH1	94.00 (±8.19)	c	***Sp06***	Ref.	89.53 (±11.56)	b
	Ref.	91.84 (±13.95)	bc		NH1	88.37 (±7.71)	b
	SW1	84.23 (±5.67)	bc		SW1	86.01 (±4.79)	b
	NH2	75.64 (±6.23)	b		NH2	77.15 (±10.38)	b
	FW2	74.38 (±5.26)	b		FW2	76.85 (±11.31)	b
	FW1	73.54 (±4.37)	b		FW1	72.10 (±6.74)	b
	SW2	50.62 (±7.14)	a		SW3	29.40 (±3.83)	a
	SW3	45.17 (±6.02)	a		SW2	29.03 (±4.45)	a


Spring 2005

Summer 2005

Fall 2005

Spring 2006

Figure 10. The mean percentage of native herbaceous species per quadrat for each site and sampling period. Error bars represent standard deviation. Letters above the data points represent results from post hoc contrasts. Completely different letters indicate significantly different means.

4.1.1.5 Shannon-Wiener Diversity Index for Herbaceous Species (Tables 7, Figure 11)

The restoration technique did not have a significant response on the Shannon-Wiener Diversity Index. However, the restoration site and transect nested within the restoration technique did have a significant response on the Shannon-Wiener Diversity Index for herbaceous species (Table 4 a, b, c, d). Mean Shannon-Wiener Indices per quadrat ± SD are reported for each site at each sampling period (Table 7 and Figure 11). Contrasts were performed to determine where the significant differences exist within the species diversity data (Table 7). These results indicate that the reference site is most similar to NH1 in terms of herbaceous species diversity.

Table 7. Mean Shannon-Wiener Diversity Indices ± SD for herbaceous species per quadrat for each restoration site at each sampling period. Post hoc contrasts are reported where completely different letters represent significant differences.

Season	Site	Mean Shannon-Wiener Index	Constrasts	Season	Site	Mean Shannon-Wiener Index	Contrasts
Sp05	FW1	2.42 (±0.47)	b	***Sum05***	FW2	2.63 (±0.18)	b
	SW2	2.39 (±0.28)	b		SW1	2.55 (±0.19)	b
	SW1	2.34 (±0.40)	b		SW3	2.50 (±0.30)	b
	SW3	2.31 (±0.13)	b		FW1	2.48 (±0.37)	b
	FW2	2.15 (±0.60)	b		SW2	2.34 (±0.36)	b
	NH2	2.11 (±0.25)	b		NH2	1.81 (±0.41)	ab
	NH1	1.42 (±0.40)	a		NH1	1.38 (±0.28)	a
	Ref.	1.38 (±0.24)	a		Ref.	1.24 (±0.28)	a
Fall05	FW2	2.53 (±0.22)	b	***Sp06***	SW2	2.29 (±0.19)	b
	SW2	2.52 (±0.22)	b		FW1	2.24 (±0.48)	b
	SW3	2.41 (±0.16)	b		SW3	2.18 (±0.32)	b
	FW1	2.38 (±0.32)	b		SW1	2.07 (±0.30)	b
	SW1	2.20 (±0.24)	b		FW2	1.99 (±0.33)	b
	NH2	1.94 (±0.47)	ab		NH2	1.96 (±0.23)	b
	Ref.	1.54 (±0.31)	a		NH1	1.14 (±0.26)	a
	NH1	1.32 (±0.54)	a		Ref.	0.79 (±0.41)	a

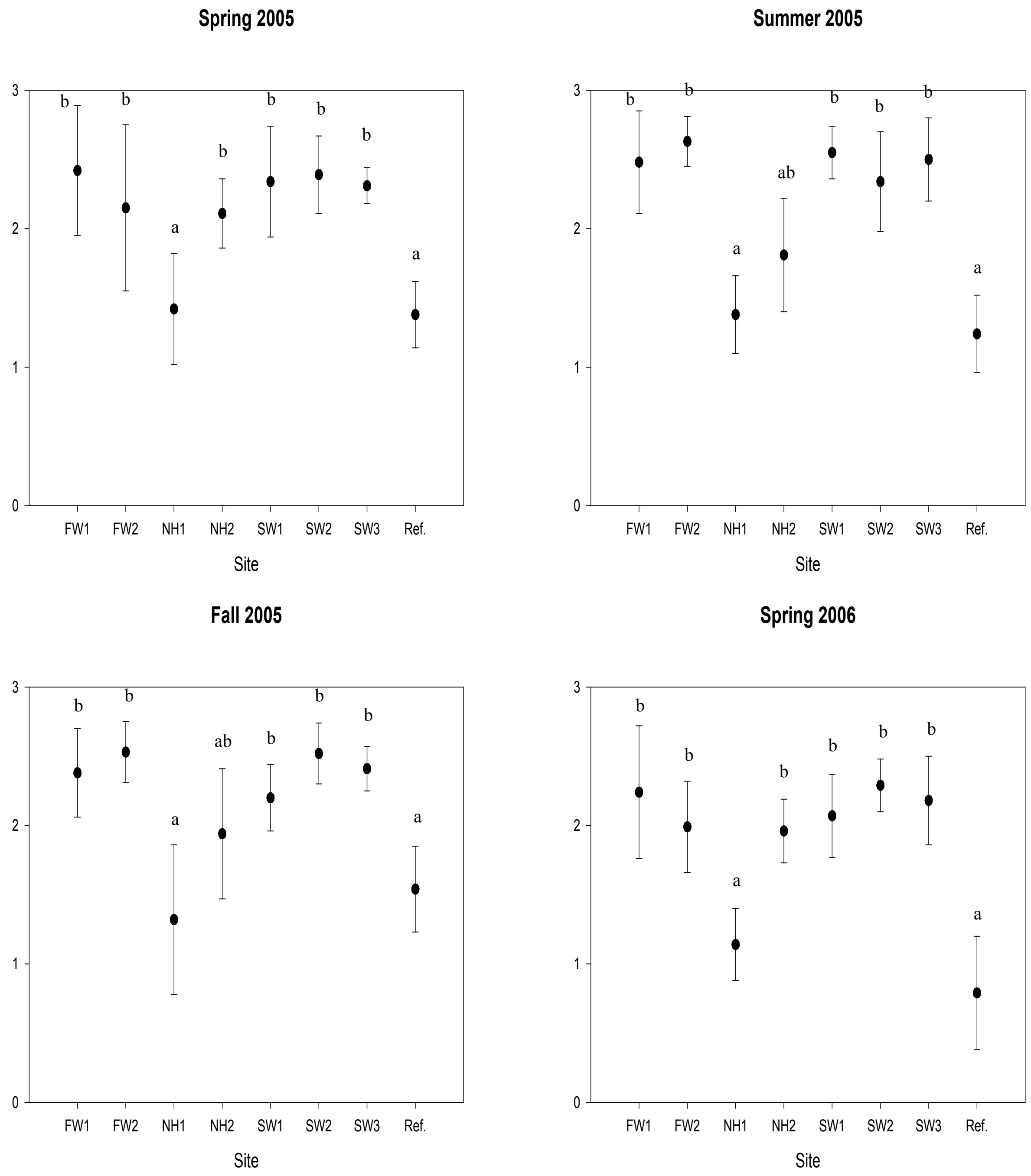


Figure 11. Mean Shannon-Wiener Diversity Indices for herbaceous species per quadrat for each site and sampling season. Error bars represent standard deviation. Letter above the data points represent results from post hoc contrasts. Completely different letters indicate significantly different means.

4.1.1.6 Bray-Curtis Ordination Values for Herbaceous Species (Table 8)

The reference site was pre-determined as the endpoint for the Bray-Curtis Ordination and all other restoration sites were ordinated relative to the reference site, based upon their similarity. The 2005 field season revealed consistent Bray-Curtis Ordination values for herbaceous species and the 2006 field season revealed slightly different values (Table 8):

- **Spring, Summer and Fall 2005:** NH1 had the highest value, followed by SW1, then FW1 and FW2, then NH2 followed by SW2 and SW3.
- **Spring 2006:** NH1 had the highest value, followed by FW2 and FW1, then SW1 and NH2, followed by SW2 and SW3.

Restoration sites with higher Bray-Curtis Ordination values are thought to be more similar to the reference site than those with lower values. This (dis)similarity is based on the multivariate analysis of the presence or absence and abundance of herbaceous species found at each restoration site relative to the reference endpoint. Results from the Bray-Curtis Ordination indicate that the reference site is most similar to NH1.

Table 8. Bray-Curtis Ordination values for herbaceous species for each site at each season. The herbaceous plant species density of each restoration site was ordinated using the reference site as the benchmark.

Season	Site	Bray-Curtis Ordination	Season	Site	Bray-Curtis Ordination
Sp05	FW1	0.13240	***Fall05***	FW1	0.01007
	FW2	0.17824		FW2	0.02995
	NH1	0.30600		NH1	0.24878
	NH2	0.05847		NH2	0.01259
	SW1	0.16086		SW1	0.14389
	SW2	0.00535		SW2	0.00000
	SW3	0.00164		SW3	0.00393
Sum05	FW1	0.01664	***Sp06***	FW1	0.22116
	FW2	0.02764		FW2	0.52765
	NH1	0.27024		NH1	0.55617
	NH2	0.03819		NH2	0.15966
	SW1	0.13885		SW1	0.11569
	SW2	0.00000		SW2	0.00253
	SW3	0.00143		SW3	0.00088

4.1.1.7 Cluster Analysis for Herbaceous Species (Figure 12)

A Cluster Analysis was conducted for the herbaceous species found at each restoration site and the reference site to reveal association and structure in the data (Figure 12). The Cluster Analysis was performed using PC-ord v. 4 (MjM Software Design, UK). Restoration sites belonging to the same cluster are thought to have stronger associations, whereas those belonging to different clusters are thought to have weaker associations. The data clustered as follows: Data collected for FW1 and FW2 during the Spring 2005 and 2006 field seasons clustered together. This cluster then clustered with the data collected for NH1 and the reference site during the Spring 2005 and 2006 field seasons, which then clustered with the data collected for FW1 and FW2 during the Summer 2005 and Fall 2005 field seasons. The next group to join the cluster was the NH2 cluster and NH1 Summer 2005 and Fall 2005 cluster, followed by the SW1 cluster, and lastly the SW2 and SW3 cluster. These results indicate that NH1 groups most closely with the reference site, followed by FW1 and FW2, then NH2, then SW1, and lastly SW2 and SW3 in terms of species diversity and abundance.

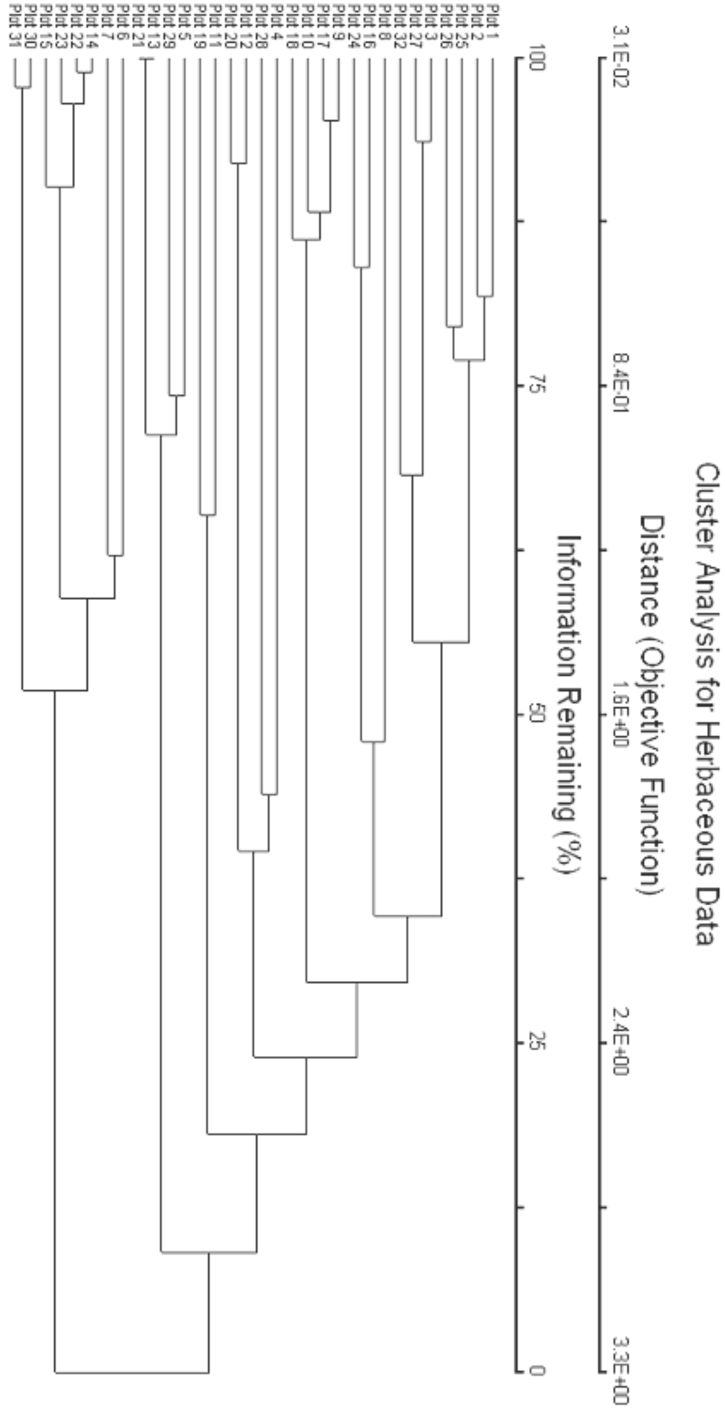


Figure 12. Cluster Analysis dendrogram for herbaceous species for each site at each season. FW1 = Plots 1, 9, 17, 25; FW2 = 2, 10, 18, 26; NH1 = Plots 3, 11, 19, 27; NH2 = Plots 4, 12, 20, 28; SW1 = Plots 5, 13, 21, 29; SW2 = Plots 6, 14, 22, 30; SW3 = Plots 7, 15, 23, 31; Reference = 8, 16, 24, 32. The first plot number for each restoration site is Spring 2005, followed by Summer 2005, then Fall 2005 and lastly Spring 2006.

4.1.2 Regenerating Woody Vegetation

4.1.2.1 Regenerating Woody Vegetation Summary Statistics (Table 9)

Summary statistics were tabulated from the data collected for regenerating woody vegetation at each restoration site and the reference site (Table 9). The summary statistics include measurements of the mean number of species encountered per quadrat, the mean percentage of species native to Waterloo Region per quadrat, the mean percentage of dead regenerating woody vegetation per quadrat, and the mean density of regenerating woody stems per quadrat. Results indicate the following:

- **Number of species per quadrat:** SW1 had the highest, followed by FW1, FW2, SW2 and the reference site, NH1, SW3 and then NH2.
- **Percentage of native species per quadrat:** the reference site had the highest, followed by SW1, SW2, FW1, NH1, FW2, SW3 and then NH2.
- **Percentage of dead stems per quadrat:** NH1 had the highest, followed by NH2, the reference site, SW1, FW2, FW1 and then SW2 and SW3.
- **Density of stems per quadrat:** FW1 had the highest, followed by SW1, FW2, the reference site, NH1, SW2, NH2 and then SW3.

Overall, NH1, NH2 and SW1 are most like the reference site in terms of regenerating woody vegetation. FW1 and FW2 are the next closest in similarity, and SW2 and SW3 are the least like the reference site in terms of regenerating woody vegetation.

Table 9. Summary statistics, including the mean number of species per quadrat, the mean percentage of native species per quadrat, the mean percentage of dead species per quadrat and the mean density of stems per quadrat, ± SD for regenerating woody species at each site. Post hoc contrasts were performed among all sites. Completely different letters indicate significant differences.

Site	# Species Per Quadrat	Contrasts	Site	% Native Per Quadrat	Contrasts
SW1	4.48 (±1.76)	b	Ref.	100.00 (±0.00)	b
FW1	3.36 (±1.35)	ab	SW1	93.52 (±14.38)	ab
FW2	3.20 (±1.35)	ab	SW2	75.67 (±40.53)	ab
SW2	2.20 (±1.38)	a	FW1	70.50 (±21.72)	ab
Ref.	2.20 (±0.96)	a	NH1	67.87 (±41.81)	ab
NH1	2.00 (±1.26)	a	FW2	66.96 (±13.26)	ab
SW3	1.20 (±1.19)	a	SW3	62.00 (±46.28)	a
NH2	1.08 (±1.00)	a	NH2	54.00 (±46.96)	a
Site	**% Dead Per Quadrat**	**Contrasts**	**Site**	**Density of Stems Per Quadrat**	**Contrasts**
NH1	28.82 (±37.25)	c	FW1	34.16 (±27.45)	b
NH2	19.81 (±31.89)	c	SW1	30.68 (±14.06)	b
Ref.	10.64 (±18.23)	bc	FW2	28.60 (±12.91)	b
SW1	3.57 (±6.63)	b	Ref.	8.08 (±6.53)	a
FW2	0.97 (±2.33)	a	NH1	6.76 (±5.68)	a
FW1	0.41 (±1.37)	a	SW2	4.20 (±4.65)	a
SW2	0.00 (±0.00)	a	NH2	2.56 (±2.12)	a
SW3	0.00 (±0.00)	a	SW3	2.40 (±3.15)	a

4.1.2.2 Nested Analysis of Variance for Regenerating Woody Vegetation (Table 10)

Results from the nested ANOVA can be found in Table 10. The density of regenerating woody stems responded significantly to the restoration site ($p<0.001$), the restoration technique nested within the restoration site ($p<0.001$), and to transects nested within the restoration technique ($p<0.01$). The total number of species found at each site responded significantly to the restoration site ($p<0.01$), the restoration technique nested within the restoration site ($p<0.05$), and transect nested within the restoration technique ($p<0.01$). The percentage of regenerating woody species that are native to Waterloo Region responded significantly to the restoration site ($p<0.05$) and to transects nested within the restoration technique ($p<0.01$), but did not respond significantly to the restoration technique nested within the restoration site. The percentage of standing dead regenerating woody species responded significantly to the restoration site (p<0.001), the restoration technique nested within the restoration site (p<0.05), and transects nested within the restoration technique (p<0.01).

Table 10. Nested ANOVAs testing the responses of woody species regeneration. Any data expressed as percentages were arcsine square root transformed prior to analyses to ensure homoscedascity**.** * = p<0.05; ** = p<0.01; *** = p<0.001.

	Density			**# Species**			**% Native**			**% Snags**		
	MS	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**	**MS**	**F**	**P**
Site	33.17	25.49	***	9.14	6.61	**	8.04	5.72	*	45.79	40.16	***
Restoration Technique Nested Within Site	14.06	10.28	***	7.20	4.39	*	1.56	0.92	0.513	7.68	4.72	*
Transect Nested Within Restoration Technique	11.30	8.02	**	13.91	9.97	**	11.59	9.36	**	16.54	12.93	**
Error	1.18			1.47			1.35			1.90		

4.1.2.3 Mean Number of Regenerating Woody Species (Figure 13 a)

Statistically significant differences in the mean number of regenerating woody species per quadrat were found among the restoration sites and the reference ecosystem (Figure 13 a). The reference site, NH1, NH2, SW2 and SW3 had significantly fewer regenerating woody species per quadrat than SW1.

4.1.2.4 Mean Percentage of Native Regenerating Woody Species (Figure 13 b)

Statistically significant differences in the mean percentage of native regenerating woody species per quadrat were found among the restoration sites and the reference ecosystem (Figure 13 b). FW1 and FW2 had significantly lower percentages of native regenerating woody species than SW1. NH1, NH2, SW2, SW3 and the reference site had lower percentages of native species than SW1 and higher percentages of native species than FW1 and FW2; however, no significant differences were found.

4.1.2.5 Mean Percentage of Dead Regenerating Woody Stems (Figure 13 c)

Statistically significant differences in the mean percentage of dead regenerating woody species per quadrat were found among the restoration sites and the reference ecosystem (Figure 13 c). FW1, FW2, SW2 and SW3 had significantly lower percentages of dead stems than SW1. NH1 and NH2 had significantly higher percentages of dead stems than SW1. The reference site had a lower percentage of dead stems than NH1 and NH2 and a higher percentage than SW1; however, no significant differences were found.

4.1.2.6 Mean Density of Regenerating Woody Stems (Figure 13 d)

Statistically significant differences in the mean density of regenerating woody stems per quadrat were found among the restoration sites and the reference ecosystem (Figure 13 d). The reference site, NH1, NH2, SW2 and SW3 had significantly fewer stems per quadrat than FW1, FW2 and SW1.

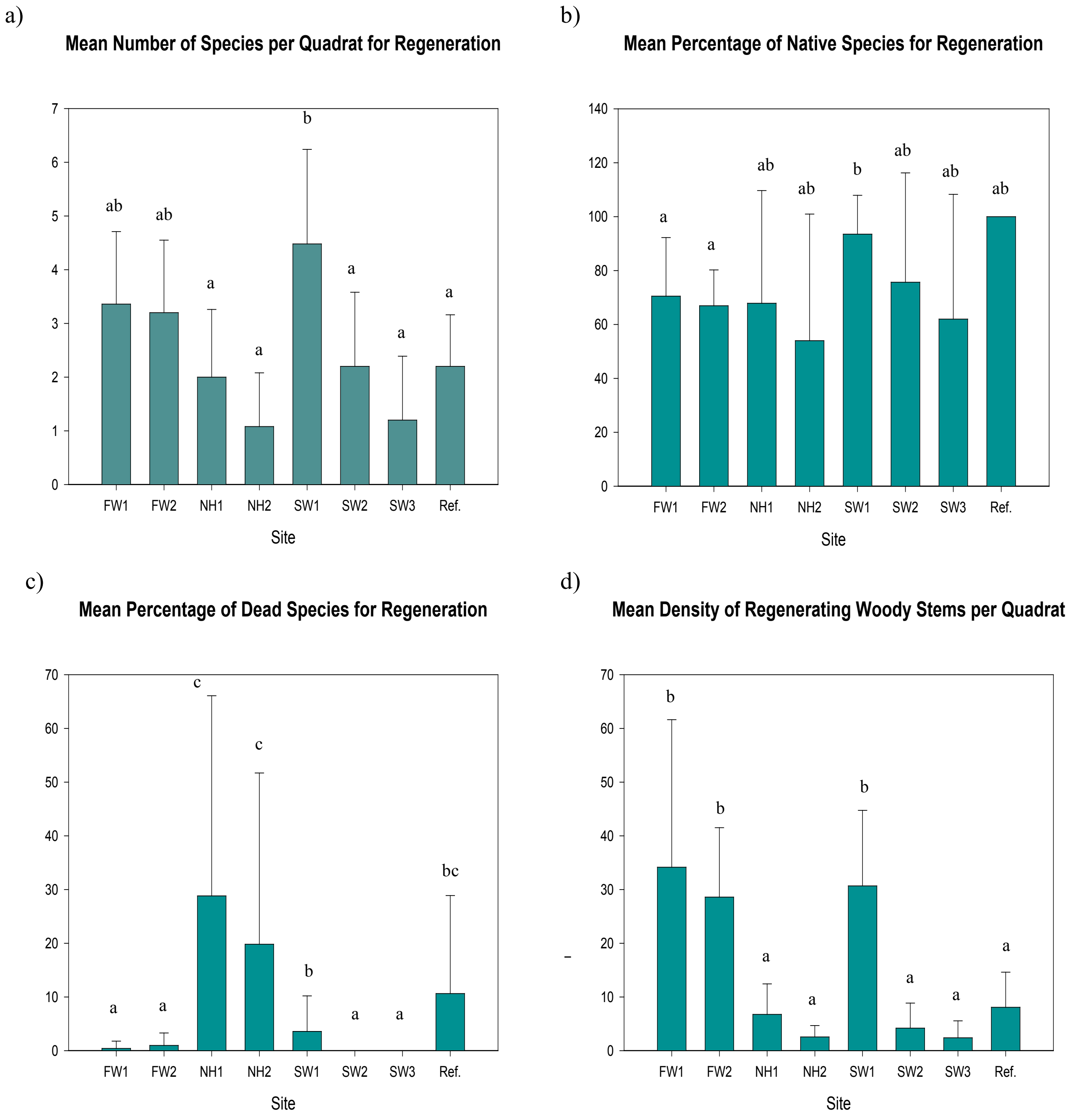


Figure 13. Means and standard deviations of the number of species per quadrat (a), the percentage of native species per quadrat (b), the percentage of dead species per quadrat (c), and the density of stems per quadrat (d) for the regenerating woody species found at each site. Letters above the data points represent results from post hoc contrasts. Completely different letters indicate means that are significantly different from each other.

4.1.3 Mature Trees (Table 11, Figure 14)

Summary statistics were tabulated from the data collected for the standing mature trees at each restoration site (Table 11 and Figure 14 a, b, c, d). The summary statistics include measurements of the total number of trees encountered at each site, the total number of species per site, the percentage of native species per site, the percentage of dead species per site, the mean distance between mature trees at each site, the two most dominant trees species found at each site, and the Simpson's Dominance Index. Results indicate the following:

- **Total number of trees:** FW2 had the highest, followed by FW1, SW1, the reference site, SW2, SW3, NH1, and then NH2 (Figure 14 a).
- **Total number of species:** FW2 also had the highest, followed by FW1, SW1, SW2, SW3, the reference site, NH1, and then NH2 (Figure 14 b).
- **Percentage of native species:** FW1 had the highest, followed by FW2, NH1, NH2, SW1, SW2, SW3, and then SW1 (Figure 14 c).
- **Percentage of standing dead trees:** the reference site had the highest, followed by SW1, NH2, NH1, SW3, FW2, FW1, and then SW2 (Figure 14 d).
- **Mean distance between trees:** FW1 had the farthest mean distance between trees, followed by FW2, SW2, NH1, SW3, NH2, the reference site, and then SW1.
- **Dominant tree species:** the reference site, FW1, FW2, NH1, SW1 all had sugar maple (*Acer saccharum*) and white ash (*Fraxinus americana*) as their two most dominant tree species. Sugar maple (*Acer saccharum*) and yellow birch (*Betula allegheniensis*) were the two most dominant tree species at NH2, yellow birch (*Betula allegheniensis*) and eastern white pine (*Pinus strobus*) at SW2, and eastern white pine (*Pinus strobus*) and staghorn sumac (*Rhus typhina*) at SW3.
- **Simpson's Dominance Index:** NH2 had the highest, followed by NH1, the reference site, SW3, SW1, SW3, and then FW1 and FW2. A higher Simpson's Index value indicates higher probabilities of picking two trees at random that are of the same species.

Overall, NH1, NH2 and SW1 are most like the reference site in terms of mature trees. SW2 and SW3 are the next closest in similarity, and FW1 and FW2 are the least like the reference site in terms of mature trees.

Table 11. Summary statistics for mature trees, including the number of trees, the number of species, the percentage of native species, the percentage of dead trees, the mean distance between trees, the 2 most dominant tree species, and the Simpson's Dominance Index. Both Dominance measures were calculated using the DBH of each tree.

Site	Total # Trees	Total # Species	% Native Species	% Dead Trees	Mean Distance (m)	Dominant Tree Species	Simpson's Index
FW1	93	13	100	0.00	3.68	*Acer saccharum* *Fraxinus americana*	0.13
FW2	119	17	100	2.52	3.29	*Acer saccharum* *Fraxinus americana*	0.13
NH1	15	3	100	6.67	2.71	*Acer saccharum* *Fraxinus americana*	0.75
NH2	13	2	100	7.69	1.89	*Acer saccharum* *Fagus grandifolia*	0.92
SW1	69	10	100	8.70	1.46	*Acer saccharum* *Fraxinus americana*	0.24
SW2	26	8	87.5	0.00	2.77	*Betula allegheniensis* *Pinus strobus*	0.16
SW3	20	6	100	5.00	2.69	*Pinus strobus* *Rhus typhina*	0.29
Ref.	48	5	100	10.42	1.67	*Acer saccharum* *Fraxinus americana*	0.62

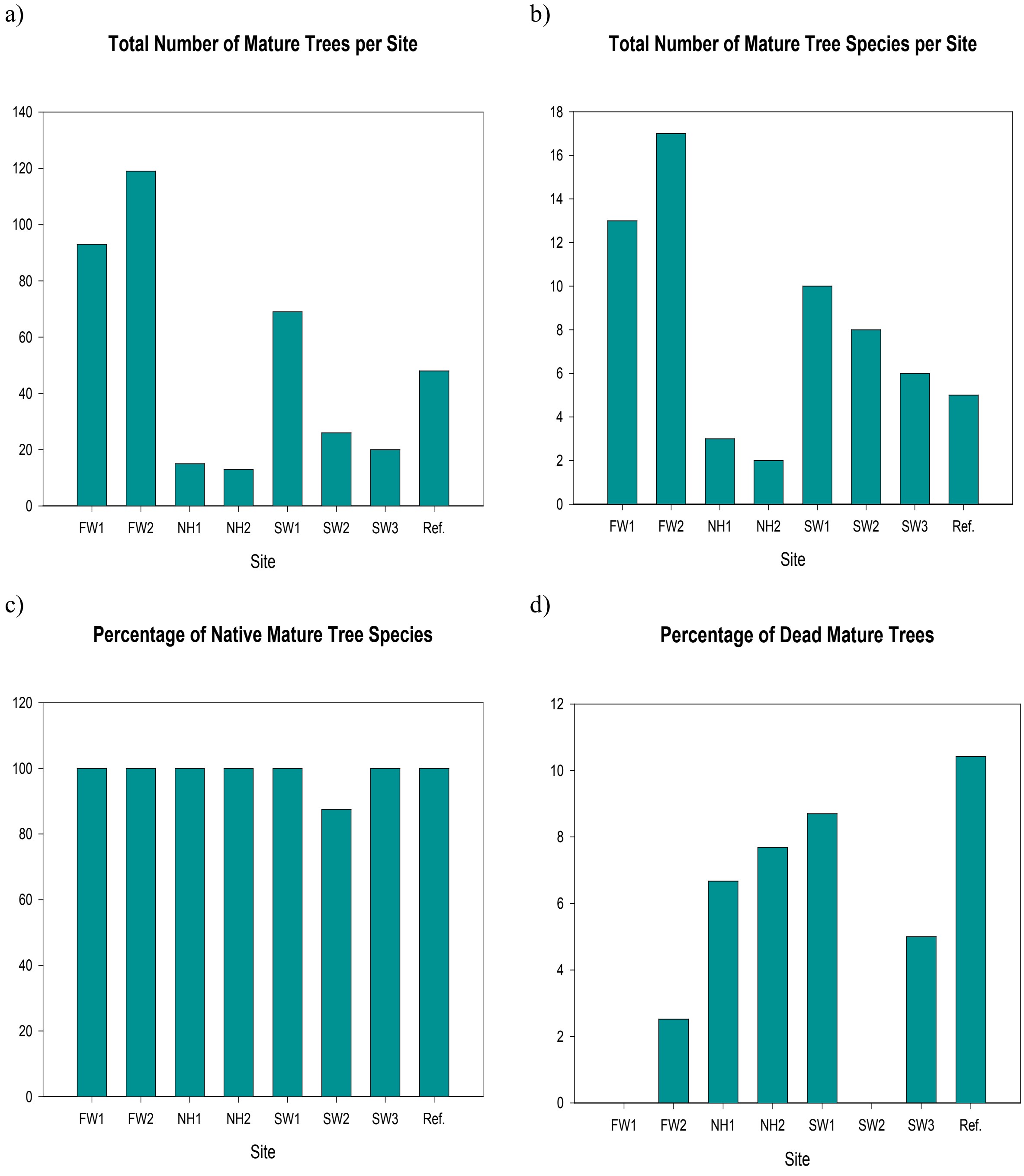


Figure 14. The total number of trees per site (a), total number of species (b), percentage of native species (c), and the percentage of standing dead trees (d) for the mature tree data collected at each site using the wandering-quarter sampling method. Areas of the restoration sites are as follows: FW1 and FW2 = 20 000 m^2 each, NH1 and NH2 = 2 000 m^2 each, SW1 = 4 000 m^2, SW2 and SW3 = 6 000 m^2, and Ref. = 15 000 m^2.

4.2 Summary of Fieldwork Results

In conclusion, the summary statistics tabulated for the herbaceous vegetation data indicate that NH1 is most similar to the reference site followed by NH2 and SW1, and lastly FW1, FW2, SW2 and SW3. In terms of the density of herbaceous stems, NH1, NH2 and SW1 are most similar to the reference site followed by FW1, FW2, SW2 and SW3. In terms of the percentage of species native to Waterloo Region, all restoration sites, with the exception of SW2 and SW3, are similar to the reference site. The Shannon-Wiener Index of Diversity indicates that NH1 is most similar to the reference site followed by the other restoration sites. The Bray-Curtis Ordination indicates that NH1 is most similar to the reference site, followed by NH2, FW1, FW2 and SW1, then SW2 and SW3. The Cluster Analysis indicates that NH1 is most similar to the reference site, followed by FW1 and FW2, then NH2 and SW1, then SW2 and SW3. Results from analyzing the regenerating woody vegetation data indicate that NH1, NH2 and SW1 are most similar to the reference site, followed by FW1 and FW2, and then SW2 and SW3. Results from the analysis of the mature trees data indicate that NH1, NH2 and SW1 are most similar to the reference site, followed by SW2 and SW3, then FW1 and FW2. Overall, NH1 is most like the reference site, followed by SW1 and NH2, then FW1 and FW2, and SW2 and SW3 are least like the reference site.

Chapter 5
Discussion and Conclusions

5.1 Interpretation of Fieldwork Results

5.1.1 General Research Findings

The restoration technique employed and the location of the restoration site are important variables in determining the rate of progress in early stage forest restoration projects in some combination of cases. It is difficult to compare the success of each restoration technique outside a given location without a replication of treatment-site combinations and none exist in this Region – a common problem when comparing actual restoration projects as opposed to using controlled experiments (Andrews & Broome 2006; Brewer 2005; Wilkins et al. 2003). Nonetheless, the nested ANOVA indicates strong evidence of a site response and a response to the restoration technique used for herbaceous species regeneration.

5.1.1.1 Effect of Site Location and Restoration Technique

Although it is not possible to separate the effects of time since restoration and the restoration site or type of restoration technique used, a strong site effect appears to exist between NH1 and NH2 for some variables. Also, SW2 and SW3 compared to SW1 indicate a major difference in response to the two different classes of restoration techniques used (i.e., the planting of native saplings versus the removal of mature pines).

5.1.1.2 Effect of Transect Nested within Restoration Site

Transects nested within each restoration site varied significantly in herbaceous species diversity ($p<0.01$) for all sampling seasons, indicating a high degree of within restoration variation. Over time, differences in transect composition within each restoration site may become exacerbated, though one may hypothesize that if the restoration is successful, they may in fact become more alike within a given restoration treatment, unless heterogeneity within the site is high. This may mean that transects within restorations that used different restoration techniques or exist at different sites could become more significantly different over time.

5.1.1.3 Response of Regenerating Woody Vegetation

Results from the analysis of regenerating woody vegetation support the findings of the herbaceous regeneration analysis. Responses in woody vegetation regeneration indicate that the restoration technique employed and the location of the restoration site are important variables in determining the rate of restoration progress. The nested ANOVA indicates strong evidence of a site response, a response to the restoration technique used (in all cases except for the percentage of native species; p=0.513), and transects nested within each restoration site. For regenerating woody vegetation, the site response appears to be stronger than the response to the restoration technique used, possibly because local conditions must first be altered by the recovery of herbaceous vegetation structure in order to facilitate the natural colonization of woody seedlings (Ruiz-Jaén & Aide 2005a; Luken 1990). However, SW2 and SW3 compared to SW1 indicate a significant difference in response to the two different classes of restoration techniques used, despite the short length of time since restoration implementation. Transects nested within each restoration site had a stronger response in the analysis of woody regeneration than in herbaceous regeneration, indicating a high amount of within-restoration variability. This variability has most likely resulted from uneven planting strategies, the closer proximity of some transects to natural sources of woody seedlings, such as a forest edge, or the inability of woody plants to compete against the dominant vegetation in certain areas.

5.1.1.4 Response of Mature Trees

Summary statistics of mature trees data indicate that NH1, NH2, and SW1 are most like the reference site. Restoration sites that were most similar to the reference site all had a closed canopy. Over time, it is expected that the structure of mature trees at restoration sites with an open canopy will begin to resemble the reference site. The mean distance between trees was calculated at each site to determine the spatial organization of mature trees. Although this measurement assumes an unjustified homogenous environment, it conveys important information about the density, size, and age of the mature trees on site. In this type of forest, which is driven by gap phase dynamics, the timing of mature tree regeneration is important, where the natural establishment of trees should occur sequentially rather than all at once to ensure a healthy forest age-class distribution.

5.1.2 Interpretation of Restoration Progress

5.1.2.1 Are any of the restoration techniques working?

Meaningful restoration evaluation must address the extent to which the restored area follows a trajectory toward some specified target state that represents a "natural" or undegraded condition (Wilkins et al. 2003; Hobbs & Norton 1996; Hobbs & Mooney 1993). Restoration strategies can be considered successful when they markedly accelerate the return of a degraded ecosystem to a desired endpoint, such as a forest. Restoration success is often viewed as a continuum from the successful establishment of the initial planting through to the successful establishment of longer-term goals, such as a closed forest canopy or certain ecosystem functions (Reay & Norton 1999). Therefore, the early stages of a restoration project must be successful if longer-term goals are to be met (Majer 1989). Through formative evaluation, the direction (i.e., towards or away) and nature (i.e., incremental or threshold) of successional change may be predicted in relation to the reference site.

The progress of restoration projects must, therefore, be evaluated at multiple stages to ensure that the ecosystem is proceeding along the desired restoration trajectory. How, then, can restoration progress be evaluated at an early stage? Some authors have indicated that structural measures are not good indicators of ecosystem function, and therefore ecological integrity. For example, Salomon et al. (2006) provides a marine example where the functional activity and species richness of a keystone species (i.e., Black Katy Chiton, *Katharina tunicata*) was found to be negatively correlated with species richness within a marine protected area (e.g., Salomon et al. 2006). So, in the context of marine protected areas, structural measures may not be good indicators. Under the circumstances of forest restoration, structural metrics are, however, arguably good indicators. For example, without the application of a restoration technique, one would not expect to find high densities of native species in the early years following a disturbance in an urban environment. Also, the presence of natural regeneration indicates that the functional processes that initiate regeneration, such as dispersal, are present (Reay & Norton 1999). Early-stage restoration sites exhibiting high species diversity, coupled with a high percentage of native species and high densities are, therefore, likely progressing along a successful restoration trajectory (Ruiz-Jaén & Aide 2005a,b; Wilkins et al. 2003; Reay & Norton 1999).

Without replications of different restoration techniques at each restoration site, the relative rate of progress of a restoration project cannot be determined. Each restoration area varied from the others, which complicates the comparison among distant restoration areas (e.g., Foxwood Golf Course and Natchez Hills). However, the question of whether or not a restoration technique appears to working at a given site can be answered by comparing each restoration site to the reference ecosystem. Overall, NH1 was most like the reference ecosystem, followed by SW1 and NH2, then FW1 and FW2, and lastly SW2 and SW3. Restoration progress and similarity to the reference ecosystem has been based on structural measurements of regenerating and remnant vegetation. Restoration sites that are structurally similar to the reference ecosystem are thought to be progressing along an expected trajectory. Those with dissimilar vegetation structures may either be progressing along an undesirable trajectory, are progressing slowly in comparison, or they may have been further back along the trajectory to begin with, in which case further restoration intervention may be required.

The reference site had a low density of herbaceous and regenerating woody stems, low diversity, a high percentage of native species, and a high percentage of dead woody regeneration and mature trees. These structural measures are characteristic of late-stage successional hardwood forests. NH1 also had a low density of herbaceous and regenerating woody stems, low diversity, a high percentage of native species, and a high percentage of dead woody regeneration and mature trees. SW1 is the next closest in similarity to the reference with a low density, medium diversity, high percentage of native species, and a high percentage of dead woody regeneration and mature trees. NH1 and SW1 grouped most closely with the reference site and are considered to be progressing well.

NH2, FW1 and FW2 are not as closely linked with the restoration site; however, results indicate that these sites are proceeding along the expected trajectory. NH2 had a low density, medium diversity, medium percentage of native species, and a high percentage of dead woody regeneration and mature trees. FW1 and FW2 had high densities, high diversities, medium percentages of native species, and low percentages of dead woody regeneration and mature trees. Although NH2, FW1 and FW2 appear to be proceeding along the expected trajectory, the return to their specified endpoint will most likely occur at a slower rate than NH1 and SW1 in the absence of further restoration intervention. A slower rate of recovery is expected for FW1 and FW2 because of the type of disturbance that occurred and the restoration strategy required. The recovery of a forest is expected to take a longer period of time than the recovery of an understorey alone. NH2 is expected to take a longer period of time to recover because of the extent of the damage, where the soil is very compacted and the forest understorey is nearly non-existent. More extensive restoration strategies could help to speed up the process in the case of NH2, and to some extent at FW1 and FW2, although time-to-restoration at FW1 and FW2 is dependent upon and thus limited by the rate at which trees can grow.

SW2 and SW3 are least similar to the reference ecosystem, despite the fact that they are closest to the reference. SW2 and SW3 have high densities, high diversities, low percentages of native species, and low percentages of dead woody regeneration and mature trees. Without further restoration intervention, it is predicted that SW2 and SW3 will proceed toward an alternate endpoint. In conclusion, the restoration techniques at all of the restoration sites, excluding SW2 and SW3, appear to be progressing along a successful restoration trajectory thus far.

5.1.2.2 Is restoration being affected by within site differences at the transect level?

The nested ANOVA showed that the response of the Shannon-Wiener Index of Diversity for herbaceous vegetation to transect nested within restoration technique was significant ($p<0.01$) for all sampling seasons. Woody species regeneration also responded significantly to transect nested within restoration technique for all tested variables (i.e., density, number of species, percentage of native species, and percentage of snags; $p<0.01$). This indicates that all restoration sites have been affected by within site differences at the transect level to some degree.

At Foxwood Golf Course, both restoration sites are thinly bordered by remnant forest. The presence of a forested border can ensure higher survival probabilities for planted vegetation populations (Jacquemyn et al. 2003) and increase the rate of re-introduced forest plant species over time. A prerequisite for successful restoration is the availability of a target species source and the ability of the species to reach the target area (Wolters et al. 2005; Zobel et al. 1998; Zobel 1997). Only woody plant species were planted at FW1 and FW2 to encourage forest regeneration. In order for forest understorey species to regenerate, suitable conditions must be made available. Once the plantings have reached mid-maturity, the herbaceous layer may resemble the pre-disturbed state more uniformly. Numerous areas that resemble forest understorey conditions already exist at Foxwood (i.e., in areas close to remnant forest borders, or in areas densely occupied by wild red raspberry, *Rubus idaeus*). Over time, differences in herbaceous plant density and diversity at the transect level will probably decrease as the density of woody plants and canopy cover increase at FW1 and FW2 (Andrews & Broome 2006; Shepherd & Debinski 2005; Kruse & Groninger 2003).

At SW1, within site differences at the transect level are most likely attributable to the pattern in which the red pine (*Pinus resinosa*) were thinned. In areas where the forest canopy was thinned to the extent that sunlight was able to reach the forest floor, considerable woody species regeneration occurred. However, in areas where gaps in the canopy of red pine do not exist, woody species regeneration was minimized. Also, many of the felled trees were not removed from the site. In areas where fallen logs were piled the growth of both woody and herbaceous plants appeared to be impeded; therefore, transects that followed along any of these areas would have yielded significantly lower herbaceous and woody regeneration data, causing significant within site variation of the successional process.

SW2 and SW3, and NH1 and NH2 did not exhibit variations in response to transects nested within the restoration techniques to the same extent as FW1 and FW2, and SW1. However, slight variations were apparent, which can most likely be attributed to the pattern in which herbaceous and/or woody species were planted. Over time, if the restoration proceeds along a successful trajectory, within-site variation at the transect level will decrease as herbaceous and woody plant species naturally colonize the restoration area to reduce the gaps in vegetation. For restoration sites that were heavily degraded, such as NH1, NH2, SW2 and SW3, more intensive restoration strategies may be necessary to improve local conditions, especially in sites where remnant sources of native diversity have been exterminated.

5.1.2.3 What happened when similar techniques were used at different sites?

Similar restoration techniques were used within restoration areas; however, distant sites restored using similar techniques were unavailable for study. Comparison of the differences among restoration sites where similar techniques have been used can, however, be made between NH1 and NH2, FW1 and FW2, and SW2 and SW3.

Similar restoration techniques were used to rehabilitate both sites at Natchez Hills, although significant differences have been noted between the progress of NH1 and NH2. The damage that occurred at Natchez Hills, which included the removal of the forest understorey and the compaction of soil, was caused by mountain biking activities. It is possible that NH2 was more heavily degraded than NH1, and since the degree of soil compaction greatly influences soil permeability and restricts the germination ability of seeds stored in seed banks (Forman 1995), NH2 would thus require a longer length of time for recovery or a more intensive restoration approach. Furthermore, evidence of mountain biking activities reoccurred in the Natchez Hills area during the 2005 and 2006 field seasons, and the effects of these activities may have been more strongly felt at NH2. For example, invasive non-native plants (e.g., garlic mustard, *Alliaria petiolata*) have been introduced to NH2 but not NH1. Aggressive invasive species strongly influence the success of a site's restoration by out-competing native plant species, particularly in urban and near-urban environments where ecological integrity has already been compromised (Palmer et al. 1997; Parker 1997).

A similar restoration technique was used to return FW1 and FW2 to a forested state. According to restoration records, the pre-restoration condition of both sites was also similar. No significant difference was found between FW1 and FW2 for the variables tested. At SW2 and SW3 a similar restoration technique was used to return old fields to a forested state. At an early-stage of restoration, no significant difference was found between SW2 and SW3 for the variables tested.

5.1.2.4 What happened when different restoration techniques were used at different sites?

An opportunity for testing the differences in different restoration techniques between sites was only available at Schneider's Woods since a different restoration technique was used to restore SW1 than at SW2 and SW3. Testing the differences in different restoration techniques between sites will indicate whether one restoration technique has been more successful than another. However, differing site conditions will confound this difference, making it difficult to conclude whether one technique should be used over another.

Contrasts from the nested ANOVA indicated significant differences among the restoration sites at Schneider's Woods. Pre-restoration conditions at SW2 and SW3 were much different than at SW1. Also, the techniques used to restore SW2 and SW3 were much different than at SW1. Results indicate that SW2 and SW3 are proceeding at a much slower rate than SW1. The high rate of progress evident at SW1 is most likely linked to the existence of a closed canopy, where the site already resembled forest-like conditions. The thinning of red pine (*Pinus resinosa*) at this site allowed for the regeneration of native woody and herbaceous plants, indicating the existence of an abundant on-site seed bank. The most successful restoration results can be expected when the target species are still present in either the established vegetation or the soil seed bank (Wolters et al. 2005; Jacquemyn et al. 2003).

SW2 and SW3 are both fairly isolated from areas of continuous forest. The establishment of a new forest in an area exhibiting non-forest characteristics occurs at a much slower and less-predictable rate than it would if pre-existing forest characteristics were present (Jacquemyn et al. 2003). Soil moisture, canopy cover and distance to continuous forest have all been found to significantly affect plant species composition and restoration progress (McLachlan & Bazely 2003; Palmer et al. 1997; Forman 1995). Moreover, SW2 and SW3 are both old fields. High levels of soil-bound nitrogen are common in old fields and can lead to higher-than-usual productivity in early-stage restoration. This could play a role in suppressing the regeneration ability of woody plants and native plant species due to high biomass and litter levels (Martin et al. 2005; Luken 1990) and impede the rate of restoration progress.

5.1.3 Comparison of Restoration Sites to Early-stage Restoration Expectations

Marked differences were expected and realized between the restoration sites (Yang et al. 2005; Moola & Vasseur 2004). Based on the literature, early-stage forest restoration projects were expected to exhibit high native plant densities (Murphy 2005; Haynes 2004; Carleton 2003), increasing native species diversity (Reay & Norton 1999; Haynes & Moore 1988; Hibbs 1983), aggrading woody biomass (Carleton 2003; Hibbs 1983), increasing snag and coarse woody debris volume (Carleton 2003), and increased numbers of highly competitive species (e.g., wild red raspberry, *Rubus idaeus*) (Archambault et al. 1998; Ricard & Messier 1996). In summary, progress at an early stage can be determined by the survival of restoration plantings, the expansion of native plant density and diversity, and the indication of a regenerating forest understorey.

Both sites at Foxwood Golf Course had high plant densities, high diversity, and a high percentage of native species. A majority of the planted tree saplings have survived and are thriving, and further regeneration is indicated by the woody regeneration and mature tree data. Wild red raspberry (*Rubus idaeus*) has overgrown much of the restoration area and is expected under the circumstances (Archambault et al. 1998; Ricard & Messier 1996). According to the expectations set out by the literature, the early-stages of restoration at Foxwood Golf Course are doing well and it is expected that the sites will continue to follow the predicted successional trajectory as time goes on. Progress at Foxwood Golf Course has been achieved most likely because restoration measures were applied quickly after the disturbance took place. Also, care was taken to prepare the site before the replanting of appropriate tree species and density occurred.

Both sites at Natchez Hills had low plant densities, low diversity, and a high percentage of native species. A healthy forest understorey, where native plant diversity and density is high and woody biomass is accumulating, is a prerequisite for ensuring long-term restoration success (Haynes 2004). Although only herbaceous species were planted, the understorey at both sites at Natchez Hills did not appear to be healthy. Populations of planted species are not thriving or expanding, and woody regeneration is very limited. The findings at Natchez Hills are not consistent with what the literature (and therefore the study) expects from early-stage restoration projects that are progressing in a desirable fashion. The restoration sites have slightly improved from times when mountain biking was rampant in the area; however, a more intensive restoration strategy that involved remediation of compacted soils and a more intensive planting regime would have greatly benefited the site. Slight differences were found between NH1 and NH2, where NH1 appears to be progressing better than NH2. These differences in restoration progress can be attributed to varying degrees of disturbance, where NH2 was more severely degraded, and evidence of continued disturbance of mountain biking at NH2 and not at NH1. Both sites should, however, be farther along than they are, considering the restoration was based on the forest understorey alone (unlike the clear-cut setting at Foxwood Golf Course). It is expected that either restoration measures should have been implemented earlier or that a more in-depth strategy should have been applied in this case.

Schneider's Woods site 1 had low plant densities, high diversity, and a high percentage of native species. A lower plant density was expected at this site because the restoration took place within a mature forest, where a closed canopy has existed for many years. Following thinning, the regeneration of woody species markedly increased as indicated by a high regenerating woody species density. The high diversity and high percentage of native species at SW1 indicate that the restoration is consistent with what was expected in terms of early-stage forest restoration progress. This outcome has been achieved most likely because the restoration involved the thinning of red pine (*Pinus resinosa*) and not the recovery from a complex and on-going disturbance. Both SW2 and SW3 had high plant densities, high diversity, and a low percentage of native species. Since restoration is occurring on old fields rather than in a forested context, there must be differences in expectations between SW2 and FW1, for example, where a faster rate of change is expected for FW1. In order for restoration to progress along the predetermined trajectory, native species must become established and dominate in terms of diversity and density. SW2 and SW3 do not currently coincide with the expectations set out by the literature for early-stage progress. Since restoration, in this case, has occurred on old fields and time-since-restoration has been less than 10 years, it is no wonder that non-native ruderal plant species continue to dominate (McLachlan & Bazely 2003). However, the goal of these restorations has been to speed up the process of succession and achieve a wooded corridor. If this goal is to be achieved in an acceptably period of time, it appears that further restoration intervention will be required to commence recovery along a desirable trajectory.

Expectations of early-stage forest restoration have been based on assumptions made in the literature on how forested ecosystems recover following a disturbance. The seven criteria (or expectations) introduced in the literature review and applied here in the discussion section appear to be justified in their discrimination between progressing and unsuccessful restorations, where justification is based on what is known about forest ecology and ecological integrity and the impression of restoration progress for each site. Evaluating early-stage forest restoration outcomes using structural measures, such as diversity, density, and percentage of native species appears to be a legitimate and worthwhile pursuit.

5.1.4 Implications of the Research Findings

Since time periods of 50-70 years or more are required for the colonization of native forest vegetation beneath early successional species (Reay & Norton 1999), the evaluation of forest restoration outcomes has largely been focused on long-term evaluation (Lake 2001; Jackson et al. 1995). However, according to Jackson et al. (1995), restoration success should be demonstrable within 10-50 years and evidence of ecosystem health should be visible within the first 1-10 years post-restoration. Since most forest restoration projects are long-term ones, the gathering of useful data requires a long-term commitment (Lake 2001). This study suggests that the evaluation of early-stage restoration outcomes is useful and necessary for predicting future restoration outcomes and testing hypotheses related to these types of projects. Early-stage evaluations and a larger formative assessment framework provide opportunities for greater success in restoration ecology.

Data were collected at each site during the early stages of restoration. This information not only provides insight into the progress achieved at each site, but also provides a measuring stick from which to gauge future restoration outcomes. Much can be learned about restoration success at an early stage. And since restoration success can be viewed as a continuum of successful outcomes (Reay & Norton 1999), the initial stages must prove successful if longer-term goals are to be achieved (Majer 1989). Evaluating restoration outcomes along the restoration trajectory will draw attention to areas where mid-course correction is required, thus facilitating the achievement of more effective and efficient restoration results.

It has been well-established that restoration projects should be evaluated in order to achieve successful restoration outcomes and maximize opportunities to learn (Jansson et al. 2005; Palmer et al. 2005; Ryder & Miller 2005; Anand & Desrochers 2004; Hobbs 2003; Lake 2001; Stanturf et al. 2001; Michener 1997; Hobbs & Norton 1996; Bradshaw 1993). Evaluating restoration outcomes throughout the restoration process contributes to the learning process by determining whether certain restoration techniques have achieved successful outcomes. Advancement in the field of restoration ecology, which is divided between science and practice, is dependent on the reporting of results from exploratory and hypothesis testing studies in related fields. Given the ecologically dire circumstances that restoration projects generally take place in, learning plays an exceedingly important role in the development of ecologically-based theories that pertain to the field of restoration ecology.

5.2 The Process of Evaluating Restoration Outcomes

5.2.1 Assessment of Restoration Outcomes

Restoration practitioners look to the field of restoration ecology for guidance when setting objectives and establishing evaluative frameworks for new restoration projects. Restoration ecologists, in turn, rely on theories of community succession and ecosystem development (e.g., Odum 1969) for models of how restoration sites can be expected to change through time (Zedler & Callaway 1999). These theories also provide restoration ecologists with the information needed to manipulate a restoration project that has veered off the desired restoration trajectory or is not progressing as expected, either in the expected way or within the expected timeframe. The ecological filtering process, theories of succession, community ecology, vegetation dynamics and disturbance ecology are some of the key theories relied upon by restoration ecologists to guide how restoration outcomes are interpreted. Restoration outcomes can be acted upon by integrating what is known about ecosystem recovery to speed up the restoration process or encourage the restoring ecosystem along a pre-determined restoration trajectory.

Measures of vegetation structure and diversity most commonly comprise the bulk of forest restoration evaluative frameworks (Ruiz-Jaén & Aide 2005a; Stanturf et al. 2001; Reay & Norton 1999). Vegetation structure is relatively simple to measure and helps to predict successional pathways

(Ruiz-Jaén & Aide 2005a; Wang et al. 2004). Measures of species diversity provide information on an ecosystem's susceptibility to exotic species invasions (Ruiz-Jaén & Aide 2005a; Higgs 1997) and provide useful comparisons between restoration sites and the reference ecosystem (Aronson et al. 1995). Year-to-year, restoring ecosystems can progress at different speeds and in different directions (Zedler & Callaway 1999). These changes are easily detected using measurements of vegetation structure and species diversity, as these measurements respond quickly to the application of restoration techniques and are sensitive to internal ecosystem fluctuations.

Some restoration sites may follow a smooth and rapid trajectory, particularly when restoration projects are found in landscapes that are more intact and where damages are less severe (Zedler & Callaway 1999). Smooth and rapid change along a restoration trajectory toward a desired endpoint or reference ecosystem is the model most commonly referred to by restoration ecologists and is the most predominant concept used to assess restoration outcomes (Wilkinson et al. 2005; Anand & Desrochers 2004; Haynes 2004; Lake 2001; Anand 2000; Carpenter et al. 1999; Reay & Norton 1999; Stanturf et al. 2001; Yates & Hobbs 1997; Westman 1991). Trajectory models and reference ecosystems are conceptually useful tools, and in some cases, have proven to be useful in the practical sense as well (Ruiz-Jaén & Aide 2005b; Reay & Norton 1999). There is, however, some reservation held by certain restoration ecologists and practitioners regarding their overall applicability.

5.2.2 Assessment of the Restoration Evaluation Process

Numerous researchers have identified problems with the tools used to evaluate restoration progress (Hughes et al. 2005; Martin et al. 2005; Choi 2004; Lake 2001; Michener 1997; Parker 1997; Hobbs & Norton 1996). For example, restoration ecologists continually face the challenge of identifying, collecting and analyzing appropriate parameters at appropriate spatial and temporal scales for predicting restoration outcomes (Michener 1997). And, since it is not known which aspects of community structure and ecosystem processes are restorable for most ecosystems (Martin et al. 2005), this challenge is compounded. Moreover, the response of the target ecosystem to a restoration technique may show a marked lag response (Lake 2001), which can greatly complicate the interpretation of restoration outcomes. Conclusions drawn from one evaluative framework using certain parameters or at different spatial or temporal scales may vary from another. Information that is crucial for achieving successful restoration along a pre-determined restoration trajectory is lacking and guesswork must often suffice.

Most likely, degraded ecosystems will only be able to overcome certain aspects because all ecosystems have historical dimensions and historic ranges of structural and functional variability (Hughes et al. 2005; Michener 1997; Parker 1997). Desired vegetation structure and composition can be achieved over the short-term by introducing appropriate species, but long-term success requires that a range of environmental processes that support and maintain ecosystem integrity become restored (Parker 1997). In order to accommodate for variability and uncertainty, restoration projects may require a broader conceptual context than the trajectory model can provide.

The current ecological paradigm is characterized by uncertainty and variability (Levin 1989). Expectations for the end-result of restoration must, then, be realistic and cognizant of the limitations placed on predicting ecosystem development (Choi 2004). How a project responds to a restoration technique in the presence of uncertainty and variability depends on the landscape context and the multitude of external influences it is subjected to. In some contexts, the impact of these processes may not be noticeable, but in some they may interfere with the achievement of restoration goals (Parker 1997). Therefore, not all systems undergoing restoration have clear and stable trajectories (Lake 2001). Instead of progressing toward a desired goal, the restoring ecosystem may proceed to an unpredicted alternative stable state (Hughes et al. 2005; Lake 2001; Hobbs & Norton 1996). Care must be taken to distinguish between unsuccessful restoration and trajectories that are only temporarily moving away from the desired endpoint (Jansson et al. 2005). Although the trajectory model considers uncertainty and variability, predictive measures are not available for avoiding the intensive management that is often required to steer a restoration back on course.

Restoring degraded ecosystems will be fraught with uncertainties - first, with the assessment of the extent of ecosystem damage, then with determining how the pre-damaged ecosystem would have looked and functioned, then with selecting and applying the most appropriate restoration technique, then with evaluating the progress of the restoration along the restoration trajectory, and lastly with determining the restoration endpoint. At this point, the ecosystem is thought to have become healthy, resilient and self-perpetuating. There is still much to be learned about how ecosystems undergo the process of restoration and how they respond to the application of different restoration techniques. The trajectory model is a useful model, although its usefulness is stunted by the lack of knowledge in a number of important areas. The unpredictability inherent in ecological systems indicates that evaluation throughout the restoration process is necessary. Planted trees will not necessary proceed to form a functioning forest. Restoration projects must be evaluated over the short-term as well as the long-term to increase ecological knowledge of restoring ecosystems and the possibility of achieving successful restoration.

Determining restoration outcomes at different stages along the restoration trajectory will provide the information needed to reduce the frequency of failed restoration projects and improve the effectiveness and efficiency of the techniques used in restoration. Over time, it is hoped that more explicit targets will become associated with different stages of progress along the restoration trajectory to help standardize the reporting of successful outcomes in restoration ecology. Jansson et al. (2005) have suggested that specific hypotheses and/or conceptual models of the ecological mechanisms by which the proposed restoration technique will achieve a sequence of predetermined restoration targets be determined. This will provide a more explicit explanation for the outcome of ecological restoration activities. With clear targets associated with different restoration stages, determining the progress of a project will become much easier for restoration practitioners and scientists alike. The more studies that are carried out in restoration ecology and other related fields the clearer these targets will become. Restoration projects will only become more successful as a result.

Although reference ecosystems are useful in determining the goals, endpoints, and assessment criteria for restoration projects (Hobbs & Norton 1996; Aronson et al. 1995), their use in evaluative frameworks can give a false sense of predictability of ecological outcomes (Hughes et al. 2005; Pickett & Parker 1994). The use of restoration trajectories, which assume ecosystem fluctuation, provides a solution for incorporating variability into the evaluation of restoration projects, unlike the method of adhering strictly to a single reference ecosystem. Over time, a range of possible ecological outcomes may be defined by the present and projected alternative stable states of forested ecosystems through the evaluation of restoration outcomes along a restoration trajectory (Hughes et al. 2005). When using an open-ended trajectory model, it is difficult to articulate when a project is complete in terms of ecological outcomes. In combination with the trajectory model, reference ecosystems are useful for providing an endpoint to gauge and guide the progress of forest restoration where trajectory models are unable.

5.3 Summary of the Research Findings

The first question addressed in the Discussion was whether or not the restoration technique used at each site was working at all. This question could be answered for all sites. At an early-stage of evaluation, restoration appears to be the most successful at NH1. SW1 and NH2 appear to be the next closest in similarity to the reference site, then FW1 and FW2. Restoration is either not working at SW2 and SW3, or is occurring at a much slower rate than at the other sites.

The next question asked was whether restoration sites are being affected by within site differences at the transect level. This question could also be answered for all sites. Results from the nested ANOVA and contrasts indicated that all sites are being affected by within site differences at the transect level, particularly in the response of woody species regeneration to the restoration technique used. Differences were the most pronounced at FW1 and FW2, and SW1 where the effect of remnant forest edges and an open forest canopy are expected to be the contributors of the variation. Differences at the transect level may be exacerbated over time; however, if the restoration is successful, this variation will most likely diminish over time.

The next question addressed was whether there were differences in similar techniques between sites. This question could not be answered for distant sites, but could be answered for sites existing in the same restoration area. No difference was found between the sites at Foxwood Golf Course, or at Schneider's Woods Site 2 and 3. Significant differences were, however, found between the sites at Natchez Hills. It has been hypothesized that the differences can be attributed to the extent of previous damage and the continuation of mountain biking induced disturbance at NH2 but not at NH1 over recent years.

The last question addressed in the Discussion was whether there were differences in different restoration techniques between sites. This question could only be answered for the restoration sites at Schneider's Woods, where two distinct restoration techniques were used. Comparisons were made between SW1, and SW2 and SW3. Significant differences were found, and although the restoration technique cannot be separated conclusively from site-effects, it is reasonable to hypothesize that the differences are at least partially attributable to pre-restoration site conditions. It is expected that restoration from an old field to a forest will require a longer length of time and perhaps a more intensive restoration strategy than a restoration occurring at an already forested site.

The fact that the effects of time since restoration and site or type of restoration could not be separated represents a limitation of the study. Also, the extent of the differences between site and type of restoration are restricted by the young age of the restoration projects and the short-term data set available. A large number of restoration sites implemented at the same time using the same restoration technique located in the same general area along with a long-term data set are required to overcome these limitations.

The current study does, however, indicate that much can be learned about restoration progress at an early stage. Four out of 7 sites have achieved expected outcomes for some restoration measures, but further evaluation will be required to determine the success of areas that require a longer length of time to recover (Ruiz-Jaén & Aide 2005a). At an early-stage, structural measures appear to be useful indicators for evaluating the progress of restoration. Generally, sites with high species diversity, a high percentage of native species, and high density indicate that the ecological restoration is progressing on the predicted successional trajectory and should lead to a successful restoration as time goes on. Although the long-term success of a restoration cannot be directly foreshadowed from these measurements, evaluating early-stage outcomes provides opportunities for mid-course correction, where unsuccessful restorations can be steered back on track or where slowly progressing restoration projects can be sped up by altering management techniques. Perhaps the greatest contribution of evaluating restoration outcomes, whether over the short-term or long, is the provision of opportunities to learn and improve restoration techniques and approaches. These opportunities are required to further the understanding of restoration ecology and the processes involved with ecosystem recovery.

5.4 Application of the Research Findings

In the current study, restoration progress has been based on the recovery of vegetation structure. Does this adequately account for progress in all areas? Most likely not, but it is impossible to study all possible ecosystem attributes (Ormerod 2003). What it does accomplish, however, is an overall indication of how the vegetation structure of the restoration is proceeding. Future restoration outcomes can be predicted using a restoration trajectory or the trajectory model based on what was found at each site. For example, if many ash seedlings were found at a site during an early-stage of evaluation, one would expect to find ash saplings at a later successional stage.

Some concern has been raised regarding the usefulness of the trajectory model. These concerns include: (1) conclusions drawn from one evaluative framework using certain parameters or at different spatial or temporal scales may vary from another (Martin et al. 2005; Lake 2001; Michener 1997); (2) restoration projects may require a broader conceptual context than the trajectory model can provide, since all ecosystems have historical dimensions and historical ranges of structural and functional variability (Hughes et al. 2005; Michener 1997; Parker 1997); (3) not all systems undergoing restoration have clear and stable trajectories (Hughes et al. 2005; Lake 2001), and (4) measures for predicting uncertainty and variability within restoring ecosystems are not yet available (Hughes et al. 2005; Choi 2004; Parker 1997; Hobbs & Norton 1996). The trajectory model is a valuable concept for guiding restoration outcomes; however, its usefulness is stunted by the lack of knowledge in a number of important areas.

Restoration projects must be evaluated over the short-term as well as the long-term to increase the possibility of achieving lasting restoration success. The unpredictability inherent in ecological systems indicates that evaluation throughout the restoration process is necessary to ensure that the restoration is proceeding in a desirable fashion. When planning a restoration project and designing and interpreting restoration trajectories, variability must then be expected, accommodated, and accounted for (Hughes et al. 2005). Perhaps the greatest contribution of evaluating restoration outcomes, whether over the short-term or long, is the provision of opportunities to learn and improve restoration techniques and approaches. These opportunities are required to further the understanding of restoration ecology and the processes involved with ecosystem recovery.

5.5 Research Suggestions and Recommendations

Although the importance of evaluating early-stage restoration outcomes has frequently been highlighted in writings on restoration ecology (Stanturf et al. 2001; Reay & Norton 1999; Hobbs & Norton 1996; Majer 1989), a large gap in the literature exists. The current study contributes to the literature by comparing multiple restorations at different sites to determine how early-stage forest restoration projects are progressing in the Regional Municipality of Waterloo.

Many important research opportunities remain, including the extent of the effects of certain restoration techniques. For example, a future research project could apply different restoration techniques in the same location and collect data over the long-term to determine the relative success of each restoration technique. This type of study could improve local restoration techniques and provide further insight into the study of vegetation dynamics, disturbance ecology, community ecology, and assembly rules.

Hobbs & Norton (1996) point out that larger and more connected restoration sites achieve better results than smaller, unconnected ones. Another important research need is to determine the extent of landscape or “matrix” effects on restoring ecosystems. Studies focusing on landscape configurations have an important role to play in the long-term health and survivability of a restoration project, particularly in areas that are highly fragmented and influenced by urbanization.

Much debate exists around the choice of parameters for monitoring ecological systems (e.g., Palmer et al. 2005; Jansson et al. 2005). Research projects focusing on early-stage restoration outcomes could work towards developing a set of indicators to detect progress in early-stage restoration projects. Having this kind of information available may encourage more restoration practitioners to follow through with completing a comprehensive evaluative framework, and may spark further research interest amongst restoration scientists. The list of future research suggestions in this area is endless. The idea of evaluation in restoration ecology is not new, yet very little is known about early-stage evaluation, particularly for those ecosystems that require a relatively long period of time to recover.

Numerous recommendations can be made from what has been learned from this study. Broader recommendations are that the evaluation of early-stage restoration outcomes should continue to be encouraged among restoration ecologists and practitioners, and that the reporting and communication of restoration outcomes should also be encouraged. More specifically, it is hoped that explicit targets will become associated with different stages of progress along the restoration trajectory over time. The setting of targets will help to standardize the reporting of successful outcomes and make the assessment process simpler for restoration practitioners and scientists alike. Setting targets will also make it easier to predict restoration progress over the short-term and provide opportunities for mid-course correction over the long-term. By setting targets throughout the process of restoration, the trajectory model will become more predictive and less subjective. In order to set restoration targets, research focusing on different stages of restoration should work towards developing a set of parameters for detecting progress. Having this kind of information available may encourage more restoration practitioners to follow through with comprehensive evaluative frameworks, and may spark further and needed debate among restoration scientists.

Exploratory and hypothesis testing studies in restoration ecology must be continued to further the field of restoration ecology as a science and improve restoration project effectiveness and efficiency. The idea of evaluation in restoration ecology is not new, yet very little is known about early-stage evaluation, particularly for those ecosystems that require a relatively long period of time to recover (Ruiz-Jaén & Aide 2005a). The more studies that are carried out in restoration ecology and other related fields the clearer and more reliable the tools used to assess restoration outcomes will become. Restoration projects will only become more successful as a result.

5.6 Conclusions of the Study

Several types of restoration projects are currently underway in southern Ontario (McLachlan & Bazely 2003), and throughout the world. Some of these projects are large-scale and have a large amount of resources at their disposal. Others are, perhaps more commonly, implemented under a limited budget and are performed in a haphazard fashion (Michener 1997). Since a majority of restoration projects must work with limited budgets, evaluation of restoration outcomes often does not occur. Numerous researchers in restoration ecology and related fields (Palmer et al. 2005; Ryder & Miller 2005; Anand & Desrochers 2004; Hobbs 2003; Lake 2001; Stanturf et al. 2001; Michener 1997; Hobbs & Norton 1996; Bradshaw 1993) have pronounced the need to evaluate restoration projects in order to determine their progress (i.e., either movement towards a particular endpoint or the achievement of a certain balance), ensure that the applied technique is working adequately, provide opportunities to learn from past mistakes, and make improvements on what is known about the ecosystem recovery process.

The current study aimed to evaluate the progress of 7 different early-stage forest restoration projects within the Regional Municipality of Waterloo using the evaluative techniques most commonly advocated in restoration ecology literature. The study also aimed to review the tools of assessment used to evaluate ecosystem recovery, or more specifically the trajectory model. If the progress of a restoration project is evaluated, most of the work is typically done at a later stage of forest restoration (Ruiz-Jaén & Aide 2005a). This study indicates that much can be learned about the progress and direction of the restoration trajectory at an early-stage of recovery. In order to correct ecosystems that are either progressing slowly or are veering off the desired restoration trajectory, early-stage evaluations must be conducted to gain insight into the status and path that the restoration project is currently on.

The 7 restoration projects were evaluated using measures of vegetation structure and diversity in comparison with a reference ecosystem. Data were collected for herbaceous, regenerating woody species, and mature trees at each site. Following collection, data were investigated, summarized and analyzed where applicable using a nested-ANOVA and post hoc contrasts to test the responses to restoration site, restoration technique nested within site, and transect nested within restoration site. Other comparisons were made using Bray-Curtis Ordination, Cluster Analysis, and Simpson's Dominance Index. Once the data were analyzed, literature on the use of the trajectory model in restoration ecology was reviewed (Jansson et al. 2005; Martin et al. 2005; Palmer et al. 2005; Hughes et al. 2005; Choi 2004; Lake 2001; Michener 1997; Parker 1997; Parker 1997; Hobbs & Norton 1996) to determine the general view of its acceptance or rejection for use in restoration evaluation. This information was summarized and reviewed to determine the adequacy of the trajectory model as an instrument of assessment in determining the recovery of desired ecosystems. Recommendations for improvements to the model were made and future research needs were highlighted.

Results from the nested ANOVA indicate strong evidence of a site response and a response to the restoration technique used. Significant differences were also found among transects nested within each restoration site for herbaceous species diversity and woody species measures, indicating a high degree of within site variation. These variables are thought to be important in determining the progress of early-stage forest restoration projects in some combination of cases. Early-stage restoration outcomes exhibiting similar vegetation structure and diversity to the reference site were considered more successful than dissimilar ones. It appears that 4 out of 7 sites have achieved success for some restoration measures; however, further evaluation will be required to determine the success of restoring ecosystem attributes that require a longer length of time to recover.

At early-stages of restoration, progress is highly dependent on the survival and establishment of native vegetation, be it through plantings or natural regeneration, and is therefore largely reliant on the management techniques used to promote ecosystem recovery. Longer-term progress is dependent on the status of earlier-stage restoration outcomes, the application of ongoing management techniques, and the existence (or non-existence) of further ecosystem disturbance. Although ultimate success has yet to be determined, evaluating early-stage outcomes provides an opportunity for mid-course correction, where unsuccessful restorations can be sped up or steered back on track by altering management techniques and on-site ecosystem conditions.

The current study provides an example of how early-stage restoration outcomes can be evaluated and reported. It also provides an indication of the variables that contribute to restoration success or failure at an early stage of restoration, where significant differences were found among the restoration sites in response to site, restoration technique nested within site, and transect nested within restoration technique. This information may motivate those who are planning to evaluate implemented projects to begin the evaluation process immediately, and not only in the long-term (e.g., in 20 years). Determining restoration outcomes at different stages along the restoration trajectory will provide information that is crucial for reducing the frequency of failed restoration projects, improving the effectiveness and efficiency of the techniques used to facilitate restoration, and improving the usefulness of the trajectory model used in restoration. This project indicates the importance and relevance of early-stage evaluation in progressing restoration ecology as a scientific field and contributor to ecology theory.

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