Upland Hardwood Forest Restoration: Testing Combinations of Vegetation in the Progress of Early Restoration

by

Kristyn Alexis Ferguson

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.
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Abstract

Progress in early ecological restoration is a measure which has not been extensively studied in the relatively new body of literature surrounding this field of study. Early restoration is an extremely beneficial area of study due to the increasing number of degraded areas which require immediate attention in order to stabilize soil, or deter exotic species invasion.

An early restoration effort was implemented and observed in Natchez Hills, an Environmentally Sensitive Policy Area in the Region of Waterloo from May 2006 to June 2007. Natchez Hills is a maple-beech dominated forest which has been severely degraded by mountain biking, and faces other pressures such as urbanization, fragmentation and invasive species encroachment. The experiment was designed so that different combinations of three understory plants could be tested for their effectiveness at progress in early restoration. The species selected for use in this study were *Erythronium americanum* Ker. (trout lily), *Podophyllum peltatum* L. (mayapple) and *Caulophyllum thalictroides* L. Michx. (blue cohosh).

The experiment was designed across four blocks of the forest study site with varying degrees of degradation, with eight 1 m^2 plots per block which contained one of the seven combinations of understory plants or the control treatment. In the spring of 2006, *E. americanum* and *P. peltatum* were planted at a density of 6 plants m^{-2}, and *C. thalictroides* was transplanted into the plots at a density of 2 plants m^{-2}. The transplants were monitored on a biweekly basis through the months of May to August in 2006. Invasive species in the plots were controlled by aboveground biomass clipping during the same period. In the spring of 2007, second season survivorship was measured by counting the number of plants which returned to the plots. *Erythronium americanum* returned at a rate of 92%, *P. peltatum* at a rate of 97% and *C. thalictroides* at a rate of 100%.

The return rates were statistically analyzed using one-way ANOVA. Results showed no significant differences ($p < 0.05$) between the seven experimental treatments. Additionally, return rates examining differences between the experimental blocks (block effect) were also not significantly different ($p < 0.05$). These results indicate, respectively, that combinations do not perform significantly better than solitary plantings of any of the three species, and that these plants can be successfully planted into varying levels of degradation.

During the 2007 field season, while measuring transplant return rates, some unexpected results were observed. These included asexual plants returning as sexual plants, bearing flowers and producing fruit (*P. peltatum* and *C. thalictroides*), and returning transplants spawning extra clonal individuals within the plots (*P. peltatum*). These occurrences added an extra layer of progress to

the early restoration effort by increasing both reproductive potential and biomass cover within the experimental plots.

Overall the restoration effort was deemed to be successful, based on the structural success obtained in this study. However, it should be noted that the field of restoration ecology still seeks a unified answer on what makes a restoration project successful, so determining that progress was achieved by structural means should be taken only within the context of this type of study.

This study was helpful in informing the overlooked areas of understory restoration, early-stage restoration and the use of combinations. Though there remains a significant demand for more research in all of these areas, this study has served the purpose of identifying a usable protocol for real world restoration efforts. The three species used can be highly recommended for future restoration within their geographical range, into a range of degradation conditions, in any combination.

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Chapter 1

Introduction

1.1 Restoration Ecology

Ecological restoration has developed as a field in response to the worldwide degradation of natural systems as a result of intensive of human activity. Today's need for restoration ecology is exceedingly great, as more and more natural systems continue to succumb to the ever-increasing damage from human impact. Yet, the science of restoration ecology is a very young one, relatively speaking (Young 2000; Palmer et al. 2003). The field is quickly evolving and growing (Young 2000) and is shaped and formed by restoration efforts and experiments on a global scale. As this magnitude of practical work is carried out in the field, answers are continuously being provided. However, there are still several of areas in the field of restoration ecology which are yet to be studied (Young et al. 2005), some of which this experiment touches upon.

Ecological restoration is an intentional activity that initiates and/or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability (SER 2004). It can be defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). Restoration can include passive efforts, in which the factor causing degradation (e.g. invasive species, mountain biking) is removed and the system is left to regenerate on its own. However, most restoration efforts necessitate the use of active restoration, which is often the case when a natural system has passed a certain threshold point of degradation. In these cases, active efforts such replanting or soil remediation are implemented.

1.2 Forest Restoration

Restoration can be put into practice in a variety of natural settings, including wetlands, grasslands, lakes and rivers, or forests. Forests have of late become a major focus in the field of restoration ecology (Jacquemyn et al. 2003), and this attention is well-deserved as they tend to be areas of high biodiversity, and house many rare woodland species. Many forests boast nutrient-rich organic soils and plentiful moisture but these conditions also provide an ideal home for invasive exotic species. Forests are also exposed to a surplus of negative human impacts which are degrading their integrity on a worldwide scale (Rayfield et al. 2005). Commercial logging is

a problem that woodlands have suffered through for centuries, and can lead to significant decreases in biodiversity, shading, soil nutrient cycling and wildlife habitat (Zausen et al. 2005; Gebrekirstosa et al. 2006). Plantation forests are replacing natural forests resulting in a decrease in biodiversity and forest ecosystem integrity globally (Brockway & Lewis 2003). Another major threat to the world's forests is the actual physical loss of forests, to agriculture, urbanization, or natural resource mining (Frédéric et al. 2006).

In the field of forest restoration, to date, there have been countless studies performed on a multitude of restoration techniques, in a variety of forest settings. Common restoration efforts include seeding or transplanting tree saplings, which are generally carried out on large scales and examined over a typical time period of 4-15 years (e.g. Fattorini 2001; Matthes et al 2003; Peterson et al 2004). However, with the emphasis in the literature on such studies, there are several factors which have been repeatedly overlooked or underrepresented. These features were noted during a thorough review of the available literature which was conducted prior to the commencement of this study. These overlooked factors include studies on small scales both spatially and temporally versus the classic long-term studies on large plots of land; the use of different combinations of vegetation to determine if synergisms or antagonisms exist; and studies focused on understory herbaceous vegetation rather than trees.

1.3 Existing Gaps in Restoration Ecology

Studies on a small spatial scale are not as omnipresent in the restoration ecology literature as those performed on large tracts of land (e.g. Hartman and McCarthy 2004; Peterson et al 2004). Because restoration experiments can be costly, in terms of both labour and materials, it is important to demonstrate the outcome of small scale studies. If successful, they are prototypes that can be mimicked by other restoration practitioners lacking the funding or space to execute larger studies. It has also been noted that small areas of restoration activity can act as cells, which, if planting is successful, will spread their plants and seeds out beyond the borders of their plot, facilitating additional restoration to areas peripheral to the plot (Daigle & Havinga 1996; Fattorini, 2001).

Studies on small temporal scales have actually been criticized to some extent, by those who believe that true success can only be measured after 5, 10, 50 or even hundreds of years. However, studies taking place in short time periods can provide a multitude of benefits. In times

of environmental crises, species that can be grown successfully in 1-2 years can be used to ward off exotic species invasions or resurgence, and can provide soil stabilization when soil erosion is posing a great threat to the forest.

Using combinations of vegetation is usually not practiced in restoration studies, in favour of growing large stocks of one species and using these for transplant into degraded areas. However, it is important to test as many varieties of vegetation as possible to learn what works best and what might not work at all in restoration experiments. Also, plant species have long been known to have interactions with one another not always visible to the naked eye. These relationships, involving things such as nutrient exchange or other facilitative interactions, could be immensely beneficial to the improvement of restoration efforts in the future.

The final factor which has tended to be less prominent in past studies is the use of understory vegetation. Tree species are instead often favoured for restoration efforts. However, understory vegetation is an extremely important guild in any forest, providing habitat, nutrition and rooting systems to the forest's wildlife and soil that trees simply cannot offer. In extremely degraded landscapes, all guilds of forest vegetation need to be repaired in order to return a forest to a more functional state. This is why understory vegetation should be studied more intensely to provide appropriate findings and answers about how, when and in what combinations it should be planted.

1.4 Purpose of this Study

The intent of this study is to draw on the gaps in the literature while incorporating the need to establish solid, replicable principles in forest restoration ecology. The specific purpose of this study is to actually test different combinations of understory plants in an early forest restoration effort in order to determine if different combinations will vary in progress toward restoration. The question posed in this study is:

Will various combinations of the three native forest species Erythronium americanum, Podophyllum peltatum and Caulophyllum thalictroides differ in the progress of early restoration of a degraded upland hardwood forest in Kitchener, Ontario?

1.5 Study Design

The experiment was carried out in four blocks of land in the forest which characterize different levels of degradation, different slope characteristics and different densities of native and invasive plants. Each of the four blocks contains eight plots, and each of the eight plots houses a different experimental treatment, or combination of the three plant species mentioned above. Thus, there are four replicates of each combination of plants, including a control plot in each block where no vegetation is planted.

This study was designed using principles drawn from the field of restoration ecology to create a mensurative experiment, which differs from the classical manipulative experiment found in traditional scientific methodology. A mensurative approach is almost always taken when conducting experiments in nature, as a manipulative approach implies full control over the variables in the study, and this is simply not possible in nature. The mensurative approach being used here is a study design set against a background full of variables. The manipulation of one variable (transplanted species) is then coupled with a thorough analysis of the background conditions implied by the varying natural landscape. The background conditions which were measured in this study were soil pH, soil organic matter content, and invasive species present in the experimental area. This analysis helps guide the results of the actual experiment involving the transplants, because any statistical differences between any of the background variables could be an influence on the outcome of the transplant success.

Restoration ecology, being the new science that it is, does not follow a set of rigid, prescribed rules for restoration of certain types of sites. Restoration ecologists choose species on the basis of historical reference structure and function of ecosystems, current availability of genetically and ecotypically appropriate stock for reintroduction, and adaptability to current site conditions that created the restoration need. Given this, combinations of three predominant forest species [*E. americanum* (trout lily), *P. peltatum* (mayapple) and *C. thalictroides* (blue cohosh)] were be tested to see which yielded the most successful progress in early forest restoration. The hope is that, in the future, individuals restoring ecosystems which are usually dominated, or at least populated, by any of these species (noting that all three species have very broad latitudinal and longitudinal distributions) will have a design to follow regarding how, and in what combinations, to plant these species for a successful restoration effort. The specific results in this study were used to create the recommendations for future restoration efforts. The underlying goal of this research was to restore this area. However, there is more to this experiment than simply restoring

the site. This forest was used to test, specifically, which combinations of certain vegetation work best for early restoration of this area. The species composition and site characteristics found in the Natchez Hills, the forest under study, are typical of a large part of the province of Ontario, and an even broader geographical range. Therefore, the information from this study can be applied to other forests in moderately degraded conditions, in the particular ecosystem type which is characteristic of a large area of Ontario.

1.6 Study Site

The forest site that was chosen for restoration is Natchez Hills forest, in Kitchener, Ontario. Natchez Hills (Figure 1) has been designated, by the Regional Municipality of Waterloo, as an ESPA (Environmentally Sensitive Policy Area) because it supports a large number of significant and rare plant and animal species, including eastern cottonwood, the yellow-spotted salamander and the red-shouldered hawk. This designation and subsequent level of protection make it an ideal choice for restoration, because the efforts will not be as easily erased by careless recreational use, or threats of development. Any positive changes undergone by the system, as a result of this particular experiment, actually have a chance at being sustained in the long-term, beyond the temporal boundaries of this study.

   Natchez Hills is located at 43°27'N and 80°25'W, at 345m above sea level. The city of Kitchener, in which the forest is located, experiences an average annual precipitation of 848mm (700mm rain, 148mm snow) and an average annual temperature of 12.1°C (high)/2.0°C (low). The soil in the forest is a sandy loam and the physiography is comprised of a rolling, hilly topography with both upland and lowland areas, though upland sites are the focus in this study.
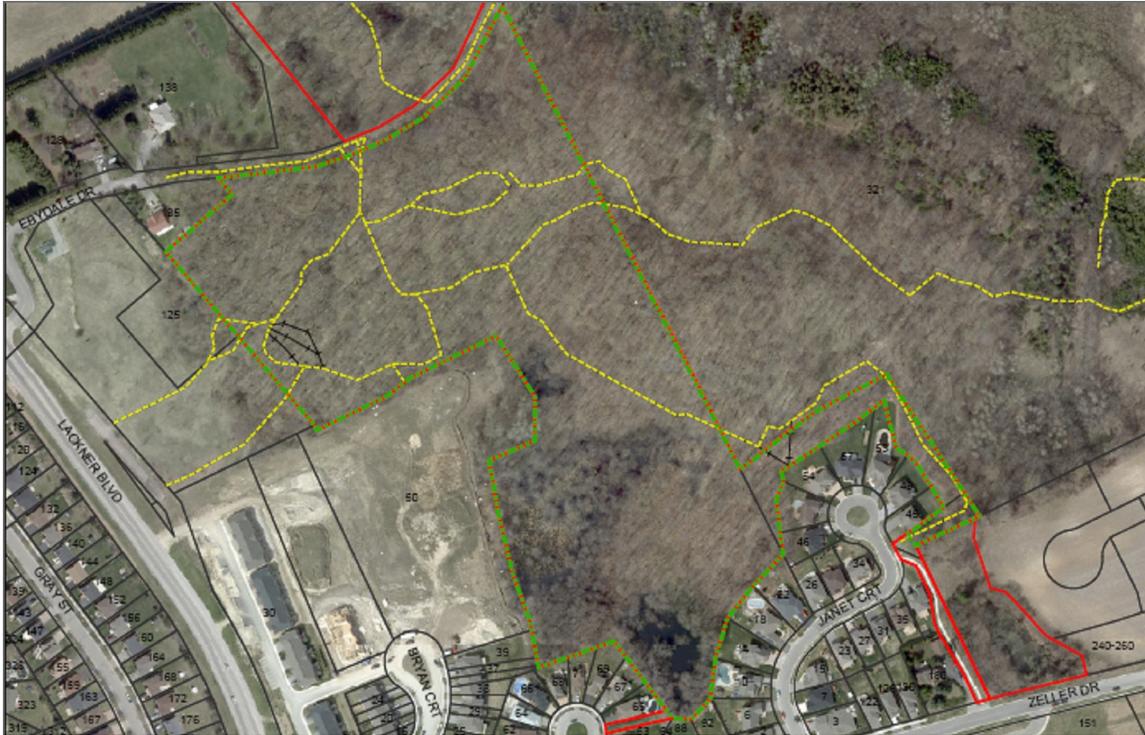
Figure 1. Map of Natchez Hills forest. Area to the south of yellow trail off Ebydale Rd. was used as study site.

Historically, the forest at Natchez Hills consisted of a sugar maple dominated upland forest. It houses vegetation typical of both the Great Lakes-St. Lawrence and Carolinian ecozones, as it lies at the border of these two regions. This site historically contained a mixture of native trees [e.g. *Acer saccharum* (sugar maple), *Quercus rubra* (red oak), *Prunus serotina* (black cherry)], shrubs [e.g. *Viburnum* spp., *Sambucus canadensis* (elderberry)] and understory vegetation [e.g. *Arisaemum triphyllum* (jack in the pulpit), *Circaea lutetiana* (enchanter's nightshade), *Dicentra cucullaria* (Dutchman's breeches)]. Today, Natchez Hills is populated by a number of invasive exotic species such as *Chelidonium majus* (greater celandine), *Solanum dulcamara* (bittersweet nightshade) and *Alliaria petiolata* (garlic mustard). Many native species still grow in the forest, including *Sanguinaria canadensis* (bloodroot), *Allium tricoccum* (wild leek), and *Maianthemum canadense* (wild lily-of-the-valley), as well as the three species used in this restoration effort. However, these species are not dominant in all areas of the forest, and are at risk for being outcompeted by the ever-increasing presence of exotic species in the site.

This influx of invasive species has been influenced by one of the major problems at this site: recreational bikers riding frequently through the forest. Freeriding, like other recreational activities, can lead to other adverse effects such as the destruction of understory plants and tree

seedlings (changes to species composition and richness), and the encouragement of invasive species encroachment (via soil disturbance) (Hall & Kuss 1989; Thurston & Reader 2001; Nepal & Way 2007). Problems associated specifically with freeriding can include soil exposure and soil compaction (Thurston & Reader 2001), all of which can make an area a less suitable growing habitat for valuable native species. Also, because of the highly urban location of the forest and its relatively small size, it is experiencing some negative effects from the surrounding urban areas, including exotic species encroachment from nearby roadsides and gardens (Borgmann & Rodewald 2005), as well as the effects of fragmentation, which include a loss of native species diversity due to a lack of sources for new seed to enter the forest (Marzluff & Ewing 2001). Thus, what exists today is a mixture of native and exotic species and an ecosystem which is losing its integrity due to lack of soil rooting structures and changing species composition, including an incursion of exotic invasive species.

1.7 Aim and Scope of this Study

This study is aimed at making a significant contribution to the field of restoration ecology, specifically upland hardwood forest restoration. The particular areas of research to which this thesis makes a contribution includes species selection and limitations in forest restoration. The clear results gained in this study have indicated which species are appropriate for use in early restoration efforts. This will help other practitioners avoid transplant failures in future efforts which unfortunately have plagued some experiments to date (e.g. Yetka & Galatowitsch 1999; Fattorini 2001). This study can also help inform basic ecological literature, with regard to the specific growth observed in the species which were planted, or any interesting findings about the species, either as initial transplants or returning transplants in the following season. Finally, this study is useful for anyone undertaking restoration experiments in the future at any scale (government, NGOs, academics), as this work can be used as a guide of what to do, providing specific information about some species which are common in North American forests. Overall this work illustrates ecological interventions which can be accomplished with minimal labour and cost.

   The scope of this study is limited to the ecological realm, and the particular ecological results of the restoration effort. In today's changing world restoration ecology cannot stand alone from the social, political and economic factors which influence its implication and outcomes. However, if these factors were to be concurrently examined in this study, it would broaden significantly in

scope, likely beyond that of a contained master's thesis project. Thus, this study recognizes that an inherent threat of further development around this forest exists; that recreational hiking and freeriding is not being mitigated as a form of passive restoration; and that there are political limitations on which geographical areas of the ESPA were able to be manipulated for study. These implications are intricately linked to the forest and the experiment at hand and the potential for future variability at this site is thus understood. However, the study of these social and political influences would have complicated the experiment and broadened it beyond a workable scope.

The benefit of studying simply the ecological impacts, influences and results of this study is that strong conclusions and solid recommendations can be realized about the plants and study area being used, and passed on to restoration practitioners in the future. The ecological work being done is in-depth and thoughtful, and this helps compensate for the lack of information gathered about the other realms of knowledge affecting the experiment and Natchez Hills forest.

1.8 Thesis Outline

The following document will commence with an extensive review of the available literature. This literature review will focus on a variety of topics pertinent to the understanding of this experiment, including environmental ethics, restoration ecology, the particular plants being used in this study and the reasoning for implementing several novel areas of restoration ecology in this experiment. Following the literature is a detailed methodology about all methods undertaken in the field and laboratory, as well as a description of all statistical tests carried out. The results section conveys the results of the soil analysis and actual experiment in order to determine which experimental treatment was most successful, and if the results were statistically significant. The discussion and conclusions section will draw logical conclusions from the results, and expand on possible reasons for the results that were found. This section also outlines the recommendations for future restoration experiments relevant to the work carried out in this project, and contains suggestions for future experiments to supplement the information from this study.

Chapter 2

Literature Review

2.1 Introduction to Literature Review

The following review of the available literature begins with an assessment of the environmental ethic, which is the driving force behind restoration efforts. The novelty of the science of restoration ecology is examined, as are some of the many successes experienced in the field to date. The concept of addressing success in restoration is touched upon next, as it is at the forefront of defining the science and an area in which a lot of debate exists. Next, the gaps which exist in the literature are addressed, including issues of size and length of studies, guilds of species used and the study of combinations of different species. Following this, the specifics about Natchez Hills are examined, including its disturbance from forces such as urbanization, fragmentation and other, more direct, human disturbances. The particular reasons for the selection of the site in Waterloo Region, as well as the rationale for all vegetation chosen for use in the restoration are then outlined. The reasoning for the specific methods used in this study (measurement of site factors, plot selection, site preparation, use of active restoration, techniques for planting vegetation and monitoring) is examined, to provide a justification for the methodology of the experiment. Finally, a section addressing the concept of progress in early restoration will be presented, followed by some thoughts and views about the natural succession that lies outside the temporal boundaries of this project.

2.2 Restoration Ecology

Restoration ecology is a field heavily influenced by environmental ethics, and is both a very young field and so far a fairly successful one. Some of the challenges in restoration ecology are answering important questions such as how, specifically, to define success. Overall it is a very broad, multi-layered and variable field with a variety of applications in today's changing world.

2.2.1 Driven by an Environmental Ethic

In the field of environmental ethics diverse viewpoints strongly support ecological restoration, while others are fiercely opposed to it. The negative views tend to focus on the idea that a restored ecosystem is simply an artifact, and that because it is manmade it is not nature, and thus nothing at all has actually been "fixed" (Schmidtz & Willott 2002). Also, critics of environmental restoration tend to feel that enabling humans to embrace the restoration of destroyed systems will disengage us from the protectionist values that exist within other disciplines, such as conservation. In turn it is thought that this will create a certain entitlement in humans who may begin to think they can treat the biophysical environment however they please because the tools and permissions are quite available to go back and restore any damage that may have been done (Schmidtz & Willott 2002).

The viewpoint which supports restoration ecology believes that restoration is an obligation which seeks to better the relationship between humans and nature, and is therefore within the boundaries of a constructive, realistic environmental philosophy (Schmidtz & Willott 2002). It is with this viewpoint in mind that this particular restoration experiment has been undertaken. Whether or not there is complete agreement that ecological restoration is philosophically sound, there is enough evidence to affirm that it is in the best interest of both nature and, as a result, humans. A common thread of thought is that the endless positive outcomes of restoration outweigh the doubts felt by philosophers about its actual value in our world today. The remainder of this literature review will show why restoration is such an irreplaceably important facet of science, ecology and the environmental movement. This begins first with a review about the novelty of the field of restoration ecology.

2.2.2 A Science in its Infancy

Restoration ecology is a science which is actually in its infancy, but is undergoing rapid development as both an academic discipline and an area of practical application (Palmer et al. 1997; Young 2000). It has been recognized by several authors that in this growing field, there is a need to develop successful protocols for restoring natural systems and expand the tools and methods available to increase both the rate and the overall success of restoration efforts (Sweeney et al. 2002; Wilkins et al. 2003; Hartman & McCarthy 2004). As restoration ecology has developed, the great deal of unknown factors and unanswered questions which exist within it have become evident. This is why restoration efforts are always executed with a precautionary approach and a strong emphasis on monitoring, and adaptive management (Dellasalla et al 2003).

It is imperative that mistakes made in the past are recognized and learned from, as every restoration effort is simply another chance to gain more information about what works, and the field itself (Hobbs 2003). The need for further research and information in the field of restoration ecology is dire and imminent in today's world.

2.2.3 Introduction to Restoration Ecology

Worldwide, environmental systems are being degraded as the largest and most technologically advanced population on the earth to date pollutes the planet while rapidly consuming natural resources. Within the environmental systems being heavily affected are forests, to which a vast number of forces are currently at work causing woodland degradation on a global scale. These forces include processes such as logging, road-building, mining, and exotic species invasions (Dellasalla et al 2003). While conservation and preservation acts can help keep these forces out of some systems, restoration ecology is required to restore those areas which have already been negatively impacted (Daigle & Havinga 1996; Young 2000; Slosser et al. 2005).

Restoration ecology is a science which functions under the assumption that many of the forces degrading natural habitats are temporary, and that ecosystems can recover from small amounts of habitat loss and degradation (Young 2000). Restoration ecologists have often been described as optimists (Young 2000), convinced that a degraded ecosystem can be restored back to a condition reminiscent of the original system. However, it is unmistakably recognized that restoration ecology is not a means to "get us off the hook" for the current denuding and destruction of ecosystems, worldwide (Young 2000).

Restoration ecology tends to be primarily focused on vegetation, which comprises the greatest abundance of ecosystem biomass (Young 2000). Forest restoration is an area of the science which focuses mainly on the regeneration or reintroduction of vegetation. As the value of native biodiversity has been widely recognized, re-establishing indigenous forests has become a major priority (Stevenson & Smale 2005).

Today employment programs are created at an unprecedented rate to shift our focus from the extraction of resources to the restoration of ecosystems (Dellasalla et al. 2003). E.O. Wilson stated explicitly that "the next century will, I believe, be the era of restoration in ecology" (in Young 2000). Restoration efforts take on many shapes and sizes, but it is the "restoration experiment" which was executed within the confines of this study.

2.2.4 Restoration Efforts

Restoration experiments are efforts which introduce different kinds and numbers of species into ecosystems (Palmer et al. 1997) and test the outcome of such manipulations, including restoration of both ecosystem structure and function. The species used can either replicate specific historic conditions of a particular region (Iannuzzi & Ludwig 2005), aim to be somewhat similar to historic conditions (Slosser et al. 2005), or be chosen on the basis of their functionality in restoring ecosystem integrity (Dellasalla et al. 2003). Generally, restoration efforts are only undertaken when such intervention will allow systems to regenerate faster than they would if left unaltered (Reay & Norton 1999), which tends to be based on the fact that restoration can be a costly, intense and timely procedure (Rayfield et al. 2005).

Restoration can be a passive effort, in which an undesirable factor is removed and the system is then allowed to regenerate naturally. Yet, if the system has passed a threshold point where critical ecosystem processes and structures (e.g. nutrient cycling, soil structure) are being seriously affected, active restoration is usually required, in the form of planting and management (Benayas et al. 2005; Rayfield et al. 2005).

Many restoration experiments are controlled, unreplicated manipulations, which is a result of the aforementioned large labour and cost involved in such efforts (Young 2000). This has led to doubt about the power of conclusions that can be drawn from restoration ecology experiments (Young 2000), but based on the limited means available, this is often the only route which can be taken in restoration research.

Restoration ecology is not an "easy" science that anyone can practice, nor is it simple "gardening". Poor seed sources, improper storage or handling of seed and seedlings and poor planting techniques have all been causes of major failures of experiments in the field (Stanturf et al. 2001). Therefore, it is easy to see why restoration ecology is an extremely delicate science, and involves a great deal of care and planning so that sound conclusions can be drawn from the work and dispel doubt about the effectiveness of the field in its entirety.

In this study, gaps which exist due to the age and relative lack of information in the field of restoration ecology have been attempted to be closed. There are several key features about this

study which have not been extensively covered in past research which will be outlined in the following section.

2.3 Past Studies vs. Experiment in Natchez Hills

In terms of length, spatial scale, the use of combinations of vegetation and the use of understory species, there is a noticeable variation between past studies and the one undertaken at Natchez Hills. The ways in which this study varies from the typical protocols followed in the literature are outlined further below.

2.3.1 Length of Restoration Studies

Generally, restoration experiments are ongoing projects which aim to achieve success in time periods ranging from 5-10 years, to 20-40 years, and often even over 50 years. However, it has been suggested that shorter, more intensive studies have application in achieving restoration success (Stanturf et al. 2001). Restoration success has often been viewed as a successful continuum from initial active restoration efforts to the establishment of a functional, self-sustaining ecosystem (Reay & Norton 1999). Yet it must be recognized that even though the final establishment of such a system is generally the "restoration goal", this stage could not be achieved without success in the initial stage (Reay & Norton 1999).

Recently, there has been significant recognition in the literature about the importance of short-term success in a field where long-term success has generally been the goal. Because long-term success can take up to decades to declare and establish sound conclusions about, it has been suggested that short-term success goals always be made alongside long-term ones (Haynes 2004). Also, projects with only short-term impacts and goals should be accepted because these projects will more than likely result in positive impacts on ecological integrity in the long-term (Dellasalla et al 2003).

This movement away from the typical length of study in a restoration experiment reveals a gap which can be filled by short-term projects which focus on the success of initial plantings, such as the work executed in Natchez Hills. Another evident gap in the literature involves the study of combinations of vegetation; an area which should certainly be focused on to a greater degree in upcoming restoration efforts.

2.3.2 Studying Combinations of Vegetation

There is some evidence in the literature which suggests that different species or guilds of vegetation do exhibit symptoms of non-negative interactions. The study of competition between different forest species has been performed on understory plants, and it has been found that competition for factors such as nutrients, light, space and water, or competition for dominance are issues which are relatively non-existent in native understory species (Rogers 1983*b*). Recently, positive interaction (facilitation), the opposite occurrence of competition, between plant species has been noted and studied in field experiments at a growing frequency (Callaway 1995; Brooker 2006; Cheng et al. 2006). With regard to restoration, it has been suggested in a previous study that planting a combination of native species, which each contribute to the ecosystem in a different manner, is an ideal method for restoration (Fattorini 2001). This supports the use of combinations as experimental treatments, because combinations are more likely to encourage a facilitative rather than a competitive effect on the plants in the experiment.

There is also support in the literature of using a species-based view of ecological communities to fully test the interaction of both the different species with one another and with their environment, based on the individual functional traits of the plants (Palmer et al. 1997). The exclusive use of understory vegetation in this study is another novel aspect of this study, and helps to fill existing gaps in the literature about the use of understory species in restoration efforts.

2.3.3 Use of Understory Vegetation

Replanting forests with trees is an extremely common practice, as seen in the restoration ecology literature. However, a much less common practice is the use of understory species in forest restoration efforts. This is likely based on the ease of availability of planting techniques and species selection for trees, and lack of such guidelines for understory species. Another contributing factor could be the newness of the entire field of restoration ecology and the specific area of study of understory species restoration simply not having been explored as of yet. There are research papers which note that restoration ecologists know little about establishing understory species in restoration efforts (Rayfield et al. 2005), and that there is a great need for the development of restoration techniques when using understory species (Cox et al. 2004). There is research which states that the introduction of understory plant species can be quite beneficial in restoration experiments, including evidence that early understory plants have been

shown to greatly improve soil quality during the first stages of re-establishment (Mohr et al. 2005; Rayfield et al. 2005).

Based on the repeated mention of the potential benefit of understory plants found in the restoration ecology literature, it is clear that there is a great need for research in this area. Understory plant restoration seems to be a sound sub-field within the context of restoration ecology in which to concentrate energy. In addition to the use of understory vegetation another area which has tended to be overlooked in the literature is the use of small scale restoration efforts to assess their potential and effectiveness.

2.3.4 Scale

One article in particular noted that the literature absolutely needs to continue addressing issues at smaller scales, as this is something which is greatly lacking in the field of rehabilitation and restoration ecology (Matthes et al. 2003). The lack of development of specific goals at small spatial scales is a major problem, especially in Waterloo Region, and Ontario as a whole (Matthes et al. 2003). Often it is only feasible to restore at small scales based on cost and labour. Therefore testing if small scale restoration can be equally as effective as large scale restoration is an area of study which should be addressed immediately. The work undertaken in Natchez Hills fills this niche, as the area being restored is relatively small compared to the majority of restoration efforts outlined in the literature. Some restoration efforts have covered areas of 28 ha (Peterson et al 2004), 65 ha (Hartman & McCarthy 2004) and even up to 10,000 ha in the large-scale restoration effort undertaken in Sudbury, Ontario, beginning in the 1978 (in Rayfield et al. 2005). The restoration effort performed in the study is decidedly smaller, covering an area of only about 0.15 ha.

Now that the specific parameters of the experiment have been explained in terms of their usefulness to the literature, it is important to look at the conditions which already exist in this forest to help fully illustrate the area in which the work was carried out. Natchez Hills is a forest which is rife with problems commonly affecting urban forests, and each of the four main factors (urbanization, fragmentation, disturbance from freeriding, and soil erosion) will be touched upon in the following sections.

2.4 The Degraded Forest: Natchez Hills

Natchez Hills is an area which is exposed to a number of degrading factors, including urbanization, fragmentation, human disturbance and soil erosion. These factors are often overlapping, synergistic and interrelated, leading to a forest which becomes more heavily degraded with each passing day.

2.4.1 Urbanization

Urbanization is a factor responsible for many landscape degradation processes, as it contributes to discontinuity, edge effects, fragmentation and invasive species encroachment. Urbanization is especially perilous because of its persistence, as it is unlike other degrading forces which can be altered or stopped, and because urbanized land is so dissimilar to natural land cover (Marzluff & Ewing 2001). Forests which are adjacent to urban areas are also at a much greater risk for invasion by exotic species (Borgmann & Rodewald 2005). This pertains exactly to Natchez Hills, especially the fragment of the forest used in this experiment, which is fairly small and adjacent to urban areas on two sides. Urbanization often goes hand in hand with fragmentation; another problem affecting this forest.

2.4.2 Fragmentation

Forest fragmentation affects ecosystems on a global scale and is expected to continue (Marzluff & Ewing 2001). Fragmentation can affect many aspects of ecosystem integrity, including water and nutrient cycles, biodiversity and the survival of native species due to increased exposure to surrounding areas which are discontinuous from the forest ecosystem (matrix effects) (Daigle & Havinga 1996; Marzluff & Ewing 2001). Like urbanization, fragmentation places forests at a much greater risk for exotic species invasions (Borgmann & Rodewald 2005). The most obvious sign of fragmentation in a forest is a decrease in total forest size, and the establishment of permanent edges (Mourelle et al. 2001). Edge effects can include the proliferation of invasive or weedy species able to exploit high light levels and disturbance regimes at the expense of native or rare interior species (Young 2000). When edges are created, areas of a forest become transitional ecotones due to their proximity to the matrix, causing permanent changes to native vegetation structure and species composition in the edge area (Stevens & Husband 1998). Fragmentation can also have subtler effects, such as increasing distances between forest patches and reducing source material available for regeneration of native species in fragmented patches (Jacquemyn et al. 2003).

It is imperative that restoration ecologists determine how to manage fragmented areas to maintain the species within them (Marzluff & Ewing 2001). This includes measures such as introducing complex vertical layers of vegetation (stratification), increasing native plant populations, and controlling exotic invasives (Marzluff & Ewing 2001).

The experimental site within Natchez Hills is experiencing fragmentation and edge effects. Marzluff & Ewing (2001) made several suggestions about methods by which to repair the damaging effects of fragmentation, and these suggestions were all followed in this experiment. However, it is important to remember that the fragmentation in Natchez Hills is confounded by other degrading forces, such as human disturbance.

2.4.3 Human Disturbance

Human disturbance is another form of degradation which enhances the likelihood of a forest being invaded by exotic species (Palmer et al. 1997). In past studies, it has been shown that vegetation is actively dislodged from the ground or trampled by people visiting natural sites such as forests (Matthes et al. 2003).

Natchez Hills is at a serious risk from human disturbance, specifically from mountain bikers in the area who remove trees and other vegetation, compact the soil and degrade the overall quality of the site. This not only makes an area more susceptible to exotic species invasions, but also endangers the native plants trying to grow in the area.

2.4.4 Soil Erosion

Due to the many overlapping issues already mentioned, soil erosion is another major problem in degraded forests including Natchez Hills. It occurs when rooting structures of plants and trees are not present to keep the soil intact. The importance of plant root systems to prevent soil erosion has been noted in the literature (Brooks & Merelander 2001; Bartha et al. 2003). Ensuring that vegetative cover is established quickly in restoration efforts is a primary means of reducing soil erosion (Bartha et al. 2003). Soil erosion has a high impact on ecosystem integrity because it decreases soil fertility and structure, and can remove a large amount of topsoil which takes hundreds of years to be renewed. Because of these issues, it is extremely important that any soil erosion occurring in Natchez Hills, due to reduced vegetative cover, is immediately halted.

As such, it is easy to justify why Natchez Hills was chosen for this restoration experiment. There are even broader reasons as to why Waterloo Region (the area in which the forest exists) was chosen in the first place to conduct this experiment, which will be addressed below.

2.5 Justification for Locality and Plants Used

The choice of restoring a forest in Waterloo region, as well as choosing the particular vegetative species to be used were not arbitrary by any means. The following will describe exactly why the parameters chosen were explicitly selected for this study.

2.5.1 Waterloo Region

The Regional Municipality of Waterloo in Ontario has been chosen for past restoration studies because of its strong conservation authority, established Environmentally Sensitive Policy Areas and overall intentions to become an environmentally sustainable community (Matthes et al. 2003). Therefore choosing suitable plant species for restoration within this area was a careful, thoroughly researched process.

2.5.2 Process of Species Selection for Restoring Natchez Hills

Plants that comprise the understory vegetation in forests can be divided into four stages: winter, spring light, summer shade, autumn light (Sparling 1967; Mahall & Bormann 1978). Based on the time period available for this work (with regard to thesis proposal completion and availability of only two growing seasons) winter would be too early to start and autumn too late, so using spring light and summer shade plants was the best alternative. There are more specific reasons why these plants were chosen, which will be touched upon momentarily.

Bierzychudek (1982) outlined many features about possible herbaceous plants which geographically could be used in this restoration effort. Based on his analysis, plants were chosen which demonstrate successful reproduction by both sexual and asexual means, and low mortality rates. All of these features helped promote better chances of survival for the plants used in this study.

Some common northern hardwood species were ruled out based on unusual breeding systems or lack of notable overwinter survival rates [e.g. *Dicentra* spp., *Sanguinaria canadensis* (Schemske 1977; Macior 1978)]. The use of any exotic species in the restoration effort was ruled out

because too little information is available about the role exotics can play in restoration (Rayfield et al. 2005); thus the precautionary principle was exercised.

Identifying species which are appropriate for use to ensure successful early restoration is most easily done by studying vegetation at congruent, adjoining sites and determining the species which would be most suitable for planting based on reference conditions (Daigle & Havinga 1996; Reay & Norton 1999). It is also important not to try to "maximize" biodiversity by using an inordinate amount of plants: generally 2-3 plants is a good number for small plots (Daigle & Havinga 1996). Both of these recommendations were strictly adhered to when choosing the experimental species to be used in this study.

2.5.3 Species Chosen: *Podophyllum peltatum*, *Caulophyllum thalictroides*, and *Erythronium americanum*

Podophyllum peltatum L. (mayapple) is a common species of the northern hardwood region (Rogers 1982). It is perennial, rhizomatous, and has shown to exhibit successful vegetative growth in the deciduous forests of eastern North America (DeKroon et al. 1991; Watson & Lu 1999; Maqbool et al. 2004). This plant has been shown to have a very high frequency and density in such forests (Brewer 1980). *Podophyllum peltatum* is clonal, and thus will help ensure that if the plants become established they are not likely to go extinct after this founding event (Hartman & McCarthy 2004). Summergreen perennials (the category into which *P. peltatum* falls) have shown a great ability to cover large amounts of the forest floor in hardwood forests, and the herb community in these forests has been shown to be dominated by long-lived perennial species (Rogers 1983*a*), which *P. peltatum* certainly is. As sugar maple forests develop, the understory species typically shift to a dominance of shade tolerant herbs, and *P. peltatum* is one of the most shade tolerant summer herbs common in these forests (Brewer 1980). This further supports the use of *P. peltatum* in a sugar maple dominated forest like Natchez Hills.

Caulophyllum thalictroides L. Michx. (blue cohosh) is an early-flowering spring wildflower found in deciduous forests of northeastern North America (Hannan & Prucher 1996; Singleton 1998). With two major varieties of this plant in existence it bears note that the variety of *C. thalictroides* used in this experiment was *C. thalictroides* var. *giganteum* Farw.. Like *P. peltatum*, *C. thalictroides* is a summergreen perennial (Rogers 1983*a*) but can be noted for its dominance throughout the entirety of the growing season as it is one of the first species to emerge in early spring. It is a common species in forests dominated by *Acer saccharum* (sugar maple)

and has found to be positively correlated with the presence of several other species, including *A. saccharum*, but also *Allium tricoccum* (wild leek), and varieties beech and bass trees (Stearns 1951; McIntosh 1957; Cappucino & Kareiva 1985; Bellemare et al. 2005) all of which can be found in abundance in Natchez Hills. It is capable of vegetative dispersal, through the spread of its rhizomes, and is known to be quite prolific at spreading in this manner (Singleton 1998). *Caulophyllum thalictroides* is a highly "contagious" species, meaning that it can quickly and efficiently spread beyond its site of initial introduction, and therefore is often found in high abundance (Whitford 1949). This supports the use of *C. thalictroides* in the restoration experiment.

Erythronium americanum Ker. (trout lily) is another very common and dominant species of northern hardwood forests (Rogers 1982; Daigle & Havinga 1996). It emerges earlier than *P. peltatum*, and slightly earlier than *C. thalictroides*, which makes it very appealing because it can take advantage of spring light conditions. *Erythronium americanum* is a spring ephemeral, which is defined as a plant able to break dormancy early, grow rapidly, and be finished expanding by the time the tree canopy closes in the spring (Risser & Cottam 1967; Anderson & Eickmeyer 2000; McKenna & Houle 2000; Lapointe 2001). Spring ephemerals have a very unique relationship to woodland plant community dynamics (Risser & Cottam 1967). In northern hardwood forests these plants act as sinks for nutrients during the early growing season and tie up nutrients from decomposing forest floor material so that they will not be lost to leaching during snowmelt and spring rain (Anderson & Eickmeyer 2000; Tessier & Raynal 2003). This is known as the vernal dam hypothesis. *Erythronium americanum* has been shown to play a distinct role in vernal nutrient cycling (Mahall & Bormann 1978). Though the phenology of emergence for *P. peltatum*, *C. thalictroides* and *E. americanum* do overlap, their life spans are significantly different, as *E. americanum* dies back as the canopy closes, while *P. peltatum* lives through the majority of the summer months, and *C. thalictroides* persists until the fall.

Of the many plants which could have been selected, showing the strict characteristics of a spring ephemeral, *E. americanum* was desirable for several reasons. It is one of two ephemerals best adapted to exploiting the high light intensity of early spring (Mahall & Bormann 1978). It has both clonal and sexual reproductive modes so genetic variability as well as ease of reproduction are ensured (Bierzychudek 1982). It has a stable demographic structure and is very stress-tolerant, helping ensure similar dominance and population size each year (Bierzychudek 1982; Rogers 1982). It has a very high density and frequency in forests within its large range

(Brewer 1980), and is particularly prominent in forests covered in beech, birch or maple (Mahall & Bormann 1978), species which all prevail in Natchez Hills.

Choosing three species allows for a fully replicated experimental design that is tractable and feasible in terms of labour. All possible combinations of species 1, 2 and 3 (e.g. 1 and 2; 3; 2 and 3; 1, 2, and 3, etc.) with four replications of each yields a total experimental plot number of thirty two. This is based on desirable numbers for statistical analysis, validity of results and amount of materials and time available. This number is also applicable to actual restoration efforts, in which resources are often limited and restoration using three species is a realistic and achievable practice. It has been noted in the literature that an efficient restoration effort, which is more economical in terms of labor and cost, is a better choice than one which is more costly and labour intensive (Higgs 1997). This further supports the choices made about the number of transplants used in this experiment.

Originally, *Acer saccharum* (sugar maple) was planned to be used in combination with *P. peltatum* and *E. americanum*, but upon survey of the forest it was found that the number of *A. saccharum* seedling and saplings was extremely low. It would have been unethical to remove stock for transplant when it occurred in such low numbers, so another species was chosen. Due to its tall, branchy stature, *C. thalictroides* was thought to be a suitable replacement for *A. saccharum* saplings because it could be integrated into the experiment without changing the configuration of the plots. Also, it allowed the experiment to focus even more exclusively on understory species restoration, which, as discussed, has been greatly overlooked thus far.

The selection of the Waterloo area and the specific understory plants used was a thorough process. It will be further complemented with an explanation of the methodological choices made for the implementation of these species into the experimental plots, as well as other measures which were taken and have been described by the literature to date.

2.6 Support for Methods Selected in this Study

Restoration ecology is a heavily methodologically-based field, and thus there were a wide array of possible methods to choose from. The justification of all methodological choices made will be described in the following.

2.6.1 Measuring Site Factors

The first important method in the collection of data for this restoration effort was an assessment of the biotic and abiotic conditions present at the plots selected. Considering biotic and abiotic site factors is as important to consider in a restoration effort as cost (Hartman & McCarthy 2004), likely because of the significant effect that things such as species present or soil conditions can have on transplanting. Measurements which have been taken in past studies include factors such as soil pH, soil moisture and nutrients, light availability, ambient temperature and humidity and percent vegetative cover (Hartman & McCarthy 2004; Rayfield et al. 2005). The wide variety of available techniques and tools to measure these various factors have been documented in a variety of papers (e.g. Rogers 1982; Mourelle et al. 2001; Rayfield et al. 2005) and were incorporated into this current study, including the size of the experimental plot.

2.6.2 Study Plots

The plot size chosen was 1m x 1m plots which is commonly used in restoration efforts (e.g. Brewer 1980; Lamb 2003; Rayfield et al. 2005). Four replicate plots per experimental treatment was another number chosen both for statistical validity and because of its use in the literature (Benayas et al. 2005). Sites in close proximity to one another, sharing similar biotic and abiotic background conditions were the most logical to select, to minimize the amount of environmental variation which might confound the results of the restoration experiment (Wilkins et al. 2003). Another factor which helped reduce the variability between the sites was the use of the same exotic invasive control methods, before commencement of the experiment, across all experimental plots.

2.6.3 Site Preparation: Exotic Invasives Control

Preliminary site preparation is often necessary to increase the chances of survival of certain plant and tree species, especially in forests which border urban or near-urban areas (Daigle & Havinga 1996), such as Natchez Hills. Exotic invasive species ("exotics"/"exotic species") are present in ecosystems on a global scale and are often responsible for lowering native species biodiversity and disrupting valuable ecosystem processes (Palmer et al. 1997; Borgmann & Rodewald 2005; Murphy 2005). There are over 700 exotic plant species growing wild in Ontario today (Daigle & Havinga 1996) and they are a threat to the success of restoration efforts (Sweeney et al. 2002; Borgmann & Rodewald 2005). Exotic species pose a particular threat to the successful restoration of the deciduous forests of northeastern North America where native seed viability tends to be short and exotic seeds are apt to dominate the seedbank (Hartman & McCarthy 2004).

Exotics may damage restoration efforts by competing with restored vegetation for resources such as water or nutrients (Benayas et al. 2005). They pose a specific threat to spring ephemeral plants, by taking over their role of acquiring nutrients in the spring and thus changing forest nutrient cycles in a detrimental way (Murphy 2005). Exotics can even cause "exotic disclimax" in which natural succession and regeneration processes are completely halted for an indeterminate amount of time (Saver 1992). Overall, it is extremely important to control exotic species to prevent them from outcompeting and extirpating native species, making this step a necessity in the restoration process (Boudry et al. 2002; Hartman & McCarthy 2004; Murphy 2005).

The removal of exotic species as a restoration technique has been very successful, especially in conjunction with planting native species directly afterwards (Wilkins et al. 2003; Hartman & McCarthy 2004; Murphy 2005; Page & Bork 2005; Rayfield et al. 2005). Some exotic removal techniques which have been used include mowing, clipping, herbicides, hand-pulling and burning (Daigle & Havinga 1996). Mowing has been shown to have a pronounced positive effect on survival of tree saplings/seedlings (Benayas et al. 2005) and avoids many of the pitfalls of hand-pulling (which disturbs the soil and invites more exotics) or herbicide application (as many herbicides can be environmental and health hazards). Mowing or similar approaches are recommended for forested areas where exotic herb competition limits the establishment of native vegetation (Benayas et al. 2005). Based on the small space used it was deemed that mowing was not necessary, and close-ground clipping would instead be used to deliver similar results with fairly minimal effort. Also, just the effort of planting a viable native seed source directly in the area where exotic species are being controlled can help exclude exotic species from returning (Rayfield et al. 2005). It is the planting of the native species which actually distinguishes this experiment from other passive restoration efforts, as active restoration is the primary method being undertaken here.

2.6.4 Choosing Active Restoration
Replanting instead of simply removing the disturbance demonstrates the distinction between active and passive restoration. Replanting as an active restoration technique has many benefits, including the addition of diversity, the inhibition of exotic invasion by preemption of space and resources available, the acceleration of natural succession and the compensation for lacking recruitment in disturbed or fragmented areas (Sweeney et al. 2002; Dellasalla et al. 2003; Hartman & McCarthy 2004). Active restoration should always be chosen when the risk of no action is greater than any risk posed by the active restoration (Dellasalla et al. 2003). This is

definitely the case at Natchez Hills, because the forest, left as it is, continues to worsen in condition every year.

There are two types of active restoration: one dimensional efforts, and multi-dimensional efforts. Planting a single species is classified as a one dimensional effort, while preparing a site, planting multiple species and maintaining the results is classified as multi-dimensional, and tends to be more rapid and effective (Rayfield et al. 2005). Based on this rationale, a multi-dimensional approach has been taken in this particular study.

Active restoration has been shown repeatedly to be a successful technique. Reforestation projects in which trees have been planted have been almost flawlessly successful at implementing desired tree species (Allen 1997). Transplanted understory plants have been shown to emerge the following season at the same time as natural plants, and sometimes even performed better than the natural species (Whigham 1974). Successful restoration, in another study, was achieved by eradicating invasives and immediately following this with restoration of the overall site diversity without waiting for passive restoration to take hold (Rayfield et al. 2005). Because it is clear that active restoration is an extremely desirable option for restoration, it is important to facilitate its usefulness with a thorough understanding of the techniques involved in actively planting native species.

2.6.5 Planting Techniques

Transplanting was the method chosen to introduce new stock into the degraded areas of the forest, and was selected over seeding for several reasons. Using seeds for restoration automatically indicates a longer period before an established plant is present at the site. Waiting for the germination and emergence of seeds can take more than one growing season, and because this project was focused on short-term restoration, time was a major constraint when considering the use of seeds. In areas with more extreme environmental conditions (such as soil damage from freeriding) transplanting has been shown to be a more effective option in terms of both reproduction and survival (Fattorini 2001). Transplants are able to reproduce in a shorter time than plants grown from seed, and transplanted forbs were shown in one study to have an 85-95% survival rate (Fattorini 2001). Though transplanting does not have a perfect record in restoration efforts, seeding has been shown to have a significantly more limited success in many settings, including wetlands, grasslands and, most importantly, woodlands (Page & Bork 2005).

Transplanting can allow species to establish rapidly in a degraded area, and this is why this method was chosen in this study.

There are many well-established methods and techniques for planting trees in restoration efforts, but methods for planting understory vegetation are underrepresented in the literature. Therefore, the guidelines for transplanting understory species adhere to the methods followed in recent research done by Murphy (2004).

Some methods that were followed from the literature include the following. Taking stock (transplants) from surrounding areas is a technique which is highly recommended in the literature, to minimize genetic variation and ensure that the plants being used are well-adapted to the specific site conditions present (Hartman & McCarthy 2004; Kellman 2004; Benayas et al. 2005). Another important management technique is irrigation, yet there is some debate surrounding this practice in restoration efforts. Low summer water is a factor which can drastically affect transplants (Benayas et al. 2005), and irrigation has been shown to significantly decrease mortality. However, watering has also been shown to have only minimal positive impact on transplant survival, and doesn't measure up when compared to the labour involved in transporting water to the transplants (Mahall & Bormann 1978). In this study the transplants were only watered once, immediately after planting to hopefully gain the benefits of reducing labour and time, but concurrently help ensure the plants' survival. Species were carefully examined before being removed for transplant, and species with noticeable herbivory or disease were avoided. Also, the species chosen for transplant were selected within a narrow range of size, to minimize experimental variability (Singleton 1998).

2.6.6 Monitoring

Monitoring restoration efforts has, in the past, followed the growing season in the north temperate zone from late April to mid-September (Brewer 1980). Further to this point, some researchers have stressed the importance of sufficient monitoring in every restoration effort (Dellasalla et al. 2003). In the literature there is a noticeably wide variability in frequency of monitoring, and thus makes this choice fairly arbitrary. It was decided that the plots in this experiment would be monitored biweekly from April to September as suggested by Brewer (1980). The reason for this seemingly low level of monitoring is that simply assessing progress is the goal; a measure which is based on survival, and not other more detailed measures of plant growth, health or fecundity.

Progress, based on highest survival of planted species, was the measure of success chosen in this study for several reasons which are described in the following section.

2.7 Progress in Early Restoration

In the restoration ecology literature, there is little agreement about what constitutes a successful restoration effort (Palmer et al. 1997; Stanturf et al. 2001; Ryder & Miller 2005). However, some researchers have stressed the need for clear objectives in a restoration project, so that "success" in restoration can be declared, or not (Daigle & Havinga 1996; Palmer et al. 1997; Stanturf et al. 2001; Hobbs 2003). There are many questions to answer when considering how to define a successful restoration effort, including what is the current state, what factors are causing ecosystem degradation, what objectives does a particular study have and how can objectives be specified in a way that success can be measured (Stanturf et al. 2001; Hobbs 2003). Out of this confusion it has been suggested that long-term success takes a very long time to monitor, analyze and eventually declare (or not), short-term success goals should instead be formulated (Haynes 2004). It is also helpful to note that another study found that species establishment in the initial stages of restoration will help ensure that the restoration is a success in the long-term (Reay & Norton 1999). The study undertaken here has short-term goals which can be assessed after only one year, which adheres to the short-term outlook on restoration "success".

To support the means by which progress was measured, the literature suggests that success has often been measured by structural or survivorship components. Structural success is a measure which has dominated the literature, and it has also been declared that a restored site should fit the species composition and structure of a given area (Stanturf et al. 2001). This is supported by the fact that while it is important to restore not just structure but also function, most functional attributes are actually linked to vegetation structure (Stanturf et al. 2001). Function and structure are also thought to have an intricately reciprocal relationship, with one being unable to exist without the other (Higgs 1997). Survivorship analysis has also been performed to assess the success of restoration experiments (Sweeney et al. 2002; Hobbs 2003). In past restoration efforts, direct counts of the shoots of surviving transplants has been used to measure restoration success (Procaccini & Piazzi 2001).

When assessing progress in early restoration, it is important to remember that steady-state conditions never have existed (and never will exist) in any ecosystem (Stanturf et al. 2001). Restoration success should be viewed as part of a larger continuum, with emphasis on both the

success occurring in the early stages of planting, as well as the eventual establishment of a functioning natural system (Reay & Norton 1999). In this case, time dictates that only early success was able to be measured, but because early success is so imminent to ensure later success, it is certainly not a measure which should be overlooked. The conclusions drawn from this study are useful as recommendations to other restoration ecologists for which species and combinations to plant to ensure the best possible results in the early stages of restoration. The measure of success (progress) used is a structural measure of survivorship, which is clearly supported by the literature. Following this restoration experiment, and assessment of initial survival (progress), natural succession is the path which this restoration effort will inevitably follow.

2.8 Natural Succession

Ecological succession is viewed as a progressive change in community composition and dynamics, occurring slowly over time (Palmer et al. 1997). Natural succession is expected, over time, to add more species to an ecosystem, resulting in a diverse, self-sustaining forest (Haynes 2004). Natural succession is a form of passive restoration, and it applies to this study because after the initial restoration effort, the experimental plots were left to naturalize and spread throughout the forest. While this work is an experiment to see what works best, the eventual outcome of the forest itself is a major concern. Due to time restraints this factor was unable to be explicitly measured, but the experiment was set up in such a way that natural succession was encouraged.

Through natural dispersal of seeds and natural spread of clonal plants from the experimental plots, a functioning forest will, in theory, develop over time (Allen 1997). This method of restoration is known as nucleation, which is defined as the planting of small native vegetation pockets in various locations across the restoration site (Daigle & Havinga 1996). As each cell matures, seeds are dispersed and plants creep outwards until the cells eventually converge into a flourishing forest community (Daigle & Havinga 1996). In the first five years after planting, it has also been proven that there is a period of activity in which about half of the species which will colonize a restored area appear at the site (Bartha et al. 2003). Therefore, it can be expected that natural succession is not a process which will take years to affect the restored plots, but something that will begin to occur shortly after the cessation of the experiment.

When considering succession it is important to remember that, as discussed, there is no ideal state (Stanturf et al. 2001). It is also not expected that the forest that was once present on a site will exactly reappear (Haynes 2004). However, as long as desired native forest species congruent with the surrounding area are being steadily established, and even shift to dominance over time, it can be declared that natural succession is occurring. Natural succession is the eventual process which takes over all restoration efforts, and luckily can occur very quickly to take over a project on which there was a very limited amount of time to work.

Chapter 3

Methodology

3.1 Introduction to Methodology

The variety of methods chosen for this study, and the justification for these particular choices is described below. This study was based on one specific experiment, carried out in one specific location, indicating that the approach taken was mensurative. However, the important question of progress in early restoration can still be addressed even in this minimal-replication approach. The experiment in this study, which has been described throughout this thesis, involves the transplanting of *E. americanum*, *P. peltatum* and *C. thalictroides* into a predetermined forest area, in different plots, in different combinations.

3.2 Choosing Blocks and Plots

Approximately two and a half hectares of land were available for use within the Natchez Hills forest. This experiment began with scouting this area of land, and choosing blocks which were appropriate for this experiment. The blocks were chosen based on qualities which distinguished them from one another so potential block effects could be analyzed in the outcome of the experiment. (Table 1). The blocks range in size from about $330m^2$ to $470m^2$. Block 1 was the steepest gradient available, a hill on which extensive mountain biking had taken place, but has since been fenced off at the top edge so mountain biking is now impossible. It was in the second to worse condition in terms of lack of native species and abundance of exotic species. Block 2 is an area on a slighter slope than Block 1, where a previous restoration effort had taken place, leaving it in a condition of high native biodiversity, with a fence erected around its boundaries. However, there was still an abundance of invasive species throughout the block. Block 3 was by far the area in worst condition, with very low native biodiversity, very low overall plant cover, and a distinct presence of exotic species. Block 3 is situated at the bottom of the hill which comprises Block 1, meaning that mountain biking was most definitely a factor in the site's degradation. Block 4 was the least degraded block, because it is situated in an area of the forest where mountain biking was probably never a major problem, likely due to the lack of slope on and around the site. However, Block 4 is closest to the residential and urban areas adjacent to this

forest fragment, and while native biodiversity seemed to be quite high, there was also a significant presence of exotic species. After the blocks were selected, each was then was scouted for the placement of eight plots within it, so all eight experimental treatments could be represented within each block.

Table 1. Information about each of the four experimental blocks selected, including size, slope, level of degradation, and presence of native and invasive species.

Block	Area (m^2)	Grade	Degradation from Freeriding	Native Species	Invasive Species
1	366	steep slope	extreme	frequent	abundant
2	469	slight slope	moderate	abundant	frequent
3	362	flat	extreme	occasional	occasional
4	329	flat	little	abundant	abundant

The plot size used was 1m x 1m, for reasons outlined in the literature review above. The grade of plot which was desired for use in the experiment was moderately degraded, which was defined as a site in which the soil structure was still intact enough that vegetation was able to grow in it. This was assessed by surveying if any exotic or native species were present on the particular patch of land, and by a visual assessment of the soil quality or evidence of upheaval. Plots which were heavily invaded by exotic species were not chosen, nor were plots which contained trees, because the saplings and seedlings in this forest are fairly scarce and their presence in the experiment might cause unnecessary variability in the results. Once thirty two appropriate plots were selected, they were carefully marked so the exact boundaries of the plots were easily distinguishable. The markers used in the summer months were bright pink flags at the top left corner of the plot, and less noticeable stakes of green bamboo to mark the bottom right corner of the plot. This marking system enabled easy placement of the 1m x 1m quadrat meter and ensured the same area of land was being studied in each visit to the site.

Thirty-two plots were chosen in order to allow four replications of all the possible combinations of the species which were transplanted. The combinations are as follows:

- *E. americanum*
- *E. americanum* and *P. peltatum*
- *P. peltatum*
- *E. americanum* and *C. thalictroides*

- *P. peltatum* and *C. thalictroides*
- *C. thalictroides*
- *P. peltatum*, *E. americanum* and *C. thalictroides*
- none (control)

The control plot is important in this study to determine if the areas in study might be suitable for spontaneous growth of *E. americanum*, *P. peltatum* or *C. thalictroides* without physically transplanting these individuals into the sites. If these plants were seen to grow in the control plot where they were not present in the first field season, it would affect the outcome of the results and therefore must be included. An example of the configuration within each plot, including the control plot (Treatment 8) is pictured in a diagram depicting Block 4 (Figure 2).
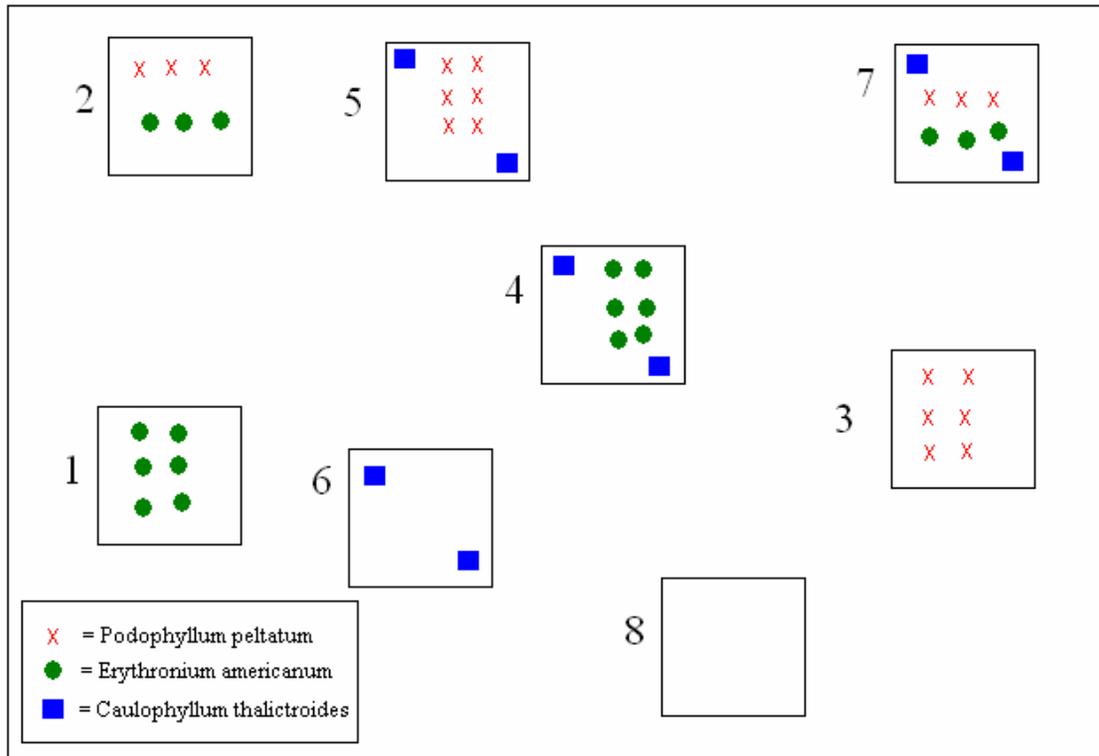

Figure 2. Configuration of transplants and experimental plots within Block 4

3.3 Invasive Species Control

The first and only means of site preparation which was executed in this study was exotic species control. This was done by clipping the aboveground biomass of any exotic plants present on the

plots which were selected. Doing so reduced any chance of the invasive plants reproducing sexually throughout this study, and thus depositing seed into the chosen plots and potentially disrupting the restoration effort being executed. Also, the removal of not just the plant sexual parts, but also their aboveground biomass reduced the possibility of strong competition between exotic invasives and the transplanted species.

3.4 Transplanting

All transplanted species were taken from source sites within areas of the forest which were previously approved by the City of Kitchener. The first source site was not immediately adjacent to the blocks isolated for this experiment. Rather, it was geographically separated by the rolling hills of the forest, subscribed to a different topography and was notably less disrupted by the effects of freeriding based on its location within the forest. The source site was selected mainly because of its large, thriving populations of *E. americanum* and *P. peltatum*. Every individual of these two species which was transplanted was obtained from this area. The second source site was, in fact, adjacent to all of the blocks in the experiment, and, surprisingly, an area used to some extent by the freeriders of the forest. However, neither of these factors were an issue, because the entire area was absolutely dominated by *C. thalictroides*, which was interesting because its presence was rare in the actual experimental blocks. This area was unequivocally the most suitable for transplant of all *C. thalictroides* plants used in the experiment.

In early spring of 2006 *E. americanum* was the first species to be transplanted. The transplants into the four different blocks were carried out on the days of May 2, 2006, May 3, 2006, May 5, 2006 and May 8, 2006. *Erythronium americanum* was planted into the four sites in each block at a density of six plants per square meter (6 plants m^{-2}), which was based on a previous study in which 5 plants m^{-2} was shown to be an optimal transplant density for understory vegetation (Murphy 2004). The number six was chosen instead of five so that the *E. americanum* and *P. peltatum* plants could be planted in even numbers (three of each) in treatments where both plants were used. The same procedure used for *E. americanum* was repeated for *P. peltatum* immediately following the *E. americanum* transplants, on the days of May 9, 2006, May 10, 2006 and May 17, 2006. *Caulophyllum thalictroides* was transplanted last as this plant is taller, branched and fuller than the other species being used and needed to be strategically placed around the smaller understory individuals as to not smother or outcompete them. The typical density for planting tree saplings is generally one tree per square meter (1 tree m^{-2}). The number, for this

study, was adjusted to two trees as competition between trees can be quite high, and survival often low, and thus the second was to serve as a failsafe. The use of two plants was kept consistent in the experimental design even when the final transplant species was switched from *A. saccharum* to *C. thalictroides* due to their similar size and shape. The *C. thalictroides* transplants were performed on May 29, 2006 and May 31, 2006.

3.4.1 Transplanting *Erythronium americanum*

Erythronium americanum was transplanted first, as described, and comprised the most simple set of transplants due to the small size and uncomplicated shape of the plant. All plants in the source population were asexual individuals, consisting of just one leaf and no flower. Sexual individuals of the population, distinct due to their two leaves and bright yellow flower, are quite rare in Natchez Hills. If they had been present they would have randomly comprised approximately half of the transplants used, but this was not the case in this study. Once a plant of an ideal size was located within the source population, the soil around the plant was carved with a trowel in a circle with a diameter of 10cm. Once the soil was sufficiently loosened in this manner, the plant was lightly tugged at while the soil was gently broken up with the trowel until the underground parts of the plant were visible. Ensuring that the corm was included with the transplant, the rhizome was broken off just below the corm with the ridged edge of the trowel, and the plant was immediately potted with its circle of soil into a simple garden planter. The bareroot stock which was typical of the transplant used is pictured in Figure 3. Three *E. americanum* plants were removed at one time, from randomly selected areas throughout their source site. The holes from which the plants were taken were quickly refilled with as much surrounding soil as possible, tamped down lightly with a stomping motion and then mulched with forest floor debris (mostly dead leaves). This repair to the donor site was carried out for all transplants performed in the study.

Figure 3. *Erythronium americanum* transplant specimen of typical age and size used in this experiment

3.4.2 Transplanting *Podophyllum peltatum*

The next round of transplants involved *P. peltatum*, and followed a slightly different protocol than *E. americanum*. Both sexual and asexual individuals were abundant in the source population, so the plants removed were alternately two-leaved with a flower or flower bud, and one-leaved with no sexual parts. The placement or volume of asexual and sexual individuals was not looked at closely during transplanting but was thought to have the potential to provide interesting results upon analysis of the study. Due to the larger size of the *P. peltatum* plant, the diameter of the hole dug out around the transplant specimen was closer to 15 cm. Next, the soil was gently scraped away from the top of the circle with the trowel until the thick, horizontal rhizome showed through. This rhizome indicates the direction of growth and contains nodes which may or may not give rise to future *P. peltatum* plants. Due to this, the rhizome was sawed at with the clawed edge of the trowel just beyond the node, to include the node in the transplant for the possibility of future clonal growth for the plant once transplanted. The soil was then cleared away gently so the entire plant could be removed (Figure 4). The disturbed soil was placed into a large bucket and the *P. peltatum* plants were promptly moved to this bucket and their underground parts were covered with soil. Like *E. americanum*, three plants were moved at a time from the transplant site. The donor site was repaired using the same procedure as described for *E. americanum*.

Figure 4. *Podophyllum peltatum* transplant specimen of typical age and size used in this experiment

3.4.3 Transplanting *Caulophyllum thalictroides*

The final transplant was *C. thalictroides*, which are much larger plants and were thus moved one plant at a time from their source site. Again, the individuals which displayed fruit and those which did not were not discriminated between during transplanting, and a roughly equal number of each were transplanted randomly throughout the four blocks. *Caulophyllum thalictroides*' huge root ball was more complicated to detach from the soil and surrounding root systems than either of the *P. peltatum* or *E. americanum* transplants. The hole dug around the plants had to be about 20-25cm in diameter. The procedure used for the *C. thalictroides* tended to be a bit rougher and involved simply locating the boundaries of the root ball, digging deeply into the soil, and severing the rhizomatous connections between plants. Some soil was encased in the root ball, which can help reduce transplant shock and was thus potentially an advantage for the *C. thalictroides* plants in this study (Figure 5). Once in the bucket, the roots of the plant were then covered with soil from the donor site, and the donor site was then repaired as described above.

Figure 5. *Caulophyllum thalictroides* transplant specimen of typical age and size used in this experiment

3.4.4 Steps Taken After Transplanting

All transplants were generously watered once, immediately after transplanting, and then directly mulched with forest floor debris to help stave off desiccation and keep the soil medium around them as moist as possible (Peterson et al. 2004). Gloves were worn throughout the entire transplanting procedure to avoid attracting herbivores to the transplants (Sinclair & Catling 2004).

3.5 Monitoring

Monitoring of the blocks and plots occurred immediately after they were selected, commencing on April 22, 2006. The main research strategy in this experiment was an analysis of the transplant success from one field season to the next. However, it was also necessary that there be some analysis of secondary data to see if relationships exist between the main experiment in question and other factors which were measured and monitored. These factors include exotic species removed from the experimental plots, and the potentially different abiotic conditions

within each block (i.e. soil pH, soil organic matter). It is important to include such factors to ensure that false conclusions are not drawn due to certain factors being overlooked.

3.5.1 Biotic Monitoring

Monitoring of the plots for species present continued biweekly throughout the spring and summer of 2006, ending on September 1, 2006. This monitoring served the main purpose of identifying invasive species for eradication, but also identified some of the native species growing naturally in the experimental plots (Table 2). Percent cover was also noted throughout this monitoring period (Figure 6). During this same time, the transplants, once secured in the experimental plots, were also monitored for health and survivorship. Monitoring slowed to about once per month through the fall and winter months, when *E. americanum* and *P. peltatum* were only present underground and the aboveground biomass of *C. thalictroides* had died back or was very minimal. The fall and winter monitoring consisted simply of assessing the state of the forest and looking for any signs of degradation by mountain bikers (there was none). Monitoring commenced again on April 23, 2007, and consisted of counts and descriptions of the plants which returned from the previous year's planting. These counts continued until May 30, 2007, and provided the data to answer the questions put forth in this experiment. Section 3.7 describes the means by which the 2007 return counts of transplants were analyzed for statistical significance. Also included in the 2007 monitoring season were counts of the additional plants which were found unexpectedly in some experimental plots, determination of the origin of such plants (seed or clone) through examination of their underground root systems, as well as fruit counts for all sexual individuals.

Table 2. Native species encountered within the plots between April and August 2006 on a biweekly basis and their overall abundance (rating taken from Larson 1996).

| Plant (Latin name)	Qualitative Abundance Rating Within Plots
Arisaema triphyllum	Abundant
Circaea lutetiana	Abundant
Grass species (var.)	Abundant
Cardamine concatenate	Frequent
Solidago flexicaulis	Frequent
Solidago Canadensis	Frequent
Allium tricoccum	Occasional
Sanguinaria Canadensis	Occasional
Hydrophyllum virginianum	Occasional
Parthenocissus quinquefolia	Occasional
Actaea rubra	Occasional
Polygonatum biflorum	Occasional
Moss spp. (var.)	Occasional
Dicentra cucullaria	Rare
Actaea pachypoda	Rare
Smilacina racemosa	Rare
Erigeron philadelphicus	Rare
Maianthemum canadense	Rare
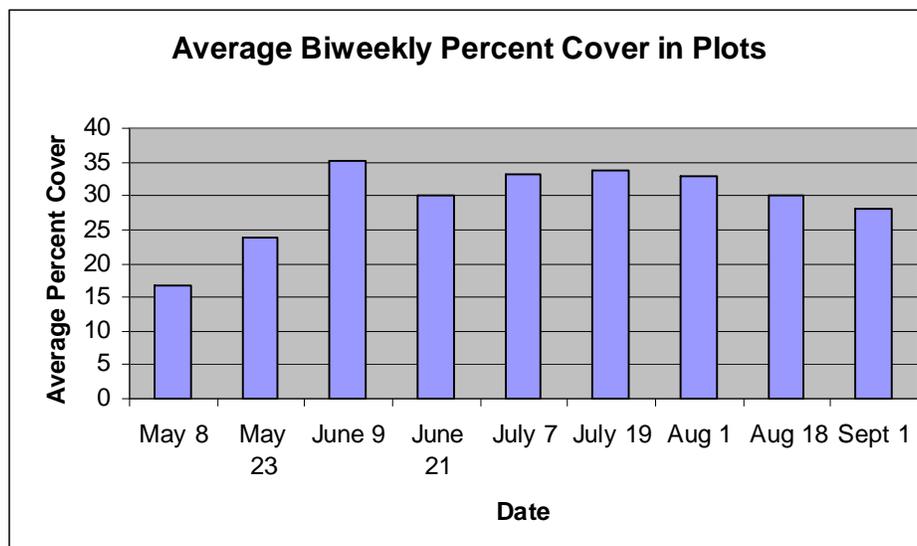
Figure 6. Average percent cover by native species in all plots on a biweekly basis throughout the 2006 growing season.

3.5.2 Abiotic Monitoring

The abiotic monitoring consisted of examination of the abiotic features chosen for analysis in this study, which were soil pH and soil organic matter. Some preliminary methods of abiotic analysis for soil nutrients were also carried out, but they were eventually determined as too simplistic for inclusion in the soil analysis section of this thesis. Budgetary constraints limited the use of more sophisticated soil analysis techniques, but future studies similar to this project would certainly benefit from the use of more rigorous soil analysis methods. For reference, the results of the preliminary soil nutrient analysis can be found in Appendix A.

3.5.2.1 Soil Organic Matter Analysis

Once every month from May to August 2006, soil was sampled in blocks 1-4. This sampling involved choosing four random spots within each of the four blocks and using a soil auger 18.7 cm deep. This soil was then placed into paper bags and immediately frozen at a temperature of -18°C for analysis in October/November 2006. At this time, the soil samples were analyzed ten or twelve at a time for determination of percent soil organic matter. The samples were removed from the freezer and immediately placed into crucibles which were then dried in a Gallenkamp Model OV-400 oven for at least 12 hours at 105°C. After this time, the samples were ground with a mortar and pestle into the consistency of a fine powder. These tests were carried out in seven rounds, using either ten or twelve samples at a time until all 64 soil samples were analyzed.

The organic matter content of the soil was analyzed by obtaining 5g of the dried, ground soil by carefully weighing it on an analytical balance. The soil was then placed into pre-weighed crucibles which had been scrupulously dried in a Lindberg Model 51894 muffle oven at 550°C, and adequately cooled. The crucibles with soil were then placed back in the muffle oven at the same temperature for an hour, cooled for 20 minutes in the 105°C oven and then weighed again. Any organic matter present in the soil samples was burned off in the oven, and thus the difference in weight was representative of the organic matter originally present in the soil. From this a measure of percent organic matter was obtained for further analysis.

3.5.2.2 Soil pH Analysis

In the months of May, June, July and August, soil pH was measured in the field by selecting twelve random spots in each block and pushing the cone-shaped 1.3 cm diameter probe of a portable pH meter 1.5 cm deep into the top layer of the soil. The readings were recorded for later

statistical analysis. The purpose of these abiotic measures was to determine if there were any significant differences in the blocks which might later account for differences in the results gained in the 2007 field season about which plants returned and which did not.

3.6 Statistical Analysis of Soil Data

Once the results for the two soil tests were obtained through the above methods, the results of the tests were analyzed statistically. The tests were first run through a multivariate ANOVA, which tested each of the soil factors (organic matter and pH) for significance against the fixed variables of Month (May, June, July, August) and Block (1, 2, 3, 4). This test also determined if interactions existed between month and block as well as the individual effects of block and month on the dependent variable being tested. When significant differences ($p<0.05$) were found in either of the variables being tested further post-hoc testing was done, using an LSD test, which assumes equal variance. This further testing illustrated the exact month or block where significant differences existed in the data. This information was later taken into account when considering the results of the overall survivorship for the transplanted species.

3.7 Statistical Analysis of Survivorship Data

The second season survivorship data was first analyzed for variation between the different treatments. Thus, the seven different treatments were analyzed, using the presence of each experimental treatment across the four blocks as replicates. After this, all eight experimental treatments were analyzed, including the control treatment. All statistical analysis was performed using SPSS v. 14.0 (SPSS Inc., Chicago, Illinois). The studentized residuals were first graphed in a Q Q Plot to determine if the data was a close enough fit to the normal distribution, a consideration taken due to the repeatedly high percentages of return rates obtained in the 2007 growing season. However, the points graphed onto the Q Q Plot were clustered around the straight line, indicating normality could be assumed for this analysis and non-parametric testing was not required. Then, a univariate ANOVA was performed, with Return Rate as the dependent variable and Treatment as the fixed factor, with a significance criteria of $p<0.05$. When significant differences were noted, a post-hoc LSD test was performed to determine where the significant differences existed.

The second season survivorship data was analyzed next for variation between the four blocks, or block effects. The individual return rates for each species, within each treatment, were used as

the replication (see Table 3). The control treatment was left out of the analysis, as the numbers returned were consistent zeros and it was obviously quite different than the experimental treatments in which plants were deliberately introduced into the plots and survived at rates of 92-100%. The studentized residuals were first graphed on a Q Q Plot and it was determined that the distribution of points around a straight line was enough to claim that the data was normally distributed. A univariate analysis of variance was then applied to the data with Return Rate (for each species in each treatment) as the dependent variable and Block as the fixed factor, with a significance criteria of $p < 0.05$.

Chapter 4

Results

4.1 Introduction to Results

The following chapter will provide an outline of all the results obtained in this experiment, both in terms of field outcomes and the outcome of all statistical analyses. A description and graphical analysis of first season survivorship is presented foremost. Following this is a thorough report on the second season survivorship for each of the three species: *E. americanum* (92% return rate), *P. peltatum* (97% return rate) and *C. thalictroides* (100% return rate). The results of each of the eight treatments are presented, as are the statistical analyses performed on the treatment data. The results of the soil data analysis with regard to both blocks and months are reported in this section, along with the results of the statistical analysis of plant return rates within the blocks. This chapter also reports on some unexpected trends such as increased numbers of sexual plants, changes in fruit production and the appearance of extra plants in experimental plots between the two growing seasons.

4.2 First Season Survivorship Data

It was initially hypothesized that the first season survivorship data would be mostly indicative of the survivorship which could be expected in the second field season. However, based on the high percentage survivorship in the second field season it is now known that the sharp dieback experienced in the first field season was not correlated to the success of the transplanted species the following spring. In the first year, *E. americanum* had the lowest survival rate, with all plants dying back within 2-4 weeks after transplant. *Podophyllum peltatum* showed a decline in surviving plants to approximately half of all individuals planted towards the end of the growing season. *Caulophyllum thalictroides* died back relatively quickly once August arrived, though the plant is known to survive naturally right up until the end of summer. The following provides a more thorough description of the results encountered during the 2006 field season with regard to all three transplanted species.

4.2.1 *Erythronium americanum* Survivorship

The *E. americanum* transplants appeared to be the least successful of the three species used, based on the first season survivorship data. In the first week after transplant, 59 of the 72 individuals planted were alive. However, it should be noted that the transplants in Block 3 were actually performed on this day, meaning all plants were assessed as 'alive' which potentially falsely inflated the appearance of the live count on this week. In the biweekly periods following the transplant, the numbers of live *E. americanum* dropped off quickly, with only 7 plants alive during the May 23 assessment and 0 plants alive by June 9 (Figure 7). Because the majority of the *E. americanum* transplants actually returned in the 2007 field season, it is now known for certain that the 2006 loss of *E. americanum* was due to different factors rather than the unsuitability of this species for transplant. It is possible that the plant was experiencing natural dieback, as it is a spring ephemeral which tends to thrive mainly from mid-April to mid-May. It is also possible that the seemingly early dieback was a symptom of transplant stress, as water is often the limiting factor in transplant success. If this was the case, *E. americanum* died back in order to conserve water and nutrients so it could make a more successful return in the following season.
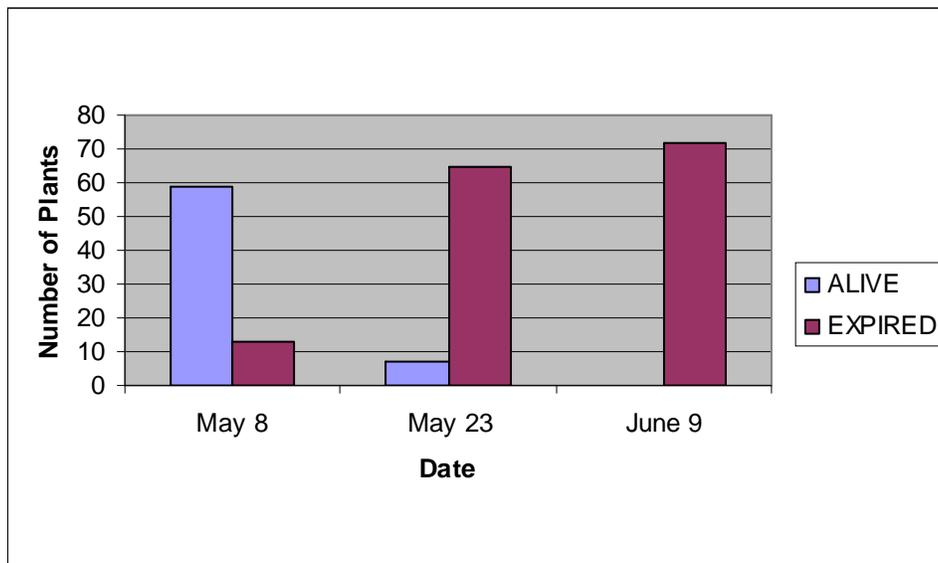
Figure 7. Graphical representation of total *Erythronium americanum* survivorship in spring 2006 from one week after transplant

4.2.2 *Podophyllum peltatum* Survivorship

The *P. peltatum* transplants were the most successful throughout the 2006 growing season, showing a survival rate greater than 50% throughout the summer until the final week of

assessment (Figure 8). In the first week after transplant, 70 of 72 plants remained, with the only two fatalities caused by animal digging and physical damage to the stem of the plant respectively. For each of the following weeks the number decreased gradually but it remained consistent that the *P. peltatum* transplants were keeping at least a 50% survivorship rate. The plants senesced slowly throughout the summer, and the majority were desiccated, discoloured and dying back by the final week of the survivorship assessment in September 2006. Because the other *P. peltatum* individuals in the forest seemed to be following the same pattern of dieback, it was inferred at the time that the decline of *P. peltatum* was due to natural dieback and not transplant failure. Based on the second season results this was a good assumption, as all but two of the *P. peltatum* transplants returned in the 2007 growing season, and one of the plants which didn't return was the mentioned digging fatality from the 2006 growing season.
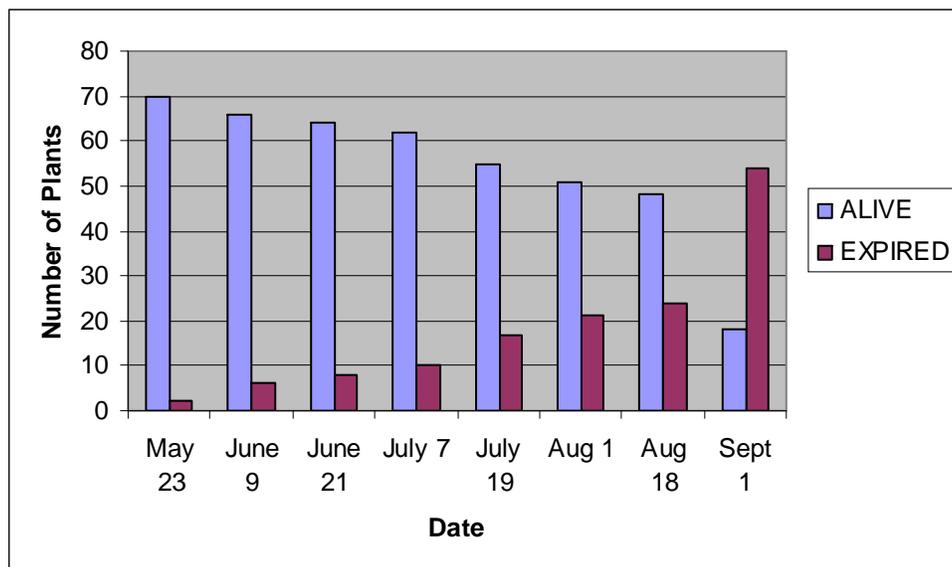
Figure 8. Graphical representation of total *Podophyllum peltatum* survivorship in spring/summer 2006 from one week after transplant

4.2.3 *Caulophyllum thalictroides* Survivorship

The *C. thalictroides* transplants were quite successful through the months of June and July 2006, maintaining a survival rate of over 50% (Figure 9). After the first week in August, however, the numbers decreased rapidly. Plants which had been senescing slightly throughout the summer months suddenly turned completely yellow or brown and died back. A majority of the *C. thalictroides* plants were expired by the last assessments in August and September (19-20 plants out of 32). Of the plants alive, many showed the same symptoms of the expired plants

(discolouration, loss of leaves, desiccation) but were recorded as 'alive' due to the presence of healthy viable fruit at the ends of their shoots. Based on the 2007 survivorship results, with *C. thalictroides* returning at an impressive 100% rate, the assumption that the presence of fruit indicated the plants were not, in fact, dead was an acceptable one.
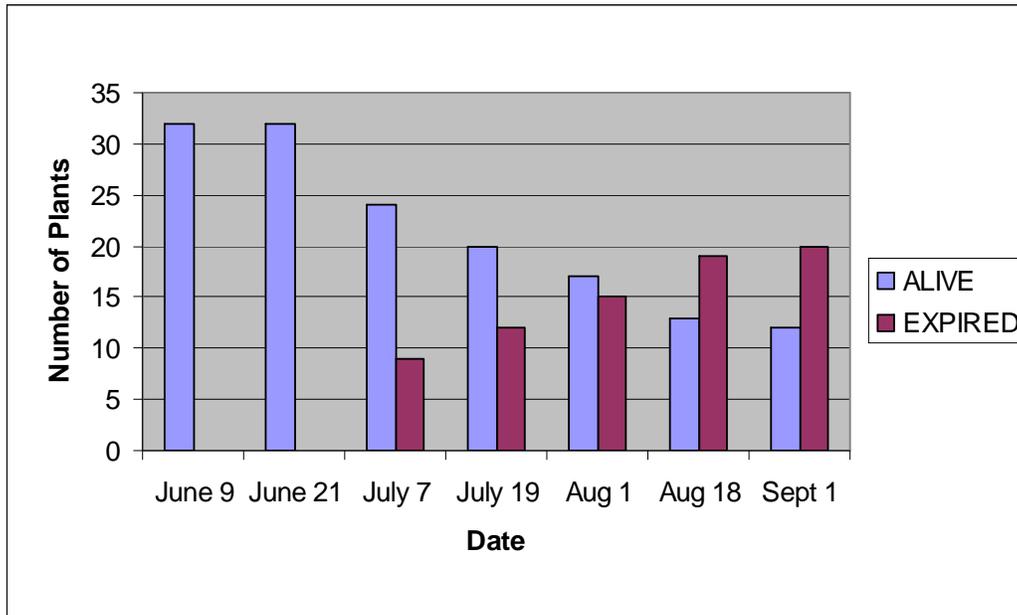
Figure 9. Graphical representation of total *Caulophyllum thalictroides* survivorship in spring/summer 2006 from one week after transplant

4.3 Second Season Survivorship Data

The second season survivorship data is presented in the following in terms of species, treatments, and blocks.

4.3.1 Per species

The return rates for each of the three transplant species are presented in the following three sections as both raw numbers and percentages. The plant with the highest survivorship in the 2007 growing season was *C. thalictroides*, followed closely by *P. peltatum. Erythronium americanum* had the lowest return rate, though the number was still actually quite high. Figure 13 depicts the return and survivorship rates for the 2007 plants through the observation period of April 23, 2007 to May 30, 2007.

4.3.1.1 *Erythronium americanum* Survivorship

It was initially expected that the survivorship of *E. americanum* in the 2007 growing season would be quite low, based on the sharp dieback of these plants in the 2006 season. However, the numbers were actually quite impressive and comparable to the other species planted. The number of live *E. americanum* return transplants peaked on Wednesday, May 15, 2007 with an impressive total of 66/72 individuals thriving in the experimental plots. Therefore the success rate of *E. americanum* was approximately 92% in this experiment. A 2007 return *E. americanum* transplant is pictured in Figure 10.

Figure 10. An *Erythronium americanum* transplant returned in the early spring of 2007.

4.3.1.2 *Podophyllum peltatum* Survivorship

Based on the results of the 2006 field season, *P. peltatum* was expected to perform quite well in the 2007 season, and it lived up to these expectations. *Podophyllum peltatum* returned at a rate of 70/72 plants, or about a 97% success rate. One of the two plants that did not return (one of the

individuals in Block 3, Treatment 2) was the individual noted in the 2006 season which was dug out of the ground and desiccated beyond return to health before it was discovered and replanted. One other individual did not return (in Block 3, Treatment 5) for unknown reasons. Two early *P. peltatum* plants are pictured in Figure 11.

Figure 11. Two *Podophyllum peltatum* transplants returning in the early spring of 2007

4.3.1.3 *Caulophyllum thalictroides* Survivorship

Caulophyllum thalictroides performed fairly well in the 2006 field season, and was expected to return at a rate between 50%-100% based on the number of live plants and presence of live fruit on several of the early-senescing plants in 2006. However, this species performed unexpectedly well, returning at a rate of 100% success, with all 32 plants thriving in the 2007 field season. An early *C. thalictroides* transplant returning in 2007 is pictured in Figure 12.

Figure 12. A *Caulophyllum thalictroides* transplant returning in the early spring of 2007.
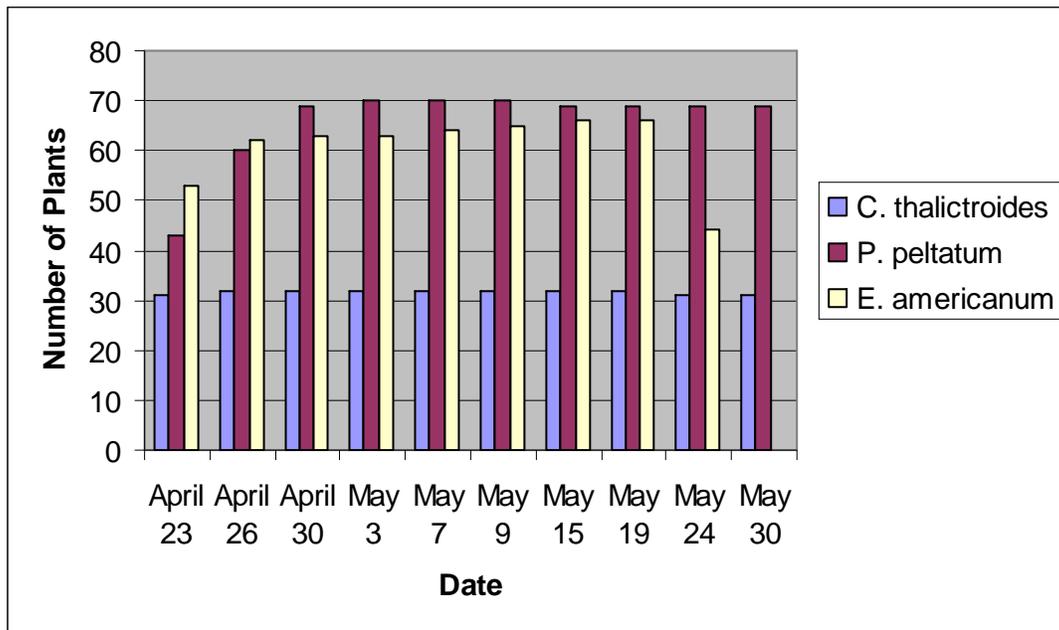
Figure 13. Graphical representation of survivorship of *Caulophyllum thalictroides*, *Erythronium americanum* and *Podophyllum peltatum* in spring 2007 throughout the monitoring period of April 23 to May 30.

4.3.2 Per treatment

Each treatment was analyzed in the 2007 growing season to assess the return rates of each of the transplants in their varying combinations. The following describes both the raw numbers for return rates, and the average return rate as a percentage for each species. The actual breakdown of each species' return rate within its treatment can be seen in Table 3.

4.3.2.1 Treatment 1

Treatment 1, the treatment consisting solely of six *E. americanum* transplants, showed return rates of 6/6 individuals (Blocks 1, 2 and 4) or 5/6 individuals (Block 3), with an overall success rate of 95.8%.

4.3.2.2 Treatment 2

Treatment 2, the treatment consisting of a combination of three *E. americanum* transplants and three *P. peltatum* transplants, showed a less consistent return rate of 3/6 (Block 1), 5/6 (Block 3) or 6/6 plants per plot (Blocks 2, 4). The *E. americanum* returned at a rate of 0/3 in Block 1, but at an otherwise constant rate of 3/3 plants (Blocks 2, 3, 4) while the *P. peltatum* returned at a rate of either 3/3 (Block 1, 2, and 4) or 2/3 (Block 3). The average return rate for this treatment was 83.3%.

4.3.2.3 Treatment 3

Treatment 3, the treatment consisting solely of six *P. peltatum* transplants, showed a constant return rate of 6/6 plants in all of Blocks 1, 2, 3, and 4, for an average return rate of 100%.

4.3.2.4 Treatment 4

Treatment 4, the treatment consisting of a mixture of two *C. thalictroides* transplants and six *E. americanum* transplants showed return rates of 8/8 (Blocks 1 and 4) or 7/8 (Blocks 2 and 3) plants per plot. The *E. americanum* plants returned at the variable return rate of 5/6 or 6/6 plants per plot, while the *C. thalictroides* plants remained steady at a return rate of 2/2 in each plot. The average return rate for this treatment was 93.8%.

4.3.2.5 Treatment 5

Treatment 5, the treatment consisting of a mixture of two *C. thalictroides* transplants and six *P. peltatum* transplants showed return rates of 8/8 (Blocks 1, 2 and 4) or 7/8 (Block 3) plants per plot. The *P. peltatum* plants returned at the varying rates of either 5/6 or 6/6 plants per plot, while the *C. thalictroides* plants returned at a steady rate of 2/2 plants per plot. The average return rate for this treatment was 96.9%. An example of the success of this treatment is pictured in Figure 14.

Figure 14. The successful return of both *Caulophyllum thalictroides* and *Podophyllum peltatum* in Block 4, Treatment 5, and a surplus of overall aboveground biomass in the plot in the 2007 growing season.

4.3.2.6 Treatment 6

Treatment 6, the treatment consisting solely of *C. thalictroides* transplants showed a constant return rate of 2/2 plants per plot in all four blocks. The average return rate for this treatment was 100%.

4.3.2.7 Treatment 7

Treatment 7, the treatment consisting of a mixture of three *E. americanum*, three *P. peltatum* and two *C. thalictroides* transplants showed a constant return rate of 8/8 plants per plot in all four blocks. The average return rate for this treatment was 100%.

4.3.2.8 Treatment 8

Treatment 8, the control treatment in which no species were transplanted, demonstrated no change between the 2006 and 2007 growing season with regard to the appearance rate for any of the three experimental species in the control plots across all blocks was 0%.

Table 3. Second season survivorship rates of all three species grouped into their respective blocks and experimental treatments (*E. a = Erythronium americanum*, *P. p = Podophyllum peltatum*, *C. t = Caulophyllum thalictroides*)

	BLOCK 1			BLOCK 2			BLOCK 3			BLOCK 4		
	E. a	*P. p*	*C. t*	*E. a*	*P. p*	*C. t*	*E. a*	*P. p*	*C. t*	*E. a*	*P. p*	*C. t*
TRT 1	6/6	-	-	6/6	-	-	5/6	-	-	6/6	-	-
TRT 2	0/3	3/3	-	3/3	3/3	-	3/3	2/3	-	3/3	3/3	-
TRT 3	-	6/6	-	-	6/6	-	-	6/6	-	-	6/6	-
TRT 4	6/6	-	2/2	5/6	-	2/2	5/6	-	2/2	6/6	-	2/2
TRT 5	-	6/6	2/2	-	6/6	2/2	-	5/6	2/2	-	6/6	2/2
TRT 6	-	-	2/2	-	-	2/2	-	-	2/2	-	-	2/2
TRT 7	3/3	3/3	2/2	3/3	3/3	2/2	3/3	3/3	2/2	3/3	3/3	2/2
TRT 8	-	-	-	-	-	-	-	-	-	-	-	-

4.3.2.9 Analysis of Variance Between Treatments

The following output was obtained from the analysis of variance of each treatment using the replications between blocks to yield four replicates of each treatment. A significant difference between treatments produces a p-value of <0.05. When the analysis was run, it was proven that there were no significant differences between any of the seven treatments (p=0.264) (Table 4). When the data was re-analyzed using all eight treatments a significant difference was noted in the ANOVA (p<0.001) and the post-hoc LSD test showed that Treatment 8 (the control treatment) was significantly different from each of the seven transplant treatments (Table 5).

Table 4. Outcome of Analysis of Variance for the seven experimental treatments, showing degrees of freedom, mean square, F and significance.

Source	d.f.	MS	F	Sig.
Treatment	6	.014	1.392	.264
Error	21	.010		
Total	28			

Table 5. Outcome of Analysis of Variance for the eight experimental treatments, showing degrees of freedom, mean square, F and significance.

Source	d.f.	MS	F	Sig.
Treatment	7	.470	52.499	.000
Error	24	.009		
Total	32			

4.3.3 Per Block

The blocks in the study were statistically analyzed with regard to two factors. The first factor is the soil, which was analyzed, as mentioned, for both pH and organic matter content. The second factor is the return rate, measured by comparing the return rates of each species across the blocks.

4.3.3.1 Per Block: Soil

As mentioned in section 3.6 organic matter and pH were tested for significant differences across the four experimental blocks. There were no significant differences between the blocks for pH (p=0.451). However, there were significant differences between the blocks for percent organic matter content (p=0.012) (Table 6). The LSD post-hoc test demonstrated between which blocks the significant differences lay. Percent organic matter was found to be higher in Block 3 than in Block 2 (p=0.006) and Block 4 (p=0.003) (Figure 15). Organic matter was not significantly different between Block 1 and Block 3, Block 1 and Block 2, Block 1 and Block 4 or Block 2 and Block 4.

Table 6. Outcome of Analysis of Variance for soil organic matter (%) and soil pH against blocks, showing degrees of freedom, mean square, F and significance (indicated with an *)

Source	Dependent Variable	d.f.	M.S.	F	Sig.
Block	O.M.	3	30.405	3.941	.012*
	pH	3	.002	.891	.451
Error	O.M.	60	7.715		
	pH	60	.002		
Total	O.M.	64			
	pH	64			
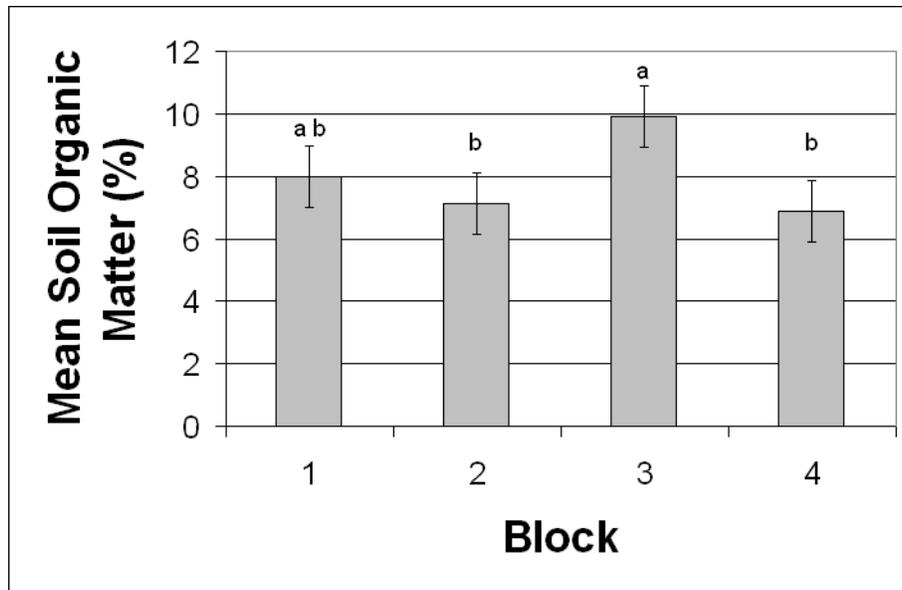
Figure 15. Mean soil organic matter percent per block, with error bars representing standard deviation. Letters above the data points represent results from post hoc contrasts. Completely different letters indicate significantly different means.

4.3.3.2 Per Block: Return Rate of Plants

To determine if there were significant differences between the blocks in terms of return rate of the transplanted species, a univariate ANOVA was used. Using the individual return rates for each species within each treatment as replications for each block, it was found that there were no significant differences between the blocks (p=0.491) (Table 7). This result was as expected, because the total return rates in the blocks fell within the narrow range of from 91% - 100%.

Table 7. Outcome of Analysis of Variance for the four blocks, showing degrees of freedom, mean square, F and significance.

Source	d.f.	MS	F	Sig.
Block	3	.020	.818	.491
Error	44	.025		
Total	48			

Because the tests for differences between blocks regarding the return rate of the transplant species showed that there were, in fact, no significant differences it was not necessary to perform any further analysis, such as regression analysis on the soil and plant data. Though organic matter content could in theory affect the growth of the plants, there were in fact no significant

differences between the blocks with regard to the plants, meaning this effect was likely not occurring.

4.4 Sexual/Vegetative Discrepancies

In 2006, 22 of the 72 *P. peltatum* plants used in the experiment were sexual (bearing two leaves and the capacity to bud, flower and fruit), while the other 50 plants were asexual (having only one leaf and no capacity to reproduce through pollination). It was interesting to note that in the 2007 growing season, 53 of the 76 (number increased because it includes extra plants, discussed in section 4.6.2) *P. peltatum* plants which emerged were sexual, and the remaining 23 plants were asexual. The percentage of sexual plants shot up significantly from 31% to 70% within a matter of one year. There was no count of the number of *C. thalictroides* plants which flowered in the 2006 field season, which is the main method of identifying if a plant is sexual or asexual. The reason for this lack of data was that the plants were moved well past their flowering stage in 2006. It is possible that the plants switched from sexual to asexual or vice versa between the growing seasons, but this cannot be declared with certainty. All *E. americanum* plants were planted as asexual individuals, and all returned as asexual individuals.

4.5 Fruit

It was thought that due to the sharp increase in sexual individuals of *P. peltatum* in 2007 that there would be greater numbers of fruit produced by these plants. Of the 22 sexual individuals in 2006, 16 plants, or about 73%, produced fruit. However, even though there were 53 sexual individuals in 2007, only 9 of these, or about 18% produced fruit. The remaining plants were either unable to flower, or flowered and were not fertilized, or were unable to carry the fertilized ovary to maturation. In summation, the potential for sexual individuals to produce fruit in 2007 was drastically reduced from 2006.

In 2006 13 of the total 32 *C. thalictroides* plants used in the experiment produced fruit, or about 41% of the total number of plants (as no sexing was possible in this season). In 2007, the plants were able to be sexed based on the presence of flowers (results may not be 100% accurate in the case of sexual plants which were unable to flower). Of the 21 flowering plants in 2007, 13 produced fruit (41% of total plants, 62% of sexual plants). The location of the fruiting plants in 2006 were noted and it was determined that the same 13 plants did not produce fruit between the

two years. In summation, the fruiting potential of the blue cohosh used in the study remained steady between the two growing seasons.

4.6 Additional Plants in Plots

In several of the plots in which the transplanted species returned at a 100% success rate, extra plants of the same species were encountered. The actual numbers are presented below with regard to each of the three experimental species.

4.6.1 *Erythronium americanum*

In twelve of the thirty-two experimental plots, one to four additional *E. americanum* individuals per plot were observed in the spring of 2007 (Table 8). Three of the twelve plots were those in which *E. americanum* was planted into as an experimental treatment, a fact which lent itself to the possibility that the original transplants were producing clones via underground spread of rhizomes from the corm. The underground root systems of the plants in plots where *E. americanum* was transplanted were carefully examined, and analyzed for connections via underground rhizomes, which would indicate asexual/clonal spread. However, no underground connections were found between any of the *E. americanum* plants. This finding leads to the conclusion that all extra *E. americanum* individuals in the experimental plots were borne of the soil seed bank, independent of the outcome of the *E. americanum* transplants.

Table 8. Number of additional E. americanum individuals found in experimental plots in 2007 (plots marked with an asterisk are those in which E. americanum was transplanted into in 2006)

	BLOCK 1	BLOCK 2	BLOCK 3	BLOCK 4
Treatment 1	1*	0	0	0
Treatment 2	0	0	0	0
Treatment 3	0	4	3	1
Treatment 4	0	0	0	1*
Treatment 5	1	0	0	1
Treatment 6	1	3	0	4
Treatment 7	1*	0	0	0
Treatment 8	0	0	0	0

4.6.2 *Podophyllum peltatum*

In four of the thirty-two experimental plots, additional *P. peltatum* individuals were counted. These plots had all been assigned the *P. peltatum* transplant treatment in 2006, and no extra *P. peltatum* individuals were found in plots not assigned this treatment. In all four of the cases, all original transplant specimens returned and one or two of the original transplants gave rise to a new sister *P. peltatum* plant (e.g. Figure 16). This was determined by exposing the underground root system of the plants in question and following rhizomes from the original plant to the new plants to prove their origin.
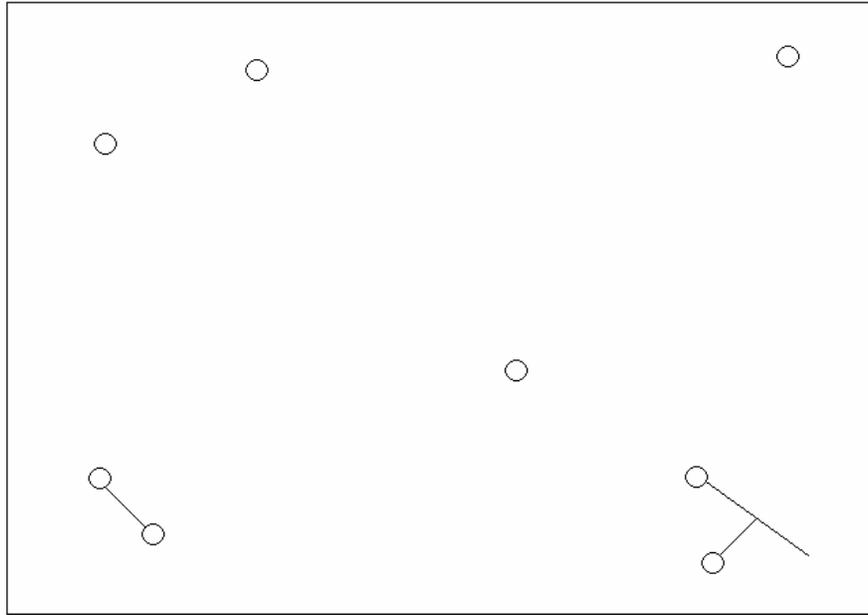
Figure 16. A diagrammatic representation of the rhizomatous connections between original *P. peltatum* transplants and the clonal plants they spawned in 2007, in Block 4, Plot 8

4.6.3 *Caulophyllum thalictroides*

No additional *C. thalictroides* individuals were found in any experimental plots.

4.7 Temporal Changes in Soil at the Study Site

The results of the two-way ANOVA on the effects of blocks and months on the two soil factors measured (organic matter content and pH) revealed that there was no significant interaction between blocks and months. With regard to each of the independent factors, organic matter showed no significant changes between months (May, June, July, August) (p=0.438) while pH was found to be significantly different across these months

(p<0.001). This means that the levels of soil organic matter were stable enough between the observation periods to not warrant further investigation into their effects, or conclusions about the effect of this factor on the project. However pH was further analyzed by means of a post-hoc LSD test and the months where differences in pH levels existed were identified (Table 9). In the month of May, pH was significantly higher in all blocks than in the month of August (p=0.027) (Figure 17). In the month of June the pH was significantly higher in all blocks than it was in the months of July (p<0.001) and August (p<0.001). pH was not significantly different between May and June, May and July or July and August (p values were not less than 0.05).

Table 9. Outcome of Analysis of Variance for soil organic matter (%) and pH against months, showing degrees of freedom, mean square, F and significance (indicated with an *)

| Source	Dependent Variable	d.f.	M.S.	F	Sig.
Month	O.M.	3	8.100	.917	.438
	pH	3	0.010	7.167	.000*
Error	O.M.	60	8.830		
	pH	60	.001		
Total	O.M.	64			
	pH	64			
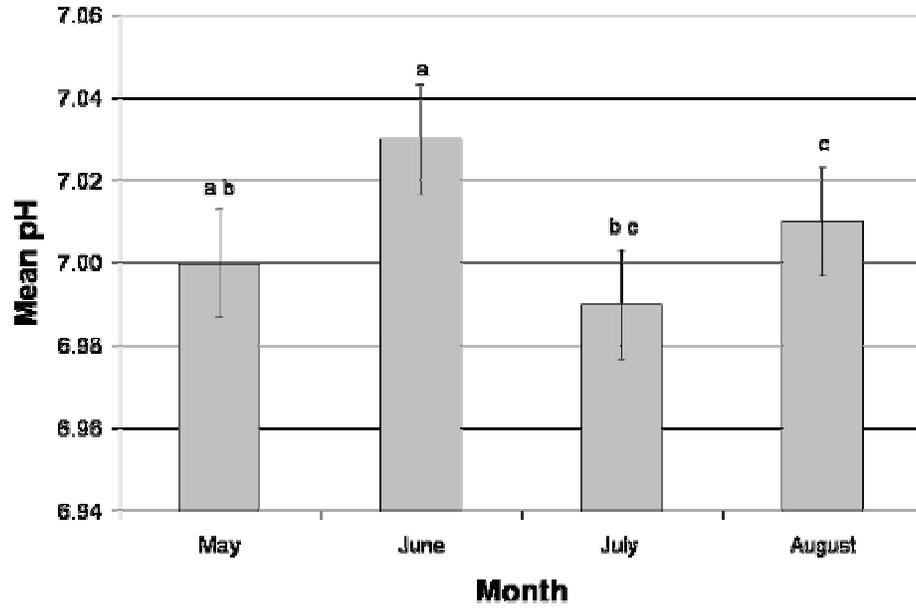
Figure 17. Mean pH per month, with error bars representing standard deviation. Letters above the data points represent results from post hoc contrasts. Completely different letters indicate significantly different means.

Chapter 5

Discussion and Conclusions

5.1 Introduction to Discussion

A discussion of the results of the main research question, which addresses the usefulness of combinations in restoration, will be addressed first, followed by some thoughts on each of the species used in this experiment. The lack of block effects found in this study will be discussed next. Following this will be some discussion of the unanticipated results found in the second growing season including sexual/asexual discrepancies and extra plants in the experimental plots. Next, the temporal abiotic changes to the site will be examined concurrently with the phenology of the experimental species used. An assessment of this experiment's contribution to progress in early restoration will be presented, followed by recommendations for restoration practitioners and also recommendations for future research.

5.2 Usefulness of Combinations

The main research question to be answered by this experiment was: Will various combinations of the three native forest species *Erythronium americanum, Podophyllum peltatum* and *Caulophyllum thalictroides* differ in the progress of early restoration of a degraded upland hardwood forest in Kitchener, Ontario? Eight treatments involving differing combinations of the three experimental species and one control treatment were implemented across four blocks within the study area. The success of each of the transplant treatments was examined statistically in section 4.3.2.9 and it was found that there were no significant differences between any of the seven treatments. Therefore, it can be concluded that any of the three plants used in this study can be selected and planted in any combination (alone, in pairs, or all three) in a forest which is geographically similar, similar in species composition, and has a degree of degradation alike to Natchez Hills. It was also found that significant differences existed between each of the seven transplant treatments and the one control treatment, which indicates that the restoration effort was having a significant impact on the forest. This is because the control treatments demonstrated the inability of the area to regenerate any of the experimental species used without the intervention of active restoration which proved so successful in the other seven treatments.

Though it was initially hypothesized that the combination of all three species would be the most successful due to some literature indicating positive interactions between plant species (Callaway 1995; Bruno et al. 2003; Brooker 2006), it is actually beneficial that no significant differences were observed between any of the treatments. This is because the recommendation to use all three species in future restoration experiments exposes a project to a variety of restraints. Some of these restraints include the availability and abundance of all three species for transplant, the extra labour involved in scouting, growing or transplanting three different species from potentially different locations, and the time constraint based on the variable optimal times for transplant of each species (e.g. *E. americanum* in April, *P. peltatum* in early May, *C. thalictroides* in late May). If time, labour and other such factors are available, Treatment 7 (the combination of all three species) could certainly be used, but if these limiting factors exist in a particular restoration effort, it is just as acceptable to use only one or two of the three different species.

It is important to note that while these three species were quite effective in creating progress in early restoration, this answer cannot necessarily be applied to longer term studies which aim to understand restoration over several years, or decades, and/or focus on the long-term functional dynamics of combinations. Though combinations and single-species plantings were found to be statistically alike in their success, this success is based only on a two-year structural restoration study. It does not address functionality of combinations with regard to nutrient dynamics, mycorrhizal interactions, pollination biology, or any of these more complex factors which actually address the much broader ecological idea of facilitation, or positive interactions between species.

Facilitation is defined as the positive impact of one plant on another plant which can improve the recruitment, survival and reproduction of the beneficiary individual (Sthultz et al. 2007). In recent years, facilitation has been receiving nearly as much attention in the literature as competition, and it has been suggested that positive interactions have been to date sorely overlooked in both primary literature and ecological theory (Callaway 1995; Bruno et al. 2003; Brooker 2006; Cheng et al. 2006). Some means by which facilitation can occur are: increased shading, increased nutrient availability, increased soil stabilization (Callaway 1995; Cheng et al. 2006; Sthultz et al. 2007) increased soil moisture, soil oxygenation, protection from herbivores and increased pollination in co-flowering species (Callaway 1995). These many different positive interactions are controlled by mechanisms which are not yet entirely understood or able to be

accurately measured. Often the initiation of facilitation (or competition) is controlled by very subtle differences between plants in terms of palatability to predators, tolerance to abiotic stress, or ecophysiology (Callaway 1995). Facilitative reactions can be both direct (e.g. amelioration of a harsh environmental condition such as too much light via provision of shade) and indirect (e.g. introduction of soil mycorrhizae or microbes) (Callaway 1995); as well they can be both specific or more diffuse (Callway 1995; Brooker 2006). On a broader scale than at the individual plant level, these facilitations can eventually scale upwards to alter community, population and ecosystem structure and function (Callaway 1995; Brooker 2006; Cheng et al. 2006). Only when a clearer understanding of facilitation is achieved will a more thorough understanding of ecosystem structure and dynamics be gained.

Based on this information, the use of combinations in restoration could in theory be a more effective planting strategy than single species plantings, as observed to date to a minimal extent in the literature (Fattorini 2001, Castro et al. 2002). However further testing would need to be done over a longer time period to determine this in certainty. Based on the results of this study alone, the solitary use of any of the three species would be just as beneficial as combining the species. Yet there is obviously a larger field of knowledge which could be tapped into to answer questions about combinations more decidedly. Recommendations for future studies about facilitation between combinations of plants to further restoration success are presented in section 5.10.

5.3 Overall Outcome of Transplant Species

All three species performed quite well in this experiment. *Caulophyllum thalictroides* came back at the highest return rate of 100%, *P. peltatum* followed at a return rate of 97%, and *E. americanum* showed a return rate of 92%. Statistical analysis could not be carried out to analyze differences between the species due to extremely low variance in the repeatedly near-perfect numbers in their return rates within the treatments. Therefore, it can be concluded that based on the high return rates, all three species are quite suitable for restoration efforts similar to the one carried out in this experiment. It is possible that *P. peltatum* and *C. thalictroides* had slightly elevated success rates based on some findings presented in the literature that plants which are larger in size do have an increased likelihood of survival in the first season after transplant (Page & Bork, 2005). However, because no statistical differences were present upon analysis, it is fair to equally recommend all three transplant species for future restoration efforts.

5.3.1 *Erythronium americanum*

With a seemingly early dieback in the 2006 growing season, *E. americanum* was anticipated to return at much lower levels in the 2007 season than the actual numbers which were observed. Though this plant is quite small and the connection between its epigeous body and underground corm is very fragile, it proved to be a very hardy species. Because this plant appears at the very commencement of the growing season, it can play an extremely important role in the vernal dam. Because of its usefulness to spring nutrient recapture, it was very promising to watch it thrive in the experimental plots and contribute to the vernal dam at the restored sites. Clearly *E. americanum* is extremely well-adapted to the harsher conditions of early spring and was as dominant and persistent as described in the ecological literature.

5.3.2 *Podophyllum peltatum*

Transplanting is known to often interfere with a plant's ability to successfully flower and produce fruit during the initial growing seasons (Boudry et al. 2002; Hellström et al. 2006). The stress imposed on a transplant can compromise its ability to successfully obtain and utilize the water and nutrients needed to carry out reproduction. In *P. peltatum*, the theory of transplant stress may have been accurate. In 2006, the number of sexual plants that flowered was a staggering 95%, but this number dropped to 77% in 2007. Fruit production was also reduced in the second growing season, with only 18% of sexual plants producing fruit, versus 73% in 2006. However, this result may just be temporary, and in future growing seasons this increased number of sexual individuals will prove to be more reproductively sound based on a greater overall potential to produce flowers and fruit. This incidence of improved reproductive ability over time for transplanted species was observed in a previous study on *Beta vulgaris* (wild beet) in which several plants that did not flower one year after transplant did flower the following year (Boudry et al. 2002). The reasons for this trend towards increased numbers of sexual plants will be discussed in more detail in section 5.5. In addition to improved sexual reproductive ability, *P. peltatum* was able to allocate resources into asexual reproduction, as several plants were able to produce new clonal *P. peltatum* individuals from their rhizomes. This will also be examined further, in section 5.6.

5.3.3 *Caulophyllum thalictroides*

Though limited information is available on *C. thalictroides*, it was used in a previous restoration effort, though saw only a limited success rate of 24% of transplants surviving (Singleton 1998). Low water was thought to be the predominant reason for the 76% mortality rate (Singleton 1998), and thus it is quite possible that the generous one-time irrigation applied to the *C. thalictroides*

transplants in this study was part of the reason these plants performed so well in Natchez Hills. As mentioned, transplanting can negatively affect a plant's ability to produce fruit and flowers after a transplant event. However, the opposite effect was observed in *C. thalictroides*, as several transplanted individuals seemed to pour their resources into producing fruit at the expense of the rest of the plant prematurely dying back. This occurrence is important to note for any future use of *C. thalictroides* in restoration: though the plants might appear to be struggling in the first season, they can still return and flourish in the following season.

5.4 Block Effects

The four blocks used in this study did have widely differing characteristics in terms of slope (none to steep), level of degradation (moderate to high), native vegetative cover (low to high) and invasive species vegetative cover (moderate to very high). However, it was found that there were no significant differences between the blocks (no block effects) with regard to how the transplant species flourished within them. This particular result has been noted in a previous experiment which also tested areas which differed in terms of their grade of slope, and vegetation composition, where it was found that survivorship was unaffected by the varying locations into which the transplants were implemented (Fattorini 2001). It should also be noted that the only soil factor found to fluctuate across the blocks was organic matter. However, since organic matter had a positive correlation with the level of degradation in the blocks, it is probable that this change was only a reflection of organic matter not being utilized in the more degraded blocks where less plants were present. Regardless, there were no differences in transplant survival, so the organic matter analysis is not of great importance to the results as it was clearly not affecting the survival of plants within the blocks.

These results indicate that any of the three experimental species can be successfully planted into a wide range of conditions, from an area on flat ground, with moderate levels of native vegetation and only moderate site degradation to an area on a sharp slope, with high levels of invasive species present and notable site degradation. The lack of differences between these areas in terms of the outcome of the transplant experiment actually shows the resilience and plasticity of the experimental species selected and indicates that they may be used in a wide variety of degraded locations. Section 5.10.5 presents some recommendations about how to further test just what type of extreme conditions these plants could be used in to still gain a successful restoration outcome.

5.5 Sexual/Vegetative Discrepancies between Seasons

The transplant specimens used in this study were not selected for the presence of flowers or fruit, thus the number of sexual vs. asexual individuals is only a symptom of the transplants being randomly selected within a certain range of sizes. However, it was noted in the 2007 field season that the numbers of sexual and asexual individuals in *P. peltatum* plants was different from the numbers in the 2006 field season, as mentioned in the results section.

5.5.1 *Podophyllum peltatum*

This occurrence is not uncommon in plants which can produce via both sexual and asexual means. Previous studies have examined cases of *P. peltatum* plants altering from year to year whether they produce either a sexual shoot or a vegetative aerial structure, which is an elongated petiole rather than a true "shoot" (Watson & Lu 1999; Jones & Watson 2001). Sexual and asexual individuals can be clearly distinguished by the presence of either one leaf (vegetative) or two leaves (sexual) (Sohn & Polincansky 1977; Laverty & Plowright 1988; DeKroon et al. 1991; Watson & Lu 1999; Jones & Watson, 2001). The number and type (sexual or vegetative) of shoots produced by a rhizome system is predetermined by the rhizome system based on a complex interaction of developmental events which affected the plant in the current and previous growing seasons (Geber et al. 1997; Watson & Lu 1999). The resource status of the plant, including rhizome content, fruit presence and shoot status, is also thought to affect the rhizome system's determination of what type of shoot to erect in the following growing season (Watson & Lu 1999; Jones & Watson 2001). The "decision" by the rhizome system to produce sexual rather than asexual shoots, an occurrence clearly observed in this project, may offer a certain benefit for the plant. Sexual shoots tend to produce leaves which are larger in area and senesce later than vegetative shoots (Jones & Watson 2001). These factors then allow a sexual plant a greater capacity to obtain and store more carbon than an asexual individual. This explanation provides an inference as to why several asexual *P. peltatum* individuals in this experiment returned as sexual individuals in the 2007 growing season. The opposite result (sexual plants returning as asexual plants) was observed, but not in nearly as high numbers, likely due to the advantage of sexual shoots over vegetative shoots.

5.5.2 *Caulophyllum thalictroides*

Very little information is available and very few studies have been performed on the reproductive biology of *C. thalictroides* (Hannan & Prucher 1996). Like *P. peltatum*, the shoots are either vegetative or sexual, and both emerge from a rhizome in the early spring (Hannan & Prucher 1996). Further inferences about this occurrence cannot be made based on the results of this study, because the *C. thalictroides* transplants were selected beyond the time of anthesis, and thus the exact number of sexual plants in 2006 is not available. It is possible that the plants switched between asexual and sexual forms between the two growing seasons, but it cannot be said for certain. Many of the plants which produced fruit in 2006 also produced fruit and/or flowers in 2007, but some did not, and some individuals which showed fruit in 2006 did not in 2007.

5.5.3 *Erythronium americanum*

Erythronium americanum did not produce any discrepancies between sexual and asexual plants between the 2006 and 2007 growing seasons. Like other truly spring ephemeral plants (those which grow only until the canopy closes), *E. americanum* is known to allocate many resources to vegetative growth and storage rather than sexual reproduction (McKenna & Houle 2000, Lapointe 2001). This is due to the fact that spring ephemerals are exposed to some of the harshest weather conditions because they grow so early in the season. Therefore, pooling resources into structures such as the corm of *E. americanum* (McKenna & Houle 2000) allows them to survive through even the most unfavourable conditions and persist as flourishing individuals into the following growing seasons.

5.5.4 Fruit

Though both *P. peltatum* and *C. thalictroides* have been reported to have low rates of fruit and seed production, and *P. peltatum* has been reported to grow less hardily when borne from seed, it is still important to note the fruiting rates in both species in this experiment.

5.5.4.1 *Podophyllum peltatum*

Usually *P. peltatum* is not particularly efficient in producing fruit, as the plant must pass several checkpoints before reaching the stage of carrying fruit to maturation. The first decision is whether to take a flower bud to anthesis, or abort it; the next is whether to produce fruit or not produce it; and the final decision is to abort the fruit or carry it to maturation (Watson & Lu 1999). Extremely low levels of seed set have been observed in some *P. peltatum* populations,

likely due to the low volume of pollinators which visit *P. peltatum* in comparison to other spring ephemerals (up to 10 times less) (Laverty & Plowright 1988). Generally only about 10% of the total number of sexual shoots will show fruit in a given growing season (Watson & Lu 1999). Therefore, it is quite impressive that 73% of the sexual *P. peltatum* transplants produced fruit before the end of the 2006 growing season, and notable that 12% of the returning *P. peltatum* plants produced fruit in the 2007 growing season. These numbers speak highly of the plant's role as a restorative species which shows little vulnerability to transplant shock, and was able to keep its reproductive ability at a level above that reported in the literature once it was transplanted.

5.5.4.2 *Caulophyllum thalictroides*

Pollination can be a limiting factor in the production of seed by *C. thalictroides* plants due to the fact that the flowers open extremely early in the season and pollinators tend to be scarce in the low temperatures of early spring (Hannan 1987). However, the plant is usually able to produce a significant amount of fruit, as witnessed by Hannan (1987) in southeast lower Michigan, who saw a seed set of 20% in one season, and by personal observation, where a seed set of 41% in 2006 and 41% in 2007 was observed in Natchez Hills.

Though there was no growth from seed witnessed in the 2007 growing season, it is possible that the *P. peltatum* and *C. thalictroides* seed distributed into the Natchez Hills seedbank in 2006 will germinate eventually and produce new plants. A previous study indicated that seed production is crucial in areas exposed to restoration efforts, to further enhance the restoration efforts by allowing the possibility of future seedling recruitment (Page & Bork 2005). Though vegetative growth appears to be the dominant method of spread for *P. peltatum*, and *C. thalictroides* did not spread at all, this study only spanned 2 years and it is impossible to predict what successes could occur in the upcoming years. Therefore, it is probably quite beneficial to transplant sexual individuals, and to use plants such as *P. peltatum* and *C. thalictroides*, who can offer an added layer of restoration success by donating viable seed to the seedbank, for potential germination in future years.

5.6 Additional Plants

In addition to plants returning with maintained or even greater potential to produce seed, there were also increased numbers of individual plants within the experimental plots. If more species are found in an experimental area than were initially planted there, it can be determined that

immigration is occurring (Fattorini 2001). It can generally be assumed that these immigrants originated from the restored species within the plots, or those species in adjacent restoration plots as both are viable sources for spread (Fattorini 2001).

5.6.1 *Erythronium americanum*

Erythronium americanum is a fairly common plant in Natchez Hills and thus it is not unusual that its seeds populate the soil seedbank and would randomly germinate throughout the blocks and plots in a year in which the weather and conditions were appropriate. The independence of the extra *E. americanum* individuals, initially determined by the unearthing of their corm and finding a lack of rhizomatous attachments, can be further asserted by the fact that none of the original transplants were seed-bearing specimens. Therefore, any of the *E. americanum* plants in the experimental plots would be unable to donate seed to the soil from which new plants could be borne. The additional *E. americanum* individuals in plots in which *E. americanum* was not transplanted can also be attested to germination from dormant seeds in the seed bank. This is because the new plants were not located near any other *E. americanum* plants, and when the root systems of several of these plants were examined it was determined that they were, in fact, growing independently within the plots.

5.6.2 *Podophyllum peltatum*

A very different case of additional transplant species in the experimental blocks was that of *P. peltatum.* The presence of additional *P. peltatum* individuals was entirely attributed to asexual reproduction, meaning the rhizome of the transplants branched underground and nodes on these branches gave rise to new, clonal individuals (Sohn & Policansky 1977; Watson & Lu 1999). It has been noted previously in the literature that in growth-limiting conditions it is common for plants which can reproduce both sexually and asexually to allocate more resources into clonal growth (Verburg & Grava 1998). This occurrence has the additional benefit of producing plants which tend to have higher growth rates and lower mortality rates than those produced through sexual means (Verburg & Grava 1998). Additionally, it has been noted that *P. peltatum* has a difficult and inefficient system of sexual reproduction (Maqbool et al. 2004). Its flowers are self-incompatible and are not particularly attractive to pollinators, its fruit set is poor, and when seeds are produced they remain dormant for a long period of time (Maqbool et al. 2004). Finally, when seedlings are produced they have poor survival rates in the wild, and remain juvenile for 4-5 years before producing a rhizome and initiating vegetative growth (Maqbool et al. 2004). These facts

all contribute to a further understanding of why the extra *P. peltatum* individuals in the plots were all vegetatively reproduced rather than grown from seed.

5.6.3 *Caulophyllum thalictroides*

No new *C. thalictroides* individuals appeared in any of the experimental plots. This indicates that the volume of *C. thalictroides* seeds, in this forest, is likely lower than, for example, *E. americanum*. It also shows that the *C. thalictroides* transplants are likely allocating their resources into areas such as flower and fruit production and leafing out, versus producing clones.

5.7 Temporal Changes in Soil vs. Phenology of Plants

The changes to the soil with regard to organic matter and pH throughout the first growing season were measured and analyzed; and the phenology of all transplant species was observed. Soil chemistry and plant phenology are discussed in terms of their potential interaction in the following section.

5.7.1 Changes to Soil throughout Growing Season: pH

As mentioned in the results section, the soil factor which was found to fluctuate throughout the growing season was soil pH. Little information was available in the literature on pH fluctuations of a seasonal nature, rather than of an impact nature (e.g. silviculture; fertilizer; liming). It is possible that the very small fluctuations in pH (6.80 minimum, 7.19 maximum) could simply be attested to spatial heterogeneity, or could be due the less desirable methods for testing pH which were used. Regardless, the results of the pH analysis showed that these minor fluctuations did not seem to affect the transplants across time, since the plants all followed the natural dieback pattern expected for each species.

5.7.2 Phenology of Transplant Species

Further supporting the theory that the seasonal fluctuations in pH levels did not notably affect the transplants was the fact that in 2006 and 2007, the transplanted species did not display any abnormal growth or dieback. Instead, the plants underwent very typical emergence and senescence patterns, as described in the literature available.

5.7.2.1 Phenology of *Erythronium americanum*

Erythronium americanum, a classic spring ephemeral, followed the typical growth pattern of ephemerals by emerging just after spring thaw and remaining until just after canopy closure (McKenna & Houle 2000). Environmental changes, such as decreased light and increased temperature appear to be involved in the induction of leaf senescence in spring ephemeral plants (Lapointe 2001). In this experiment, the first *E. americanum* individuals were observed on April 13, 2006 and April 11, 2007 and total dieback had occurred by June 9, 2006 (likely earlier, but monitoring was only biweekly) and June 6, 2007. Most ephemerals usually grow epigeously for approximately 7-9 weeks (McKenna & Houle 2000) or 40-60 days (Lapointe 2001) after emergence. These numbers are in keeping with the trend observed in *E. americanum* in this study in the 2006 and 2007 growing seasons (~8 weeks of growth). Canopy closure and seasonal temperature increases accompanied the senescence of *E. americanum* in both growing seasons. It does not appear that the temporal changes noted in the soil pH levels affected the growth of *E. americanum*, as its growth followed the phenological timeline seen in the literature.

5.7.2.2 Phenology of *Podophyllum peltatum*

Podophyllum peltatum is often classified in literature as a spring ephemeral, but can be more aptly described as a summergreen perennial, based on the fact that it does not die back immediately after canopy closure. Rather, the leaves of *P. peltatum* maintain positive CO_2 uptake rates well after the canopy has closed (DeKroon et al. 1991). Though it does emerge in the early spring while the canopy is still open, it generally does not die back for at least 12 weeks after its emergence (Constable et al. 2007). The period of senescence generally extends over a period of about 30 days (Watson & Lu 1999). In the 2006 growing season the first *P. peltatum* individuals were observed on April 19, 2006 and the first signs of dieback appeared on June 9, 2006, though some plants persisted up until the end of the monitoring period at the end of the season. In the 2007 growing season, the first *P. peltatum* individuals were observed on April 17, 2007, with the first signs of dieback occurring on June 18, 2007. The time until total senescence (based on 2006 field observations) was similar to the 12 week epigeous growth period noted by Constable et al. (2007) including the 30 day senescence period noted by Watson & Lu (1999). It is mainly important to note that there did not seem to be any outstanding events to indicate that the seasonal changes in soil composition (higher pH in May and June) were in any way affecting the *P. peltatum* plants used in this study.

5.7.2.3 Phenology of *Caulophyllum thalictroides*

Data on the phenology of *C. thalictroides* was not available in the literature. However, as a majority of the *C. thalictroides* plants were noted to persist from the early spring (first observed on April 19, 2006 and April 11, 2007) until the end of the observation period in both growing seasons (past September 1, 2006 and past June 18, 2007), it does not seem likely that significant fluctuations in pH at differing times throughout the growing season had any real effect on this plant's seasonal growth.

5.7.3 Temporal Changes in Soil vs. Plant Phenology: Conclusion

Due to the predictable growth patterns observed, it was determined that there was no need to further investigate the significant differences in soil pH across the months of the growing season. Whatever the actual explanation is for the change in pH through the summer months, no dramatic effect was observed on the transplant species, which all were observed to follow their respective species' typical growth and dieback patterns.

5.8 Progress in Early Restoration

The measure of progress which was initially established in this study was structural success, or survivorship of the transplanted species. This study, because of temporal restraints was only able to examine progress in restoration after two growing seasons. It has been noted in the literature that early progress is extremely important as it can help ensure enduring progress (Reay & Norton 1999). Early progress through planting new species is also a sound starting point in any restoration experiment, especially for areas in which degradation is high and factors such as soil instability put the system at great risk for soil erosion and invasive species encroachment (Bartha et al. 2003; Gretarsdottir et al. 2004; Groeneveld & Rochefort 2005).

The results of this restoration effort showed extremely high structural progress, with all three transplant species returning at rates between 92-100%. In highly degraded areas in which restoration is being undertaken, even low levels of transplant survival can be considered successful restoration (Page & Bork 2005). In terms of early progress, this restoration effort clearly contributed to a sound starting point for potential longer term success. As noted, measuring success or progress in restoration is a point which has been highly contested to date. Because a clearly defined endpoint (high transplant return rate) was set forth in this study, it can be claimed that sound progress toward successful restoration has occurred. However, it cannot be

ignored that a large debate exists around what makes a restoration effort successful, and this will be touched upon briefly as it is a limitation to the claim of progress which is being made at the cessation of this study.

Higgs published a paper in 1997 which has since been cited in numerous restoration papers, including those examining both the social and technical realms of the field of restoration. It is believed that rather than just technical criteria such as structural or compositional goals being considered as endpoints to restoration, the community and social contexts of restoration should be considered as well (Higgs 1997). Higgs suggests that structural replication, functional success and durability are the three key factors which define good restoration. However, he also points out that social, moral, political, aesthetic, and historical contexts all factor in to the durability of any restoration effort (Higgs, 1997). It is proposed that a scale be created for restoration efforts which includes all social factors mentioned, and each restoration effort should be ranked with regard to all of these factors, as well as with regard to technical criteria such as structural or functional success (Higgs 1997). Based on these findings and ideas put forth in this highly regarded and frequently cited paper, it is important to realize that while the restoration effort achieved at Natchez Hills may be deemed a success in terms of early progress in restoration, there are a plethora of factors which have been overlooked. These include community involvement in the area, the aesthetic value of the restored site, the historical and future use of the site (e.g. freeriding) and the durability of the restoration effort in face of these many features. Though creating a scale to rank the restoration effort in these social-based terms is beyond the scope of this strictly technical experiment, it is important to recognize this other face of restoration ecology. It should be noted that while progress is being claimed in this restoration effort, the limitation to this claim is the entire other realm of social factors which were not examined and certainly should receive more attention in current and future restoration efforts.

5.9 Recommendations for Restoration

Based on the results of this particular restoration effort, some recommendations can be put forth to restoration practitioners planning to undertake similar restoration efforts in the future. Many of the recommendations made can also be applied to peripheral studies, as the recommendations are thought to be simply good practice in general in the field of restoration ecology, both by myself and previous reports in the literature. These recommendations include the use of *E. americanum*, *P. peltatum* and *C. thalictroides* and suggestions on how to successfully transplant them.

Recommendations also include using combinations when restoration aims are more long-term or functionally based; planting species with regard to moisture conditions and the use of irrigation when this is not possible; controlling invasive species; and using the appropriate density for understory plants within plots. These recommendations are laid out more fully in the following.

5.9.1 Understory Plant Species

Based on the outcome of this experiment, it is clear that any of the three species used in the restoration effort (*Erythronium americanum, Podophyllum peltatum* and *Caulophyllum thalictroides*) are excellent choices for future restoration efforts. These species should be used in areas within their geographic range, but can also be used in moderately to highly degraded soils, on any grade of slope and can be planted in any combination. These three species fared well when they were transplanted near the beginning of the growing season. This allowed them to take advantage of spring light and moisture, which may have helped solidify their health and fecundity in the new location. Plants in this study were transplanted when they had reached their full, or near-full growing size, as this helped ensure that they had adequate nutrient stores and the capacity to absorb light, nutrients and water in the transplant location. Following these timing and size recommendations would likely be very beneficial in future studies.

5.9.2 Combinations

Based solely on this study, using combinations of *E. americanum, P. peltatum and C. thalictroides* cannot be recommended for use over any of these plants on their own. The results of this study point towards the use of either single species restoration efforts or combination restoration efforts using any of these species, when the aim is to achieve early structural success. Any study looking to anchor eroding soil, alleviate dominance by invasive species or offer some measure of native plant abundance when it has been lost from a degraded area would be well advised to use any of these species, in any combination. However, beyond the scope of this project, some restoration efforts could likely benefit more from the use of combinations instead of monotypic planting of only one species.

Based on some previous literature that supports the use of combinations on both theoretical and practical levels, combinations are certainly a restoration technique which warrant some attention. Fattorini (2001) planted a combination of several different grasses, forbs and legumes on degraded sites in the Swiss Alps and concluded that each species' contribution to ecosystem

function in a unique way was part of the reason for the success of his experiment. In the mountains of the Mediterranean, Castro et al. (2002) noted that seedling survivorship was much higher when the seedlings were planted alongside native shrubs, due to facilitative interactions between the two guilds. Burton et al. (2006) undertook a reseeding effort in sites degraded by industrial forest operations or agriculture in British Columbia using a mixture of native seed species. This seed mixture contained species which showed varying stature, growth form, phenology and rooting structure, as this combination of factors was better capable of improving productivity in these restored ecosystems (Burton et al. 2006).

Though combinations, as tested in this study, did not prove to be more successful in terms of early structural progress, there may still be a place in restoration ecology for the use of varying guilds and species of vegetation. Two such places are in restoration efforts which are focused on a longer time period, and those in which more complex functional progress in restoration is the desired outcome. This study was focused strictly on the short-term (two growing seasons), and it may be possible that over a longer time period combinations of species could fare better than single species. Because different species provide different effects in terms of the pollinators they attract to the area, their capacity to retain soil moisture, the way they cycle nutrients through an ecosystem and the overall way in which they compliment the growth of other native species (Callaway 1995; Brooker 2006; Cheng et al. 2006; Sthultz et al. 2007), combinations could be quite useful in studies aimed at these or any other facet of ecosystem function. Therefore, more complex, function-based restoration efforts, and restoration efforts aimed at long-term progress might benefit from the use of combinations. Suggestions for further research on this topic have been put forth in section 5.10.3.

5.9.3 Moisture

Desiccation has been found to be a major factor which can negatively affect transplant survival, and it has been found that planting during moister periods and/or irrigating new transplants can increase the survivorship of transplanted individuals (Helenurm 1998, Peterson et al. 2004; Page & Bork 2005). Though no explicit testing or statistical analysis were performed in this study on the effect of irrigation or planting after rainfall, it has been recommended by previous studies (mentioned above), and was used in this study which had particularly successful results. A safe recommendation for future restoration experiments is to work with the weather by transplanting during or after significant rainfall events to help ensure the plants receive adequate moisture.

Irrigation should be carried out when feasible, especially when rainfall is not providing sufficient soil moisture.

5.9.4 Invasive Control

The exotic control employed in this study was, as mentioned, carried out on a biweekly basis throughout the summer. A decrease in the biomass of exotic species encountered was observed as the 2006 growing season neared an end. Although the same type of invasive species were being encountered every two weeks, their level and presence was much lower than during the initial control effort at the beginning of the growing season. In the 2007 season, the overall volume of invasive species appeared to be slightly lower in the experimental plots in which the plants had been controlled in 2006 (personal observation).

The decrease in biomass of invasive species in 2006 which was noted was likely a result of the continued intervention not allowing adequate time for the invasive species to grow and spread. However, this decrease could also be a factor of the successful transplants potentially outcompeting the invasive species for resources such as water, light and nutrients. Overall, the invasive species control was not an experimental treatment, but rather just a method of site preparation and maintenance. However, it is important to note that a continued aggressive intervention during the first field season will keep the number of invasive species down to allow the transplants a better chance to survive. The invasive species present in the plots in the 2007 field season did appear to be significantly less than in the 2006 field season. Yet, as invasive control was not an experimental treatment there is no way of telling if this is directly because of the 2006 invasive control, or because of the 2007 return of competitive transplant species. Either way it is important to note that invasive control is certainly an important measure to consider in any restoration project. It was likely a contributing factor to the overall success of the transplant specimens in this study.

The following table provides an approximation of the frequency and abundance of invasive species which might be encountered in a forest with similar geography and species composition to Natchez Hills (Table 10).

Table 10. A summary of the frequency in which particular invasive species were encountered and controlled during initial site preparation and through the months of April to August, 2006.

Plant (Latin name)	Number of Instances Encountered and Controlled	Qualitative Abundance Rating Within Plots
Chelidonium majus	96	Abundant
Alliaria petiolata	55	Frequent
Geranium robertianum	47	Frequent
Nepeta cataria	27	Occasional
Taraxacum spp.	14	Occasional
Solanum dulcamara	8	Rare
Rhamnus cathartica	6	Rare

5.9.5 Density

The density used in this study was six *P. peltatum* or *E. americanum* plants (or three of each when used in combination) per square meter, and two *C. thalictroides* plants per square meter. The 6 plants m^{-2} was a number formed based on two studies done by Murphy where 7, 9 and 11 plants m^{-2} were found to be the most successful densities for a forest understory plant, *S. canadensis* (2005), and 5 plants m^{-2} was found to be the most successful density for a guild of early spring plants (2004). The density of 2 plants m^{-2} for *C. thalictroides* was a remnant of the original study design in which *A. saccharum*, a tree species, was to be used. This tree has been observed in a natural setting at a density of 1 tree m^{-2} (Murphy 2005) making 2 trees m^{-2} a failsafe in case of mortality, which can be quite high in tree saplings. Because *C. thalictroides* is sapling-like in stature (branched, tall) it was treated as if it was a tree species in this study.

These densities appeared to be favourable for the survival of all three of the understory plant species used in this study, and did not appear to invite competition between any of the transplants. *Erythronium americanum* and *P. peltatum* exhibited very high return rates when planted at a density of 6 plants m^{-2}. Therefore it would be safe practice to plant these individuals at this density in future restoration efforts in which they are being transplanted as adult plants. Had *C. thalictroides* been planted according to the understory density recommended (~6 plants m^{-2}), the plants would have almost definitely been in competition with one another, and with other native species including the other two transplant species, for resources such as light, nutrients, water and space. Therefore, the density of *C. thalictroides* which should be used in future restoration efforts involving this species is approximately 2 plants m^{-2} in order to avoid inviting competitive interaction.

Though some work has been done to date on the appropriate planting density for understory species, it is an area of study which could benefit from further testing on a larger variety of understory plant species. Further recommendations for other areas which could benefit from future research have been made in the following.

5.10 Recommendations for Future Research

Based on the work carried out in this experiment, there are many areas of forest restoration which have shown that they could benefit from further investigation. The decreased volume of invasive species in 2007 which appeared to be a result of exotic control in 2006 is certainly something that warrants further testing to obtain clear answers so better recommendations can be made for future restoration efforts. Determining whether combinations are useful with regard to positive interactions between plants, with restoration goals that are more functional than structural in nature would be quite informative. Studies which test the three species used in this experiment over a longer time period than two years would also be informative to the restoration ecology field. Testing a broader scope of species to determine which have the greatest tendency to spread and multiply would help inform the choice of which understory species to plant in future restoration efforts. Finally, testing the ultimate level of degradation that a transplant can be successfully planted into would be an excellent baseline study to inform the restoration ecology field about the degradation "point of no return" beyond which areas cannot be restored by a simple method like the one used in this study.

5.10.1 Control Exotics as a Test

Because exotic control has been hailed in the past as a successful active restoration technique which enhances the survivorship of transplants, it is an area which could certainly benefit from further research. Experiments that could be beneficial would include variations on the frequency of invasive control (e.g. weekly, biweekly, monthly), or variations on the scale at which invasives were controlled at (e.g. plot level, block level, landscape level).

Specifically, studies focused on the prominent problematic invasive species in maple-beech forests such as Natchez Hills could help answer questions about which species are most important to control and those for which highly intensive efforts are not as necessary. Some key invasive species in the Natchez Hills forest are *Chelidonium majus* (Figure 18), *Geranium robertum*, and

Alliaria petiolata. G. robertum does not grow or seed in as aggressive a manner as the other two species, so studies focusing instead on aggressive, potentially damaging invasives such as *C. majus* and *A. petiolata* would be the most beneficial. Some research has been done to date on the seedfall potential of a *C. majus* population in Natchez Hills (Ferguson et al. in review). Controlling *A. petiolata* has been examined in the context of the competition between itself and restored *Sanguinaria canadensis* (Murphy 2005). Still, further work could test the fate of highly successful transplant species (*P. peltatum, C. thalictroides*) in areas heavily invaded by *A. petiolata* to determine if the invasive could be outcompeted by these dominant native species.

Figure 18. A patch of *Chelidonium majus* shown in its early summer growth phase, in Natchez Hills, 2007

5.10.2 Testing Combinations for Facilitative Interactions

Though it was not demonstrated in this study that combinations were statistically better for restoration aimed at structural success in the first two years, it does not mean that combinations should be discarded as an area for future research. It has been noted by several authors that more work needs to be done to further understand the mechanisms and outcomes of facilitation (Brooker 2006; Cheng et al. 2006). It has also been stated that in a time of great environmental change, it is vital to further understand plant-plant interactions (Brooker 2006). Facilitative

interactions, to date, have mainly been studied in deserts, arid and semiarid locations, alpine areas, salt marshes and other such severe environments (Brooker 2006). However, the majority of the positive interactions that have been studied occur between vascular plants (Brooker 2006) though there has been little research done on this topic in forested ecosystems. Thus, a major gap in research and literature lies in the understanding of facilitation between forest understory plants. Therefore, an excellent area in which research could be focused is plant-plant interactions in restoration, with an emphasis on discovering which combinations of species demonstrate facilitation. It would be a benefit to any restoration project to use species which fare better in combination than on their own. A variety of studies in this area could be created, tailoring to different facets of facilitation including, but not limited to, pollination, soil nutrient enhancement, soil stabilization and shading. If it could be determined that certain species are indeed exhibiting facilitation, they could be recommended with confidence in future restoration efforts.

5.10.3 Long-term and Function-Based Studies

This study was decidedly short in nature, which is why the research question was aimed solely at answering questions about planting combinations of species to achieve progress in early restoration. Though short-term success is the first step towards long-term success (Reay & Norton 1999), it is extremely important that longer term studies be implemented to understand restoration over a broader temporal scale. Many longer term studies have been carried out, or are in the process of being carried out today in the field of restoration ecology. However, there is still a distinctive lack of literature which addresses combinations of vegetation in long-term studies. Therefore, an ideal area in which future work could take place would be the study of combinations of vegetation over the long-term. Because combinations, in the short-term, were seen to be only equally as valuable as monotypic transplant techniques, it would be very informative to study how combinations fare in the long-term. This again brings the research into the area of ecosystem function rather than structure, as a longer term study would be able to research and describe functions such as nutrient and water retention beneath experimental plots, or pollinator activity with regard to the different combinations of these plants, or the ability of certain combinations to defend their plots against invasion by exotic species. Though the short-term did help answer valuable questions, and determine that E. americanum, P. peltatum and C. thalictroides are highly appropriate species for restoration, a longer term and function-based study on these individuals would give an idea of their ability to interact and persist in the long-term. Because a restoration effort should never be something ephemeral, but rather should persist as

long as possible, there would be a great deal of merit in such a study on the plants used in this experiment, and eventually other species as well.

5.10.4 Determination of Species' Proliferation

Something which was not expected to be observed after only two growing seasons was the multiplication seen in *P. peltatum* as the rhizomes of the transplanted individuals were able to spawn additional plants in the 2007 growing season. Though not necessarily anticipated, this was certainly a welcome event, as one of the goals of any restoration experiment is to utilize nucleation (Daigle & Havinga 1996). Based on this finding, it would be extremely beneficial to undertake a study which would examine which species of plants are most likely to multiply between growing seasons, either in a short-term (two years) or longer term (five to ten year) study. These answers are pertinent, as they can then guide restoration efforts in the future in terms of the selection of species for transplant which are most likely to multiply and spread throughout the restoration site. This is an example of an active restoration being facilitated by passive means, which means that less labour could be used upfront if the plants were able to spread themselves successfully in the years following a restoration effort. Recommendations from such a study would be an innovative, useful and informative addition to the field of restoration ecology.

5.10.5 Severity of Degradation which can be Restored through Transplanting

This particular study demonstrated that anywhere from a moderate degree of degradation (Block 4) to a high degree of degradation (Block 3) will yield results which are not significantly different. Therefore, an informative future study could look at just how extreme a degree of degradation plants such as *P. peltatum*, *C. thalictroides* and *E. americanum* could be planted into. It is arguable that a greater degree of degradation warrants a more urgent need for restoration, as highly degraded areas are much more susceptible to loss of soil structure and function, loss of biodiversity and invasions by exotic species. Areas which are extremely degraded (this is still a qualitative scale as criteria are missing for what exactly constitutes degradation) should be worked with in a study designed like this one with noticeable variations in the degree of degradation. In this manner, it can be determined how effective the transplant species would be in an area suffering a defined level of degradation.

5.11 Conclusions

There are several gaps in the restoration ecology literature which have been noted in this thesis. Those include studies focused on early restoration, studies focused exclusively on understory vegetation, and studies regarding the use of combinations of vegetation. This experiment helped address many of those gaps to provide clear answers which can be applied to future restoration efforts, and identified areas in which further research is still required.

The main question answered by this research was that combinations are not significantly more useful than solitary plantings when restoring areas with *E. americanum*, *P. peltatum* or *C. thalictroides*. However, all species returned at impressive levels (92%, 97%, and 100% respectively) and therefore are all highly recommended for future restoration efforts. It is extremely important that the question of the effectiveness of combinations not be discarded, though. Facilitation is a process which has received extensive attention over the past twenty years, but has yet to be applied to the field of restoration ecology where it could provide very useful guidance regarding the use of combinations in forest understory restoration. Thus, longer studies and studies aimed more towards ecosystem function than ecosystem structure could benefit from the study of combinations and how they affect restoration outcomes.

In terms of progress in early restoration, all three species used fared quite well in restoring structure to a degraded ecosystem. Across varying levels of degradation, all species performed statistically the same, returning at extremely high rates in the second growing season. Further research can be done to determine the level of degradation these species could withstand being planted into, but this experiment showed that the range is already quite wide.

Some surprising results appeared in this study, such as *P. peltatum* plants returning in the second growing season with reproductive bodies when they were initially planted as asexual individuals. Also, several *P. peltatum* individuals exhibited the ability to produce extra clonal plants from their rhizomes, highlighting the extra layer of restorative success this species can offer. These results illuminated areas in which further study would be beneficial to help determine which plants are best in restoration efforts with regard to factors such as increasing reproductive ability, and the ability to multiply post-transplant.

Overall this restoration effort was deemed to be successful, based on terms set forth at the beginning of this study that a high return rate would indicate positive progress of the early

restoration effort. However, as discussed, there is still a need to define the terms of progress, or success, in restoration, as it is such a new science that a concrete set of rules for what defines success are still lacking. Overall, though, there is a clear lack of agreement about what constitutes progress in restoration. Based on some of the terms set out in certain pieces of literature, constituting progress as structural success or early overall success, which is thought to lead to later overall success, it can be tentatively concluded that this restoration effort was successful. Because the restoration effort did accomplish the personal goals set at the beginning of the experiment to revegetate this degraded area of forest, this restoration attempt is viewed as a success. It is clear, though, that this statement could be contradicted based on any one person's view of what constitutes success or progress, including the all-encompassing view of restoration success proposed by Higgs (1997), which was discussed in section 5.8.

It was very important that this research follow protocols and methods which would be applicable in the real world. The reasoning for this was the hope that this exact restoration effort could be replicated in areas in need of immediate restoration without heavy constraints on time or labour. It has been noted in the literature that efficiency is a key factor in restoration efforts. The restoration effort carried out in this study was extremely efficient, with low labour and no actual fiscal cost. Because the methods were simple and transparent, from the transplant technique to the method of irrigation, this restoration effort could easily be replicated in a real world setting with a goal of efficient, successful early restoration. This area will likely be of particular interest to municipal forest managers who tend to seek out restoration methods which are feasible, effective and do not require large inputs of money or labour.

The main recommendation which can be taken from this study is that *E. americanum*, *P. peltatum* and *C. thalictroides* would be good choices to transplant in an early restoration effort. This recommendation comes with the stipulation that it should only be applied to maple-beech dominated upland hardwood forests similar to Natchez Hills, as this is as far as the research has gone for the time being. Within similar geographic settings, these species can be planted into a variety of settings with regard to slope, level of degradation and intensity of invasion by exotic species. These species are quite appropriate for areas in which immediate attention is needed for facets such as soil stabilization or the staving off of invasions by exotic species. Further research will ultimately answer deeper questions about these species, in terms of their functionality or long-term success as restoration transplants.

This project has set the stage for the use of understory plants in future restoration efforts, and supports the use of both small scale and short-term studies. The progress shown by the three species used enables practical recommendations to be made to restorationists today so that future restoration efforts can apply the techniques used in this project, and thus follow a similar trajectory of success. Overall this study feeds the relatively young field of restoration ecology and provides answers in areas which have been greatly overlooked to date.

Appendix A

The following outlines the procedures for the two additional soil nutrients measured in a laboratory setting: phosphorus, potassium. The method for analyzing the third important soil nutrient, nitrate nitrogen, was later found to be erroneous and thus was omitted from this section.

Using the same procedure described for acquiring, freezing, and drying the soil for the organic matter test, the soil samples were tested for potassium and phosphorus content. Once dry and ground into a coarse powder, a LaMotte Soil Testing Kit (STH-14) was used to further analyze the soil. To obtain an appropriate medium for nutrient sampling, a measure of the dried soil was mixed with the LaMotte Universal Extracting Solution and filtered to obtain a filtrate. This liquid extraction was then used to test the nutrient (P, K) content of each of the soil samples. These tests were carried out in seven rounds, using either ten or twelve samples at a time until all 64 soil samples were analyzed. All reagents used are provided in the LaMotte STH-14 test kit.

Phosphorus

The original soil extract was moved by transfer pipette from the number of samples being tested into a corresponding number of Phosphorus B Tubes. These tubes were filled to the solid line with the original soil extract. Next, six drops of Phosphorus Reagent 2 were added to each of the samples. The tubes were thoroughly shaken until the Phosphorus Reagent 2 was dissolved into the soil extract. One Phosphorus Reagent 3 Tablet was then added to each of the test tubes, which were then shaken one at a time until the tablet was completely dissolved. Immediately at this point, the colour was compared to the Phosphorus Colour Chart and the closest colour match was recorded for each of the samples, representing Available Phosphorus in pounds per acre.

Potassium

The soil extract was again moved from the samples being tested into a corresponding number of Potash A Tubes. The tubes were filled to the lower of two solid lines indicated on them with soil extract. At this point a Potassium Reagent B Tablet was added to each of the tubes, and the tubes were shaken until the tablet was completely dissolved. Next, Potassium Reagent C was added to the second solid line indicated on the Potash A Tubes by running the reagent slowly down the side of the tubes using a transfer pipette. The tubes were then swirled gently until the reagent was mixed within them. At this point, a precipitate either formed or did not form to indicate the presence or absence of potassium.

Next, a Potash B Tube was secured to a stand attached to the Potassium Reading Plate, a rectangular piece of white Plexiglas with a dark line down the middle. Each sample was measured, one at a time, by running the extract/reagent/tablet solution slowly down the side of the Potash B Tube and observing the black line on the reading plate. When the black line was no longer visible due to the opaqueness of the solution, the addition of solution was immediately stopped, and a reading was taken from the side of the Potash B Tube. This value, taken from the side of the tube, represents Available Potassium in pounds per acre.

Results of Preliminary Soil Nutrient Tests

No significant differences were found between the potassium levels with regard to either block or month. However, significant differences were found for the phosphorus levels across the blocks ($p<0.001$). Based on the results of a univariate ANOVA and a post-hoc LSD it was found that phosphorus was significantly higher in Block 1 than Block 2 ($p<0.001$), Block 1 than Block 4 ($p<0.001$), Block 3 than Block 2 ($p=0.003$), Block 2 than Block 4 ($p=0.031$) and Block 3 than Block 4 ($p<0.001$). Block 1 and 3 were the only blocks not significantly different in terms of phosphorus content. This result is interesting as it warrants further investigation into the cause of varying phosphorus levels across a forested landscape. However, since there were no significant differences between the return rates of transplants within the blocks, further investigation would likely have been fruitless.

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