Invasive Species in an Alvar Ecosystem: A soil seed bank study and *in-situ* vegetation surveys studying the effects of *Euphorbia cyparissias* on the Burnt Lands Nature Reserve

by

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A thesis submitted in conformity with the requirements for
the degree of Master of Science
Graduate Department of Geography and Environmental Studies
Carleton University

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ISBN: 0-494-00788-5

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ISBN: 0-494-00788-5

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Abstract

In-situ vegetation surveys and a greenhouse soil seed bank study were conducted on the Burnt Lands Nature Reserve alvar located in Almonte, Ontario. The purpose of this study was to assess the effects of invasive alien plant species, particularly *Euphorbia cyparissias*, on native alvar plant communities in both the surface vegetation and at the soil seed bank level. Sixty plots were established randomly where vegetation surveys were conducted and soil samples were collected for the soil seed bank study. Spearman's Rank correlation analyses were applied to the percent crown closure of *Euphorbia cyparissias* in relation to soil depth, soil type, nutrient levels, above ground plant diversity and soil seed bank diversity. Results showed no statistically significant relations between measured variables and the presence or absence of *Euphorbia cyparissias* in the field.

Acknowledgements

First and foremost, I would like to thank both of my supervisors Dr. Céline Boutin and Dr. Ken Torrance for their unique contributions. Both supervisors provided support during phases of my research and their time and guidance was appreciated. I would also like to thank Dr. Chris Burn, a member of my supervisory committee, who provided direction as needed. A special thank you to Hazel Anderson who is always willing to help and make the life of a grad student a little easier; I would have been lost without her.

Don Cuddy, a taxonomy wizard, assisted this research by helping to identify numerous plant species in the field and laboratory. His advice and expertise about plants and the Burnt Lands Nature Reserve was paramount. Corina Bradshaw from the OMNR provided maps and species records as well as granted permission to conduct research on the Burnt Lands Nature Reserve. Mike Fox provided assistance with statistics and his time was greatly appreciated. Thank you to Gilles Bechdolff who was both a field and laboratory assistant, and Lisa Benedetto who helped collect the soils for the soil seed bank study despite the abundance of poison ivy!

Finally, I would like to thank my husband Chris; without his support this academic endeavour would not have been possible.

Dedication

This thesis is dedicated to my daughter *Kiara* who reminds me every day what is really important in life.

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1 INTRODUCTION

Invasive plant species are plants that, if introduced into a natural area, reproduce so aggressively that native vegetation, unable to compete, is displaced (White *et al.*, 1993; Haber, 2002). These aggressive plant invaders are able to alter significantly the invaded natural ecosystem by reducing the amount of light, water, nutrients and space available for native species, and by changing hydrological patterns, soil chemistry, moisture-holding capacity, and fire regimes. The damage caused by invasive plants to native plant communities and biodiversity in natural ecosystems is so extensive that these invaders are reported to be the second leading cause of natural habitat destruction in North America (Hobbs & Humphries, 1995; APWG, 1999; Lonsdale, 1999; With, 2001). Indeed, few if any regions in the world are exempt from the negative impacts posed by invasive plant species (Lonsdale, 1999; Allendorf & Lundquist, 2003).

Since the 1950s, attempts at developing predictive models have been made for the determination of which alien species are likely to become successful invaders (Elton, 1958; Mooney & Drake, 1986; Rejmanek & Richardson, 1996; Allendorf & Lundquist, 2003) and alternatively, which ecosystems are likely to be susceptible targets for invasion (Swincer, 1986; Groves & DiCatri, 1991; Goodwin *et al.*, 1999; Lonsdale, 1999).

Unfortunately, these endeavours have been largely unsuccessful. One of the reasons is a lack of empirical evidence from which to build and test the strength of predictive models (Perrins *et al.*, 1993).

Although the full extent of their utility is still a topic of debate, studies that focus on individual species and their functional role within a specific ecosystem can render valuable information to the understanding of a particular invader. The study of one species in a specific ecosystem can reduce the complexity of ecosystem studies for the purpose of understanding specific aspects of a particular invader and how it operates within an ecosystem. Such investigations can complement holistic studies, which focus on communities and their multiple inter-relations to biotic and abiotic factors, by providing insight that may act as a foundation for expanding the several existing hypotheses on the success of alien invasive species.

One area of invasive species research that has received little attention is the study of the soil seed bank in relation to invasive alien species. The primary means of reproduction for plant species is through the dispersal of seeds from the parent plant and it is known that many plant species produce seeds that maintain their viability in the soil seed bank for several years (Leck *et al.*, 1989). Although a vast literature on seed ecology and plant population biology exists, little is known about the effects that invasive plant species have on native seed abundance and viability.

Soil seed bank studies provide information about the types and viability of seeds present in, or absent from, the soil. Furthermore, soil seed bank studies can answer questions such as: Do the seeds of native plant communities persist in the soil seed bank given the presence of a particular invasive plant species? Are the seeds of native plants able to germinate under altered ecosystem conditions imposed by the invasive plant species? Do

the native plant seeds remain viable and able to germinate if pre-invasion conditions are restored? If the latter were the case, a valuable source of native seeds would still be present in the soil. Such knowledge concerning seed viability in the soil seed bank could be significant for restoration ecologists who are struggling to find appropriate tools to assess and manage the effects of invasive plant species. Restoration, loosely defined as returning an ecosystem to a prior state for the purpose of preserving or maintaining native species is necessary if ecologists are to conserve native plant communities that are threatened by invasive plant species (Bradshaw, 1997; Gilbert & Anderson, 1998; Rana, 1998; Holloway, 2000; Throop, 2000). Today, most restoration ecology techniques related to invasive plant species control are applied in an *ad hoc* manner or use a 'wait and see' approach due to a lack of type-specific ecosystem models. Understanding how an ecosystem operates and how an invasive alien species interacts within that ecosystem need to be understood before restoration techniques are applied. A soil seed bank study designed to test the effects of a particular invader within a particular ecosystem could serve as the foundation for such a model.

This research project was conducted at the Burnt Lands Nature Reserve [See Figure 1], an alvar ecosystem that is listed as an Area of Natural Scientific Interest (ANSI) by the Nature Conservancy of Canada. Alvar ecosystems are globally rare and the Burnt Lands is cited as the largest and best example of this ecosystem type in North America (Brownell & Riley, 2000). For these reasons, the long-term viability of vegetative communities on this site is a priority for the Ministry of Natural Resources in Ontario. Several invasive alien species are already present in this nature reserve but they do not

appear to be seriously threatening native plant communities at this time. A variety of buckthorn (*Rhamnus* spp.), purple loosestrife (*Lythrum salicaria*) and cypress spurge (*Euphorbia cyparissias*) are among the invaders that have the potential to become serious threats to the native plant communities. An assessment of the vegetative community and the soil seed bank in an area of the Burnt Lands Nature Reserve where one of these invaders is present may provide insight into future impacts that the invader may have on this ecosystem.

1.1 Thesis Statement and Objectives

This thesis will examine the effects of cypress spurge (*Euphorbia cyparissias*) on native plant communities in an alvar ecosystem (Burnt Lands Nature Reserve) using vegetative surveys, a soil seed bank study and soil analysis. The purpose is to further the understanding of the impacts that invasive plant species pose on natural ecosystems and their soil seed banks, with specific applicability to alvars and to *Euphorbia cyparissias* as an invasive alien species.

1.2 Research Objectives

The objectives of this research are:

1. To determine if native plant communities in natural alvar ecosystems can persist in the soil seed bank in the presence of *Euphorbia cyparissias* by conducting a soil seed bank study;

2. To investigate the relation between the above ground vegetation at the Burnt Lands Nature Reserve and the germination results of the soil seed bank study by comparing *Euphorbia cyparissias* in an *in-situ* vegetation survey to the species that germinate in the soil seed bank study in the same plot; and
3. To detect significant relations by the use of Spearman's Rank correlation analysis between the presence of *Euphorbia cyparissias* in plots and measured values of species richness, number of invasive species, number of native species, soil depth and soil nutrients.

2. LITERATURE REVIEW

2.1. Terminologies Defined

Universally accepted definitions of alien species, invasive species and weeds have not permeated current literature and the use of these terms often overlap or imply entirely different meanings. Given this tendency towards non-uniform terminology, these terms are defined for use in this study based on a compilation of definitions derived from the broad literature on alien invasive species, and are not attributed to any one author.

Alien Plant Species

Alien plants are species that did not naturally evolve in the ecosystem or region in which they currently reside. The majority of alien plants in Canada come from northern European nations and were introduced in the 1800s by European settlers. Other species have come from Asia and Northern Africa where climates are similar to those of their host environments in North America.

Invasive Plant Species

The majority of invasive plant species are also alien species that have been accidentally or intentionally introduced by humans for various cultivation purposes but have escaped their intended boundaries and successfully colonised natural ecosystems. Invasive species aggressively compete with native vegetation, reproduce rapidly and have the ability to form pure stands that, in severe cases, displace native plant species and alter the functioning of natural ecosystems.

Weeds

Weeds are species that can be both alien and invasive but tend to colonise highly disturbed areas such as roadsides, old fields, pasture lands, gardens and agricultural areas. The term weed is mainly used in reference to unwanted species that grow in cultivated areas and are considered pests because of their tendency to be invasive or to harbour harmful attributes that affect livestock or crops. Weeds are primarily defined by their undesirability. Some native species, such as *Asclepias syriaca*, are also classified as weeds in some provinces and in the United States. The principal difference between a weed and an invasive species is that weeds tend to colonise highly disturbed areas but generally do not invade intact natural ecosystems.

2.2 Invasive Alien Plant Species

Alien plants are species that have been intentionally or accidentally introduced into an ecosystem in which they did not naturally evolve (Cronk & Fuller, 1995; McNeely *et al.*, 2001; Scudder, 2002). The vast majority of alien plant species are intentionally introduced for human economic or social benefits. Most of these species have minor impacts on the natural ecosystems because they rarely establish themselves beyond their intended cultivation boundaries (Heffernan, 1998; Primack, 1993).

Haber (2002) estimates that out of Canada's 4200 identified vascular plants, approximately 27 per cent (1134) are alien. Six per cent (68) of these alien species are known invasive species (Haber, 2002). Invasive alien species (IAS) are species that have

escaped their intended bounds and successfully colonised natural areas in such abundance that they have significantly altered or impaired natural ecosystem functioning (Barrett & Richardson, 1996; Cronk & Fuller, 1995; Heffernan, 1998; Scudder, 2002). IAS have the ability to alter ecosystems by reducing light, water, nutrients and space available for native species. IAS also have the ability to change hydrological patterns, soil chemistries, moisture-holding capacities, fire regimes, as well as to reduce biodiversity and introduce diseases harmful to native species (Hobbs & Humphries, 1995; Gordon, 1998; Heffernan, 1998; Higgins *et al*, 1999; McNeely *et al.*, 2001; Evans, 2003). The impacts of IAS are enormous. It is estimated that within the United States 138 billion dollars are spent each year to control or eradicate IAS (Evans, 2003). This figure only accounts for areas where they pose an economic problem for humans, such as farming (Evans, 2003).

Due to the harmful effects imposed on natural areas by IAS, the goals of research investigating them are to predict their introduction, their likelihood of spread and the amount of damage that a given species may cause in a particular ecosystem. Scientists believe that if they are able to predict such occurrences, they will be better able to successfully manage or eradicate these invaders. Researchers have focused primarily on two popular areas pertaining to the study of IAS: the physiology of invasive plant species, and ecosystem susceptibility.

2.2.1 Physiology and Life History of Invasive Alien Species

If the life history and physical properties of a plant are adequately understood, there is a possibility of isolating and identifying the attributes that make a species an invader (Hobbs & Humphries, 1995; Newsome & Noble, 1986; Luken, 1997; Rejmanek & Richardson, 1996; Goodwin *et al.*, 1999; McNeely *et al.*, 2001). Not all alien plants are invasive; therefore, it has been hypothesised that IAS contain unique traits that are absent in non-invasive species.

In 1965, Baker, a pioneer in the field of invasive species, developed a list that identified the characteristics believed to be common amongst invading species [Table 1]. This list was designed as a guideline for assessing the likelihood of a particular species becoming an invader. Newsome & Noble (1986) refer to Baker's list as a "wish list" because no one species is likely to possess all 14 characteristics. Moreover, if a plant does possess one or more of the identified characteristics, this does not imply that the species is in fact an invader. Perrins *et al.* (1993) tested Baker's list by applying it to a field study of introduced *Impatiens* in the British Isles. In this study, forty-nine British annuals were scored against Baker's list. The results showed that the most invasive species contained only two of Baker's characteristics while individual native species possessed ten or more. Many of the characteristics on Baker's list do apply to invasive species, although the general nature of such characteristics allows them to be applied to most plant species – invasive or not. Baker's list is too general to have adequate predictive value for the

Table 1: Baker's List

Characteristics for an Ideal Weed*	
1.	Has no special environmental requirement for germination.
2.	Has discontinuous germination (self-controlled) and great longevity of seed.
3.	Shows rapid seedling growth.
4.	Spends only a short period of time in the vegetative condition before beginning to flower.
5.	Maintains a continuous seed production for as long as growing conditions permit.
6.	Is self-compatible, but not obligatorily self-pollinated or apomictic
7.	When cross-pollinated, this can be achieved by a non-specialised flower visitor or by wind.
8.	Has very high seed output in favourable environmental circumstances.
9.	Can produce some seed in a very wide range of environmental circumstances. Has high tolerance of climate and edaphic variation.
10.	Have special adaptations for both long distance and short distance dispersal.
11.	If a perennial, has vigorous vegetative reproduction.
12.	If a perennial, has brittleness at the lower nodes of the rhizomes or root-stock.
13.	If a perennial, shows an ability to regenerate from severed portions of the root-stock.
14.	Has ability to compete by special means: rosette formations, choking growth, exocrine production (but no fouling of the soil for itself).

* In Baker's work, the use of the term 'weed' is used as a synonym for invasive species.

Source: Newsome & Noble, 1986

purpose of determining which species are likely to become successful invaders (Newsome & Noble, 1986; Perrins *et al.*, 1993).

Attempts to expand upon Baker's work have yielded little or no success. Some scientists believe that individual plants must be studied more rigorously by discovering and understanding biological attributes that promote invasibility (Allendorf & Lundquist, 2003). Others believe that the advancement of the field can be achieved by examining the ecosystem instead of isolating a single species. One such method is the study of ecosystem susceptibility, an approach that includes the study of plant communities, the state of the natural environment, presence and type of disturbance, climate, nutrient availability, and human presence (Hobbs & Humphries, 1995; Lonsdale, 1999).

2.2.2 Ecosystem Susceptibility

Ecosystem susceptibility is the study of whether a certain type of ecosystem is more likely to be invaded due to abiotic, biotic or anthropogenic elements (Swincer, 1986; Wilson, 1990; Richardson & Bond, 1991; Goodwin *et al.*, 1999). The three leading hypotheses examined by proponents of ecosystem susceptibility are: the climatic conditions of the host environment must be similar to the native environment for the invasive plant species to survive; a high level of species richness hinders the invasion process; and disturbance facilitates invasion.

Climate

Plants are naturally restricted to geographical regions because they are unable to cross major environmental barriers (Wilson, 1990). Even moderate climatic changes may cause extirpation or extinction of a species (Primack, 1993). Scientists are able to predict that invasive plant species are unlikely to persist outside of their climatic tolerance limits or to invade ecosystems that vary widely climatically from their native habitats (Swincer, 1986; Richardson & Bond, 1991; Goodwin *et al.*, 1999). Although climatic restrictions appear to be rudimentary when considering species range, the physical study of these variables is often more obscure. Temperature, wind, moisture and light are climatic variables that are easy to measure. However, there are complex interactions among these variables, such as the interactions between temperature and moisture, especially when coupled with the effects that these interactions impose on other processes such as nutrient dynamics in the soil. Interactions play a significant role in determining which plant communities thrive in a given area. Richardson & Bond (1991) suggest that there are many elements that have yet to be investigated concerning climatic effects on vegetation. While climate may be a good predictor of invasive potential on a broad scale, we still know relatively little about the exact causes of why this is true.

Species Richness Hypothesis

The species richness hypothesis was derived from the classic notion that more diverse ecosystems are inherently more stable. Extrapolations from this once accepted truism suggest that as species richness increases, so does competition for available resources. Since the ecosystem is being taxed by the existing species, it is more difficult for an

invasive species to successfully establish itself within that system. It has been argued that an invasive species would be more successful in an ecosystem with fewer species because the invader would be able to find a niche by making use of untapped resources in that ecosystem (Case, 1991; Fox & Fox, 1986; Cronk & Fuller, 1995; Richardson & Bond, 1991; Swincer, 1986). While it has been shown that stability and diversity are not synonymous, the argument that more diverse ecosystems more successfully repel invaders continues to be debated.

In his now classic book *The Ecology of Invasions of Plants and Animals*, Elton (1958) was the first to clearly state that species-rich communities resist invaders. Early rebuttals of this hypothesis were largely ignored due to the influence Elton held in this field of study. However, more recent examinations pose serious questions regarding the legitimacy of such a statement. The most extensive study has been performed by Lonsdale (1999) who collected data on the number of alien species, the number of native species, site area and the fraction of the total flora that was alien for 184 sites across the globe. He then performed various statistical analyses of these data and was unable to conclusively support the species richness hypothesis. While there were some cases where invasive species were less numerous in highly diverse ecosystems; the opposite was more common. The diversity of microclimates, habitat heterogeneity, and available nutrients are favourable to the invader in the same way that these elements are favourable to native species. Therefore, chances of colonisation success for the invader are the same as or greater than for the native flora (Levine & D'Antonio, 1999; Lonsdale, 1999; McNeely, 2000). Furthermore, there are now several studies that show invasive species are serious

threats to highly diverse ecosystems across the globe (Levine & D'Antonio, 1999; Lonsdale, 1999; McNeely *et al*, 2001). Lonsdale (1999) concluded that the only result that can be derived from the species richness hypothesis is that richer plant communities are evidence of greater habitat diversity.

Disturbance

Disturbance to an ecosystem, either anthropogenic or natural by, for example, fire, flooding, or simply the dying and replacement of species, is a necessary ingredient for the facilitation of invasion. This hypothesis is widely accepted with few opposing views. Anthropogenic disturbances to ecosystems are the most widely studied by ecologists in relation to invasive species. Invasive species tend to be greatest in ecosystems that have been severely impacted by humans. Activities such as clear-cutting, farming, urbanisation, human visitation, and the creation of roads all provide potential opportunities for invasive species (Fox & Fox, 1986; Richardson & Bond, 1991; Hobbs & Huenneke, 1992; White *et al*, 1993; Luken, 1997; Woods, 1997).

Luken (1997) points out that although disturbance appears to be necessary in the preliminary stages of invasive species colonisation, scientists have a difficult time distinguishing the exact cause and effect relations. Human impacts tend to be so highly complex and multiform that determining the source of disturbance that resulted in the onset of invasion is troublesome. Furthermore, species vary in their response to disturbances, which also complicates the analysis. While invasive species do appear to favour highly disturbed sites, this observation has "little practical importance as all

ecosystems experience some form of disturbance” (Perrins *et al.*, 1993, p 43).

Disturbance is an important element in the invasion process; however, it needs to be better understood in order for it to have predictive value.

To date, these areas of inquiry, individually and collectively, have not yielded predictive indicators. Some scientists believe that the lack of progress in this is the result of ignoring important data, such as failed invasion attempts (Rejmanek & Richardson, 1996). Other scientists believe that a holistic approach, which includes the examination of several interactive factors, as opposed to isolating attributes in the plant or ecosystem, is necessary to understand the establishment of invasive species (Hobbs & Humphries, 1995; Lonsdale, 1999; With, 2002). The development of general rules may aid ecologists in preventing invasive plant species spread, minimise the damage to an infected ecosystem and aid in restoration goals (Newsome & Noble, 1986; Hobbs & Humphries, 1995; Allendorf & Lundquist, 2003). However, many of the hypotheses presented in the literature are not supported by experimental evidence. Regardless of the approach taken to further the understanding of invasiveness, scientific experimentation for the purpose of validation is necessary (Burke & Grime, 1996).

2.3 Soil Seed Bank Studies

A soil seed bank is the totality of viable seeds present within the soil and litter layer.

Most of the seeds in the soil seed bank come from the plant communities in the above ground vegetation that is locally present within an ecosystem (Leck *et al.*, 1989; Begon *et al.*, 1990; Bekker, 1998). Long range dispersal of plant species, usually spread by wind,

water, or animals, is less common but can make substantial contributions to the soil seed bank (Leck *et al.*, 1989; Warr *et al.*, 1993). Some species do not propagate through seeds; rather, they reproduce through vegetative propagation. These species create a bud bank that consists of bulbs, bulbils, buds on rhizomes, corms and tubers. A bud bank is similar to a seed bank insofar as the species are able to disperse through time and space in addition to requiring specific germination cues such as fire or drought (Leck *et al.*, 1989). However, as opposed to seeds, a bud bank does not introduce any genetic novelty.

The study of soil seed banks originated under the banner of population biology, which is concerned with how natural selection works and how species adapt over time in a geographical area (Harper, 1977; Solbrig *et al.*, 1979; Silvertown, 1982). Historically, the study of soil seed banks was closely related to weed studies by agronomists in order to understand the contribution of seeds in the establishment of weeds in agricultural systems. Seed population models were built to determine the emergence rate of different species from the soil seed bank for the purpose of crop management, which incorporated weed control programs and the ability to determine how many seeds needed to be sown to obtain an economically viable crop (Roberts, 1981). This later expanded to include the density at which seeds should be sown, the causes of mortality, and the effects of competitors, predators and disease (Silvertown, 1982).

Academically, soil seed banks were studied spatially for the purpose of understanding how plant populations functioned. Darwin's theory of evolution was adopted by plant ecologists which led them to believe that soil seed banks could provide evolutionary

information, such as selective environmental conditions of the past, because seeds are thought to conserve genetic variability that aids in their adaptation to survive (Leck *et al.*, 1989). Recently, temporal dynamics have been included in the study of soil seed banks. An important element of temporal dynamics is the classification of seeds as transient or persistent. Transient seeds germinate within one year of their dispersal from the parent plant, while persistent seeds can remain viable, but dormant, in the soil for more than one year (Silvertown, 1982).

Not all seeds become a part of the soil seed bank because many are lost to predators, pathogens, chemical deterioration and the species' inherent seed longevity. Due to these losses and a variety of abiotic and biotic factors that permit or prohibit germination, the above ground vegetation will not necessarily reflect that of the soil seed bank (Leck *et al.*, 1989; Begon *et al.*, 1990; Kirkham & Kent, 1997). What remains viable in the soil seed bank is vital to the ecosystem processes of renewal insofar as the seeds present may determine future plant communities if appropriate germination requirements are met. Dormant seeds form the largest part of a seed bank and generally come from annuals or ephemerals because these species have short life spans and tend to reproduce an abundance of small seeds (Begon *et al.*, 1990; Bekker *et al.*, 1998). Longer living plant species have more opportunities for reproduction over time and are less likely to produce large persistent seed banks (Baskin & Baskin, 1998). Differences between the above ground vegetation and viable seeds in the soil seed bank are also attributed to the inherent persistence of a particular species and current management of the vegetation, if it differs from past practices (Bekker *et al.*, 1997; Kirkham & Kent, 1997; Akinola *et al.*, 1998).

Seed dispersal from neighbouring areas can also contribute seeds that are absent in the above ground vegetation to the soil seed bank although such contributions are generally minor. The majority of seeds produced from vascular plants are deposited near the base of the plant or, if aided by flight appendages, within one meter of the plant (Silvertown, 1982).

The practical importance of soil seed banks studies is to manage the vegetation above ground. Ecologists believe that if they adequately understand what is in the soil seed bank, such as viable seeds of persistent species and the quantitative numbers of these species, they may be able to manipulate the ecosystem to promote the germination of the desired species (Harper, 1977; Begon *et al.*, 1990). The practice of manipulating ecosystems to promote the growth of desired species has been used for centuries by foresters, conservationists, agriculturists and gardeners. For example, if a conservationist wanted to restore a prairie and knew that the ecosystem was fire-dependent, performing a controlled burn would likely promote the germination of the desired species if the ecosystem had a persistent seed bank. Similarly, foresters know that by creating openings in the canopy, the bud bank and seed bank will begin to grow.

Some plant ecologists believe that if soil seed banks were thoroughly understood predictions could be made about which species would dominate after a specific disturbance. Although research is still in its infancy, the study of the soil seed bank in conjunction with natural or created disturbances, such as fire or a change in current management practices, has been conducted in a few ecosystem types (Leck *et al.*, 1989;

Akinola et al., 1998). Researchers are still not able to predict the community structure that will develop above ground but progress is being made in this field. In order to promote native plant communities, researchers know that the soil seed bank must contain viable seeds of the native species and few of the unwanted seeds. This is unlikely to occur in ecosystems that contain multiple invaders that have been present in the ecosystem for some time. Furthermore, the biotic and abiotic conditions must also favour the preferred species for success (Leck *et al.*, 1989).

There are several elements that can influence the soil seed bank, such as climate, seed mortality rates, seed longevity, allelopathy, seed persistence, seed dormancy, and abiotic and biotic factors that vary depending on the ecosystem type. Moreover, studies that exist are often difficult to compare or assimilate because of a lack of standardised techniques (Leck *et al.*, 1989). Another problem is that most of the experiments reported have been conducted in laboratory settings with direct control over important aspects of ecosystem functions such as climate, moisture and light. Laboratory studies are referred to as *the safe site* (Silvertown, 1982). Safe sites are not sufficient to predict germination in the field because seeds are highly responsive to micro differences in the abiotic environment at the soil surface level. Furthermore, safe sites allow many of the seeds to escape the risks associated with the pre-germination phase, such as predation or exposure to various pathogens. In nature, many of these seeds would die (Harper, 1977; Silvertown, 1982). As the complexities of selective pressures on seeds in the soil seed bank and the role that specific species play within a community are better understood, general patterns that are ecosystem specific may emerge to form the foundation of a soil seed bank general theory.

2.4 Alvar Ecosystems

"Alvars are natural communities centered around areas of glaciated horizontal limestone or dolomite bedrock pavement with a discontinuous thin soil mantle. These communities are characterized by distinctive flora and fauna with less than 60% tree cover, that is maintained by associated geological, hydrologic and other landscape processes."

International Alvar Conservation Initiative, 1995.

Alvars are natural open areas characterized by bare limestone or dolomite interspersed with thin soils. Vegetation primarily consists of shrubs and herbaceous plants. There is a distinct lack of trees since they can not be supported by the thin soils nor survive the dry conditions that exist during the growing season. What makes the vegetation of these rare ecosystems so diverse is the presence of northern, western and southern plant species coexisting. Alvar plant communities are believed to have originated in tundra-like habitat during the last period of glaciation and have since maintained their resemblance to that era due to unique microclimates influenced by unusual geological and hydrological processes (Brunton, 1988; Catling & Brownell, 1995; Bouchard & Wheeler, 1997; Schaefer & Larson, 1997).

Alvars exist only in two regions of the world - the Baltic Sea Region and the Great Lakes Basin of Canada and the United States. There are approximately 300 known alvar sites in North America. The majority of sites are located in southern Ontario in the area that extends from the Smiths Falls Limestone Plain in the east to Lake Huron in the west, and north to the contact line of the granitic Canadian Shield (Belcher *et al.*, 1992; Bouchard &

Wheeler, 1997; Brownell & Riley, 2000). Ontario has six alvar regions: Manitoulin Island, the Bruce Peninsula, Carden Plains, Smiths Falls Plains, Napanee Plains and Pelee Island. Within these six regions, six types of communities have been identified [Table 2].

Table 2: Alvar community type classifications

	Open Alvar: <10% tree cover	Savannah: 10 – 15% tree cover
>50% exposed bedrock <50% herbs <50% shrubs	Pavement Alvar	Pavement Savannah
< 50% exposed bedrock >50% herbs <25% shrubs	Grassland Alvar	Grassland Savannah
<50% exposed bedrock <50% herbs >25% shrubs	Shrubland Alvar	Shrubland Savannah

Source: Bouchard & Wheeler, 1997.

The Nature Conservancy of Canada has classified pavement alvars and grassland alvars as globally imperilled. Aside from the unique composition of species found in these areas, alvars contain many plants and insects that are either threatened or endangered (White, 1979; Catling & Brownell, 1995; Bouchard & Wheeler, 1997; Brownell & Riley, 2000). A small number of endemic plants, such as the Lakeside Daisy (*Hymenoxys herbacea*), Dwarf Lake Iris (*Iris lacustris*) and Pitcher's Thistle (*Cirsium pitcheri*), are now restricted to the alvars in Ontario (Bouchard & Wheeler, 1997; Brownell & Riley, 2000).

Until recently, many of the known alvar sites within the Great Lakes Basin were considered in relatively pristine condition. However, urban development, quarrying, timber operations and site selection for landfills are threatening these unique ecosystems (Brownell & Riley, 2000). Aside from containing a high concentration of rare or endangered species, alvars are important for future biological research in the fields of natural history, plant physiology and for the preservation of biodiversity (Bouchard & Wheeler, 1997; Brownell & Riley, 2000). For these reasons, the Ontario Federation of Naturalists, the Nature Conservatory of Canada and various government departments, especially the Ontario Ministry of Natural Resources (OMNR), are emphasising research on alvars in an effort to assist in making sound conservation decisions (Bouchard & Wheeler, 1997).

2.5. The Burnt Lands Nature Reserve

The Burnt Lands, listed as an Area of Natural and Scientific Interest (ANSI) and rated as having outstanding significance (Class B1) by the International Alvar Conservation Initiative, is one of North America's best examples of an alvar due to its size and the presence of globally rare plant communities. Located approximately five kilometres northeast of Almonte, Ontario [Figure 1], the Burnt Lands is jointly owned by the Crown and the Nature Conservancy of Canada (NCC) [Figure 2].

The Burnt Lands is 2338 ha in size and contains a mosaic of ecosystem types including alvar, mixed and coniferous forests and portions of three elevated wetlands (White, 1979; Brownell & Riley, 2000). One hundred and thirty-five hectares are classified as a nature

reserve by the Ontario Ministry of Natural Resources, due to the presence of Annual Alvar Pavement Grasslands and Poverty Grass Dry Alvar Grasslands, both of which are considered the best examples of these communities in the world (Bouchard & Wheeler, 1997; OMNR, 2000).

Figure 1: Map showing Almonte in relation to Ottawa, Ontario. Source: ESRI, 2005.

The Burnt Lands gained its name following a severe wildfire that swept through the area in 1870. In the 1940s and 1950s, this area was logged and subsequently used for grazing until the 1960s (Brownell & Riley, 2000). In the era of the Cold War, a 135 ha area was purchased by the Department of National Defence (DND) for the construction of communication towers. In the 1950s an atomic bomb shelter (known as the ‘Diefenbunker’) was built in Carp, Ontario and the communication site at the Burnt Lands was meant to act as a fail-safe communication system in the event that the systems in Carp were bombed or failed. This area is now known as the ‘former DND property’ and

Figure 2: Map of Burnt Lands Nature Reserve. The North Block, NCC block and the South Block are publicly owned. The vast majority of the Burnt Lands is privately owned as shown in this map which outlines the entire Burnt Lands Alvar. Source: OMNR, 2000.

has recently been donated to the Nature Conservancy of Canada (Cuddy, personal communication, 2004). The former Regional Municipality of Ottawa-Carleton designated 750 ha of the Burnt Lands as conservation land in 1974. However, in the 1990s this status was changed to 'managed resource restricted' allowing the construction of several private residential homes (Brownell & Riley, 2000). The most recent major disturbance at the Burnt Lands was another wildfire in 1999. This fire occurred in heavily wooded areas on Crown land and was contained to approximately 150 ha (Catling

et al., 2001; Catling & Sinclair, 2002). Today, the majority of the Burnt Lands is privately owned. The public areas of the Burnt Lands are used for a variety of recreational purposes including horseback riding, hiking, hunting and the use of all terrain vehicles (personal observations).

The Burnt Lands Nature Reserve has been studied intensively since the 1970s. Once described in the literature as rock flats or old fields, the term alvar was first applied by Beschel who was familiar with alvar ecosystems in Sweden, Denmark and Estonia (Brownell & Riley, 2000). Alvar ecosystems are of general interest to researchers for the diversity and number of rare species they support (White, 1979; Brunton, 1988). These rare species have generated interest taxonomically, which is the primary reason that the Burnt Lands have been studied. In 1986, Daniel Brunton created a life science inventory of the Burnt Lands for the OMNR. This life science inventory, a comprehensive list of the vascular plants present on the public portions of the Burnt Lands Nature Reserve held by the OMNR, has been updated over the past 18 years by V. Brownell, P. Catling, D. Cuddy and various staff at the OMNR.

The Burnt Lands is listed as *Class B* (good condition) by the Federation of Ontario Naturalists (Brownell & Riley, 2000). Eight species found in the Burnt Lands Nature Reserve are listed as provincially important and 16 species are classified as locally significant because they are rare or extirpated from much of the region (OMNR, 2000) [Table 3].

Since most of the Burnt Lands is privately owned, there are risks of future development and management practices that could destroy this unique ecosystem. Furthermore, invasive plant species, such as Buckthorn (*Rhamnus spp.*), Barberry (*Berberis vulgaris*), Purple loosestrife (*Lythrum salicaria*) and Cypress Spurge (*Euphorbia Cyparissias*), that are not serious threats to this site at present, may become serious competitors in the future if they are not managed.

Table 3: List of significant plants present on the Burnt Lands Nature Reserve

	Scientific name	Common name	Provincial Rank
Provincially Significant	<i>Arabis pycnocarpa</i>	Hairy Rock-cress	S1
	<i>Pterospora andromeda</i>	Giant Pinedrops	S2
	<i>Astragalus neglectus</i>	Cooper's Milk-vetch	S3
	<i>Sporobolus heterolepis</i>	Prairie Dropseed	S3
	<i>Cirsium discolor</i>	Field Thistle	S4
	<i>Ceanothus herbaceus</i>	Narrow-leaved New Jersey Tea	S4
	<i>Ceanothus americanus</i>	New Jersey Tea	S4
	<i>Amaranthus tuberculatus</i>	Water-hemp	S4
Locally Significant	<i>Astragalus canadensis</i>	Canada Milk-vetch	
	<i>Gnaphalium viscosum</i>	Clammy Everlasting	
	<i>Melampyrum lineare</i>	Cow-wheat	
	<i>Carex crawei</i>	Crawe's Sedge	
	<i>Dracocephalum parviflorum</i>	False Dragonhead	
	<i>Viola adunca</i>	Hooked Violet	
	<i>Viola renifolia</i>	Kidney-leaved Violet	
	<i>Proserpinaca palustris</i>	Mermaid-weed	
	<i>Epilobium leptophyllum</i>	Narrow-leaved Willow-herb	
	<i>Viola nephrophylla</i>	Northern Bog Violet	
	<i>Panicum philadelphium</i>	Panic Grass	
	<i>Carex richardsonii</i>	Richardson's Sedge	
	<i>Pyrola rotundifolia</i> ssp. <i>americana</i>	Round-leaved Pyrola	
	<i>Halenia deflexa</i>	Spurred Gentian	
	<i>Malaxis monophylla</i>	White Adder's Mouth	
	<i>Cynoglossum boreale</i>	Wild Comfrey	

S1: extremely rare in Ontario S2: very rare in Ontario S3: rare to uncommon in Ontario S4: common in Ontario

The Ontario Natural Heritage Information Centre, for the purpose of establishing protection priorities for rare species and natural communities, provides rank classifications. These ranks are not legal. Locally significant plants are considered rare to a region but these species are not ranked or monitored by the Ontario Natural Heritage Information Centre (OMNR, 2000).

Source: Brownell & Riley, 2000; OMNR, 2000

2.6 Alvar Soil Seed Bank Studies

Two alvar soil seed bank studies have been reported. The first study was conducted in dry alvar grassland on the Baltic Island of Oland in Sweden (Bakker *et al.*, 1996). Its purpose was to determine if the soil seed bank could play a vital role in the restoration of this ecosystem. This dry alvar grassland had been grazed for many centuries. In areas where grazing has ceased, common juniper has taken over and replaced the native diversity of grassland alvar species. Researchers attempted to discover if the native species would re-establish from the soil seed bank if the juniper were removed. They found that the seeds in the alvar were transient and, therefore, unable to aid in restoration goals.

The second study was conducted on five alvar sites located in the Bruce Peninsula National Park in Ontario, Canada (Stark *et al.*, 2003). It is the first soil seed bank study on a North American alvar ecosystem. Stark *et al.* (2003) had two main objectives:

1. To determine if the surrounding forest was encroaching on the alvar sites by assessing vegetation cover and soil seed banks for both open alvar sites and forest margins; and,
2. To determine relations between vegetation cover, soil seed bank species and soil characteristics.

They found that the surrounding forest was not encroaching on open alvar habitat even when there was adequate soil and nutrients to support tree species. They found a lack of woody forest species in alvar plots as well as a lack of alvar grassland species in the forest margins. Furthermore, they did not detect significant relations between vegetation

cover, seed bank species and soil characteristics, although there was a weak relation between plots with high vegetation cover and a greater soil depth (Stark *et al.*, 2003).

2.7 *Euphorbia cyparissias* as a Target Species

Euphorbia cyparissias is a semi-woody perennial plant that is a member of the Euphorbiaceae family. This species originated in Eurasia and is considered native throughout Europe, from southern Finland to northern Greece and from England in the west to central Siberia in the east (Stahevitch *et al.*, 1988; Van Driesche, 2002).

Euphorbia cyparissias, commonly known as graveyard weed, was introduced to North America in the 1860s as an ornamental plant that was widely cultivated in graveyards [Figure 3]. Since its introduction to North America, *Euphorbia cyparissias* has escaped its intended cultivated areas and colonised other ecosystems. In Canada, this species is most prevalent in the east from Nova Scotia to Ontario. Although there are accounts of this species as far west as the eastern border of Alberta, there are only 19 sites reported to contain *Euphorbia cyparissias* west of Lake Huron (Stahevitch *et al.*, 1988).

There are three cytogenetic variants of *Euphorbia cyparissias*, which include a fertile diploid, a sterile diploid and a fertile tetraploid. Only the sterile diploid and fertile tetraploid are found in Ontario (Stahevitch *et al.*, 1988; Van Driesche, 2002). The sterile diploid is the most common and reproduces solely through underground parts, namely through rhizomes or parts of the root stock (Ontario Ministry of Agriculture and Food, 2003). The fertile tetraploid reproduces through both underground parts and fertile seeds. The fertile tetraploid has been reported in both Dufferin County and eastern Renfrew

County where it occupies thousands of hectares of pasture lands and other open habitats such as roadsides (Stahevitch *et al.*, 1988; Ontario Ministry of Agriculture and Food, 2003). The cytogenetic variant present at the Burnt Lands Nature Reserve is not currently known.

Figure 3: Artist sketch of *Euphorbia cyparissias*. Source: Plant National Database (U.S.A.), 2005.

Euphorbia cyparissias is typically found in open habitats, such as roadsides, pasture lands or abandoned fields but rarely appears on heavily cultivated soils. This species prefers sandy, sandy loam or gravel-based soils that are fairly dry. Although its tolerance range extends from drought-like impoverished conditions to moderately wet sites, this species has also adapted to a wide range of climatic conditions, from the warm temperate climates of Tennessee to cooler, snow climates in the Gaspé Peninsula of Quebec. In

Ontario, *Euphorbia cyparissias* favours dry sandy soils on limestone substrate

(Stahevitch *et al.*, 1988; Ontario Ministry of Agriculture and Food, 2003).

Euphorbia cyparissias has an extensive root system that consists of a persistent and indeterminate taproot and lateral roots. Young seedlings produce the taproot that reaches a length of 3 metres or more. Lateral roots form off the taproot and produce several adventitious buds. In early spring, shoots form from the crown and buds develop in masses (Van Driesche, 2002). Due to this extensive root system, control of *Euphorbia cyparissias* is difficult to achieve. Normal applications of pesticide appear to have little effect on this species. Research suggests that pesticide must be applied frequently in order to control the spread of *Euphorbia cyparissias*; these applications do not eradicate the species (Stahevitch *et al.*, 1988; Ontario Ministry of Agriculture and Food, 2003). Biological control has been attempted in Canada but has not been fully successful. Three root-boring moths that feed on *Euphorbia* spp. were introduced in Belleville and Sidney, Ontario, but failed to establish. Chrysomelidae, a root-feeding beetle, was subsequently introduced into these ecosystems and showed some promise as a biological control (Stahevitch *et al.*, 1988). Follow-up of this experiment is not publicly documented.

For many years, the appearance of cypress spurge was not noteworthy. The public found this species to be an attractive ground cover along roadsides and other open urban places. However, *Euphorbia cyparissias* has escaped its intended bounds and invaded other ecosystems, such as pastures, dry grasslands and alvars. All parts of *Euphorbia cyparissias* contain a milky latex that is toxic to cattle and other range animals. Cases of

cattle dying after the ingestion of *Euphorbia cyparissias* have been reported in the United States. Humans also suffer adverse effects from being in contact with this milky latex, including dermatitis and severe irritation of the skin, mouth and gastrointestinal tract (Stahevitch *et al.*, 1988; Van Driesche, 2002; Ontario Ministry of Agriculture and Food, 2003). Furthermore, this species has the ability to choke out native vegetation by forming pure stands, thereby drastically reducing biodiversity in natural ecosystems (Stahevitch *et al.*, 1988; Van Driesche, 2002; Ontario Ministry of Agriculture and Food, 2003; OVMA, 2003). *Euphorbia cyparissias* also has the potential to become a serious competitor in natural ecosystems. For example, in 1975, the United States reported the presence of *Euphorbia cyparissias* in 26 states. By the year 2000, *Euphorbia cyparissias* was present in 42 states (Van Driesche, 2002). Today, *Euphorbia cyparissias* has fallen into disfavour as an ornamental due to its toxicity to livestock and invasive potential. This species is now listed as a noxious weed in most provinces and states (Stahevitch *et al.*, 1988).

3. METHODOLOGY

Combinations of fieldwork and laboratory methods were used in this study. The fieldwork consisted of: A visual reconnaissance of the Burnt Lands for the purpose of selecting an appropriate site for the soil seed bank study; selection of sixty plots placed along six transects at ten plots per transect; measurement of the crown closure of cypress spurge and soil depth in each plot; collection of soil samples for the soil seed bank study and soil analysis; and a vegetation survey in each of the 60 plots to compare with the soil seed bank. Laboratory research consisted of a soil seed bank study conducted in a greenhouse at the National Wildlife Research Centre located on campus at Carleton University, Ottawa. Each of these methods is outlined in detail in the following sections.

3.1 Visual Reconnaissance and Site Selection

During the summer of 2003, field visits to Burnt Lands Nature Reserve were made on June 26th, July 1st, and August 9th 2003 for the purpose of site selection based upon visual reconnaissance. The Nature Conservancy of Canada (NCC) property (formerly occupied by the Department of National Defence) was selected as the primary focus for this study. This 135-hectare section of the Burnt Lands Alvar contains two vegetation communities considered to have significance: *Grassland Alvar* and *Pavement Alvar* [Table 2 in Section 2.3]. This area has experienced extensive damage from use by both the former occupants (DND) and the general public. Specific damage includes the removal of shrubs and trees, the installation of permanent structures (DND bunker), road maintenance, horseback riding, illegal garbage dumping and the use of all-terrain vehicles. Despite these

disturbances, this property continues to support important alvar plant communities that are both rare and endangered.

A gravel roadway accessed from Regional Road 49 runs north - northeast through this property. *Euphorbia cyparissias* is present along both sides of the gravel roadway, with significant communities extending approximately 25 meters east and west of the road, extending north of a barbed wire fence and south of the DND bunker. This area was selected as the research site because it is the only area on this property where *Euphorbia cyparissias* was present [Figure 4].

3.2 Site Layout

There is no single acceptable methodology for conducting soil seed bank studies or vegetation surveys; therefore, the methods employed must be designed in accordance with the research objectives (Jones, 2000; Barker, 2001). Because the Daubenmire Scale is a proven and accepted tool for estimating ground level canopy cover, species frequency, species composition, vegetation conditions and trends (Jones, 2000; US Fish and Wildlife Service, 2003), it was selected as an appropriate protocol for the vegetation survey and the assessment of canopy cover for the target species in this study.

Figure 4: Aerial photograph of the Burnt Lands Nature Reserve showing the selected research site. Dashed box indicates research area; solid lines indicate transect locations (not to scale).

Six transects 100 meters in length, 10 meters apart and orientated at 25 degrees magnetic north were established in the field. Three transects were located along each side of the gravel road. The central point of commencement (POC) was the junction of the first fence post on the western side of the road and the edge of the gravel road. Each transect commenced 10 meters north of the fence line, with the first transect on each side being 10

meters from the edge of the gravel road. The transects crossed areas where *Euphorbia cyparissias* has invaded and extended into areas where this species is not yet present. Temporary markers were placed in the field to indicate the POC and the transect lines. Permanent markers were not permitted within the site and the temporary markers have since been removed as requested by the OMNR at the time that approval was granted to conduct this research.

3.3 Sampling

On September 17, 2003, ten quadrats (quadrat size 20cm x 50cm) were placed along each transect at random meter locations that were determined prior to the commencement of the fieldwork through the use of a random number table (Berenson *et al.*, 1988). The quadrat frames were positioned with the lower left corner located at the meter point to the east of the transect line. In the event that one of the predetermined quadrats landed on alvar pavement (where no soil was present), the quadrat was moved to the first available meter point further along the transect that contained soil.

Canopy cover of the target species (*Euphorbia cyparissias*) was assessed using per cent cover. The cover of *Euphorbia cyparissias* was determined by visual observation and included individual plant canopies that extended into the quadrat regardless of whether the plant was physically rooted within the quadrat. For the purpose of statistical analysis where *Euphorbia cyparissias* was used as the independent variable, per cent cover was used to ascertain differences between levels of this species in each plot. The majority of *Euphorbia cyparissias* had bloomed in late June and early July of 2003 and was

beginning to die. This resulted in a net decrease in per cent cover at the time of this survey. For this reason, crown closure was re-assessed in early July of 2004 during the peak bloom season. The per cent crown closure for 2004 was used for statistical analysis.

Scientists recommend that soils for soil seed banks studies should be collected in early spring before species flower and set seeds. However, it is also acceptable to collect samples in the late fall after the final seed rain if the soils receive subsequent treatment such as cold stratification to mimic natural conditions (Leck *et al.*, 1989). Two soil cores were obtained from each quadrat using a bulb planter. Soil cores were 6.5 cm in diameter and 10 cm deep. If the soil did not reach a depth of 10 cm, three or four soil cores were collected within the quadrat to account for the one litre of soil required from each plot. These samples were bagged and labelled for the soil seed bank study and soil analysis. The vegetation and the litter layer were not removed from cores at the time of collection because they may have contained seeds valuable for this study. The soil cores collected within each plot were bulked to form one composite sample per plot. Soil depth within each plot was measured in centimetres where one of the cores was extracted.

3.4 Soil Seedbank Study

The soil samples collected on September 17, 2003, were taken to Environment Canada's National Wildlife Research Centre (NWRC) located at Carleton University where they were refrigerated for a period of three weeks. On October 8, 2003, the soil samples were removed from the refrigerator where they had been stored between 0 and 4 degrees Celsius to mimic winter conditions under snow cover. Soil samples were cleaned of

debris and rock by hand. Five hundred millilitres of the soil material were removed from each plot and spread evenly into individually labelled plastic trays that contained drainage holes. Each tray was lined with a fine weave cotton cloth to prevent seed loss during the experiment. Trays were placed in the greenhouse at NWRC where they were watered daily. Greenhouse conditions were monitored and the temperatures ranged between 17.2 degrees Celsius and 30.8 degrees Celsius. Lights were turned on daily between the hours of 6 AM to 9 AM and again from 5 PM to 10 PM from October, 2003 through March, 2004. The extended hours of light exposure simulated summer conditions in the field. Three control trays containing sterile soil were placed among the samples to detect any cross contamination of seeds between trays.

By November 7, 2003, the germination process began but the seedlings were not growing and at risk of dying due to a lack of nutrients in the soil. Most of the seedlings were less than 0.5 cm tall and changing colour from green to a reddish brown or yellow. To avoid the premature death of these seedlings before the species could be identified, the soils were fertilised using an all-purpose fertiliser. This fertiliser contained 20% nitrogen, 20% available phosphoric acid, 20% soluble potash, actual boron 0.02%, actual chelated copper 0.05%, actual chelated iron 0.1%, actual chelated manganese 0.05%, actual molybdenum 0.0005%, actual chelated zinc 0.05%, and EDTA chelating agent 1.0. Five litres of water with 3.5 g of fertiliser per litre were evenly distributed across all samples on November 7, 2003. Additional applications of fertiliser were applied on November 21, 2003, January 9, January 23 and February 8, 2004.

Within each of the 60 samples, plant species were identified, counted and recorded as they germinated. Once the species were identified and recorded, they were removed from the planters thereby allowing space and nutrients for remaining viable seeds to germinate. Species not positively identified were removed from the trays and transplanted into individual pots until their identification could be determined. Once germination appeared to have ceased, the soils were stirred in order to bring remaining seeds to the surface layer where they could germinate. Soils were stirred on December 27, 2003, and on February 8, 2004. The majority of viable seeds will germinate within the first two months (Warr *et al.*, 1993) following planting; samples were monitored daily for this period. However, seedlings continued to germinate in excess of this two-month period, allowing an extension of the experiment until March 27, 2004 when the soil seed bank study was terminated.

3.5 Vegetation Survey

On July 5, 2004, a vegetation survey was conducted in the field at the Burnt Lands. The 6 transect lines were re-established in the field using the original post markers. The original 60 plots used for the soil seed bank study were surveyed for species content and crown closure of *Euphorbia cyparissias* was assessed again. Don Cuddy, a botanist and local taxonomist with extensive experience at the Burnt Lands Nature Reserve, assisted with species identification during the field survey. Species lists and crown closure cover classes of cypress spurge were recorded on field records by plot.

3.6 Soil Analysis

Thirty soil samples were sent for soil analysis at Acutest™, an independent, accredited private laboratory in Ottawa, Ontario. The high cost associated with laboratory testing and the limited resources available precluded soil analysis of all 60 plots. Thirty samples were selected based upon the presence and absence of *Euphorbia cyparissias* determined during the initial field investigation of crown closure in September, 2003. Eighteen of the soil samples had cypress spurge present in the vegetation layer and were selected for analysis along with 12 randomly chosen samples where cypress spurge was not present. These samples were stored in the refrigerator at the NWRC until they were sent for analysis on December 19, 2003. The soil samples were analysed for the parameters outlined in Table 4.

3.7 Statistical Analysis

Histograms were constructed to assess the frequency distribution of each variable [Appendix A]. Since not all variables follow a normal distribution without the removal of the outliers, a non-parametric test was chosen to assess correlations between variables and the per cent crown closure of *Euphorbia cyparissias*. Spearman's Rank Correlation is a technique used to test the direction and strength of the relation between two variables using Spearman's r_s coefficient. Spearman's Rank Correlation is a distribution free analogue of correlation analysis and is often used on non-parametric data (Conover, 1980; Hoaglin *et al.*, 1983; Sregel & Castellan, 1988)

Table 4: Soil analysis – parameters and units

Parameter	Units
N-N03	ppm (parts per million)
P	ppm
K	ppm
Mg	ppm
pH	
Organic Matter	%
Sand	%
Silt	%
Clay	%

The formula used for Spearman's Rank Coefficient is:

$$r_s = 1 - \frac{6 \sum d^2}{n^3 - n}$$

where n is the sample size for the paired measurements, and
 d is the difference in rank between each pair of measurements.

The coefficient (r_s) falls between +1 (a perfect positive correlation) and -1 (a perfect negative correlation). A value of 0 indicates that there is no relation (Tukey, 1977; Berenson *et al.*, 1988). Spearman's Rank Correlation was applied using SPSS V. 10, to

assess the statistical strength and relation with the presence and amount of *Euphorbia cyparissias* to the remaining measured variables in this study.

Histograms and scatter plots are used in this thesis as visual representations of the data for the purpose of showing distribution and correlation.

4. RESULTS & DISCUSSION

4.1 Crown Closure of *Euphorbia cyparissias*

Euphorbia cyparissias was in 32 of the 60 plots examined [Appendix B]. The per cent of crown closure ranged between 0%, where no *Euphorbia cyparissias* was present, to 30%. The mean was 3.9% distributed across all 60 plots [Figure 5].

Figure 5: Histogram showing the distribution of *Euphorbia cyparissias* as % crown closure in 2004.

Crown closure of *Euphorbia cyparissias* is treated as the independent variable against which all other components of this study will be evaluated.

4.2 Species Composition

Species composition was determined by identifying and counting species that germinated in the soil seed bank study and that rooted within each of the 60 plots for the vegetation survey. A total of 25 species germinated in the soil seed bank study and 51 species were recorded during the vegetation survey. In the vegetation survey, 8 plants were unidentified because they were immature; they are recorded as unknown. In addition to these unknown plants, three plants were identifiable only by family (*Agrostis* spp., *Solidago* spp. and *Viola* spp.). Unknown species that could be duplicates of identified species were not included in the statistical analysis due to the possibility of biasing the results. There was only one plant from the violet family identified in the vegetation survey and this plant was included in the species composition because there was no chance of duplication. A total of 49 species were used in the statistical analysis for the vegetation survey [Table 5].

Species in the soil seed bank were recorded by date and number of individuals as they germinated [Appendix C]. The vegetation survey identified plant species by plot but the number of individual plants of each species in each plot was not determined. Therefore, only the number of species can be cross-compared between the two surveys. Nine species, including *Acer* spp., that grew in the soil seed bank study did not appear in the above ground vegetation during the field survey and 33 species from the vegetation survey were not found in the soil seed bank study. The first species to germinate, if its seeds were present in the plot, was *Hypericum perforatum*, followed in order by *Verbascum thapsus*, *Leucanthemum vulgare*, *Daucus carota*, *Melilotus alba*, and

Table 5: Species composition in the soil seed bank study and vegetation survey

Species Present in the Soil Seed Bank Study	Species Present in the Vegetation Survey
Acer spp.	Agropyron trachycaulum Agrostis gigantea Ambrosia artemisiifolia Antennaria howellii Aster cordifolius Bromus kalmii Campanula rotundifolia Carex aurea Carex crawei Carex richardsonii Carex umbellata Ceanothus americanus Chaenorrhinum minus Leucanthemum vulgare Comandra umbellata Danthonia spicata Daucus carota Deschampsia flexuosa Echium vulgare Echium vulgare Equisetum arvense Euphorbia cyparissias Fragaria virginiana Hieracium piloselloides Hypericum perforatum Isanthus brachiatus Linaria vulgaris Lythrum salicaria Maianthemum canadense Melilotus alba
Campanula rotundifolia	
Chaenorrhinum minus	
Leucanthemum vulgare	
Danthonia spicata	
Daucus carota	
Deschampsia flexuosa	
Echium vulgare	
Euphorbia cyparissias	
Fragaria virginiana	
Hieracium piloselloides	
Hypericum perforatum	
Melilotus alba	
Minuartia michauxii	
Oenothera biennis	
Oxalis stricta	
Panicum linearifolium	
Poa compressa	
Rumex acetosella	
Scutellaria parvula	
Senecio pauperculus	
Solidago nemoralis	
Stachys palustris	
Verbascum thapsus	
Viola adunca	
	Panicum linearifolium Penstemon hirsutus Poa compressa Polygala senega Potentilla recta Prunella vulgaris Prunus virginiana Rhamnus cathartica Rhus radicans Rhus typhina Rosa blanda Scutellaria parvula Senecio pauperculus Sisyrinchium montanum Smilacina stellata Solidago nemoralis Solidago ptarmicoides Sporobolus vaginiflorus Trifolium aureum Vicia cracca Viola spp

Oxalis stricta. All of these species are considered alien and with the exception of *Leucanthemum vulgare*, they are also invasive species (White *et al.*, 1993). This pattern of species appearance occurred each time that the soils in the trays were stirred to promote further germination.

When the results of the soil seed bank study and vegetation survey were combined, there was a total of fifty-seven plant species. The majority of these species were perennials with five annuals and five biennials [Table 6]. A greater percentage of annuals were expected to appear in the soil seed bank because annuals are generally reported to form large persistent soil seed banks (Begon *et al.*, 1990; Bekker, 1998). However, only two annuals were identified in the soil seed bank study while the remaining three appeared in the vegetation survey. Twenty of the total species were alien, and thirty-seven were native. Thirteen of the alien species were present in the soil seed bank and sixteen alien species were recorded in the vegetation survey, with nine of these alien species being common to both. The single *Acer* representative that germinated in the soil seed bank study could not be identified at the species level and could be either native or alien. One significant, although not surprising, finding was that sixteen of the twenty alien species identified are considered to be invasive in Canada (White *et al.*, 1993).

No plant species listed in Table 3 as *Significant Species* by the Ontario Natural Heritage Information Centre was present in either the soil seed bank study or the vegetation survey. In the vegetation survey, two locally significant species, *Carex crawei* and *Carex*

Table 6: Species origin and growth pattern

Origin	Growth Pattern	Species (Scientific Name)	Species (Common Name)	Number of Plots Species is Present (Soil Seed Bank Study)	Number of Plots Species is Present (Vegetation Survey)
Alien	Annual	Chaenorrhinum minus	Dwarf Snapdragon	8	2
		Melilotus alba*	White Sweet-Clover	7	7
	Biennial	Daucus carota*	Wild Carrot	3	2
		Echium vulgare*	Blue-weed	14	7
		Trifolium aureum	Hop Clover	0	5
		Verbascum thapsus*	Common Mullein	23	0
	Perennial	Agrostis gigantea*	Redtop	0	1
		Leucanthemum vulgare	Ox-eye Daisy	12	12
		Euphorbia cyparissias*	Cypress Spurge	4	32
		Hieracium piloselloides*	King Devil Hawkweed	5	39
		Hypericum perforatum*	Spotted St. John's-wort	56	7
		Linaria vulgaris*	Yellow Toadflax	0	2
		Lythrum salicaria*	Purple Loosestrife	0	1
		Oxalis stricta*	European Yellow Wood-sorrel	32	0
		Poa compressa*	Canada Blue Grass	48	29
		Potentilla recta*	Sulphur Cinquefoil	0	7
		Rhamnus cathartica*	Common Buckthorn	0	1
		Rumex acetosella*	Sheep Sorrel	2	0
		Stachys palustris*	Marsh Hedge-Nettle	2	0
		Vicia cracca	Tufted Vetch	0	3
Native	Annual	Ambrosia artemisiifolia	Common Ragweed	0	4
		Isanthus brachiatus	False Pennyroyal	0	5
		Sporobolus vaginiflorus	Ensheathed Dropseed	0	24
	Biennial	Oenothera biennis	Common Evening Primrose	2	0
	Perennial	Agropyron trachycaulum	Slender Wheat Grass	0	1
		Antennaria howellii	Canadian Pussy-toes	0	10
		Aster cordifolius	Heart-leaved Aster	0	4
		Bromus kalmii	Kalm's Brome Grass	0	2
		Campanula rotundifolia	Harebell	20	17
		Carex aurea	Golden Sedge	0	5
		Carex crawei	Crawe's Sedge	0	24
		Carex richardsonii	Richardson's Sedge	0	16
		Carex umbellata	Parasol Sedge	0	8
		Ceanothus americanus	New Jersey Tea	0	1
		Comandra umbellata	Bastard Toadflax	0	1
		Danthonia spicata	Poverty Oat Grass	5	52
		Deschampsia flexuosa	Wavy Hair Grass	6	0
		Equisetum arvense	Wild Horsetail	0	1
		Fragaria virginiana	Common Strawberry	26	16
		Maianthemum canadense	Canada Mayflower	0	1
		Minuartia michauxii	Rock Sandwort	2	0
		Panicum linearifolium	Narrow-leaved Panic Grass	17	39
		Penstemon hirsutus	Hairy Beardtongue	0	6
		Polygala senega	Seneca Snakeroot	0	1
		Prunella vulgaris	Heal-all	0	9
		Prunus virginiana	Red Choke Cherry	0	1
		Rhus radicans	Poison Ivy	0	4
		Rhus typhina	Staghorn Sumac	0	1
		Rosa blanda	Smooth Wild Rose	0	4
		Scutellaria parvula	Small Skullcap	4	23
		Senecio pauperculus	Balsam Ragwort	35	41
		Sisyrinchium montanum	Common Blue-eyed Grass	0	2
		Smilacina stellata	False Solomon's Seal	0	10
		Solidago nemoralis	Gray Goldenrod	11	34
		Solidago ptarmicoides	Upland White Goldenrod	0	12
		Viola adunca	Hooked-spur Violet	1	0
		Viola spp	Violet species	0	1
N/A	Perennial	Acer spp.	Maple species	1	0

* Species is considered invasive.

richardsonii, were present. In the soil seed bank study, *Viola adunca* was the only locally significant species that grew.

Although the vegetation survey [Appendix D] contained more than twice the number of species that grew in the soil seed bank study, comparison of the number of species per plot between the two sets of data revealed a significant positive correlation at the 0.05 confidence level [Figure 6]. Spearman's correlation coefficient (r_s) was 0.300 with a 2-tailed probability value (p) of 0.0198. This statistic indicates that as the number of species found in each plot for the vegetation survey increased, the number of species in corresponding plots in the soil seed bank study also increased.

In the soil seed bank study, there is a non-significant, weak positive correlation between the number of species per plot and the soil depth of that plot. However, in the vegetation survey, there was no correlation between the depth of the soil and the number of species present [Table 7]. The distribution of alien species between the soil seed bank study and the vegetation survey also show a trend [Figure 7]. The number of alien species in each plot in the soil seed bank study closely corresponds to the number of aliens found in the vegetation survey, although the specific alien species found in the soil seed bank study often differed from those recorded in the vegetation survey. As the number of alien species increased, species richness increased.

Figure 6: Comparison of species by plot between the soil seed bank study and the vegetation survey. NB: 60 plots are represented. Plots with the same values are superimposed; plots values can be found in Appendix E.

There was a significant positive correlation at the 0.05 confidence level between the amount of phosphorus in the soil and the number of species that germinated in the soil seed bank study (r_s 0.405, p 0.026). Phosphorus, an element that enables plants to grow and complete their life cycle, is primarily recycled through the decomposition of organic matter. Phosphorus compounds commonly found in soil are often insoluble and unavailable for plant consumption (Brady & Weil, 1999). The significant correlation between phosphorus and species richness did not extend to the vegetation survey where no correlation was found.

The remaining soil properties analysed did not show significant correlations with species richness in either the soil seed bank study or the vegetation survey.

Figure 7: Distribution of alien species in the soil seed bank study and the vegetation survey. Dots in black to the left of each transect line represent the number of alien species that grew in the soil seed bank study. Grey dots to the right of the transect lines represent alien species that were recorded in the vegetation survey. Markers on the transect lines represent 10 metre intervals.

Table 7: Table of Spearman's Correlation

		Correlations												
		# of species per plot (SSBS)	% Crown Closure	# of species per plot (VS)	Soil Depth	N (ppm)	pH	P (ppm)	K (ppm)	Mg (ppm)	Organic Matter (%)	Sand (%)	Silt (%)	Clay (%)
Spearman's rs	# of species per plot (SSBS)	Correlation Coefficient Sig. (2 tailed) N	1.000 60											
	% Crown Closure	Correlation Coefficient Sig. (2 tailed) N	0.242 0.062 60	1.000 60										
	# of species per plot (VS)	Correlation Coefficient Sig. (2 tailed) N	*0.300 0.020 60	0.131 0.319 60	1.000 60									
	Soil Depth (cm)	Correlation Coefficient Sig. (2 tailed) N	0.092 0.484 60	0.137 0.298 60	-0.001 0.996 60	1.000 60								
	N (ppm)	Correlation Coefficient Sig. (2 tailed) N	0.157 0.408 30	0.025 0.896 30	-0.147 0.438 30	-0.111 0.558 30	1.000 30							
	pH	Correlation Coefficient Sig. (2 tailed) N	-0.356 0.054 30	-0.130 0.495 30	-0.191 0.312 30	0.109 0.567 30	-0.197 0.298 30	1.000 30						
	P (ppm)	Correlation Coefficient Sig. (2 tailed) N	*0.405 0.026 30	0.333 0.072 30	0.092 0.630 30	0.214 0.257 30	*0.444 0.014 30	-0.328 0.080 30	1.000 30					
	K (ppm)	Correlation Coefficient Sig. (2 tailed) N	0.187 0.321 30	0.115 0.546 30	0.150 0.936 30	-0.005 0.978 30	0.023 0.903 30	0.010 0.958 30	0.125 0.511 30	1.000 30				
	Mg (ppm)	Correlation Coefficient Sig. (2 tailed) N	0.320 0.084 30	0.316 0.089 30	0.120 0.529 30	0.327 0.078 30	0.003 0.989 30	0.298 0.110 30	0.286 0.126 30	**0.628 0.000 30	1.000 30			
	Organic Matter (%)	Correlation Coefficient Sig. (2 tailed) N	0.334 0.071 30	0.097 0.609 30	0.077 0.687 30	-0.199 0.291 30	*0.400 0.029 30	*-0.387 0.035 30	0.167 0.379 30	**0.636 0.000 30	0.251 0.182 30	1.000 30		
	Sand (%)	Correlation Coefficient Sig. (2 tailed) N	0.030 0.876 30	0.214 0.256 30	0.128 0.500 30	0.307 0.099 30	-0.165 0.384 30	0.167 0.377 30	0.344 0.062 30	*-0.383 0.037 30	0.054 0.755 30	**0.568 0.001 30	1.000 30	
	Silt (%)	Correlation Coefficient Sig. (2 tailed) N	-0.039 0.837 30	-0.211 0.262 30	-0.156 0.410 30	-0.308 0.098 30	0.207 0.271 30	-0.232 0.217 30	-0.332 0.073 30	0.316 0.089 30	-0.135 0.478 30	**0.560 0.001 30	**0.973 0.000 30	1.000 30
	Clay (%)	Correlation Coefficient Sig. (2 tailed) N	0.180 0.342 30	0.089 0.641 30	0.077 0.684 30	-0.269 0.151 30	-0.037 0.846 30	0.011 0.954 30	-0.099 0.603 30	0.067 0.724 30	0.116 0.543 30	0.018 0.924 30	*-0.409 0.025 30	0.247 0.188 30

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). SSBS: Soil Seed Bank Study. VS: Vegetation Survey

The per cent crown closure of *Euphorbia cyparissias* was not significantly correlated with the number of species in each plot in either the soil seed bank study or the vegetation survey [Table 7]. A weak positive correlation is counter intuitive because the presence of *Euphorbia cyparissias* has commonly been associated with a decrease in the number of species due to this plant's ability to aggressively compete and displace other species (Van Driesche, 2002).

Euphorbia cyparissias was subtracted from the number of species in each plot, where it was present, so that this species was not included in total species richness. Four plots in the soil seed bank study and 32 plots in the vegetation survey were affected by this change. With the elimination of *Euphorbia cyparissias* from the total number of species per plot, the Spearman's correlation changed from a positive trend to no correlation in both sets of data.

The Spearman's correlation was also recalculated for the total number of species by plot in the soil seed bank study to crown closure of *Euphorbia cyparissias* using only the 32 plots that contained *Euphorbia cyparissias* in the vegetation survey. The purpose of this calculation was to determine if the correlation strength and direction would change using only the plots that contained *Euphorbia cyparissias*, thereby detecting possible effects of *Euphorbia cyparissias* in the vegetation survey on the soil seed bank study. The results were similar to the findings when using all 60 plots. The correlation coefficient changed to r_s 0.31, p 0.083 in the 32 plots from r_s 0.24, p 0.062 in all 60 plots. Using the same 32 plots that contained *Euphorbia cyparissias* for the recalculation of Spearman's r_s for

crown closure and the number of species per plot in the vegetation survey data, the r_s statistic changed from 0.131, p 0.319 in all 60 plots to r_s -0.19, p 0.298 indicating a shift from a positive trend to a negative trend. While non-significant, a negative trend is in the direction that would be anticipated indicating that as the per cent crown closure of *Euphorbia cyparissias* increases, species richness declines.

4.3 Soil Analysis

The soil parameters measured were organic matter, pH, nitrogen, phosphorous, potassium, magnesium and the per cent of sand, silt and clay [Table 8]. The objective of analysing soils was to determine the fertility status of the site and whether the presence of *Euphorbia cyparissias* significantly affected or was significantly affected by differences in soil parameters within the site. Invasive species as a whole are believed to have a competitive advantage over native species because they usually germinate early, and thereby, co-opt the available resources in the soil to the disadvantage of the resident native species (Gordon, 1998; Heffernan, 1998; Higgins *et al.*, 1999; Allendorf & Lundquist, 2003).

The soils at the study site are classified texturally as sandy loam, with a mean sand content of 61%. Silt contents have a mean value of 29% and clay content averages 10%. The relatively high sand content and the low clay content coupled with the relatively shallow depth of the soil to bedrock limits the ability of the soil to hold both water and chemical nutrients in plant-available form (Brady & Weil, 1999). In this study, both potassium (r_s -0.383, p 0.037) and the per cent of organic matter (r_s -0.568, p 0.001)

decrease at a significant level as the percentage of sand increases. The level of nitrate in the soil also shows a negative trend when compared to sand content but not at a significant level ($r_s -0.165, p 0.384$) [Table 7].

Table 8: Results of the analysed soil parameters by plot

Plot	%CC (2004)	Organic Matter (%)	pH	Nitrate (ppm)	P (ppm)	K (ppm)	Mg (ppm)	Sand (%)	Silt (%)	Clay (%)
A33	0	4.27	7.1	8	3	33	36	59	29	12
A37	0	5.82	6.9	14	3	38	35	59	31	10
A62	5	5.86	7.3	10	3	42	26	61	31	8
A70	10	9.07	7.1	11	3	43	27	50	40	10
B23	5	7.54	7.5	9	4	80	61	59	29	12
B38	5	4.73	7.2	5	4	44	30	67	23	10
B58	10	3.72	7.6	1	2	39	47	86	4	10
B60	20	5.77	7.5	6	3	51	68	80	10	10
B61	5	7.19	7.5	7	4	72	73	77	17	6
B78	5	6.64	7.4	8	1	30	44	57	31	12
C10	0	4.93	7.6	6	3	43	54	65	27	8
C25	10	4.69	7.7	10	2	39	52	67	23	10
C30	5	3.29	7.7	6	2	31	44	71	19	10
C35	5	4.44	7.6	7	2	38	51	57	31	12
C51	0	4.33	7.6	2	1	44	52	67	25	8
C67	0	5.83	7.5	9	1	52	46	52	38	10
C88	0	3.67	7.7	2	2	34	44	65	25	10
D50	5	7.13	7.4	5	2	69	57	47	43	10
D84	5	6.91	7.3	5	1	51	46	54	36	10
D85	5	5.33	7.6	7	0.5	57	46	51	39	10
D95	5	8.16	7.5	16	4	93	106	63	29	8
D96	5	6.72	7.6	15	4	92	93	55	35	10
E23	0	6.06	7.6	12	2	54	37	56	34	10
E63	5	4.79	7.6	0.5	1	61	49	58	30	12
E78	0	6.06	7.4	5	1	49	33	56	34	10
E98	5	5.17	7.5	1	1	46	37	64	26	8
F16	0	5.90	7.6	5	0.5	54	40	56	34	10
F36	0	4.77	7.6	10	1	30	24	69	23	8
F64	0	7.84	7.7	6	1	107	58	45	35	20
F79	0	5.47	7.6	6	1	31	26	57	35	8

Typical well-drained soils contain between 1% to 6% organic matter (Tisdale & Nelson, 1975; Brady & Weil, 1999). The mean level of organic matter in the 30 samples was

5.73%. Organic matter as it decomposes is a major source of available phosphorus, sulphur and nitrogen for plants. Results of the soil analysis show that as organic matter increases, so do levels of nitrate (r_s 0.400, p 0.029) and potassium (r_s 0.636, p <0.001). With an increase in organic matter, a soil's moisture holding capacity also increases (Brady & Weil, 1999). This is significant for alvar habitats because they are subjected to extreme climatic fluctuations during the seasons. In spring, alvars are typically flooded or heavily saturated, but they commonly experience severe drought throughout much of the growing season. A soil with a higher percentage of organic matter would hold marginally more water, which should promote nutrient cycling and influence the germination of seeds in the soil seed bank (Leck *et al.*, 1989).

4.4 Soil Depth

Soil depths ranged from 5 cm to 27.5 cm [Appendix F] with the majority of plots containing between 10 cm and 20 cm of soil [Figure 8]. No significant correlation was found between soil depth and species richness, per cent crown closure of *Euphorbia cyparissias*, soil nutrients or soil types [Table 7]. The statistical analysis showed no significant correlation between the per cent crown closure of *Euphorbia cyparissias*, a species well adapted, but not restricted to, shallow soils and soil depth.

Figure 8: Histogram showing the distribution of soil depth.

4.5 Trees and Shrubs

Most of the plant species identified by vegetative and soil seed bank studies qualify as herbaceous plants. Two tree species and five woody shrub species were found. The tree species (*Acer* spp.) in the soil seed bank study occurred in plot B61 where the soil depth was 20 cm. No mature specimens of this species exist in close proximity to the site and it is unknown how the seed was transported there. If this seed had germinated under field conditions, it is improbable that it would reach maturity because the soil depth is too shallow. *Rhus typhina* was located in plot C67 with a soil depth of 17 cm during the vegetation survey. *Rhus typhina* is present on this site and has reached maturity outside of the study area.

Five woody shrub species were recorded in the vegetation survey. *Prunus virginiana* and *Rhamnus cathartica* were both located in plot A37 with a soil depth of 14.8 cm and *Ceanothus americanus* was located in plot A33 with a soil depth of 15 cm. *Rhus radicans* and *Rosa blanda* were the most common shrubs located in the study site with each species appearing in 4 plots. *Rhus radicans* was located in plots; A89, A97, B78 and F97 with soil depths of 6.5 cm, 10 cm, 16 cm, and 11 cm respectively. *Rosa blanda* was located in plots A33, B41, D0 and F16 with soil depths in order 15 cm, 17 cm, 18cm and 14 cm. These shrub species are common throughout this section of the Burnt Lands Nature Reserve and have reached maturity directly outside of the study area. *Rhamnus cathartica* is the only shrub species that has reached maturity within the study area.

5. SYNTHESIS & CONCLUSIONS

The soil seed bank study and the vegetation survey were conducted for the purpose of gaining information that would assist in determining the extent to which native alvar species have been successful in surviving the presence of the invasive alien species, specifically, *Euphorbia cyparissias*. Information from this study also provides input for addressing the relative degree to which native species would be successful in surviving the disturbance that would be expected to accompany attempts to eradicate *Euphorbia cyparissias* from the site, by mechanical or other means, in the face of the potential success of the invasive species present in the soil seed bank study.

The 25 species that grew in the soil seed bank study consisted of 11 native species, 13 alien species and 1 *Acer* spp., unknown as to whether alien or invasive. Twelve of the alien species are known to be invasive in Canada (White *et al.*, 1993). On the basis of the number of seeds that germinated, *Hypericum perforatum* displayed the most aggressive invasive potential with 590 individual plants growing across 56 plots during the soil seed bank study. *Poa compressa*, *Oxalis stricta* and *Verbascum thapsus*, respectively, were the next most widely distributed species appearing in 48, 32 and 23 plots in the soil seed bank study. In the vegetation survey, the four invasive alien species that had the greatest germination in the soil seed bank study, *Poa compressa*, *Hypericum perforatum*, *Oxalis stricta* and *Verbascum thapsus* were present in 29, 7, 0 and 0 plots respectively. The relative performances of these invasive species across the two studies may provide valuable clues to the ecosystem response following a substantial disturbance that might accompany the eradication of *Euphorbia cyparissias*. It might be expected that the

responses to disturbance in the field situation, including the order of species appearance, the frequency of species appearance and the distribution of species that would germinate and grow may parallel those in the soil seed bank study.

If the above were the case, the first and most prolific species to germinate following disturbance would be *Hypericum perforatum*, a herbaceous perennial native to Europe that spreads through seed production and vegetatively through rhizomes. *Hypericum perforatum* is capable of producing more than 100 000 seeds per plant annually and these seeds can remain viable in the soil seed bank in excess of 50 years (Kivilaan & Bandursky, 1981; Crompton *et al.*, 1988). This species is widely dispersed throughout Canada and has a preference for open habitats such as meadows, forest openings and agricultural lands (Harris *et al.*, 1969; Crompton *et al.*, 1988).

It is interesting, and possibly significant, that *Hypericum perforatum* was not dominant in the vegetation survey. While this species is an aggressive invader and prefers disturbed sites in open habitats, such as the study site, it was found growing in only 7 of the 60 plots. This is consistent with the observations of Catling and Brownell (1998), who conducted a vegetation survey of the former DND property of the Burnt Lands Nature Reserve and found that *Hypericum perforatum* appeared frequently but with low cover. The great success of this species in the soil seed bank study may have been caused by the repeated applications of fertiliser as demonstrated in a field experiment conducted by Catling in 1995, in addition to the temperature, moisture and light conditions provided in the greenhouse environment. Before fertiliser was added to the soil seed bank study, the

Hypericum perforatum seedlings did not survive. The combined results of the soil seed bank study before fertilisation and the vegetation survey suggest that *Hypericum perforatum* may have some success as an initial coloniser at the study site, but that it is unlikely to be a strong competitor or exhibit long term dominance. Additional evidence to support this interpretation is that the section of the Burnt Lands where this study was conducted is highly disturbed by the public for recreational purposes such as horseback riding and the use of all-terrain vehicles. The limited presence of *Hypericum perforatum* in the vegetation survey suggests that the current level of disturbance has not facilitated aggressive invasion by *Hypericum perforatum*. Furthermore, *Hypericum perforatum*, while widely dispersed throughout Canada, is only recorded as highly problematic in southern British Columbia. In Eastern Canada, the literature reports this species as a minor problem with the appearance of individual plants or small infestations (Crompton *et al.*, 1988; Harris *et al.*, 1969).

Poa compressa was the second most prolific species to germinate in the soil seed bank study with 206 stems removed across 48 plots. This species is typically an early coloniser and is significant for its abundance in both the soil seed bank study and the vegetation survey where it appeared in 29 of the 60 plots examined. *Poa compressa* is considered an alien invasive species that is widely dispersed throughout Canada (Reader & Bonser, 1993). *Poa compressa* prefers nutrient poor soils on clay or gravel in open habitats and is able to reproduce through seeds and rhizomes (Turkington, 1994). *Poa compressa* is able to resist invasion by other grasses once the initial colonies are established, however, this species matures late in the season and is intolerant of shade (Turkington, 1994). Early

colonisers are able to compete with *Poa compressa* by providing shade, which leads to reduced seedling growth and survival. Furthermore, unlike many invasive alien species, *Poa compressa* has a host of predators including cattle, horses, and sheep and is susceptible to several pathogens, such as cocksfoot mild mosaic sobemovirus, *Poa* semilatifolia virus and wheat streak mosaic virus (Turkington, 1994; Reader & Bonser, 1993). Although *Poa compressa* is widely dispersed throughout the Burnt Lands, it is not seen as a major competitor or a threat to the native vegetation at this time (Catling & Brownell, 1998).

Neither *Oxalis stricta* nor *Verbascum thapsus* appeared in the vegetation survey although their numbers were substantial in the soil seed bank study. Both of these species thrive in open places, along roadsides or abandoned fields and produce a large number of small persistent seeds (Niering & Olmstead, 1995). While these species have the potential to become aggressive invaders at this site, their absence in the vegetation survey indicates that these species are not serious competitors at this time.

Euphorbia cyparissias produced only 4 individual stems in 4 plots during the soil seed bank study but appeared in 32 plots during the vegetation survey. It is highly probable that the variant present in the Burnt Lands Nature Reserve is the sterile diploid that only reproduces vegetatively. Severed pieces of rootstock could have been missed during the hand cleaning of the soil, which could have led to the propagation of the 4 individuals that were found. *Euphorbia cyparissias* is a dominant invasive alien species at the study site and occupies a substantial portion of ground cover in relation to the other species

present in the surface vegetation. Brunton (1985c) first noted the appearance of *Euphorbia cyparissias* at the Burnt Lands Nature Reserve in 1985. In almost twenty years since its documentation, this species has not proliferated to its full potential at this site despite its success in nearby surrounding areas (Stahevitch *et al.*, 1988).

Euphorbia cyparissias is an invasive species that forms pure stands with extensive root networks and is known for its ability to displace other plant species (Stahevitch *et al.*, 1988; Van Driesche, 2002). However, crown closure of *Euphorbia cyparissias* did not show any significant correlation with the other measured variables in this study. While species richness and nutrient levels were expected to decrease as the per cent crown closure of *Euphorbia cyparissias* increased, this trend was not observed. This trend could be explained by the fact that the extensive root system associated with *Euphorbia cyparissias* may act as a 'resource island' by retaining slightly higher levels of moisture and nutrients (Burke *et al.*, 1998). Slight increases of water and nutrients in an impoverished environment would promote nutrient cycling, which would create more opportunities for the germination of viable seeds in the soil seed bank (Harper, 1977; Leck *et al.*, 1989; Brady & Weil, 1999).

Most nutrients in the soil showed only a very weak positive correlation with per cent crown closure of *Euphorbia cyparissias*. The most probable explanation for the lack of significant correlations with crown closure is that the per cent crown closure in most of the plots was relatively low and, therefore, not sufficient to have a significant impact on species richness or nutrient availability in the soil. If the crown closure of *Euphorbia*

cyparissias increases at this site, nutrient levels and species richness may decrease significantly. The lack of significant correlation coefficients does not mean that *Euphorbia cyparissias* is not impacting the ecosystem; rather, the impacts are still relatively minor or not detectable at significant levels.

Precipitation levels during the two years over which this research was conducted were above average (Environment Canada, 2004), and recorded per cent of crown closure may appear to be misleading at the study site in comparison to per cent crown closure in dry years. In 1988, Stahevitch *et al.* documented the appearance of *Euphorbia cyparissias* in a lightly grazed pasture in Braeside, Ontario. The authors stated that *Euphorbia cyparissias* was dominant in dry summers comprising 56% of the total vegetation. In wet summers, *Euphorbia cyparissias*, at the same test site, accounted for only 26% of the total vegetation (Stahevitch *et al.*, 1988). Furthermore, one of the *Euphorbia cyparissias* specimens that grew in the soil seed bank study was removed and transplanted into an individual planter. While in the greenhouse, this plant was watered daily. During this time, it formed one healthy spike that was 16.9 cm in height. It was then removed from the greenhouse and watered once a week for a period of 5 months. Two weeks after the frequency of watering was decreased, this plant began to form multiple rhizomes through the drainage holes in the pot and just below the soil surface. One month after the decrease in watering frequency, 9 rhizomes ranging from 8.2 cm to 56.4 cm in length had extended from the original parent plant (personal observation, 2004). While this species has a wide tolerance range for moisture, it is evident that it flourishes in drought-like conditions.

Out of the eleven native species that grew in the soil seed bank study, four species are distinctively alvar species. *Scutellaria parvula* and *Senecio pauperculus* are two species that are primarily confined to alvar ecosystems in Ontario (Catling, 1995). *Minuartia michauxii* and *Viola adunca* are two additional alvar species that are commonly found in the boreal forest region and the sub-arctic. Although their range is not restricted to alvars, they are rarely found this far south except in alvar ecosystems (Brunton, 1985b, Brunton, 1985c). *Campanula rotundifolia*, *Danthonia spicata*, *Deschampsia flexuosa*, *Panicum linearifolium*, and *Solidago nemoralis* are common species that thrive in dry grassland ecosystems and alvars. *Oenothera biennis* and *Fragaria virginiana* are very common species that are not characteristic of alvars or dry grasslands.

The vegetation survey contained 12 plant species that are significant alvar species. *Campanula rotundifolia*, *Danthonia spicata*, *Panicum linearifolium*, *Scutellaria parvula* and *Senecio pauperculus* were identified in both the soil seed bank study and the vegetation survey as presented above. In addition to these species, the vegetation survey contained *Sporobolus vaginiflorus*, a species rare in Canada (White, 1979) and *Ceanothus americanus* which is common in Ontario but listed by the Ontario Natural Heritage Information Centre as a provincially significant species. Other species growing on the test site that are considered rare in the Ottawa-Carleton district and are primarily confined to alvar or dry grassland ecosystems include: *Bromus kalmi*, *Carex crawei*, *Carex richardsonii*, *Penstemon hirsutus*, and *Polygala senega* (White, 1979; Brunton, 1985b, Brunton, 1985c).

The differences in species composition between the above ground vegetation and the plants that grew in the soil seed bank study are substantial but such differences are common and well represented in the literature on alvars and dry grassland ecosystems (Leck *et al.*, 1989; Warr *et al.*, 1993; Kirkhan & Kent, 1997; Schaefer & Larson, 1997, Stark *et al.*, 2003). There was a total of fifty-one species, excluding the ten unidentified plants, present in the vegetation survey compared to twenty-five species that grew in the soil seed bank study. Thirty-three of the plant species identified in the vegetation survey did not appear in the soil seed bank study and nine of the species that grew in the soil seed bank study did not appear in the vegetation survey. There are several possible reasons for the absence of species in the soil seed bank study. The most likely reasons are that (1) seeds never became incorporated into the soil seed bank, (2) abiotic and biotic conditions supplied in the greenhouse did not favour germination for these species, (3) the seeds were not inherently persistent and did not survive the transition to the soil seed bank, or (4) the seeds suffered mortality by predators or pathogens. The nine species that were absent in the vegetation survey included both native and alien species. The four native species that were absent in the vegetation survey appeared in the soil seed bank study in only small numbers. These species may not have had favourable field conditions for germination or may simply have been missed during the random sampling of species in the vegetation survey. The four alien species that germinated in the soil seed bank study but were absent in the vegetation survey presumably had their seeds transported to this site where they have remained viable in the soil seed bank and were likely waiting for favourable conditions, provided in the greenhouse, to germinate.

Annual species are cited as the largest contributors to soil seed banks because annuals have a relatively short life cycle to reproduce so they tend to produce an abundance of persistent seeds (Silvertown, 1982; Leck *et al.*, 1989). Only two annual species germinated in the soil seed bank study; likewise, there was a distinct paucity of annuals in the above ground vegetation at the study site.

The soil was chemically analysed to determine if the presence of *Euphorbia cyparissias* altered soil nutrient levels. Results from this study showed no significant differences between plots that contained *Euphorbia cyparissias* when compared to plots void of this species. Soils in alvar ecosystems are characterised by shallow sandy soils that have low nutrient levels and a low moisture holding capacity. In addition, alvar soils in this region are subjected to significant seasonal climatic fluctuations (Brunton, 1988; Brownell & Riley, 2000). The soils at the study site contain notably fewer nutrients when compared to the study performed by Stark *et al.* (2003) on the Bruce Peninsula open pavement alvar ecosystems. However, species observed in the vegetation survey did not exhibit some of the signs of stress typical of nutrient deficiencies, such as discolouration or the inability to complete their life cycle (Tisdale & Nelson, 1975; Brady & Weir, 1999). The lack of these stress indicators suggests that these species are well adapted to, or at least tolerant of, the relatively harsh environmental conditions presented at the study site.

During the initial phase of the soil seed bank study a small number of seedlings began to germinate and grow. When these seedlings were only a few millimetres in height, they

stopped growing and began to turn yellow and red indicating insufficient nutrients to support the plants' survivability and continued growth. After the soils were fertilised, species began to recover and the emergence of new seedlings was observed. Low nutrient content in the soil seed bank study could have three reasons. First, the nutrients in the soil were already naturally low. Second, the soils were planted in plastic trays with drainage holes and watered daily, which could have leached nutrients from the soil. Third, the soils were cleaned of debris and organic matter, which acts as a storehouse for nutrients in the soil (Burke *et al.*, 1998; Grime *et al.*, 1997; Kohler *et al.*, 2001; Critchley *et al.*, 2002). Without the debris and organic matter present in the soil, organic matter decomposition would be limited, exacerbating a deficiency of nutrients to support the growth of plant seedlings.

The results of this study are consistent with other soil seed bank studies conducted on alvar ecosystems. Species in the soil seed bank differed dramatically from above ground vegetation; moreover, variables tested for correlation such as crown cover, soil depth, and nutrient levels did not produce correlation coefficients at significant levels (Bakker *et al.*, 1996; Stark *et al.*, 2003). The study conducted by Stark *et al.* (2003) showed that although soil depths and nutrients are suitable for the growth of woody and tree species that surround the alvars on the Bruce Peninsula, the local alvar soil seed bank study did not contain seeds from the adjacent forest. The lack of invasion by both alien invasive plant species and tree species into alvar ecosystems despite favourable conditions for such invasions gives rise to the natural processes of alvar ecosystems. The absence of significant correlation coefficients would suggest that something other than the measured

variables are naturally maintaining alvars or, alternately, repelling invasion. Burke *et al.* (1998) suggests that water, not nutrients, is the key factor for stability and the ability to recover from disturbance in dry grassland ecosystems. These authors hypothesise that

“the strong limitation of soil water leads to complete (though uneven) occupation of the soil by roots, but insufficient resources to support continuous above-ground plant cover. Discontinuous above ground cover leads to strong biological and physical forces that result in the accumulation of soil materials beneath individual plants in resource islands... Resource islands may have a great deal of significance as a index of recovery from disturbance, an indicator of ecosystem stability or harbinger of desertification, or because of possible feedbacks to plant establishment” (Burke *et al.*, 1998, pg. 124).

Soil moisture was not measured in this study but undoubtedly it plays a significant parallel role in alvar ecosystems. Furthermore, if the soil is completely occupied by roots that create ‘resource islands’, then it is possible that alien invasive plant species are not able to compete in alvar ecosystems below ground. This may account for the lack of success of alien invaders above ground but their relative success in the soil seed bank study after the soil was cleaned of roots and debris.

The study of invasive alien plant species is an important field of investigation for understanding and thereby mitigating some of the harmful effects these species cause to the functioning of natural ecosystems. Individual plants, plant communities, biotic and abiotic processes interact to form a highly complex system that is difficult to study. Although ecosystem interactions are significant aspects of any ecosystem, the reduction of complexities allows for the investigation of possible relations that can compliment ecosystem studies. The study of a specific invasive alien plant species and its interactions

in a particular ecosystem has the ability to form a foundation for understanding the effects invasive alien plant species pose on natural ecosystem processes specific to an ecosystem type. The Burnt Lands Nature Reserve is a highly diverse ecosystem with multiple distinct communities ranging from bare limestone pavement to forested communities.

Considering the relatively high numbers of alien invasive species in the soil seed bank study, the study site would not normally be considered a good candidate for self-recovery of the native species in the soil seed bank should the surface *Euphorbia cyparissias* be removed. The lack of several native alvar species in the soil seed bank study may indicate that the native alvar species present in the above ground vegetation are relying on underground roots and rhizomes to maintain their presence (Burke *et al.*, 1998; Rosburg, 2001). The desired native alvar species that rely on roots and rhizomes may be adversely affected by the removal of *Euphorbia cyparissias* from the surface vegetation.

Disturbance is a natural process necessary for the regeneration of plant communities (Perrins *et al.*, 1993; Luken, 1997) but the type of disturbance that would promote the regeneration of desired species while discouraging invasive alien species is not known. The study site is highly disturbed by the public for recreational purposes and the invasive alien species that appeared in the soil seed bank study have not fully taken advantage of such disturbances. Future research that examines different types of disturbance and their effect on the existing plant communities is necessary prior to the removal of *Euphorbia cyparissias* from this site.

5.1 Limitations

The soil seed bank study was conducted in a safe-site (greenhouse) where temperature, light and water was supplied at a fixed rate each day. Safe-sites are known to promote species propagation but can also impose limitations to the study. One possible limitation is that species in the soil seed bank may not have germinated due to the lack of specific biotic and/or abiotic conditions presented. For example, alvar ecosystems contain many ephemerals that can be easily missed in a vegetation survey because these species only germinate under very specific conditions and complete their life cycle in short periods of time. Furthermore, fire is a historically natural process on North American alvar ecosystems that is necessary for the propagation of some alvar species, such as the rare alvar perennial *Astragalus neglectus* (Catling *et al.*, 2001; Catling & Sinclair, 2002).

Conditions provided in the greenhouse may not have been suitable for the germination of all species in the soil seed bank. Conducting a seed assay where the soil is washed over a 0.2mm sieve of mesh to collect the seeds in the soil and then test for viability would have eliminated this unknown (Silvertown, 1982; Bekker *et al.*, 1997; Bekker *et al.*, 1998).

Alternately, a soil seed bank study could have been conducted on site, thereby, eliminating bias found in safe-site conditions (Silvertown, 1982; Graham & Hutchings, 1988; Akinola *et al.*, 1998).

Based upon the research conducted by Stahevitch *et al.* (1988), coupled with personal observations of the drought tolerant nature of *Euphorbia cyparissias*, it is reasonable to assume that there is a possibility that other species in this ecosystem may have similar preferences for drought-like conditions. Sufficient amounts of water, light and nutrients

are essential for the propagation of most plant species (Harper, 1977; Silvertown, 1982; Begon *et al.*, 1990). Although the soil samples for the soil seed bank study were placed in plastic trays with drainage holes, the daily watering of these samples may have limited germination in some species. Experimenting with water levels among duplicate samples would have eliminated this unknown.

The soil seed bank study took place over one growing season and the vegetation survey was conducted once during one growing season. Subsequent studies that extended beyond one growing season would eliminate anomalies, allow the researcher to re-survey the study area for possible expansion of target alien invasive species as well as gain a better understanding of alvar ecosystems through successive studies. For example, the year the vegetation survey was conducted was unusually wet which may have created a non-average representation of per cent of crown closure for *Euphorbia cyparissias*.

5.2 Future Research

Future research on alvar ecosystems in relation to invasive alien plant species and the effects that these species may have at the soil seed bank level would provide a valuable source of information to scientists as well as those involved with ecological restoration efforts. Further examination of the soil seed bank may reveal possible successive plant communities in a post-disturbed ecosystem, the number and type of viable native seeds, and the ratio of native seeds to invasive alien seeds. Because alvar ecosystems contain many rare and endangered plant species, viable native plant seeds present in the soil seed bank may be used in ecological restoration efforts for the preservation of these species.

A continuation of the research conducted in this thesis might include an *in-situ* soil seed bank study or a laboratory soil seed bank study that would include multiple soil samples from the same plot but different applications of water, nutrients, and light. This is the second soil seed bank study conducted on alvar ecosystems in North America. Further soil seed bank studies on alvar ecosystems would provide a base for comparisons of results and perhaps a better understanding about how these systems operate.

Another area for future inquiry is the removal of invasive alien plant species in alvar ecosystems. Using multiple methods for removing invasive species followed by annual monitoring to detect ecosystem responses to both the method of removal and its reaction to the disturbance created by removal would provide valuable insight for conservation managers trying to restore and preserve these ecosystems. Monitoring would need to be conducted over several years to assess the rate of success for the removal method and for determining which plant communities would grow and evolve within the alvar in the absence of invasive alien plants.

Future research should include an extension of measured variables such as moisture content levels and above and below ground competition experiments. Finally, a host of restoration techniques applied to the removal of *Euphorbia cyparissias* would promote a more elaborate understanding of the alvar successional plant communities in addition to alvar ecosystem response to disturbance and ability to self-recover through the soil seed bank.

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Appendix A: Distribution of Measured Variables

Appendix A: Distribution of Measured Variables (Continued)

Appendix A: Distribution of Measured Variables (Continued)

Appendix B: Per cent Crown Closure of *Euphorbia cyparissias*, 2004

Plot ID	%CC 2004	Class Cover	Plot ID	%CC 2004	Class Cover
A33	0	1	D0	25	2
A37	0	1	D4	5	2
A43	0	1	D8	5	2
A49	0	1	D10	0	1
A60	5	2	D50	5	2
A61	0	1	D84	5	2
A62	5	2	D85	5	2
A70	10	2	D86	5	2
A89	0	1	D95	5	2
A97	0	1	D96	5	2
B22	5	2	E22	0	1
B23	5	2	E23	0	1
B38	5	2	E34	0	1
B41	5	2	E55	5	2
B58	10	2	E56	0	1
B60	20	2	E63	5	2
B61	5	2	E71	5	2
B78	5	2	E78	0	1
B89	0	1	E81	5	2
B93	5	2	E98	5	2
C0	30	3	F7	0	1
C10	0	1	F16	0	1
C11	5	2	F20	0	1
C14	5	2	F36	0	1
C25	10	2	F56	0	1
C30	5	2	F64	0	1
C35	5	2	F76	0	1
C51	0	1	F79	0	1
C67	0	1	F81	0	1
C88	0	1	F97	0	1

Appendix C: Soil Seed Bank Study Results

Row	Plot	Date	Species	Quantity
A	33	20-Nov-04	Hypericum perforatum	10
A	33	06-Dec-03	Hypericum perforatum	1
A	33	11-Dec-03	Poa compressa	7
A	33	11-Dec-03	Verbascum thapsus	1
A	33	27-Dec-03	Hypericum perforatum	2
A	33	10-Jan-04	Hypericum perforatum	2
A	33	10-Jan-04	Chaenorhinum minus	1
A	33	10-Jan-04	Stachys palustris	1
A	33	10-Jan-04	Rumex acetosella	1
A	33	24-Jan-04	Hypericum perforatum	2
A	33	08-Feb-04	Oxalis stricta	1
A	33	27-Feb-04	Poa compressa	2
A	33	27-Feb-04	Hypericum perforatum	3
A	37	20-Nov-03	Hypericum perforatum	9
A	37	30-Nov-03	Hypericum perforatum	2
A	37	06-Dec-03	Verbascum thapsus	1
A	37	11-Dec-03	Echium vulgare	1
A	37	20-Dec-03	Fragaria virginiana	1
A	37	10-Jan-04	Stachys palustris	1
A	37	10-Jan-04	Oenothera biennis	1
A	37	10-Jan-04	Poa compressa	4
A	37	10-Jan-04	Hypericum perforatum	2
A	37	18-Jan-04	Oxalis stricta	1
A	37	21-Jan-04	Hypericum perforatum	2
A	37	24-Jan-04	Poa compressa	2
A	37	24-Jan-04	Oxalis stricta	1
A	37	24-Jan-04	Hypericum perforatum	1
A	37	08-Feb-04	Oxalis stricta	1
A	37	27-Feb-04	Hypericum perforatum	4
A	37	27-Feb-04	Oxalis stricta	1
A	43	20-Nov-03	Hypericum perforatum	9
A	43	20-Nov-03	Melilotus alba	1
A	43	06-Dec-03	Verbascum thapsus	2
A	43	06-Dec-03	Hypericum perforatum	2
A	43	11-Dec-03	Poa compressa	9
A	43	11-Dec-03	Hypericum perforatum	1
A	43	20-Dec-03	Fragaria virginiana	4
A	43	27-Dec-03	Senecio pauperculus	1
A	43	27-Dec-03	Solidago nemoralis	4
A	43	10-Jan-04	Verbascum thapsus	1
A	43	18-Jan-04	Fragaria virginiana	5
A	43	18-Jan-04	Hypericum perforatum	1
A	43	21-Jan-04	Hypericum perforatum	2

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
A	43	21-Jan-04	Fragaria virginiana	1
A	43	24-Jan-04	Poa compressa	1
A	43	24-Jan-04	Hypericum perforatum	1
A	43	01-Feb-04	Hypericum perforatum	2
A	43	01-Feb-04	Poa compressa	2
A	43	27-Feb-04	Fragaria virginiana	2
A	43	27-Feb-04	Poa compressa	2
A	49	30-Nov-03	Hypericum perforatum	2
A	49	10-Jan-04	Poa compressa	2
A	49	01-Feb-04	Hypericum perforatum	2
A	49	27-Feb-04	Hypericum perforatum	1
A	60	20-Nov-03	Hypericum perforatum	4
A	60	11-Dec-03	Poa compressa	2
A	60	20-Dec-03	Fragaria virginiana	1
A	60	27-Dec-03	Hypericum perforatum	1
A	60	27-Dec-03	Campanula rotundifolia	1
A	60	27-Dec-03	Solidago nemoralis	1
A	60	27-Dec-03	Senecio pauperculus	1
A	60	18-Jan-04	Hypericum perforatum	1
A	60	24-Jan-04	Poa compressa	1
A	60	27-Feb-04	Hypericum perforatum	1
A	60	27-Feb-04	Solidago nemoralis	1
A	61	20-Nov-03	Hypericum perforatum	8
A	61	20-Nov-03	Leucanthemum vulgare	1
A	61	30-Nov-03	Hypericum perforatum	1
A	61	20-Dec-03	Fragaria virginiana	1
A	61	10-Jan-04	Solidago nemoralis	2
A	61	10-Jan-04	Oxalis stricta	1
A	61	18-Jan-04	Fragaria virginiana	1
A	61	18-Jan-04	Hypericum perforatum	1
A	61	18-Jan-04	Oxalis stricta	1
A	61	01-Feb-04	Hypericum perforatum	3
A	61	01-Feb-04	Oxalis stricta	2
A	61	08-Feb-04	Poa compressa	1
A	61	27-Feb-04	Panicum linearifolium	1
A	61	27-Feb-04	Fragaria virginiana	1
A	61	27-Feb-04	Hypericum perforatum	1
A	62	20-Nov-03	Hypericum perforatum	13
A	62	30-Nov-03	Hypericum perforatum	3
A	62	06-Dec-03	Hypericum perforatum	1
A	62	11-Dec-03	Echium vulgare	1
A	62	18-Jan-04	Fragaria virginiana	1
A	62	24-Jan-04	Echium vulgare	1
A	62	08-Feb-04	Melilotus alba	1

Appendix C: Soil Seed Bank Study Results Continued

Row	Plot	Date	Species	Quantity
A	62	08-Feb-04	Oxalis stricta	1
A	62	08-Feb-04	Senecio pauperculus	1
A	70	20-Nov-03	Hypericum perforatum	7
A	70	30-Nov-03	Hypericum perforatum	3
A	70	11-Dec-03	Chaenorrhinum minus	1
A	70	20-Dec-03	Fragaria virginiana	1
A	70	27-Dec-03	Hypericum perforatum	1
A	70	27-Dec-03	Solidago nemoralis	3
A	70	24-Jan-04	Minuartia michauxii	1
A	70	01-Feb-04	Oxalis stricta	1
A	70	01-Feb-04	Campanula rotundifolia	1
A	70	01-Feb-04	Hypericum perforatum	2
A	70	27-Feb-04	Solidago nemoralis	1
A	70	27-Feb-04	Poa compressa	1
A	70	27-Feb-04	Hypericum perforatum	7
A	89	20-Nov-03	Oxalis stricta	3
A	89	20-Nov-03	Hypericum perforatum	12
A	89	06-Dec-03	Hypericum perforatum	4
A	89	11-Dec-03	Poa compressa	9
A	89	11-Dec-03	Chaenorrhinum minus	1
A	89	11-Dec-03	Verbascum thapsus	2
A	89	20-Dec-03	Hypericum perforatum	1
A	89	27-Dec-03	Minuartia michauxii	1
A	89	27-Dec-03	Hypericum perforatum	1
A	89	10-Jan-04	Solidago nemoralis	1
A	89	10-Jan-04	Senecio pauperculus	1
A	89	18-Jan-04	Hypericum perforatum	1
A	89	21-Jan-04	Oxalis stricta	1
A	89	24-Jan-04	Hypericum perforatum	2
A	89	27-Feb-04	Hypericum perforatum	2
A	89	27-Feb-04	Minuartia michauxii	1
A	97	20-Nov-03	Hypericum perforatum	2
A	97	20-Nov-03	Melilotus alba	1
A	97	06-Dec-03	Hypericum perforatum	1
A	97	06-Dec-03	Oxalis stricta	1
A	97	11-Dec-03	Verbascum thapsus	1
A	97	20-Dec-03	Fragaria virginiana	1
A	97	27-Dec-03	Hypericum perforatum	2
A	97	27-Dec-03	Echium vulgare	2
A	97	10-Jan-04	Poa compressa	2
A	97	18-Jan-04	Hypericum perforatum	1
A	97	21-Jan-04	Hypericum perforatum	4
A	97	24-Jan-04	Poa compressa	2
A	97	24-Jan-04	Echium vulgare	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
A	97	24-Jan-04	Hypericum perforatum	2
A	97	08-Feb-04	Hypericum perforatum	1
B	22	20-Nov-03	Hypericum perforatum	9
B	22	20-Dec-03	Fragaria virginiana	1
B	22	27-Dec-03	Campanula rotundifolia	1
B	22	27-Dec-03	Senecio pauperculus	2
B	22	27-Dec-03	Echium vulgare	1
B	22	10-Jan-04	Senecio pauperculus	1
B	22	10-Jan-04	Poa compressa	1
B	22	24-Jan-04	Poa compressa	1
B	22	01-Feb-04	Oxalis stricta	1
B	22	08-Feb-04	Hypericum perforatum	1
B	23	20-Nov-03	Melilotus alba	1
B	23	20-Nov-03	Hypericum perforatum	19
B	23	20-Nov-03	Leucanthemum vulgare	4
B	23	20-Nov-03	Verbascum thapsus	1
B	23	30-Nov-03	Echium vulgare	1
B	23	06-Dec-03	Oxalis stricta	1
B	23	11-Dec-03	Poa compressa	3
B	23	20-Dec-03	Fragaria virginiana	1
B	23	20-Dec-03	Campanula rotundifolia	1
B	23	27-Dec-03	Campanula rotundifolia	3
B	23	27-Dec-03	Senecio pauperculus	1
B	23	10-Jan-04	Echium vulgare	1
B	23	10-Jan-04	Hypericum perforatum	1
B	23	10-Jan-04	Viola adunca	1
B	23	21-Jan-04	Oxalis stricta	1
B	23	24-Jan-04	Danthonia spicata	1
B	23	24-Jan-04	Oxalis stricta	1
B	23	01-Feb-04	Solidago nemoralis	2
B	38	20-Nov-03	Verbascum thapsus	1
B	38	20-Nov-03	Hypericum perforatum	8
B	38	06-Dec-03	Echium vulgare	1
B	38	11-Dec-03	Poa compressa	3
B	38	27-Dec-03	Scutellaria parvula	1
B	38	18-Jan-04	Hypericum perforatum	1
B	38	21-Jan-04	Hypericum perforatum	1
B	38	01-Feb-04	Hypericum perforatum	1
B	38	27-Feb-04	Hypericum perforatum	2
B	41	20-Nov-03	Hypericum perforatum	7
B	41	06-Dec-03	Panicum linearifolium	1
B	41	11-Dec-03	Hypericum perforatum	2
B	41	14-Jan-04	Hypericum perforatum	4
B	41	14-Jan-04	Verbascum thapsus	1
B	41	24-Jan-04	Campanula rotundifolia	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
B	41	24-Jan-04	Senecio pauperculus	2
B	41	08-Feb-04	Campanula rotundifolia	1
B	58	20-Nov-03	Hypericum perforatum	8
B	58	06-Dec-03	Verbascum thapsus	2
B	58	11-Dec-03	Poa compressa	7
B	58	27-Dec-03	Campanula rotundifolia	3
B	58	27-Dec-03	Senecio pauperculus	2
B	58	27-Dec-03	Fragaria virginiana	1
B	58	10-Jan-04	Daphnia spicata	1
B	58	10-Jan-04	Deschampsia flexuosa	1
B	58	14-Jan-04	Leucanthemum vulgare	1
B	58	24-Jan-04	Oxalis stricta	1
B	58	24-Jan-04	Hypericum perforatum	2
B	58	01-Feb-04	Oxalis stricta	1
B	60	20-Nov-03	Hypericum perforatum	30
B	60	20-Nov-03	Leucanthemum vulgare	5
B	60	30-Nov-03	Verbascum thapsus	1
B	60	06-Dec-03	Verbascum thapsus	1
B	60	06-Dec-03	Euphorbia cyparissias	1
B	60	11-Dec-03	Poa compressa	16
B	60	11-Dec-03	Chaenorhinum minus	1
B	60	20-Dec-03	Fragaria virginiana	4
B	60	27-Dec-03	Campanula rotundifolia	3
B	60	27-Dec-03	Senecio pauperculus	2
B	60	27-Dec-03	Solidago nemoralis	5
B	60	27-Dec-03	Hypericum perforatum	3
B	60	10-Jan-04	Verbascum thapsus	1
B	60	10-Jan-04	Poa compressa	2
B	60	14-Jan-04	Hypericum perforatum	6
B	60	18-Jan-04	Verbascum thapsus	1
B	60	24-Jan-04	Poa compressa	2
B	60	24-Jan-04	Oxalis stricta	1
B	60	24-Jan-04	Leucanthemum vulgare	1
B	60	01-Feb-04	Oxalis stricta	1
B	60	08-Feb-04	Senecio pauperculus	1
B	60	08-Feb-04	Hypericum perforatum	1
B	60	27-Feb-04	Hypericum perforatum	4
B	60	27-Feb-04	Senecio pauperculus	3
B	61	20-Nov-03	Melilotus alba	1
B	61	20-Nov-03	Hypericum perforatum	23
B	61	20-Nov-03	Leucanthemum vulgare	5
B	61	30-Nov-03	Verbascum thapsus	2
B	61	06-Dec-03	Verbascum thapsus	2
B	61	06-Dec-03	Hypericum perforatum	1
B	61	06-Dec-03	Panicum linearifolium	1

Appendix C: Soil Seed Bank Study Results Continued

Row	Plot	Date	Species	Quantity
B	61	11-Dec-03	Poa compressa	2
B	61	11-Dec-03	Chaenorrhinum minus	1
B	61	20-Dec-03	Fragaria virginiana	2
B	61	20-Dec-03	Hieracium piloselloides	1
B	61	27-Dec-03	Campanula rotundifolia	3
B	61	27-Dec-03	Senecio pauperculus	3
B	61	10-Jan-04	Oenothera biennis	1
B	61	10-Jan-04	Hypericum perforatum	4
B	61	10-Jan-04	Leucanthemum vulgare	1
B	61	18-Jan-04	Hypericum perforatum	1
B	61	24-Jan-04	Campanula rotundifolia	1
B	61	01-Feb-04	Hypericum perforatum	1
B	61	27-Feb-04	Senecio pauperculus	2
B	61	27-Feb-04	Hypericum perforatum	6
B	61	27-Feb-04	Acer spp.	1
B	78	20-Nov-03	Hypericum perforatum	14
B	78	20-Nov-03	Daucus carota	1
B	78	30-Nov-03	Hypericum perforatum	2
B	78	06-Dec-03	Verbascum thapsus	1
B	78	06-Dec-03	Panicum linearifolium	3
B	78	11-Dec-03	Hypericum perforatum	3
B	78	11-Dec-03	Poa compressa	8
B	78	20-Dec-03	Hypericum perforatum	1
B	78	27-Dec-03	Campanula rotundifolia	3
B	78	10-Jan-04	Hypericum perforatum	5
B	78	14-Jan-04	Verbascum thapsus	1
B	78	18-Jan-04	Fragaria virginiana	1
B	78	24-Jan-04	Poa compressa	1
B	78	24-Jan-04	Hypericum perforatum	3
B	78	24-Jan-04	Campanula rotundifolia	1
B	89	20-Nov-03	Hypericum perforatum	5
B	89	30-Nov-03	Leucanthemum vulgare	1
B	89	30-Nov-03	Hypericum perforatum	1
B	89	06-Dec-03	Panicum linearifolium	5
B	89	11-Dec-03	Senecio pauperculus	1
B	89	20-Dec-03	Hypericum perforatum	4
B	89	20-Dec-03	Oxalis stricta	1
B	89	27-Dec-03	Senecio pauperculus	2
B	89	10-Jan-04	Verbascum thapsus	2
B	89	10-Jan-04	Senecio pauperculus	1
B	89	10-Jan-04	Danthonia spicata	1
B	89	10-Jan-04	Verbascum thapsus	1
B	89	10-Jan-04	Poa compressa	1
B	89	10-Jan-04	Hypericum perforatum	3
B	89	24-Jan-04	Hypericum perforatum	2

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
B	89	01-Feb-04	Poa compressa	1
B	93	20-Nov-03	Hypericum perforatum	3
B	93	30-Nov-03	Hieracium piloselloides	1
B	93	30-Nov-03	Hypericum perforatum	1
B	93	11-Dec-03	Verbascum thapsus	2
B	93	27-Dec-03	Campanula rotundifolia	1
B	93	10-Jan-04	Hypericum perforatum	3
B	93	10-Jan-04	Deschampsia flexuosa	1
B	93	14-Jan-04	Hypericum perforatum	1
B	93	24-Jan-04	Poa compressa	2
B	93	24-Jan-04	Campanula rotundifolia	1
B	93	24-Jan-04	Hypericum perforatum	1
C	0	20-Nov-03	Hypericum perforatum	2
C	0	20-Nov-03	Melilotus alba	4
C	0	11-Dec-03	Senecio pauperculus	1
C	0	11-Dec-03	Chaenorrhinum minus	1
C	0	20-Dec-03	Panicum linearifolium	1
C	0	10-Jan-04	Poa compressa	3
C	0	18-Jan-04	Oxalis stricta	1
C	0	24-Jan-04	Panicum linearifolium	1
C	0	01-Feb-04	Senecio pauperculus	1
C	0	01-Feb-04	Poa compressa	1
C	10	20-Nov-03	Hypericum perforatum	5
C	10	06-Dec-03	Verbascum thapsus	1
C	10	06-Dec-03	Oxalis stricta	1
C	10	11-Dec-03	Senecio pauperculus	1
C	10	11-Dec-03	Poa compressa	2
C	10	27-Dec-03	Senecio pauperculus	2
C	10	10-Jan-04	Solidago nemoralis	1
C	10	10-Jan-04	Hypericum perforatum	1
C	10	10-Jan-04	Deschampsia flexuosa	1
C	10	18-Jan-04	Oxalis stricta	1
C	10	18-Jan-04	Fragaria virginiana	1
C	10	24-Jan-04	Poa compressa	1
C	10	01-Feb-04	Hypericum perforatum	1
C	10	08-Feb-04	Daucus carota	1
C	10	27-Feb-04	Hypericum perforatum	3
C	10	27-Feb-04	Echium vulgare	1
C	11	20-Nov-03	Hypericum perforatum	3
C	11	20-Nov-03	Daucus carota	2
C	11	06-Dec-03	Euphorbia cyparissias	1
C	11	06-Dec-03	Panicum linearifolium	1
C	11	20-Dec-03	Fragaria virginiana	4
C	11	26-Dec-03	Fragaria virginiana	1
C	11	26-Dec-03	Echium vulgare	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
C	11	27-Dec-03	Senecio pauperculus	1
C	11	10-Jan-04	Senecio pauperculus	1
C	11	10-Jan-04	Hypericum perforatum	2
C	11	10-Jan-04	Poa compressa	2
C	11	14-Jan-04	Fragaria virginiana	1
C	11	08-Feb-04	Oxalis stricta	1
C	11	27-Feb-04	Fragaria virginiana	5
C	14	11-Dec-03	Senecio pauperculus	2
C	14	11-Dec-03	Poa compressa	1
C	14	27-Feb-04	Senecio pauperculus	1
C	25	30-Nov-03	Hypericum perforatum	1
C	25	18-Jan-04	Hypericum perforatum	3
C	25	01-Feb-04	Poa compressa	1
C	30	20-Nov-03	Hypericum perforatum	1
C	30	20-Dec-03	Fragaria virginiana	1
C	30	10-Jan-04	Hypericum perforatum	3
C	30	21-Jan-04	Hypericum perforatum	1
C	30	24-Jan-04	Fragaria virginiana	1
C	35	20-Nov-03	Hypericum perforatum	5
C	35	06-Dec-03	Euphorbia cyparissias	2
C	35	11-Dec-03	Poa compressa	2
C	35	27-Dec-03	Campanula rotundifolia	1
C	35	10-Jan-04	Poa compressa	1
C	35	18-Jan-04	Hypericum perforatum	5
C	35	18-Jan-04	Fragaria virginiana	1
C	35	01-Feb-04	Hypericum perforatum	1
C	51	20-Nov-03	Hypericum perforatum	5
C	51	06-Dec-03	Panicum linearifolium	2
C	51	11-Dec-03	Poa compressa	5
C	51	11-Dec-03	Chaenorrhinum minus	1
C	51	10-Jan-04	Deschampsia flexuosa	1
C	67	20-Nov-03	Hypericum perforatum	4
C	67	06-Dec-03	Panicum linearifolium	1
C	67	11-Dec-03	Echium vulgare	1
C	67	10-Jan-04	Poa compressa	1
C	67	18-Jan-04	Hypericum perforatum	1
C	67	24-Jan-04	Hypericum perforatum	1
C	67	24-Jan-04	Fragaria virginiana	1
C	67	24-Jan-04	Campanula rotundifolia	1
C	68	20-Nov-03	Hypericum perforatum	2
D	0	20-Nov-03	Hypericum perforatum	3
D	0	20-Nov-03	Leucanthemum vulgare	1
D	0	30-Nov-03	Hypericum perforatum	2
D	0	06-Dec-03	Verbascum thapsus	1
D	0	06-Dec-03	Panicum linearifolium	1

Appendix C: Soil Seed Bank Study Results Continued

Row	Plot	Date	Species	Quantity
D	0	11-Dec-03	Poa compressa	10
D	0	20-Dec-03	Fragaria virginiana	4
D	0	20-Dec-03	Echium vulgare	1
D	0	27-Dec-03	Senecio pauperculus	1
D	0	10-Jan-04	Hypericum perforatum	1
D	0	24-Jan-04	Poa compressa	3
D	0	24-Jan-04	Fragaria virginiana	1
D	0	27-Feb-04	Hypericum perforatum	2
D	0	27-Feb-04	Fragaria virginiana	3
D	0	27-Feb-04	Echium vulgare	1
D	4	20-Nov-03	Hypericum perforatum	1
D	4	30-Nov-03	Verbascum thapsus	2
D	4	11-Dec-03	Poa compressa	1
D	4	20-Dec-03	Hypericum perforatum	1
D	4	20-Dec-03	Oxalis stricta	1
D	4	27-Dec-03	Scutellaria parvula	1
D	4	10-Jan-04	Hypericum perforatum	2
D	4	18-Jan-04	Oxalis stricta	1
D	4	18-Jan-04	Hypericum perforatum	1
D	4	18-Jan-04	Echium vulgare	2
D	4	18-Jan-04	Leucanthemum vulgare	1
D	4	21-Jan-04	Hypericum perforatum	1
D	4	01-Feb-04	Hypericum perforatum	2
D	4	01-Feb-04	Senecio pauperculus	1
D	4	08-Feb-04	Scutellaria parvula	1
D	8	06-Dec-03	Hypericum perforatum	2
D	8	11-Dec-03	Poa compressa	2
D	8	20-Dec-03	Fragaria virginiana	1
D	8	20-Dec-03	Hypericum perforatum	1
D	8	10-Jan-04	Solidago nemoralis	2
D	8	10-Jan-04	Hypericum perforatum	1
D	8	18-Jan-04	Hypericum perforatum	3
D	8	24-Jan-04	Poa compressa	1
D	8	24-Jan-04	Hypericum perforatum	2
D	8	08-Feb-04	Solidago nemoralis	1
D	8	27-Feb-04	Hypericum perforatum	1
D	10	30-Nov-03	Hypericum perforatum	5
D	10	11-Dec-03	Oxalis stricta	1
D	10	26-Dec-03	Senecio pauperculus	1
D	10	10-Jan-04	Hypericum perforatum	4
D	10	18-Jan-04	Hypericum perforatum	3
D	10	01-Feb-04	Senecio pauperculus	1
D	10	27-Feb-04	Oxalis stricta	1
D	50	20-Nov-03	Hypericum perforatum	1
D	50	06-Dec-03	Verbascum thapsus	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
D	50	06-Dec-03	Panicum linearifolium	1
D	50	11-Dec-03	Verbascum thapsus	2
D	50	10-Jan-04	Senecio pauperculus	2
D	50	10-Jan-04	Poa compressa	2
D	50	08-Feb-04	Poa compressa	1
D	84	20-Nov-03	Hypericum perforatum	5
D	84	30-Nov-03	Leucanthemum vulgare	1
D	84	11-Dec-03	Poa compressa	2
D	84	27-Dec-03	Hypericum perforatum	1
D	84	27-Dec-03	Senecio pauperculus	1
D	84	27-Dec-03	Oxalis stricta	1
D	84	10-Jan-04	Hypericum perforatum	4
D	84	18-Jan-04	Hypericum perforatum	2
D	84	24-Jan-04	Hypericum perforatum	1
D	84	01-Feb-04	Campanula rotundifolia	1
D	84	27-Feb-04	Hypericum perforatum	4
D	85	20-Nov-03	Hypericum perforatum	6
D	85	06-Dec-03	Hypericum perforatum	3
D	85	11-Dec-03	Poa compressa	2
D	85	26-Dec-03	Senecio pauperculus	1
D	85	27-Dec-03	Campanula rotundifolia	3
D	85	10-Jan-04	Hypericum perforatum	3
D	85	18-Jan-04	Hypericum perforatum	2
D	86	20-Nov-03	Hypericum perforatum	3
D	86	06-Dec-03	Oxalis stricta	1
D	86	11-Dec-03	Poa compressa	11
D	86	20-Dec-03	Senecio pauperculus	1
D	86	27-Dec-03	Senecio pauperculus	1
D	86	27-Dec-03	Campanula rotundifolia	1
D	86	10-Jan-04	Danthonia spicata	2
D	86	18-Jan-04	Hypericum perforatum	1
D	86	18-Jan-04	Senecio pauperculus	1
D	95	30-Nov-03	Hypericum perforatum	1
D	95	20-Dec-03	Fragaria virginiana	5
D	95	10-Jan-04	Poa compressa	1
D	95	10-Jan-04	Hypericum perforatum	1
D	95	18-Jan-04	Fragaria virginiana	3
D	95	18-Jan-04	Hieracium piloselloides	1
D	95	24-Jan-04	Poa compressa	2
D	95	24-Jan-04	Fragaria virginiana	1
D	95	24-Jan-04	Hieracium piloselloides	1
D	95	01-Feb-04	Fragaria virginiana	1
D	96	20-Nov-03	Hypericum perforatum	1
D	96	20-Nov-03	Euphorbia cyparissias	1
D	96	30-Nov-03	Verbascum thapsus	4

Appendix C: Soil Seed Bank Study Results Continued

Row	Plot	Date	Species	Quantity
D	96	06-Dec-03	Verbascum thapsus	1
D	96	11-Dec-03	Poa compressa	10
D	96	11-Dec-03	Hypericum perforatum	2
D	96	20-Dec-03	Fragaria virginiana	6
D	96	20-Dec-03	Hypericum perforatum	1
D	96	20-Dec-03	Hieracium piloselloides	1
D	96	27-Dec-03	Echium vulgare	1
D	96	10-Jan-04	Rumex acetosella	1
D	96	18-Jan-04	Fragaria virginiana	4
D	96	24-Jan-04	Poa compressa	1
D	96	01-Feb-04	Hypericum perforatum	1
D	96	27-Feb-04	Hypericum perforatum	1
E	22	20-Nov-03	Hypericum perforatum	3
E	22	11-Dec-03	Senecio pauperculus	3
E	22	26-Dec-03	Senecio pauperculus	1
E	22	27-Dec-03	Campanula rotundifolia	1
E	22	10-Jan-04	Hypericum perforatum	1
E	22	24-Jan-04	Hypericum perforatum	1
E	22	24-Jan-04	Oxalis stricta	1
E	22	27-Feb-04	Hypericum perforatum	2
E	23	30-Nov-03	Hypericum perforatum	1
E	23	11-Dec-03	Hieracium piloselloides	1
E	23	27-Dec-03	Campanula rotundifolia	2
E	23	08-Feb-04	Oxalis stricta	1
E	34	20-Nov-03	Hypericum perforatum	3
E	34	30-Nov-03	Hypericum perforatum	2
E	34	06-Dec-03	Panicum linearifolium	1
E	34	11-Dec-03	Poa compressa	1
E	34	20-Dec-03	Fragaria virginiana	4
E	34	26-Dec-03	Hypericum perforatum	1
E	34	10-Jan-04	Campanula rotundifolia	2
E	34	24-Jan-04	Oxalis stricta	2
E	34	24-Jan-04	Hypericum perforatum	1
E	34	08-Feb-04	Oxalis stricta	1
E	34	08-Feb-04	Poa compressa	1
E	34	08-Feb-04	Hypericum perforatum	1
E	55	20-Nov-03	Hypericum perforatum	1
E	55	06-Dec-03	Panicum linearifolium	1
E	55	11-Dec-03	Senecio pauperculus	1
E	55	27-Dec-03	Oxalis stricta	1
E	55	27-Dec-03	Solidago nemoralis	1
E	55	10-Jan-04	Hypericum perforatum	1
E	55	18-Jan-04	Oxalis stricta	1
E	56	11-Dec-03	Poa compressa	1
E	56	18-Jan-04	Oxalis stricta	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
E	56	08-Feb-04	Oxalis stricta	1
E	63	20-Nov-03	Hypericum perforatum	3
E	63	30-Nov-03	Hypericum perforatum	1
E	63	06-Dec-03	Oxalis stricta	3
E	63	06-Dec-03	Panicum linearifolium	1
E	63	11-Dec-03	Poa compressa	1
E	63	20-Dec-03	Hypericum perforatum	3
E	63	20-Dec-03	Senecio pauperculus	2
E	63	26-Dec-03	Echium vulgare	1
E	63	27-Dec-03	Senecio pauperculus	2
E	63	10-Jan-04	Senecio pauperculus	1
E	63	10-Jan-04	Poa compressa	1
E	63	18-Jan-04	Echium vulgare	1
E	63	24-Jan-04	Poa compressa	1
E	63	08-Feb-04	Hypericum perforatum	2
E	71	20-Nov-03	Hypericum perforatum	2
E	71	30-Nov-03	Hypericum perforatum	1
E	71	11-Dec-03	Chaenorrhinum minus	1
E	71	20-Dec-03	Hypericum perforatum	1
E	71	27-Dec-03	Campanula rotundifolia	1
E	71	27-Dec-03	Senecio pauperculus	3
E	71	27-Dec-03	Hypericum perforatum	1
E	71	01-Feb-04	Leucanthemum vulgare	1
E	71	27-Feb-04	Poa compressa	1
E	71	27-Feb-04	Senecio pauperculus	1
E	78	20-Nov-03	Hypericum perforatum	11
E	78	06-Dec-03	Poa compressa	1
E	78	11-Dec-03	Poa compressa	2
E	78	24-Jan-04	Hypericum perforatum	1
E	78	27-Feb-04	Hypericum perforatum	5
E	78	27-Feb-04	Panicum linearifolium	1
E	78	27-Feb-04	Echium vulgare	1
E	81	10-Jan-04	Senecio pauperculus	1
E	81	18-Jan-04	Senecio pauperculus	1
E	81	18-Jan-04	Oxalis stricta	1
E	81	24-Jan-04	Senecio pauperculus	1
E	81	01-Feb-04	Verbascum thapsus	1
E	98	20-Nov-03	Hypericum perforatum	2
E	98	10-Jan-04	Hypericum perforatum	2
E	98	01-Feb-04	Leucanthemum vulgare	2
F	7	20-Nov-03	Hypericum perforatum	1
F	7	11-Dec-03	Poa compressa	2
F	7	20-Dec-03	Senecio pauperculus	1
F	7	27-Dec-03	Scutellaria parvula	1
F	7	10-Jan-04	Hypericum perforatum	1

Appendix C: Soil Seed Bank Study Results Continued

Row	Plot	Date	Species	Quantity
F	16	20-Nov-03	<i>Hypericum perforatum</i>	1
F	16	06-Dec-03	<i>Oxalis stricta</i>	1
F	16	27-Dec-03	<i>Senecio pauperculus</i>	1
F	16	10-Jan-04	<i>Danthonia spicata</i>	1
F	16	24-Jan-04	<i>Poa compressa</i>	1
F	16	01-Feb-04	<i>Verbascum thapsus</i>	1
F	20	20-Nov-03	<i>Hypericum perforatum</i>	6
F	20	06-Dec-03	<i>Hypericum perforatum</i>	2
F	20	11-Dec-03	<i>Senecio pauperculus</i>	3
F	20	10-Jan-04	<i>Deschampsia flexuosa</i>	4
F	20	18-Jan-04	<i>Hypericum perforatum</i>	1
F	20	24-Jan-04	<i>Senecio pauperculus</i>	1
F	20	01-Feb-04	<i>Poa compressa</i>	1
F	36	20-Nov-03	<i>Hypericum perforatum</i>	1
F	36	06-Dec-03	<i>Panicum linearifolium</i>	2
F	36	11-Dec-03	<i>Senecio pauperculus</i>	1
F	36	18-Jan-04	<i>Hypericum perforatum</i>	4
F	36	18-Jan-04	<i>Oxalis stricta</i>	1
F	36	18-Jan-04	<i>Senecio pauperculus</i>	3
F	36	27-Feb-04	<i>Hypericum perforatum</i>	1
F	56	20-Nov-03	<i>Hypericum perforatum</i>	6
F	56	20-Nov-03	<i>Leucanthemum vulgare</i>	1
F	56	20-Nov-03	<i>Verbascum thapsus</i>	1
F	56	06-Dec-03	<i>Verbascum thapsus</i>	1
F	56	11-Dec-03	<i>Poa compressa</i>	14
F	56	20-Dec-03	<i>Fragaria virginiana</i>	6
F	56	20-Dec-03	<i>Hypericum perforatum</i>	1
F	56	27-Dec-03	<i>Hypericum perforatum</i>	1
F	56	10-Jan-04	<i>Solidago nemoralis</i>	1
F	56	10-Jan-04	<i>Poa compressa</i>	1
F	56	18-Jan-04	<i>Fragaria virginiana</i>	2
F	56	18-Jan-04	<i>Hypericum perforatum</i>	1
F	56	24-Jan-04	<i>Poa compressa</i>	3
F	56	24-Jan-04	<i>Hypericum perforatum</i>	1
F	56	01-Feb-04	<i>Verbascum thapsus</i>	1
F	64	20-Nov-03	<i>Verbascum thapsus</i>	1
F	64	30-Nov-03	<i>Hypericum perforatum</i>	2
F	64	11-Dec-03	<i>Senecio pauperculus</i>	1
F	64	20-Dec-03	<i>Fragaria virginiana</i>	1
F	64	27-Dec-03	<i>Campanula rotundifolia</i>	1
F	64	18-Jan-04	<i>Fragaria virginiana</i>	1
F	64	18-Jan-04	<i>Hypericum perforatum</i>	1
F	64	08-Feb-04	<i>Oxalis stricta</i>	1
F	76	30-Nov-03	<i>Hypericum perforatum</i>	1
F	76	06-Dec-03	<i>Hypericum perforatum</i>	1

Appendix C: Soil Seed Bank Study Results Continued				
Row	Plot	Date	Species	Quantity
F	76	20-Dec-03	Fragaria virginiana	1
F	76	27-Dec-03	Hypericum perforatum	1
F	76	18-Jan-04	Hypericum perforatum	2
F	76	24-Jan-04	Oxalis stricta	1
F	76	08-Feb-04	Poa compressa	2
F	76	27-Feb-04	Oxalis stricta	1
F	79	11-Dec-03	Poa compressa	1
F	79	10-Jan-04	Deschampsia flexuosa	1
F	79	10-Jan-04	Hypericum perforatum	2
F	79	18-Jan-04	Senecio pauperculus	3
F	79	24-Jan-04	Oxalis stricta	1
F	79	24-Jan-04	Hypericum perforatum	1
F	81	11-Dec-03	Poa compressa	2
F	81	18-Jan-04	Senecio pauperculus	1
F	97	20-Nov-03	Hypericum perforatum	3
F	97	30-Nov-03	Hypericum perforatum	6
F	97	06-Dec-03	Panicum linearifolium	1
F	97	11-Dec-03	Senecio pauperculus	2
F	97	11-Dec-03	Poa compressa	1
F	97	20-Dec-03	Melilotus alba	1
F	97	10-Jan-04	Scutellaria parvula	1
F	97	10-Jan-04	Hypericum perforatum	2
F	97	24-Jan-04	Oxalis stricta	1

Appendix D: Vegetation Survey Results

Plot	Species	Plot	Species
A33	<i>Danthonia spicata</i>	A60	<i>Senecio pauperculus</i>
A33	<i>Rosa blanda</i>	A60	<i>Solidago nemoralis</i>
A33	<i>Panicum linearifolium</i>	A60	<i>Penstemon hirsutus</i>
A33	<i>Poa compressa</i>	A60	<i>Scutellaria parvula</i>
A33	<i>Carex richardsonii</i>	A61	<i>Potentilla recta</i>
A33	<i>Antennaria howellii</i>	A61	<i>Hieracium piloselloides</i>
A33	<i>Ceanothus americanus</i>	A61	<i>Senecio pauperculus</i>
A33	<i>Leucanthemum vulgare</i>	A61	<i>Solidago nemoralis</i>
A37	<i>Prunus virginiana</i>	A61	<i>Poa compressa</i>
A37	<i>Danthonia spicata</i>	A61	<i>Danthonia spicata</i>
A37	<i>Solidago spp.</i>	A61	<i>Carex umbellata</i>
A37	<i>Leucanthemum vulgare</i>	A61	<i>Sporobolus vaginiflorus</i>
A37	<i>Poa compressa</i>	A62	<i>Euphorbia cyparissias</i>
A37	<i>Carex crawei</i>	A62	<i>Danthonia spicata</i>
A37	<i>Panicum linearifolium</i>	A62	<i>Hieracium piloselloides</i>
A37	<i>Fragaria virginiana</i>	A62	<i>Poa compressa</i>
A37	<i>Rhamnus catharticus</i>	A62	<i>Sporobolus vaginiflorus</i>
A37	<i>Hieracium piloselloides</i>	A62	<i>Scutellaria parvula</i>
A37	<i>Hypericum perforatum</i>	A62	<i>Solidago nemoralis</i>
A37	<i>Campanula rotundifolia</i>	A62	<i>Panicum linearifolium</i>
A37	Unknown species	A62	Unknown species
A37	<i>Potentilla recta</i>	A70	<i>Euphorbia cyparissias</i>
A37	<i>Bromus kalmii</i>	A70	<i>Danthonia spicata</i>
A37	<i>Solidago nemoralis</i>	A70	<i>Scutellaria parvula</i>
A43	<i>Poa compressa</i>	A70	<i>Panicum linearifolium</i>
A43	<i>Danthonia spicata</i>	A70	<i>Solidago nemoralis</i>
A43	<i>Sporobolus vaginiflorus</i>	A70	<i>Sporobolus vaginiflorus</i>
A43	<i>Scutellaria parvula</i>	A70	<i>Isanthus brachiatus</i>
A43	<i>Solidago nemoralis</i>	A89	<i>Poa compressa</i>
A49	<i>Danthonia spicata</i>	A89	<i>Danthonia spicata</i>
A49	<i>Poa compressa</i>	A89	<i>Agrostis spp</i>
A49	<i>Senecio pauperculus</i>	A89	<i>Rhus radicans</i>
A49	<i>Solidago nemoralis</i>	A89	<i>Antennaria howellii</i>
A49	<i>Carex aurea</i>	A89	<i>Hieracium piloselloides</i>
A49	<i>Scutellaria parvula</i>	A89	<i>Solidago nemoralis</i>
A49	<i>Antennaria howellii</i>	A89	<i>Carex crawei</i>
A49	<i>Hieracium piloselloides</i>	A89	<i>Scutellaria parvula</i>
A60	<i>Euphorbia cyparissias</i>	A89	<i>Fragaria virginiana</i>
A60	<i>Leucanthemum vulgare</i>	A89	<i>Vicia cracca</i>
A60	<i>Campanula rotundifolia</i>	A97	<i>Panicum linearifolium</i>
A60	<i>Danthonia spicata</i>	A97	<i>Danthonia spicata</i>
A60	<i>Poa compressa</i>	A97	<i>Rhus radicans</i>

Appendix D: Vegetation Survey Results Continued			
Plot	Species	Plot	Species
A60	Hieracium piloselloides	A97	Hieracium piloselloides
A60	Potentilla recta	A97	Solidago nemoralis
A97	Carex crawei	B58	Scutellaria parvula
A97	Scutellaria parvula	B58	Carex aurea
A97	Fragaria virginiana	B58	Fragaria virginiana
B22	Euphorbia cyparissias	B58	Carex crawei
B22	Fragaria virginiana	B58	Chaenorrhimum minus
B22	Senecio pauperculus	B58	Panicum linearifolium
B22	Scutellaria parvula	B58	Danthonia spicata
B22	Solidago nemoralis	B58	Campanula rotundifolia
B22	Poa compressa	B58	Solidago nemoralis
B22	Danthonia spicata	B58	Leucanthemum vulgare
B22	Campanula rotundifolia	B58	Hieracium piloselloides
B22	Leucanthemum vulgare	B60	Euphorbia cyparissias
B22	Hieracium piloselloides	B60	Melilotus alba
B23	Euphorbia cyparissias	B60	Carex richardsonii
B23	Melilotus alba	B60	Linaria vulgaris
B23	Potentilla recta	B61	Euphorbia cyparissias
B23	Daucus carota	B61	Danthonia spicata
B23	Leucanthemum vulgare	B61	Trifolium aureum
B23	Senecio pauperculus	B61	Fragaria virginiana
B23	Scutellaria parvula	B61	Hieracium piloselloides
B23	Hypericum perforatum	B61	Campanula rotundifolia
B23	Poa compressa	B61	Solidago nemoralis
B23	Trifolium aureum	B61	Melilotus alba
B23	Fragaria virginiana	B61	Panicum linearifolium
B23	Danthonia spicata	B61	Hypericum perforatum
B23	Hieracium piloselloides	B61	Bromus kalmii
B38	Euphorbia cyparissias	B78	Euphorbia cyparissias
B38	Poa compressa	B78	Prunella vulgaris
B38	Danthonia spicata	B78	Solidago nemoralis
B38	Solidago nemoralis	B78	Carex aurea
B38	Penstemon hirsutus	B78	Fragaria virginiana
B38	Leucanthemum vulgare	B78	Vicia cracca
B38	Senecio pauperculus	B78	Rhus radicans
B38	Sporobolus vaginiflorus	B78	Melilotus alba
B38	Hypericum perforatum	B78	Viola spp
B38	Unknown species	B78	Panicum linearifolium
B41	Euphorbia cyparissias	B78	Danthonia spicata
B41	Rosa blanda	B78	Poa compressa
B41	Echium vulgare	B78	Equisetum arvense
B41	Panicum linearifolium	B89	Smilacina stellata
B41	Danthonia spicata	B89	Campanula rotundifolia
B41	Carex richardsonii	B89	Danthonia spicata

Appendix D: Vegetation Survey Results Continued

Plot	Species	Plot	Species
B41	<i>Solidago nemoralis</i>	B89	<i>Carex crawei</i>
B41	<i>Hieracium piloselloides</i>	B89	<i>Carex richardsonii</i>
B41	<i>Penstemon hirsutus</i>	B89	<i>Panicum linearifolium</i>
B41	<i>Poa compressa</i>	B89	<i>Hieracium piloselloides</i>
B58	<i>Euphorbia cyparissias</i>	B89	<i>Solidago nemoralis</i>
B93	<i>Euphorbia cyparissias</i>	C11	<i>Hieracium piloselloides</i>
B93	<i>Maianthemum canadense</i>	C11	<i>Aster cordifolius</i>
B93	<i>Echium vulgare</i>	C11	<i>Solidago ptarmicoides</i>
B93	<i>Campanula rotundifolia</i>	C14	<i>Euphorbia cyparissias</i>
B93	<i>Melilotus alba</i>	C14	<i>Panicum linearifolium</i>
B93	<i>Carex crawei</i>	C14	<i>Danthonia spicata</i>
B93	<i>Carex richardsonii</i>	C14	<i>Antennaria howellii</i>
B93	<i>Hieracium piloselloides</i>	C14	<i>Hieracium piloselloides</i>
B93	<i>Trifolium aureum</i>	C14	<i>Sporobolus vaginiflorus</i>
B93	<i>Antennaria howellii</i>	C14	<i>Scutellaria parvula</i>
B93	<i>Vicia cracca</i>	C14	<i>Carex crawei</i>
B93	<i>Solidago nemoralis</i>	C25	<i>Euphorbia cyparissias</i>
B93	<i>Poa compressa</i>	C25	<i>Poa compressa</i>
B93	<i>Danthonia spicata</i>	C25	<i>Danthonia spicata</i>
B93	<i>Panicum linearifolium</i>	C25	<i>Campanula rotundifolia</i>
B93	<i>Senecio pauperculus</i>	C25	<i>Hieracium piloselloides</i>
B93	<i>Leucanthemum vulgare</i>	C25	<i>Carex crawei</i>
C0	<i>Euphorbia cyparissias</i>	C25	<i>Panicum linearifolium</i>
C0	<i>Senecio pauperculus</i>	C25	<i>Carex richardsonii</i>
C0	<i>Hieracium piloselloides</i>	C25	<i>Solidago nemoralis</i>
C0	<i>Linaria vulgaris</i>	C30	<i>Euphorbia cyparissias</i>
C0	<i>Poa compressa</i>	C30	<i>Campanula rotundifolia</i>
C0	<i>Danthonia spicata</i>	C30	<i>Danthonia spicata</i>
C0	<i>Panicum linearifolium</i>	C30	<i>Senecio pauperculus</i>
C0	<i>Fragaria virginiana</i>	C30	<i>Scutellaria parvula</i>
C0	<i>Aster cordifolius</i>	C30	<i>Potentilla recta</i>
C0	<i>Leucanthemum vulgare</i>	C30	<i>Sporobolus vaginiflorus</i>
C0	<i>Daucus carota</i>	C35	<i>Euphorbia cyparissias</i>
C0	<i>Hypericum perforatum</i>	C35	<i>Danthonia spicata</i>
C10	<i>Prunella vulgaris</i>	C35	<i>Carex crawei</i>
C10	<i>Leucanthemum vulgare</i>	C35	<i>Poa compressa</i>
C10	<i>Poa compressa</i>	C35	<i>Scutellaria parvula</i>
C10	<i>Carex crawei</i>	C35	<i>Penstemon hirsutus</i>
C10	<i>Melilotus alba</i>	C35	<i>Potentilla recta</i>
C10	<i>Scutellaria parvula</i>	C35	<i>Sporobolus vaginiflorus</i>
C10	<i>Danthonia spicata</i>	C35	<i>Panicum linearifolium</i>
C10	<i>Panicum linearifolium</i>	C35	<i>Senecio pauperculus</i>
C10	<i>Fragaria virginiana</i>	C51	<i>Hieracium piloselloides</i>
C10	<i>Penstemon hirsutus</i>	C51	<i>Senecio pauperculus</i>

Appendix D: Vegetation Survey Results Continued			
Plot	Species	Plot	Species
C10	Hypericum perforatum	C51	Sporobolus vaginiflorus
C11	Euphorbia cyparissias	C51	Danthonia spicata
C11	Panicum linearifolium	C51	Poa compressa
C11	Senecio pauperculus	C51	Fragaria virginiana
C11	Carex crawei	C51	Panicum linearifolium
C11	Danthonia spicata	C51	Solidago nemoralis
C11	Sporobolus vaginiflorus	C51	Ambrosia artemisiifolia
C11	Unknown species	C67	Campanula rotundifolia
C67	Senecio pauperculus	D10	Campanula rotundifolia
C67	Poa compressa	D10	Hieracium piloselloides
C67	Danthonia spicata	D10	Solidago nemoralis
C67	Scutellaria parvula	D50	Euphorbia cyparissias
C67	Leucanthemum vulgare	D50	Smilacina stellata
C67	Sporobolus vaginiflorus	D50	Fragaria virginiana
C67	Solidago nemoralis	D50	Carex richardsonii
C67	Rhus typhina	D50	Panicum linearifolium
C88	Danthonia spicata	D50	Senecio pauperculus
C88	Poa compressa	D50	Solidago nemoralis
C88	Panicum linearifolium	D50	Hieracium piloselloides
C88	Solidago nemoralis	D50	Isanthus brachiatus
C88	Senecio pauperculus	D84	Euphorbia cyparissias
D0	Euphorbia cyparissias	D84	Danthonia spicata
D0	Poa compressa	D84	Penstemon hirsutus
D0	Melilotus alba	D84	Poa compressa
D0	Rosa blanda	D84	Senecio pauperculus
D0	Solidago nemoralis	D84	Solidago nemoralis
D4	Euphorbia cyparissias	D84	Carex umbellata
D4	Danthonia spicata	D84	Campanula rotundifolia
D4	Echium vulgare	D85	Euphorbia cyparissias
D4	Solidago spp.	D85	Carex umbellata
D4	Trifolium aureum	D85	Senecio pauperculus
D4	Solidago ptarmicoides	D85	Danthonia spicata
D4	Poa compressa	D85	Hieracium piloselloides
D4	Hieracium piloselloides	D85	Poa compressa
D4	Senecio pauperculus	D86	Euphorbia cyparissias
D4	Panicum linearifolium	D86	Solidago ptarmicoides
D4	Solidago nemoralis	D86	Danthonia spicata
D8	Euphorbia cyparissias	D86	Senecio pauperculus
D8	Danthonia spicata	D86	Carex umbellata
D8	Panicum linearifolium	D86	Isanthus brachiatus
D8	Carex umbellata	D95	Euphorbia cyparissias
D8	Senecio pauperculus	D95	Solidago ptarmicoides
D8	Panicum linearifolium	D95	Carex umbellata
D8	Solidago nemoralis	D95	Campanula rotundifolia

Appendix D: Vegetation Survey Results Continued

Plot	Species	Plot	Species
D8	Campanula rotundifolia	D95	Hieracium piloselloides
D8	Sisyrinchium montanum	D95	Agrostis gigantea
D10	Lythrum salicaria	D95	Senecio pauperculus
D10	Carex crawei	D95	Echium vulgare
D10	Danthonia spicata	D95	Ambrosia artemisiifolia
D10	Sisyrinchium montanum	D96	Euphorbia cyparissias
D10	Fragaria virginiana	D96	Carex crawei
D10	Ambrosia artemisiifolia	D96	Hieracium piloselloides
D10	Panicum linearifolium	D96	Scutellaria parvula
D10	Prunella vulgaris	D96	Unknown gramineae
D10	Senecio pauperculus	E22	Solidago spp.
E22	Danthonia spicata	E63	Carex richardsonii
E22	Panicum linearifolium	E63	Solidago ptarmicoides
E22	Hieracium piloselloides	E63	Scutellaria parvula
E22	Fragaria virginiana	E71	Euphorbia cyparissias
E22	Senecio pauperculus	E71	Poa compressa
E22	Carex richardsonii	E71	Scutellaria parvula
E23	Danthonia spicata	E71	Agrostis spp.
E23	Carex aurea	E71	Danthonia spicata
E23	Panicum linearifolium	E71	Carex richardsonii
E23	Solidago ptarmicoides	E71	Senecio pauperculus
E23	Senecio pauperculus	E71	Chaenorrhinum minus
E23	Aster cordifolius	E71	Sporobolus vaginiflorus
E23	Hieracium piloselloides	E71	Solidago nemoralis
E34	Danthonia spicata	E71	Echium vulgare
E34	Panicum linearifolium	E78	Senecio pauperculus
E34	Senecio pauperculus	E78	Carex crawei
E34	Isanthus brachiatus	E78	Danthonia spicata
E34	Prunella vulgaris	E78	Hieracium piloselloides
E34	Carex aurea	E78	Sporobolus vaginiflorus
E34	Solidago ptarmicoides	E78	Solidago nemoralis
E34	Solidago nemoralis	E78	Prunella vulgaris
E34	Agropyron trachycaulum	E81	Euphorbia cyparissias
E55	Euphorbia cyparissias	E81	Smilacina stellata
E55	Danthonia spicata	E81	Senecio pauperculus
E55	Solidago ptarmicoides	E81	Carex crawei
E55	Smilacina stellata	E81	Carex richardsonii
E55	Hieracium piloselloides	E81	Panicum linearifolium
E55	Echium vulgare	E81	Solidago nemoralis
E55	Panicum linearifolium	E81	Hieracium piloselloides
E55	Senecio pauperculus	E81	Danthonia spicata
E55	Sporobolus vaginiflorus	E81	Sporobolus vaginiflorus
E55	Unknown species	E98	Euphorbia cyparissias
E56	Smilacina stellata	E98	Echium vulgare

Appendix D: Vegetation Survey Results Continued

Plot	Species	Plot	Species
E56	Senecio pauperculus	E98	Carex richardsonii
E56	Solidago ptarmicoides	E98	Danthonia spicata
E56	Panicum linearifolium	E98	Solidago nemoralis
E56	Sporobolus vaginiflorus	E98	Solidago spp.
E56	Carex richardsonii	E98	Hypericum perforatum
E56	Carex umbellata	E98	Panicum linearifolium
E56	Prunella vulgaris	E98	Poa compressa
E63	Euphorbia cyparissias	E98	Fragaria virginiana
E63	Poa compressa	E98	Campanula rotundifolia
E63	Danthonia spicata	E98	Carex crawei
E63	Solidago nemoralis	E98	Antennaria howellii
E63	Hieracium piloselloides	F7	Danthonia spicata
E63	Senecio pauperculus	F7	Carex crawei
E63	Panicum linearifolium	F7	Panicum linearifolium
F7	Poa compressa	F64	Potentilla recta
F7	Senecio pauperculus	F76	Danthonia spicata
F7	Hieracium piloselloides	F76	Panicum linearifolium
F7	Sporobolus vaginiflorus	F76	Scutellaria parvula
F7	Ambrosia artemisiifolia	F76	Senecio pauperculus
F16	Rosa blanda	F76	Sporobolus vaginiflorus
F16	Solidago ptarmicoides	F76	Carex crawei
F16	Leucanthemum vulgare	F76	Carex richardsonii
F16	Hieracium piloselloides	F76	Hieracium piloselloides
F16	Prunella vulgaris	F76	Solidago ptarmicoides
F16	Antennaria howellii	F76	Antennaria howellii
F16	Senecio pauperculus	F79	Carex crawei
F16	Panicum linearifolium	F79	Solidago ptarmicoides
F16	Polygala senega	F79	Sporobolus vaginiflorus
F20	Senecio pauperculus	F79	Senecio pauperculus
F20	Solidago spp.	F79	Antennaria howellii
F20	Danthonia spicata	F79	Scutellaria parvula
F20	Antennaria howellii	F79	Unknown species
F20	Hieracium piloselloides	F79	Danthonia spicata
F20	Sporobolus vaginiflorus	F79	Campanula rotundifolia
F20	Scutellaria parvula	F81	Carex crawei
F20	Panicum linearifolium	F81	Smilacina stellata
F20	Carex crawei	F81	Danthonia spicata
F36	Senecio pauperculus	F81	Hieracium piloselloides
F36	Smilacina stellata	F81	Aster cordifolius
F36	Panicum linearifolium	F81	Prunella vulgaris
F36	Danthonia spicata	F81	Sporobolus vaginiflorus
F36	Sporobolus vaginiflorus	F81	Panicum linearifolium
F36	Carex umbellata	F81	Senecio pauperculus
F56	Prunella vulgaris	F97	Carex crawei

Appendix D: Vegetation Survey Results Continued			
Plot	Species	Plot	Species
F56	Danthonia spicata	F97	Fragaria virginiana
F56	Solidago spp.	F97	Smilacina stellata
F56	Smilacina stellata	F97	Senecio pauperculus
F56	Hieracium piloselloides	F97	Danthonia spicata
F56	Senecio pauperculus	F97	Panicum linearifolium
F56	Carex richardsonii	F97	Rhus radicans
F56	Carex crawei	F97	Solidago spp.
F56	Unknown species	F97	Hieracium piloselloides
F64	Campanula rotundifolia	F97	Scutellaria parvula
F64	Solidago nemoralis	F97	Carex richardsonii
F64	Carex crawei	F97	Sporobolus vaginiflorus
F64	Hieracium piloselloides	F97	Isanthus brachiatus
F64	Scutellaria parvula	F97	Comandra umbellata
F64	Smilacina stellata		
F64	Sporobolus vaginiflorus		
F64	Senecio pauperculus		
F64	Trifolium aureum		

Appendix E: Number of Species by plot in the Vegetation Survey and the Soil Seed Bank Study

Plot ID	# of Species per Plot (Soil Seed Bank Study)	# of Species per Plot (Vegetation Survey)	Plot ID	# of Species per Plot (Soil Seed Bank Study)	# of Species per Plot (Vegetation Survey)
A33	7	8	D0	8	5
A37	8	16	D4	8	11
A43	7	5	D8	4	9
A49	2	8	D10	3	12
A60	6	11	D50	5	9
A61	7	8	D84	6	8
A62	6	9	D85	4	6
A70	7	7	D86	6	6
A89	8	11	D95	4	9
A97	7	8	D96	8	5
B22	7	10	E22	4	7
B23	13	13	E23	4	7
B38	5	10	E34	6	9
B41	5	10	E55	5	10
B58	10	12	E56	2	8
B60	11	4	E63	6	10
B61	12	11	E71	5	11
B78	8	13	E78	2	7
B89	8	8	E81	3	10
B93	7	17	E98	2	13
C0	8	12	F7	4	8
C10	9	11	F16	6	9
C11	9	10	F20	4	9
C14	2	8	F36	4	6
C25	2	9	F56	5	9
C30	2	7	F64	6	10
C35	5	10	F76	4	10
C51	5	9	F79	5	9
C67	6	9	F81	2	9
C88	1	5	F97	7	14

Appendix F: Soil Depth by Plot

Plot ID	Soil Depth (cm)	Plot ID	Soil Depth (cm)
A33	15	D0	18
A37	14.8	D4	20
A43	16.5	D8	12
A49	10.2	D10	12
A60	16.5	D50	17
A61	14	D84	27.5
A62	10	D85	13
A70	10	D86	11
A89	6.5	D95	20
A97	10	D96	27.5
B22	10	E22	17
B23	13	E23	14.5
B38	20	E34	23
B41	17	E55	11.5
B58	24	E56	18
B60	5	E63	14.5
B61	20	E71	16
B78	16	E78	14.5
B89	17	E81	12.5
B93	11	E98	16
C0	19	F7	14
C10	20	F16	14
C11	19	F20	13
C14	15	F36	17
C25	19	F56	16
C30	16	F64	13
C35	16	F76	13
C51	18	F79	13
C67	17	F81	11
C88	19	F97	11