Development of Ecological Management Plans for Conservation Lands in Westborough, Massachusetts with Emphasis on Invasive Species Control

BY

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~ This thesis is dedicated to the memory of my grandmother, Hazel Young. She always believed in me and showered me with encouraging words in everything I accomplished ~

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Abstract

This project studies four pieces of conservation land located in Westborough, Massachusetts that are negatively impacted by invasive species. Three of the properties are owned by the Westborough Community Land Trust (WCLT), and one is owned by the Town of Westborough but is managed by the WCLT. The goal for each site was to document the prevalence of invasives through field work and then suggest an appropriate management plan with an emphasis on how to eliminate or control invasive species. The three components of each management plan are: the desired outcome and goals of management, the means by which the management can be achieved, and a follow up assessment of the success of the management effort. In addition to suggesting a management plan for each site, this paper reviews the ecology of selected invasive species and reviews general characteristics for each study site.

This project will be useful to the WCLT because they currently do not know how many invasive species are on the properties. The results of this project will be presented to the WCLT and the Westborough Conservation Commission for their use in guiding management of these sites in the future. In addition, the baseline data collected in this report will provide the WCLT with a reference point to evaluate the future success of their progress in management of the sites.

Chapter 1

Review of Invasive Species

Introduced, or non-native, species are species that are not indigenous to an area but have been transported, intentionally or unintentionally, to a new location by humans. With the aid of humans, organisms previously unable to travel across inhospitable landscapes such as mountains and oceans can take a flight on a plane or a ride on a truck to a completely new habitat thousands of miles away. Most species that find themselves in a new home fail to survive, but a few are able to establish a self sustaining and expanding population and become a problem. These types of exotic species that spread and persist in their new habitat are known as invasive species. The magnitude of biological invasions across the globe is enormous. Today, introduced species can be found almost everywhere, and only a few untouched habitats, such as deep sea hydrothermal vents, remain free of human introductions. In many areas, more than 20% of the plants present are non-native, with this number jumping to more than 50% on many oceanic islands (Vitousek et al., 1997). Of the approximately 3,000 vascular plants that are found in New England, about 1,000 are non-native, and of those around 200 are considered invasive (Bauman, 1999).

Biological invasions are not a new phenomenon; species increase their range and spread to new habitats on their own, but they do this incrementally and at a very slow rate. Human-mediated invasions, mainly due to the expansion of worldwide commerce over the past 200 years, differ from these natural invasions because of the unprecedented rate of long distance dispersals and the sheer number of plants and animals being distributed (Mack et al., 2000). For example, it is estimated that at least 7,000 different species of marine plants and animals alone are transported around the world every day through vectors such as ships, canals, seaplanes, floating marine debris, the aquarium pet industry, restoration efforts, and marine aquaculture (Carlton, 2001).

Successful invaders often share common traits that allow them to become easily established and expand. In terms of reproduction, species have a clear advantage if they can reproduce asexually or by fragmentation, produce a lot of offspring, and reach sexual maturity quickly. Other traits that are common in invasives include the ability to grow rapidly, the ability to tolerate a wide range of environmental conditions such as light or nutrient levels (known as phenotypic plasticity), the ability to eat a wide variety of foods, and the ability to survive at low population densities initially.

In addition to common traits shared by successful invasive species, generalizations can also be made about predicting the vulnerability of a certain community to invasion. Communities that are particularly vulnerable to invasions include communities with unoccupied niches, such as some islands (an unoccupied niche is an ecological position or resource in the community that is not being utilized to its full extent by the species which live there), communities that lack the native biological constraints of invaders (such as predators and diseases), communities that have a low species richness, and communities that have been disturbed (Mack et al., 2000). The location of a region also plays a role in predicting its vulnerability to invasives. Areas with seaports and major points of entry such as the Northeastern United States are more vulnerable to invasions than continental interior areas, and thus have a high number of naturalized non-native plants and animals (Mack et al., 2000).

Invasive species are a major threat to native ecosystems for many reasons. Over the past several decades, introduced organisms have become one of the most serious causes of species declines, biodiversity loss, and habitat degradation (D'Antonio and Meyerson, 2002). Only second to habitat destruction, invasive species are considered one of the worst causes of the loss of biological diversity (Vitousek et al., 1997). Invaders can have ecoysystem-level effects by altering and destroying the habitat in which they invade. For example, the invasive purple loosestrife has altered siltation rates in estuaries and along shorelines (Blossey, Skinner, and Taylor, 2001). As another example, the once dominant American chestnut tree in the eastern United States has almost disappeared from forests due to the introduced Asian chestnut blight fungus that arrived in the 20th century. Invasive species can also predate and graze on native species or compete with them for necessary resources. As an example, invasive bush honeysuckle plants shade out native understory plants and compete with them for light. Another way invasives can harm natives is by mating with them and creating a hybrid species (Mack et al., 2000). When introduced species mate with natives, the existence of the native species can be threatened through the creation of a competitive hybrid or even a hybrid which becomes another invader.

In the past, this habitat destruction and biodiversity loss mostly occurred only on the local scale (there are a few exceptions, however, such as Norway rats), but today, with the enormous number of invasions, invasive species are beginning to alter not only local populations but whole ecosystems. For example, the white-tailed deer, although native to the Northeastern United States, has recently exploded in population because of habitat modification and the removal of its predators. This species is greatly altering the structure and composition of forest ecosystems because of the intense browsing pressure. Deer grazing has been shown to reduce the regeneration capability of some forest trees and decrease the cover of understory herbaceous plant species (Rooney and Waller, 2003).

Invasive species are having much larger scale effects on the community and ecosystem levels such as altering the fire regime, nutrient cycling, hydrology, and energy budgets of a habitat (Mack et al., 2000). Invasives often overtake whole areas, replacing native species, which in turn often transforms the area into poor habitat for many native organisms. Some invasive species including many invasive grasses also cause more frequent or intense fires in areas where the natives are not well adapted to this change. *Myrica faya*, a tree which has invaded the nitrogen-poor volcanic soils of Hawaii, has the ability to fix its own nitrogen through its mutualistic relationship with nitrogen-fixing *Rhizobium* bacteria in its root nodules. Nitrogen gas is prevalent in the air, however native plants cannot fix the nitrogen gas into a useable charged form as *Myrica faya* can. As a result, *Myrica faya* can grow in many environments where native plants cannot grow and thus has made the surrounding soil unnaturally rich in nitrogen. In turn, the rich soil has made it even easier for more nonnative plants and invertebrates (such as earthworms) to invade and colonize these areas (Vitousek and Walker, 1989).

Furthermore, invasive species can have adverse effects on the economy. The threats that invasives pose to our earth's biodiversity and ecosystem processes can cause monetary losses in farming, forests, fisheries, and grazing capacity (Mack et al., 2000). There are two ways that invasions can have a negative economic impact – loss in potential economic output, such as a decrease in crop production from invasive pests, and the direct cost of controlling invasive species. It has been estimated that the total cost of all non-native weeds in crop fields costs the U.S. agriculture industry about $27 billion per year, based on a total potential crop value of $267 billion (Mack et al., 2000). The control of the invasive Atlantic cordgrass (*Spartina alterniflora*) in Washington State is an example of the high cost of controlling invasives. Atlantic cordgrass, a grass native to New England salt marshes, has become a threat to west coast mudflat habitats because it is transforming these formerly bare areas into meadows of grass. In just the one year period of 1999-2000, control of the cordgrass cost $1.17 million (Carlton, 2001).

Invasive exotic species have become recognized as a serious threat to native species and habitats and thus are becoming an increasingly significant management problem for parks, reserves, and homeowners (D'Antonio and Meyerson, 2002). To complicate matters worse, it is now common to see long-established invaders and multiple invaders at once on a site, which makes eradication even more difficult and expensive (Zavelata, Hobbs, and Mooney, 2001). Reserve managers spend huge amounts of their annual budgets to simply control exotic species each year. At Hawaii Volcanoes National Park, it is estimated that up to 80% of their annual budget is spent each year to simply control their high number of invasive species (D'Antonio and Meyerson, 2002). More locally, Laura Mattei (2006) from the Sudbury Valley Trustees reported that small scale invasive species removal in Massachusetts costs $300-500 per acre for herbicide treatment or $1,000-$1,200 per acre for complete clearing.

Once an ecosystem becomes infested, it is often very difficult if not impossible to return the altered ecosystem to its native, more desirable, condition. Returning the ecosystem to its original condition is difficult and expensive. This desired condition, consisting of a certain species composition, structure, and ecosystem function, is often difficult to precisely define. Frequently, the area has been altered by humans and infested by invasive species for so long that its natural condition may not even be known (Steneck and Carlton, 2001). Even worse, altered communities may appear natural to the average person, which makes it hard to define what exactly the prior “more desirable” condition actually is.

Effective control and prevention of invasive species requires the development of a long-term management plan with appropriate follow-up studies. Eradication of invasive species is sometimes feasible if the invasion is detected early and action is taken quickly. More often, however, if complete eradication is not feasible because the species will continually reinvade for example, a species can be maintained and controlled at an acceptable level. The three main approaches to control of invasives are chemical, mechanical, and biological control (Mack et al., 2000). Chemical control is often the main tool used, but it does have its drawbacks such as creating health hazards for humans and non-target species. Mechanical control is sometimes effective, especially in small areas, but the expense and time required often make this option impossible. Biological control, introducing a natural enemy of an invasive species to control it, has been experimented with, but in most cases, has been warned against because of the risk to non-target species and the possibility that the control may become invasive itself (Mack et al., 2000). System-wide approaches, those that focus on the interactions of all the organisms in the ecosystem rather than just the invader, are generally favored and are more effective than simply focusing on one species at a time, but this approach is rarely undertaken today (Mack et al., 2000).

This thesis studied four pieces of conservation land located in Westborough, Massachusetts that contain invasive species. The goal for each site was to document the current ecological condition of the land and describe the prevalence of invasives through conducting field work. Following the collection of this baseline data, I developed an appropriate management plan in addition to a long-term monitoring plan for each site. I will begin by giving an overview of the four most prevalent invasive species found at the sites (bush honeysuckles, Oriental bittersweet, multiflora rose, and hemlock woolly adelgid) followed by the project description, methods, results, and management recommendations.

Chapter 2

Description of Common Invasive Species

The species I will discuss in this section were the most prevalent invasive species found at the four study sites and are all common invasives in Massachusetts. For each species, this chapter gives a general description and discusses the history of introduction to the United States, the species' habitat, traits that make the species a good invader, ecological impacts of the species, and control options.

2.1 Bush Honeysuckles

*This section on Honeysuckle was also submitted as an assignment for Biology 401, a senior seminar class titled "Alien Invasion".

2.1.a Description of Species

There are several species of invasive bush honeysuckle present in Massachusetts. They are all part of the honeysuckle family, *Caprifoliaceae*, and include Amur honeysuckle (*Lonicera maackii*), Morrow's honeysuckle (*L. morrowii*), Tartarian honeysuckle (*L. tatarica*), and Bell's honeysuckle (*L. x bella*). All of the species are upright, multi-stemmed deciduous shrubs that can grow to be 6-15 feet tall. The best way to distinguish these similar species is by their leaves, flowers, and fruits.

Amur honeysuckle, also known as Maack's honeysuckle, has broad, 2-3 inch long dark green leaves that are pale and slightly fuzzy on the underside that taper to a sharp point at the end (Luken and Thieret, 1996). This species produces white tubular paired flowers in May and June which turn yellow with age. The flower stems are short (2-4 mm) and pubescent, which means they are covered with soft, short hairs (Ohio DNR, 2005). The fruits are small, red, fleshy berries that mature in September through November and may persist on the plant as long as December.

Morrow's honeysuckle has 1-2 inch long, slightly gray-green egg-shaped leaves that are also hairy on the underside (Ohio DNR, 2005). Its flower stems are long (10-12 mm) and also pubescent. Its fruits have a similar appearance to those of Amur honeysuckle, except that they ripen in late June - early August (Rhoades and Block, 2002).

Tartarian honeysuckle also has oval, egg-shaped leaves, however they lack hair on the underside. The flowers of Tartarian honeysuckle are similar to the above two species, except that they are a pale pink color. The flower stems are long (10-15 mm) and glabrous, which means they are smooth and without hairs (Ohio DNR, 2005).

Belle's honeysuckle, also known as bella, pretty, and showy bush honeysuckle, is a hybrid cross between Morrow's and Tartarian honeysuckle first made in Russia in the late 1800's, which has many traits of both parents (USDA Forest Service, 2006). The leaves are oval in shape, slightly hairy, and 1-2.5 inches long. The flowers are pink and fade to yellow with age. The fruit of this species ripens in late summer to early fall. All four of these exotic honeysuckle species have hollow stems, unlike our native honeysuckle species which have solid stems.

2.1.b Introduction to the United States

The native range of the four honeysuckle species is northeastern China, Korea, and parts of Japan, where they are commonly found in floodplains and open woodlands (Luken and Thieret, 1996). They all have similar introduction histories, but the introduction of Amur honeysuckle has been followed in the most detail. In the 1800's, U.S. plant hunters began traveling to Asia to find living plants to export, and honeysuckle was widely collected because of its attractive fruit and floral display. The first record of the seeds arriving in the United States was in 1897 from a collecting expedition to Russia by agricultural explorer Niels E. Hansen. At this same time, a new unit within the USDA called the Section of Foreign Seed and Plant Introduction (SPI) was founded, and it served as a center for distributing seeds to gardens, farms, and individuals within the United States. From 1898 to 1927, honeysuckle seeds were released at least seven times from the SPI. During the period from the 1960's through 1984, the USDA Soil Conservation Service was interested in developing improved cultivars of Amur honeysuckle. Their goals were to improve soil stabilization (honeysuckle seeds have a high cold tolerance and they are easy to mechanically harvest which facilitates distribution and establishment at reclamation projects), improve habitat for birds (because of the plant's high fruit production), and also to serve ornamental purposes (Luken and Thieret, 1996).

Evidence of populations in the wild outside of cultivation began to appear in the late 1950's. Thus, this species shows the 'lag period' common for invasive species between their first introduction (in this case 1897) and their more widespread escape in the 1950's. One explanation for this lag period is that the shrub has to be 3-5 years old to reproduce for the first time (Luken and Thieret, 1996). Currently, Amur honeysuckle has been reported in 27 eastern U.S. states (Hartman and McCarthy 2004).

2.1.c Habitat

All of the bush honeysuckles thrive in a wide range of habitats and light environments. In its original range in eastern Asia, honeysuckle thrives in disturbed habitats (Luken and Thieret, 1996). In the United States, it is commonly found along forest edges and in abandoned fields, pastures, roadsides, and other open habitats.

Disturbed woodlands are especially invasible by honeysuckle species. Morrow's honeysuckle has the widest habitat range in that it can inhabit some bogs, fens, lakeshores, and sand plains. Because its seeds are bird-dispersed, honeysuckle is commonly found in areas which act as perch sites for birds, such as under trees, tall shrubs, and along fences.

2.1.d Traits that make it a good invader

Honeysuckle has many traits that make it a good invasive species. First, it has a high phenotypic plasticity because it can change its branching morphology in response to changing light availability, which gives it an advantage over native forest plants. Luken et al. (1995) found that plants grown in full light were taller and wider than plants grown in the forest interior. The plants grown in full light showed increased branching and produced longer shoots, which allowed the arching branches of the honeysuckle to overtop its neighbors.

Another study by Luken et al. (1997b) demonstrated differences in growth in response to enhanced light between Amur honeysuckle and a native Ohio species, spicebush. When the forest-grown shrubs were moved to increased light conditions, honeysuckle was able to maximize growth all the way up to the 100% light treatment, while maximum stem growth of spicebush occurred at the 25% light treatment. This study suggests that when light availability is increased in disturbed forests such as by fragmentation, honeysuckle is able to take advantage of the increased light and assume a greater importance, while the native spicebush and other low-resource species are not able to take full advantage. This plant's ability to change its leaf display with changes in light availability may allow it to occupy a wider range of habitats with different light levels than native plants which lack this phenotypic plasticity.

Second, honeysuckle readily re-sprouts from its base, and its tissues are readily replaced when lost or damaged. A study by Luken and Mattimiro (1991) determined the relative resilience of forest- and open-grown honeysuckle shrubs by repeatedly clipping the bases of the plants. They found that plants growing in both forest and open sites maintained their re-sprouting potential even after clipping, and that sprouting ability did not decline with age as in other native shrub species in Kentucky. After repeated clipping, however, many of the forest-grown shrubs died while the open-grown shrubs persisted. They concluded that the stress of clipping drained the carbohydrate reserves of forest-grown honeysuckle shrubs, but open-grown shrubs were able to store enough carbohydrates between clippings because of their higher productivity from higher light levels. This study concluded that honeysuckle species make good invaders because they have both persistent seed production and persistent re-sprouting (even under stressed conditions), which allows them to regenerate in areas with a wide range of disturbances.

Third, honeysuckle has a high reproductive output because each adult produces a large crop of seeds every year that are efficiently dispersed by birds and occasionally by small mammals (Luken and Mattimiro, 1991). Seed dispersal is necessary for maintaining populations of honeysuckle, because it has not been observed to spread by vegetative reproduction (Deering and Vankat, 1999). Plants begin to produce seeds after 3-5 years, and although the seeds do not form a persistent seed bank (they lack well developed dormancy mechanisms), the large yearly crop more than makes up for this. The seeds are released in a non-dormant condition, and seedling germination can occur year-round with pulses during warm, wet periods in winter and early spring (Luken and Thieret, 1996). The seedlings can germinate in both light and dark environments, however, honeysuckle is moderately shade intolerant, and so growth in forests can be lowered under low light conditions.

Other traits that make honeysuckle a good invader include its lower rate of herbivory than most of the native woody species in this area, and the fact that it leafs out earlier in the spring than native species and retains its leaves later in the fall (Gorchov and Trisel, 2003). These traits allow honeysuckle to continue gaining necessary carbon while native shrubs are leafless. Lastly, Amur Honeysuckle appears to have allelopathic properties, which means it can excrete a chemical which inhibits the growth of other plants (Gorchov and Trisel, 2003). In greenhouse experiments, germination of *Fraxinus americana* (white ash) and seedling growth of *Acer saccharum* (sugar maple) were reduced when they were watered with leaf extracts of Amur honeysuckle. The resulting effects on the plants were comparable to those of a 10^{-4} solution of juglone, which is a known allelopathic chemical.

2.1.e Ecological Impacts

The exotic bush honeysuckles are a threat to the native forest communities they invade for several different reasons. First, because of its aggressive and dense growth, honeysuckle can compete with native tree and shrub species for resources such as light, pollinators, soil moisture, and nutrients. The dense growth of honeysuckle can be seen in a study that measured the net primary production of a stand of Amur honeysuckle. The study found the net primary production of the stand to be 1350 $g/m^2/yr^{-1}$, which approaches the level of entire woodland communities (Luken and Thieret, 1996). Several studies have shown the effects of competition, i.e. reduced recruitment, richness, and diversity of native species, from exotic honeysuckles.

In a study by Luken et al. (1997a), the removal Amur honeysuckle was correlated with an increase in herb density. The study, conducted in a northern Kentucky forest, cut gaps 5 meters in diameter in dense honeysuckle thickets to determine if gap formation in these dense thickets might enhance the establishment of native understory plants. They concluded that the gaps provided a “window of establishment” for various species, but further methods are required to augment the growth of desirable species.

Gould and Gorchov (2000) demonstrated direct effects of Amur honeysuckle on populations of annuals. The reproduction of three native annual species of herbs (*Galium aparine, Impatiens pallida,* and *Pilea pumila)* was higher in experimental plots where the honeysuckle was removed versus plots where it was present. This study suggests that annuals that are intolerant of shade or which only photosynthesize early in the spring will see population declines in areas invaded by honeysuckle because of its early leaf expansion.

Gorchov and Trisel (2003) tested the effects of Amur honeysuckle on the growth and survival of transplanted seedlings of four native tree species and found that above ground competition between native canopy tree species and invasive honeysuckle was a major cause of reduced tree seedling density. In their experiment, they removed above ground competition around the seedlings by removing honeysuckle shoots, and they removed below ground competition (competition from roots) by digging a trench around the transplanted seedlings. They found that removing the shoots increased the native tree seedling's survival, except for one species, whose survival was only enhanced by the trenching. For the surviving seedlings of one native species, *Acer saccharum*, the authors protected some with cages and left others unprotected. They found that removing shoots of honeysuckle increased the growth of caged *A. saccharum* seedlings (from 27% in the control to 90% in the shoot removed/root trenched treatment), but it reduced the growth of uncaged seedlings. One explanation for this is that the thick honeysuckle shoots provide some sort of protection from browsing deer. Even with this apparent positive interaction with honeysuckle shoots, the authors concluded that the overall effect of honeysuckle is harmful for the natural regeneration of forests.

Hutchinson and Vankat (1997) also studied the relationship between Amur honeysuckle and the abundance of tree seedlings and herbs. After surveying 93 forest stands in Ohio, the authors found that honeysuckle cover was inversely correlated with the density and species richness of tree seedlings and with the cover of herbs. The implications of this study show that where honeysuckle is abundant, native herb species become threatened, and the natural composition of the forest community can change. They also studied what makes a forest invasible by this honeysuckle, and found that high light levels and distance from an abundant seed source increased forest invasibility.

Woods (1993) examined the effects of Tartarian honeysuckle on herbaceous species and tree regeneration in three forests in Vermont and one in Massachusetts. He found that in stands with rich soil, herb species richness, cover, and tree seedling density was lowered when honeysuckle cover exceeded 30%. He noted that evergreen and understory vine species were more tolerant of the honeysuckle, likely because vines can grow quickly towards light, and the evergreen trees are able to photosynthesize when honeysuckle can not in the winter. He concluded that the effects of this honeysuckle on the forest community may be related to competition for seasonal light.

A second impact of honeysuckle, related to its effects on the recruitment and density of native tree seedlings, is its potential to change forest succession patterns. By reducing seedling recruitment and density in the habitats it invades, forests can be converted into shrub communities following invasion. A study by Collier et al. (2002), which investigated the impact of Amur honeysuckle on species richness and plant abundance in secondary forests, demonstrates this impact. They found that the richness and abundance of both herbs and tree seedlings was significantly lower under honeysuckle shrubs than away from them. For all species, the mean species richness was 53% lower, and the plant cover was 63% lower. In addition, they found that 86% of herbs, 100% of trees, and 56% of seed bank taxa had lower abundance under honeysuckle crowns. The effects of honeysuckle on tree seedlings indicates that normal patterns of forest succession may be altered – early successional species may be the only species to persist in the canopy layer if honeysuckle inhibits the regeneration of mid and late successional species. If regeneration is inhibited and the canopy species die, forests may turn into open-canopied woodlands or honeysuckle dominated shrub lands.

A third ecological impact of honeysuckle is its impact on nest predation rates of songbirds that use the species as a nesting site. Honeysuckle is an attractive plant for many bird species because it provides a suitable branch architecture and height. A study by Schmidt and Whelan (1999) found that American robins which nested in honeysuckle experienced a significantly higher nest predation rate than robins which nested in native shrubs, specifically *Crataegus* and *Viburnum.* The daily mortality rate of robins which nested in honeysuckle was around 0.055 deaths/day, while it was around 0.015 deaths/day in *Crataegus*. One explanation for this is that honeysuckle has sturdier branches and a reduced basal cover of leaves compared to *Viburnum*, which may facilitate predator movement, such as raccoons, hawks and squirrels, within the plant. The study also found that robins typically nest in honeysuckle most often early in the season, possibly because of the attraction of honeysuckles' early leaf-out. Thus, exotic honeysuckle plants may act as an 'ecological trap' for robins because of the higher nest predation rates.

A fourth ecological impact of honeysuckle is its root system. Because honeysuckle has a shallow root system, it reduces available water and nutrients in the upper layer of soil for other plants (Collier et al., 2002). One last impact of honeysuckle is its berries – while they are abundant in carbohydrates, they do not have the high fat content needed for long distance migrating birds such as thrushes, grosbeaks, and orioles (Ingold and Craycraft, 1983). Because of their low fat content, they are considered a low quality fruit and do not provide migrating birds the energy needed for longer flights.

2.1.f Control and Management

Honeysuckle can be controlled either mechanically or chemically; there are no biological controls currently known. Mechanical controls are most effective for small initial populations, plants in forest interiors, and areas where herbicides cannot be used. In forests, repeated clipping without using herbicides is sufficient because the stress of repeated clipping kills honeysuckle plants. Clipping should be conducted at least once a year for at least three years. It is important that the clipping be repeated every year, because if it is only cut once and then abandoned, a denser population will develop (Luken and Mattimiro, 1991). To remove the plants, a weed wrench or polaski axe can be used, but care must be taken to remove all the roots or else the plants will be able to re-sprout. A heavy duty weed wrench which has a jaw capacity of 2.5 inches can be purchased for $189 at www.weedwrench.com (Weed Wrench Co., 2005).

To control large dense thickets of honeysuckle plants or plants in more open areas, herbicides are usually necessary. Herbicides can either be applied using a foliar spray, cut stump, or injection method. The foliar spray method is effective for large thickets of the plant where there is little risk to non-target species. A 1% foliar glyphosate (N-phosphonomethyl glycine) spray has been used to control both seedlings and adult *L. maackii* along heavily invaded edge habitats (Hartman and McCarthy, 2004). Glyphosate (with trade names Roundup or Rodeo) is a non-selective systematic herbicide, and so it kills all plant types. It can be bought at Home Depot in concentrations of 2%, 18%, or 50%.

The cut stump method (cutting the plant and then applying herbicide to the stump) has proven to be effective and is a widely used eradication procedure for woody invasive plants (Hartman and McCarthy, 2004). The method is effective as long as the ground is not frozen. In forest interiors, a 20% glyphosate solution has been found to be effective for honeysuckle control, and in open habitats where the plant is more resistant, a 50% solution should be used.

In the injection method, a glyphosate-filled 22-caliber capsule is pushed through the bark of the stem or stem base of the plant using an injection tool, where it enters the vascular system. The capsule should be injected only into stems 1.5 cm in diameter or larger, and on larger plants with more than one stem, each stem should be injected separately. When comparing the cut stump and injection methods, Hartman and McCarthy (2004) found that the injection method was the most favored because it was the most effective on large *L. maackii* plants (>1.5 cm in diameter), it was 43% faster than cutting and painting, it was less tiring to the applicator, it decreased the operator's exposure to herbicide, it used less herbicide, and it minimized the impact on non-target vegetation. Fall injections are generally more effective than spring injections.

After the actual plants are controlled, seedling populations must be managed. However, this is not as difficult a task as for some other invasive species because honeysuckle seeds are not long-lived in the soil, and once adult plants are gone, the seed bank will not persistently produce new plants. However, even though honeysuckle seeds are not long lived in the soil, birds still readily disperse the seeds to new areas. Managed sites should be monitored yearly for new seedling growth from the soil bank, and any new seedlings should be pulled out.

In general, it is best to control invasive honeysuckle populations when they are small and in their early stages of invasion before they become reproductively mature. Early control is less costly and has a greater chance of success (Hartman and McCarthy, 2004). It is best to remove all plants from an area, or else reinvasion will be more likely.

2.2 Oriental Bittersweet

2.2.a Description of Species

Oriental bittersweet (*Celastrus orbiculatus*) is a woody deciduous vine in the staff-tree family (Celastraceae) that has the ability to grow very quickly. It has alternate round and glossy leaves with finely toothed margins, light to dark brown branches with noticeable lenticels, and bright orange outer root surfaces (IPSAWG, 2005). It usually grows as a climbing vine that can reach heights up to 20 m, but it can also behave like a shrub. Female plants produce small greenish flowers in clusters in the leaf axils. In the fall, three-valved yellow globular fruits are produced which at maturity split open to show the three reddish-orange arils, each containing 1-2 seeds (PCA, 2006). The seeds are smooth, light orange in color, and are usually around 2.5 mm by 1.5 mm. The seeds are dispersed by birds and small mammals in the fall, winter, and early spring (Ellsworth, Harrington, and Fownes, 2003). In addition to being able to reproduce sexually, this species can also reproduce asexually through root suckering (Ma and Moore, 2003).

This species looks very similar to American bittersweet (*Celastrus scandens*) which is native to eastern North America. American bittersweet produces its flowers and fruits at the branch tips while Oriental bittersweet produces small clusters in the leaf axils. In addition, American bittersweet has fewer, larger clusters of fruit while Oriental bittersweet produces many fruit clusters all along the stem. These species can also be told apart by their leaves – American bittersweet has tapered leaves which are twice as long as wide which is in contrast to Oriental bittersweet's more round leaves (PCA, 2006).

2.2.b Introduction to the United States

The native range of Oriental bittersweet is Eastern Asia, Korea, China, and Japan, with the Yangtze River being its southern limit. In its native area, it is reported to inhabit lowland slopes and thickets. The elevations of these native areas range from 450 to 2,200 m (Ma and Moore, 2003). The plant was brought to the United States in the 1860's for cultivation, and it is now naturalized in 21 states from Maine south to Georgia and west to Iowa (IPSAWG, 2005). After its initial introduction, the plant became popular for ornamental plantings which further aided in its spread. Today, Oriental bittersweet is still planted and used as an ornamental vine in some areas.

2.2.c Habitat

Oriental bittersweet is an aggressive invader that can grow in a variety of habitats. In the United States, it is commonly found in upland meadows, thickets, young forests, forest edges, fencerows, along roadsides, and on beaches. It does particularly well in recently disturbed habitats (Ma and Moore,2003). It can be found as scattered plants or extensive infestations. While it is mostly found in sunny sites, it can tolerate shade, allowing it to spread to forested areas. McNab and Loftis (2002) devised a rapid survey technique to model the probability of finding Oriental bittersweet in relation to environment, competition, and disturbance in forested stands. Using a logistic regression model they developed, they found that the probability of occurrence of Oriental bittersweet increases with: overstory canopy not dominated by oaks, disturbance of the forest floor, concavity of the landscape around the site (which is indicative of sites with high moisture availability), and wind disturbance.

2.2.d Traits that make it a good invasive species

Oriental bittersweet has many traits that make it a good invasive species. First, it has the ability to colonize by both prolific vine growth and by seedlings. Oriental bittersweet vines are able to climb and effectively cover other woody vegetation. The vines can grow very fast – they can overtop tall trees in a single growing season, causing them to collapse. Each plant produces a high number of seeds annually that have a high viability and germination rate. Clement et al. (1991, as cited in TNC, 2003) found that in Connecticut, Oriental bittersweet can produce 4.2 viable seeds per fruit, while our native bittersweet can only produce 3.2 viable seeds per fruit. In the lab, germination rates of Oriental bittersweet have been measured at 66% (Ellsworth, Harrington, and Fownes, 2003). Another study by Dreyer, Baird, and Fickler (1987) measured germination rates of the native American and invasive Oriental bittersweet. They found the seed germination rate to be only 27% for American bittersweet while it was a much higher 71% for Oriental bittersweet. Oriental bittersweet's seeds are also readily dispersed by many species of birds such as mockingbirds, blue jays, and European starlings as well as humans who spread the plant through decorative arrangements (PCA, 2006).

Oriental bittersweet seedlings do not persist long in the seed bank, making the current year's seed input the main source of seedling recruitment (Ellsworth, Harrington, and Fownes, 2004). The seeds do not persist long in the seed bank for two reasons. First, the seeds are generally larger (10-12 mg) than most seed bank species (less than 2 or 3 mg), which increases the ability for seed predators to detect them. Second, the seeds do not have a thick seed coat. Species that have large seeds which have the ability to persist in the seed bank generally have thick seed coats, however, Oriental bittersweet does not have this thick coat that would allow it to survive multiple years in the soil.

Even though Oriental Bittersweets' seeds do not persist long in the seed bank, the large amount of seeds that are produced every year make up for this fact. A study by

Ellsworth, Harrington, and Fownes (2004) researching Oriental bittersweet in the understory of a young, mixed-deciduous forest stand in Amherst, Massachusetts measured the seed input, seedling emergence with seed rain, and seedling emergence without seed rain. They found that the mean seed rain of Oriental bittersweet was 168 seeds m^{-2} and the mean seedling emergence was 107 m^{-2}. In other studies, Oriental bittersweet seedling density have been observed at densities up to 400 germinated fruits per m^2, which corresponded to a seed density of approximately 1,600 seeds dropped per m^2 (Greenberg et al., 2001, as cited in Ellsworth, Harrington, and Fownes, 2003). In the study by Ellsworth, Harrington, and Fownes (2003), there was a strong correlation between seed rain and seedling emergence. They concluded that very few seeds entered the persistent seed bank because the ratio of germinated seedlings to seed input (.61) was close to the seed viability (.66). When seed rain was excluded, a low number of seedlings sprouted, which suggests that recruitment from the persistent seed bank is minimal and seedlings originate primarily from the current year's seed input. The authors go on to further predict that the relatively low degree of seed bank persistence is likely due to high summer germination rates.

A second trait which allows Oriental bittersweet to be a good invader is the ability of its seedlings to establish and grow even under dense leaf litter. Ellsworth, Harrington, and Fownes (2004) found that fragmented litter (leaf litter run through a 6 mm mesh) had no effect on seedling emergence, and a majority of seedlings were able to emerge from all but the highest amounts (16 Mg ha^{-1}) of intact litter (whole litter not run through a mesh). The plants were able to grow horizontally by elongating their hypocotyls until they could find a gap in the leaf litter. The hypocotyls could grow as long as 9 cm, which suggests that it is likely the seedlings could find an open gap in the forest floor leaf litter in all but the densest forest floors. For comparison, this experiment's highest amount of leaf litter was 16 Mg ha^{-1}, while the average amount of leaf litter in temperate deciduous forests during the summer is around 6 Mg ha^{-1} and during the autumn is around 9 Mg ha^{-1}. Thus, even the intact forest floor litter of undisturbed forests cannot prevent seedling establishment of Oriental bittersweet. The ability of the seedlings to grow best in fragmented litter suggests that areas with conifer litter, which is finer-textured than deciduous litter, may be more prone to Oriental bittersweet invasion (Ellsworth, Harrington, and Fownes, 2004).

A third trait which allows Oriental bittersweet to be a good invader is its ability to grow and survive in shady areas such as a dense forest understory. Once established, Oriental bittersweet can photosynthesize, survive, and grow at very low, partial, or full sunlight levels (Ellsworth, Harrington, and Fownes, 2003). Even though photosynthesis and growth of the plant decreases in shade, it is still able to survive under deep shade conditions. The plant can survive in shady areas for several years, growing rapidly once a gap is created or the canopy layer is removed. Ellsworth, Harrington, and Fownes (2003) found that Oriental bittersweet was able to adjust to shade by making morphological adjustments to low light levels in its leaves. They found that the plant was able to reduce its leaf mass per unit leaf area by 60% relative to that in full sun. Thus, this plant can survive even the darker conditions of intact, non-disturbed forests.

Another study by Leicht and Silander (2006) compared how Oriental bittersweet and the native American bittersweet responded to changes in light quality by lowering the red and far red light. Light quantity is the amount of irradiance a plant receives in a given environment, and is affected by the forest canopy, while light quality is the spectral distribution of the light that plants are receiving when growing under a canopy or close to other plants (Leicht and Silander, 2006). In full sunlight, the ratio of R: FR ranges from 1.10-1.25, however in shaded areas such as under an intact canopy, it can be as low as 0.10. The R: FR ratio has many effects on plant growth processes and development such as the internode length, plant height, branching patters, patterns of tissue allocation, leaf size, and biomass. When plants living in the forest understory are shaded from the leaf canopy or other plants, they experience both reduced light quantity and quality in lowered red: far red light (R: FR). Plants which are able to effectively grow in low red and far red light have the ability to successfully grow in a forest understory and effectively forage for the limiting light resources.

Oriental bittersweet increased its height, aboveground biomass, and total leaf mass in reduced red and far red light compared to the neutral shade, while American bittersweet only showed an increased stem diameter, leaf area, and leaf mass to stem mass ratio. Overall, Oriental bittersweet increased its height to 15 times that of American bittersweet when under low red and far red light. These differences allow Oriental bittersweet to increase its height and actively seek light resources in the forest understory while American bittersweet was unable to seek out light and had to depend upon gap forming in the canopy.

A fourth trait that allows Oriental bittersweet to invade areas quickly is its fast growth rate in response to even moderate light levels. In either full or partial sun, plants can overtop shrubs up to 2 meters high in just one growing season (Ellsworth, Harrington, and Fownes, 2003).

2.2.e Ecological Impacts

This species is considered a significant threat to native plant communities in the United States. Once it becomes established in an area, it rapidly grows over and overtops trees and shrubs along roads, in clearings, and in forest gaps. In areas where it grows densely, it can form nearly pure stands and can halt forest succession by blocking out necessary light and preventing photosynthesis required for growth. In addition to blocking light, it can also strangle the plants it grows over. It weakens mature trees by girdling the trunk, weighing down the crown, and overall makes the tree more susceptible to damage (IPSAWG, 2005).

With the ability to survive under even deep shade conditions despite its slow growth, even intact non-disturbed forests are vulnerable to invasion. If this species is present in the understory of an undisturbed forest even in low numbers, a disturbance that results in increases in light can trigger rapid growth and the eventual dominance of Oriental bittersweet (Ellsworth, Harrington, and Fownes, 2003).

Oriental bittersweet's invasion into early successional habitats, which have historically been maintained in part by fire, can also alter the normal fire regimes. The overall flammability of the area may be decreased if the invaded species are left untreated, while it may be increased if management activities such as cutting are undertaken (Richburg, Dibble, and Patterson, 2002).

Lastly, it is also believed that Oriental bittersweet can hybridize with American bittersweet, cross-pollinating to the extent that the genetic differences between the two are being modified. This hybridization threatens the genetic identity of American bittersweet (IPSAWG, 2005). Hybridization in the wild has been detrimental to

American bittersweet, causing its abundance to decline even further and making it harder to find actual American Bittersweet. Eventually, American bittersweet may be eliminated altogether because of hybridization with Oriental bittersweet.

2.2.f Control and Management

Once Oriental bittersweet is established in an area, it is very difficult to eliminate. Management options include mechanical and chemical controls; there are currently no biological controls available for this species. If the infestation is small, mechanical control is best. Plants can be hand-pulled or cut, but for effective removal, the entire plant including all the root portions must be removed. Pruning snips can be used for smaller stems, and a hand axe or chain saw are effective for larger stems. If the plant is in fruit, the vines should be bagged and disposed of in a landfill (PCA, 2006).

Chemical methods can also be combined with these mechanical methods for effective control. Once the stem is cut close to the ground, systematic herbicides such as 25% solutions of triclopyr (3,5,6-trichloro-2-pyridinye oxoacetic acid) or glyphosate can be applied to the stem tissue. Triclopyr is a systematic herbicide similar to glyphosate, except that it is more selective as it does not kill monocots such as grasses. Triclopyr is sold under the brand name of Garlon and can be bought at Home Depot at a concentration of 8%. These applications can be made at any time of the year as long as temperatures are above 40 degrees Fahrenheit and rain is not expected in the next 24 hours. Applying the herbicide in the fall or winter has the added advantage of minimizing impacts to native plants and animals. Repeatedly treating the stem may be necessary. Foliar sprays can be used to control extensive patches of dense bittersweet. A 2% solution of triclopyr has proven to be effective. The foliage should be wet before the spray is applied, and the ideal time to spray is October-November, after which most of the native vegetation is dormant (PCA, 2006).

2.3 Multiflora Rose

2.3.a Description of Species

Multiflora rose (*Rosa multiflora*) is a vigorous shrub with long greenish red arching stems. The plant's stems bear many sharp thorns and generally grow upright for 4-5 feet after which they begin to arch towards the ground. Under some conditions, the tips of branches can reach the soil and form roots (Doll, 2006). The plant can grow up to 10 feet tall and sometimes even higher when the branches are supported by surrounding trees or shrubs (Rhoads and Block, 2002). The leaves are pinnately compound and contain 5-11 alternate toothed leaflets. At the base of the leaf petiole, fringed stipules are found. In late May to early June, white or slightly pink flowers show up in clusters along the ends of the branches. The fruits are small red hips that can stay on the plant into the winter. The fruits do not release their seeds, but become leathery and can stay on the plant through the winter if they are not eaten sooner (Doll, 2006).

2.3.b Introduction to the United States

Multiflora rose is native to eastern Asia (Korea, Japan, and China), but was introduced to the United States in 1866 for the use as a rootstock for ornamental roses (Hartzler and Owen, 1992). Rootstocks are trunk or root material which can serve as a foundation for a grafted bud or twig. This species was desirable as a rootstock because it is able to grow in a variety of soil types and environmental conditions. Starting in the 1930's before its invasive characteristics were well known, it was widely planted in many regions of the country for the purpose of aiding soil conservation and for wildlife benefits, including nesting and cover sites for song birds cover for pheasant, bobwhite, and cottontail rabbit (Evans, 1983). Interestingly, the spread north of the northern mockingbird has been correlated with the spread of multiflora rose. The shrubs are ideal breeding and wintering habitat for the birds (Derrickson and Breitwisch, 1992). It has also been promoted as a living fence for animals, highways, and even around prisons to prevent escapes because of its thorny nature (Hartzler and Owen, 1992). Between the 1940's and 1960's, West Virginia alone planted more than 14 million plants for the above purposes (Doll, 2006). Only a few states such as Kentucky refused to plant this species as a living fence, and as an interesting result, many areas of Kentucky are void of Multiflora rose (Amrine, 2002). It is estimated that more than 45 million acres in the eastern part of the United States are now overgrown with Multiflora rose (Doll, 2006).

2.3.c Habitat

Multiflora rose grows well in a variety of soil types and environmental conditions. It can be found along hillsides, fence rows, stream banks, and on recreational lands, fields, edges of forest, and in grazed woodlots. It has been found to be especially well adapted to steep hillsides where control efforts are difficult (Doll, 2006). The plants can survive in full sun or partial shade, but they grow less well in wet soils (Evans, 1983). It can moderately tolerate cold, but cold winters in some northern areas can kill the plants. Multiflora rose can grow either as isolated plants in open areas or as dense thickets particularly in shaded areas and along slopes (Doll, 2006). Multiflora rose is currently abundant from the Great Plains to the east coast and south to Georgia. Its northern distribution in New England is limited by its sensitivity to severely cold winters (Amrine, 2002). Thus, with global warming, it may continue to spread northward.

2.3.d Traits that allow it to be a good invasive species

Multiflora rose has several traits which allow it to be a good invasive species. First, its leaves emerge early in the spring season, well before the leaves of any native woody plants emerge (Rhoades and Block, 2002). This gives the plant the advantage of photosynthesizing before any of the other plants have leafed out.

A second trait which allows multiflora rose to be a good invasive species is its reproductive ability. It has been reported that robust bushes can form an average of 50 flower clusters per branch, with each cluster having 50 fruits with 7 seeds each, which means 17,500 seeds per branch and up to half a million seeds per plant per year (Doll, 2006). The seeds have a high germination rate and viability – they can remain in the soil up to 20 years (Rhoades and Block, 2002 and Szafoni, 1990). A winter dormancy period of 1-5 months is generally necessary for germination (Doll, 2006 and Meyer, 2006). Many small mammals and birds such as American robins, cedar waxwings, wild turkeys, mice, rabbits, and white-tail deer eat the rose hips which help in their dispersal. The tough seed coat protects the seed as it passes through the digestive system (Evans, 1983). New shoots have the ability to sprout from existing root systems, but the plant primarily uses its seeds to spread and grow in new areas. The plants grow slowly for the first year or two, but become quickly anchored and are hard to pull up after this point (Schery, 1977).

In addition to leafing out early and having a high reproductive ability, the plant is also tolerant to many North American insects (Japanese beetles are an example of an insect that does eat multiflora rose; Amrine, 2002) and can tolerate a wide variety of light conditions from full sun to partial shade (Doll, 2006).

2.3.e Ecological Impacts

The main threat this species poses to natural areas is its ability to outcompete native vegetation for sunlight. It can also form such dense stands that it can interfere with the establishment of other woody species in old-field succession, thus stopping succession (Block, 2002). It has invaded a wide range of habitats from pastures, fence rows, roadsides, forest edges, and edges of marshes where it can form impenetrable thickets (Doll, 2006). Where plants have become established, the seed bank generally contains a large number of viable multiflora rose seeds that can continue to produce seedlings for at least 20 years after the removal of mature plants (Amrine, 2002).

Economic damage from this plant is also very high. Many states have lost pasture land to this shrub, especially pastures on hilly terrain, which has resulted in a reduction in potential beef production. It is estimated that a 10 year control program for Multiflora rose in West Virginia will cost more than $40 million (Amrine, 2002).

2.3.f Control and Management

Multiflora rose is very difficult to control because of its thorny nature and prolific seed production. Light, scattered infestations can be managed by pulling out individual plants from the soil. Significant amounts of carbohydrates are stored in the root system so the plant can survive the winter, thus it is important to pull up the entire root or else the plant will resprout from the root base (Doll, 2006). Digging down at least 6-8 inches into the ground is needed to remove the root crown which can grow up to a diameter of 8 inches.

If pulling up individual plants and roots is not feasible, repeated mowing can be tried for larger infected areas. Because removing plant leaves takes away the site of photosynthesis and energy production, repeated defoliation will exhaust the energy reserves in the roots and the plant will eventually die (Bryan, 1994). One study by Bryan and Mills (1988) found that mowing bushes down to 7.5 inches or less and then repeatedly cutting them back every month killed the majority of the plants after 2 years regardless of the plant size. In general, if mowing or defoliation is performed 3-4 times a year for 3 years, most plants will be killed. Infrequently mowing plants will not kill them, but if they are mowed before seeds are formed, it can reduce the seed production for that year (Doll, 2006).

Because large seed banks can develop in areas where plants are well developed, new seedlings can sprout from the ground even up to 20 years after removal of mature plants (Amrine, 2002). Therefore, it is necessary to continually monitor and remove seedlings from areas where mature plants have been removed for many years after the initial control effort was conducted.

Chemical controls can also be used to control this species. Herbicides such as a 10-20% solution of glyphosphate can be applied directly to cut stems using a sponge applicator (Szafoni, 1990). This treatment is most effective late in the season in July-September or during the dormant season. A solution of 50% Triclopyr can also be sprayed on cut surfaces within a few hours of the initial cutting. A foliar spray can be used in heavily impacted areas. A 1% solution of Dicamba (2,5-dichloro-6-methoxybenzoic acid) has been proven to be effective if applied anytime during the growing season. It is best to spray Dicamba in May-June when the plants are actively growing (Szafoni, 1990).

Animal grazing by goats or sheep has also been utilized to control Multiflora rose. This is an especially useful strategy along steep terrain where mechanical removal devices cannot be used. Bryan (1994) reported that Multiflora rose bushes were killed after several seasons of grazing. Goats are generally the best animals to use, because they are not affected by thorny vegetation, and by standing on their hind legs, they can defoliate plants up to 5 feet high. Goats reduced the brush cover in a study pasture from 45% to 15% in one season, while it took sheep three seasons to show this same reduction in vegetation. Bryan (1994) recommends using 8-10 goats per acre during spring and early summer to control this shrub.

Four agents of potential biological control for this species have been found in the United States – a virus that causes rose rosette disease, an eriophyid mite (*Phyllocoptes fructiphilus*), a seed chalcid (an insect) whose larvae feed on immature seeds (*Megastigmus aculeatus)*, and a stem girdler (*Agrilus aurichalceus*) (another insect) that kills rose stems (Amrine, 2002). All four agents are found in the United States, and show potential to reduce levels of Multiflora rose, but more studies need to be conducted before these agents are used as control measures (Amrine, 2002 and PCA, 2005).

2.4 Hemlock Woolly Adelgid

2.4.a Description of Species

Hemlock woolly adelgid (*Adelges tsugae*; HWA) is a small aphid-like insect that is a pest of eastern hemlock (*Tsuga canadensis*) in the northeastern United States. The adelgid damages and kills hemlock trees by sucking their sap. The species is called a woolly adelgid because for much of its life it is covered with a waxy "woolly" cocoon-like structure. The species is mostly found on the undersides of young hemlock branches where it feeds on the sap from the tree. HWA is considered the single greatest threat to hemlock health and sustainability in the eastern United States. The devastation to hemlock from the adelgid is similar to the devastation of elm trees from the Dutch elm disease and chestnut trees from the chestnut blight (USDA Forest Service).

2.4.b Introduction to the United States

HWA is native to Japan where it is widely distributed. In Japan, the native populations of HWA occur at low densities on hemlock trees (*Tsuga diversifolia* and *T. sieboldii*) because of a combination of natural enemies and host resistance. Examples of natural enemies in Japan include an oribatid mite (*Diapterobates humeralis*), a coccinellid beetle (*Pseudoscymnus tsugae*), a chrysopid lacewing (*Nallada prasina*), and a cecidomyiid fly (*Lestodiplosis* spp.), which have been reported to kill between 91-99% of adelgid eggs in forests (McClure and Cheah, 1999).

HWA first appeared in the western United States in Oregon in 1924. It is believed that the adelgid was brought over unknowingly on imported ornamental hemlocks (Lenox, 2001). The species was first reported in the eastern United States in Virginia around 1950. It is thought that the adelgid got to the eastern United States through a plant collector. In the late 1960's, it appeared in Pennsylvania, in the 1980's it appeared in Connecticut and Massachusetts, and has since spread to 15 eastern states (Smith-Fiola, 2004). Currently, it is spreading at a rate of 20-30 km per year (Foster, 2000).

2.4.c Habitat

HWA is currently found in both the western and eastern United States. In the western United States, the adelgid is found on mountain hemlock (*Tsuga mertensiana*) and western hemlock (*T. hereophylla*), both of which show some resistance to the adelgid (Lenox, 2001). In the eastern United States, HWA is found on Eastern hemlock and Carolina hemlock (*T. caroliniana*) both of which show no resistance to the adelgid. Currently, HWA infests around one half of the native range of hemlock in the eastern United States. It ranges from New Hampshire south to northern Georgia and west to central Pennsylvania (USDA Forest Service). Although HWA is only passively dispersed by wind, birds, mammals, and humans through logging, recreational, and nursery activities, it continues to spread at an alarming rate, and isolated patches of HWA have been found in Maine, Michigan, and Ohio.

2.4.d Life Cycle

The complicated biology of HWA has been well studied and the different life stages and seasonal developments are important to understand for control measures. HWA has a polymorphic life cycle, which means that it appears in different forms at different stages of development. It is also a parthogenetic species, which means all of the individuals are females and produce offspring without mating. Two generations of development are completed by the insect each year. From February to April, adults of the overwintering generation lay around 100 eggs each into a spherical cottony mass, or ovisac. In April and May, nymphs, who are called crawlers, hatch from these eggs and settle on young twigs near the base of needles. Here, they insert their stylets, piercing and sucking mouth parts, into parenchyma cells and begin feeding on the cell fluids (McClure and Cheah, 1999). It is thought that it may also inject a toxic saliva into the tree during feeding (Smith-Fiola, 2004). The crawlers are .3 mm long and are reddish brown with a black and white fringe around the body and down the center of the back (Malinoski). During the next few weeks, they keep feeding at the base of needles and eventually develop into adults 2 mm long by the middle of June.

Two different types of adults are produced – wingless individuals which start a second generation on the hemlock tree, and winged individuals which cannot reproduce on Hemlock. These winged species leave the hemlock tree in search for a spruce tree, which is necessary for them to reproduce. The wingless individuals lay their eggs in the middle of June on Hemlock trees in the same manner as described above. Crawlers hatch from these eggs in early July, settle on new growth, but then become dormant until

October when feeding resumes (McClure and Cheah, 1999). The nymphs feed and develop during late autumn and into winter and mature by February.

HWA has the same stages of development both in Japan and the United States. In the eastern United States, however, there are no suitable host spruce species, so the winged individuals are not able to reproduce and they all die (McClure, 1998). In Japan, there are suitable spruce species for the winged adelgids to reproduce on.

2.4.e Traits that Allow it to Easily Invade

HWA has several traits that allow it to easily invade the eastern United States. First, it is cold-hardy, and has the ability to spread throughout the entire natural range of the two eastern hemlock species (McClure and Cheah, 1999). Even though some severely cold winters can kill from 90-96% of the adelgids, the surviving adelgids are able to flourish the following spring and can easily recover to their previous population levels. Second, it is not limited to a certain age or size class of hemlock, and can attack trees of all sizes and ages (McClure and Cheah, 1999). Third, it is easily spread by wind, animals, birds, and humans. Currently, the adelgid is expanding its distribution in the eastern United States by around 30 km every year (McClure and Cheah, 1999).

2.4.f Ecological Impacts

HWA causes damage to hemlock trees by feeding on their sap. The damage from feeding first shows up as needle discoloration (the needles turn deep green to grayish green to yellow), which is followed by premature needle dropping, branch desiccation, and finally loss of vigor. Gradually, the limbs of the tree die back beginning at the base of the tree. Limb die back usually begins 2 years after infection, while the eventual death of the tree occurs after 4-8 years. The amount of time it takes the HWA to kill the tree depends on the tree's size, the environmental stress level, and the site of the tree (Smith-Fiola, 2004).

In the western United States, HWA has not caused significant damage to western and mountain hemlock trees because they are resistant to the pest. In the eastern United states, however, HWA is a huge threat to hemlock health and sustainability and has been responsible for the extensive decline and mortality of hemlock trees. HWA is rapidly spreading and is a serious threat to all hemlocks in eastern North America. To date, the impact of HWA has been the worst and most severe in Virginia, New Jersey, and Connecticut. Heavy infestations in some areas of New Jersey have resulted in more than 90% mortality. In a 2001 survey in New Jersey, more than 87% of stands surveyed showed signs of significant hemlock mortality (USDA Forest Service).

Another study by Orwig and Foster (1998) examined the response of hemlock stands in central Connecticut to HWA. They found that since 1995, the mortality of overstory and understory trees rose to over 60% in half of the stands studied and continues to increase by 5-15% each year. The trees that weren't killed decreased in vigor and had lost much of their foliage. They observed no tree recovery on the sites and predict that all of the trees in the infected stands will die within a few years.

In the Eastern United States, hemlock stands occur on millions of acres of land, and can be found in a variety of sites, soil types, and climate conditions (USDA Forest Service). Hemlock is a long-lived species, and tolerates shade very well. Hemlock is an ecologically important late-successional species and provides habitat for many species of wildlife which depend on the tree's dense canopy layer for shelter, food, and breeding sites. The species is also associated with riparian areas and plays an important role in preventing erosion along river and stream banks and maintaining cool water temperatures. In these habitats the tree is a very important shelter to wildlife as it can moderate temperatures in both the colder winter and warmer summer (USDA Forest Service). Hemlocks are also important aesthetically and are valued in recreational areas and as plantings in urban areas (USDA Forest Service). Without intervention, the impacts of HWA on hemlock ecosystems are expected to spread and intensify.

Once hemlock trees are gone from a stand, other species will eventually replace them. Because hemlock forests provide a lot of shade and prevent species which are not shade-tolerant from growing in the understory, if this hemlock canopy is lost, more sun will be let in which will allow a different set of species to grow. It is predicted that opportunistic herbaceous species as well as black birch, red maple, and oak will recolonize the forests following hemlock dieback. Orwig and Foster (1998) state that in stands where hemlock trees have died, black birch, red oak, and red maple are present in the overstory and are beginning to also become established in the understory. They found that the seed bank does still contain a high level of hemlock seedlings, but once they germinate, they are quickly infested with HWA, and the hemlock seeds do not remain viable for more than 2 years. Thus, they predict that HWA will eventually cause a shift from a hemlock-dominated habitat to hardwood-dominated forests across a wide area.

2.4.g Control and Management

HWA is difficult to manage for several reasons. First, there are no natural enemies in North America to keep its population in check. Second, it is difficult to detect HWA on hemlock trees until its population levels are high and current monitoring techniques are expensive and often inadequate. Third, only trees that are readily accessible can be managed for the insect. Despite these difficulties, there have been attempts to manage HWA.

HWA can be successfully managed with insecticides, however, the infected tree must be readily accessible, which makes this option unfeasible in large forest tracks. The most common and effective way for controlling HWA is by spraying infested trees with a horticultural oil or insecticidal soap. These sprays can be applied at any time of the year , however, application of the products is most effective in late March – April, when the adelgids have just hatched, and in late August – October, before the new woolly covering is produced ("Save our Hemlocks", 2005). The sprays should not be applied at temperatures above 75 degrees Fahrenheit or below 45 degrees Fahrenheit. One treatment a year is generally enough if there are no other infected hemlocks nearby, but two sprays a year are needed in most cases (McClure, 1998). Both of these products are highly effective in killing HWA and they are relatively safe to beneficial insects and the environment. These products are considered relatively safe because they only kill soft-bodied insects by suffocation rather than poisoning all the beneficial insects on the tree. However, because of the nature of these products, it is necessary that all parts of the infested tree are drenched, which can be difficult on larger trees.

Pesticides can also be applied by stem injection. This method is preferred in trees that are very tall or trees that are growing in areas where spraying is impossible or undesirable such as near water bodies. Small shallow holes are drilled into the root flares at the tree's base, and then pressurized plastic capsules containing pesticide are injected into the holes. The insecticide moves up into the tree where it is fed on by the adelgids. This technique works best when applied in mid-May, and can control adelgids for up to 6 months. One drawback to this method, however, is that for the insecticide to move up the tree through the sap flow, the tree must be newly infested and uninjured. Highly infected trees are generally restricted in their ability to uptake water because of the HWA's feeding (McClure, 1998).

Another option for applying pesticide is by soil drenching. Systematic pesticide can be introduced into the roots of hemlocks in May, or the soil beneath the tree's crown can be drenched with the pesticide. The pesticide is taken up by the tree's roots, where the HWA eventually feeds on it. An advantage of this system is that it does not harm the tree by drilling holes in it, but as was the case above, the tree must be healthy enough for the sap flow to be able to carry the pesticide into the tree (McClure, 1998).

All of the chemical methods are effective, but they can only be used on trees that are easily accessible. Thus, biological controls that can be used on a wide scale and across broad portions of hemlock's native range are being seriously studied. The best hope for a biological control agent found so far is a coccinellid beetle (*Pseudoscymnus tsugae*). Extensive laboratory studies of this insect have been conducted, and it has been found that the beetle feeds on all life stages of the HWA, its lifecycle is well synchronized with HWA, and it can survive the winter months. In studies, the beetle has reduced densities of HWA by 47-88% in 5 months at study sites. This insect seems promising, but studies are still being done to determine its effectiveness against HWA (CmClure and Cheah, 1999 and Lenox, 2001). In 2002, the national Park Service began releasing these beetles as a trial to control adelgid infestations at the Great Smoky Mountains National Park (National Park Service, 2006). As of 2006, it is still too early to assess the overall success of the control effort, but they report that preliminary results are encouraging.

Homeowners can also help control the spread of HWA by taking simple measures. Because stress increases the risk of attack by HWA, hemlock trees should be watered during times of drought so they do not become stressed. Dead and dying branches should be removed from trees, and care should be taken when logs and firewood are moved from infested to uninfested areas. Lastly, infected trees should not be fertilized when they are infected with HWA, as nitrogen fertilizers help adelgids thrive and increase their reproduction (Lenox, 2001).

Chapter 3

Project Description

This project studies four distinct pieces of land located in Westborough, Massachusetts - three are owned by the Westborough Community Land Trust (WCLT) and one is owned by the Town of Westborough. The WCLT is a private, nonprofit organization that was created to protect Westborough's natural resources and to preserve open space. The first two sites, **Gilmore Pond and its surrounding upland area** and the **Gravel pit and its Headwaters Conservation area** are both pieces of property that have been degraded by human alterations and invasive species. The third site, the **Meadow restoration site near Bowman Conservation area**, is currently being managed by the Westborough Community Land Trust in an attempt to create a meadow habitat. The fourth site, the **Hemlock forest at Hero Property**, is one of the least disturbed areas in Westborough and contains old growth hemlock trees.

The goal for each site is to document the current ecological condition of the land in terms of the prevalence of invasive species. Based on my field observations and monitoring data, I will determine the most desirable management goal for each site, develop a management plan that is the most effective against the present invasive species while being least damaging to the ecosystem, and develop a follow up long-term monitoring plan. The management plan for each site will include information on:

1. What will happen to the site if no management is conducted.
2. Management recommendations:
    a. The desired outcome and goals of management.
    b. The means by which this management can be achieved.
    c. A follow-up assessment of the success of the management effort.

3.1 SITE #1: Gilmore Pond and its surrounding upland area ("Gilmore Pond")

This site, which is part of the 35.1 acre Orchard Hill property owned by the Westborough Community Land Trust, consists of a small pond, Gilmore pond, surrounded by upland forested area (See Figures 1, 2, and 3). The Orchard Hill open space is a thin area of land centered around three developments in Westborough – the Orchard, Orchard Hill, and Pheasant Hill developments. The site is bounded by Adams Street to the west and south and Ruggles Street to the east. The property is one of the newest open spaces in town open to the public and the trail winding around the pond is a popular walking trail. The site can be accessed by a trail beginning at the end of Isaac Miller Road or on Gilmore Farm Road. Gilmore pond is 2.25 acres in size (Aquatic Control Technology, Inc., 2005) and contains a small island in the center. The Gilmore Pond watershed is around 32 acres, and contains one stream entering the pond from the northwest corner (Aquatic Control Technology, Inc., 2005). The pond outflows on the eastern side into Jackstraw Brook, which is a tributary of the Sudbury River.

Gilmore Pond is human-made - it was built in the 1930's as a water source for fire control. Over a decade ago, this site was once farmland. The farm included apple orchards to the south of the pond, which is now an open grassy area (D. Burn, personal communication, March 26, 2007). Aerial photographs I viewed from 1999 also show an apple orchard with regularly spaced trees. The reason for choosing to investigate this site is the prevalence of invasive species, particularly honeysuckle, along the sides of the walking trail. A management plan is currently being developed for the Gilmore Pond property by Waterman Design Associates, Inc (2007). The plan is being developed for the Westborough Community Land Trust and has yet to be approved by the Westborough Conservation Commission.

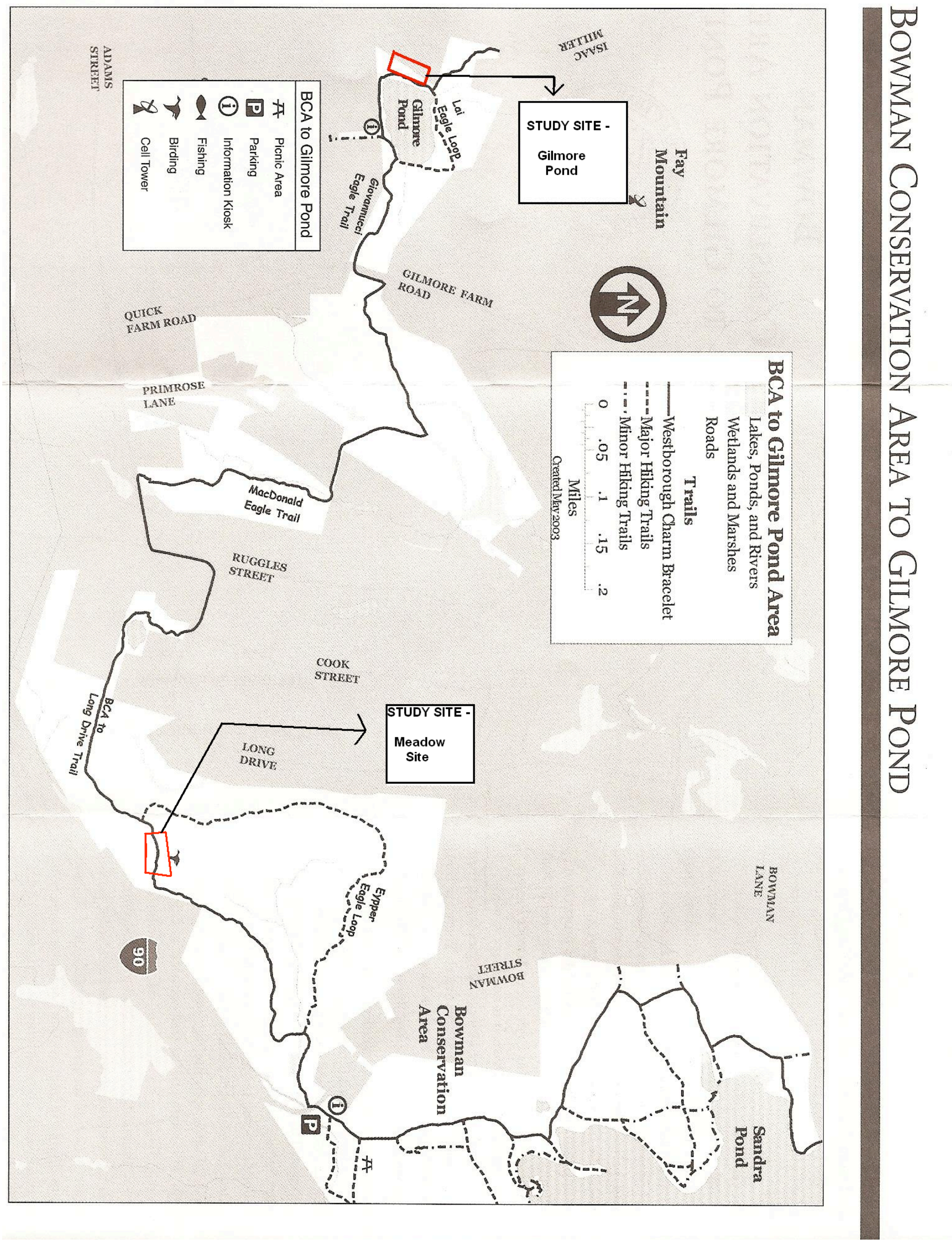

Figure 1. Map of Gilmore Pond and the meadow site showing general study areas outlined in red. Map from: WCLT/Open Space Preservation Committee (2003).

Figure 2. Aerial image of Gilmore Pond (Google Earth, 2007). Approximate study area is outlined in red.

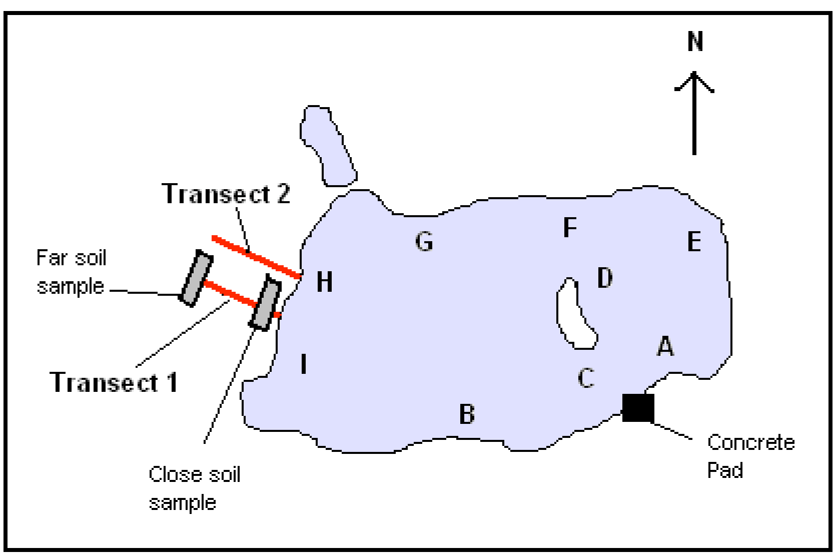

Figure 3. Diagram of study sites at Gilmore Pond. Letters in pond refer to aquatic vegetation sampling sites.

3.2 SITE #2: Meadow restoration site near Bowman Conservation Area ("Meadow site")

This site is a roughly 3-4 acre cleared meadow plot surrounded by woodlands located adjacent to the Bowman Conservation Area (See Figures 1, 4, and 5). It is part of the 29.9 acre "Bowman West" area, which are pieces of property given to the WCLT by the developers of Valley View Estates. The developers, the Toll Brothers, abandoned the land after the subdivision was built. The town of Westborough took the land and transferred the two large pieces, the meadow and a stream corridor, to the WCLT. The meadow site is accessed by a trail starting from the Bowman Street parking lot or by a trail on the opposite side leading to Long Drive. It is believed that the meadow was once an old hay field that extended easterly to a stone wall (M. Fox, personal communication, March 26, 2007).

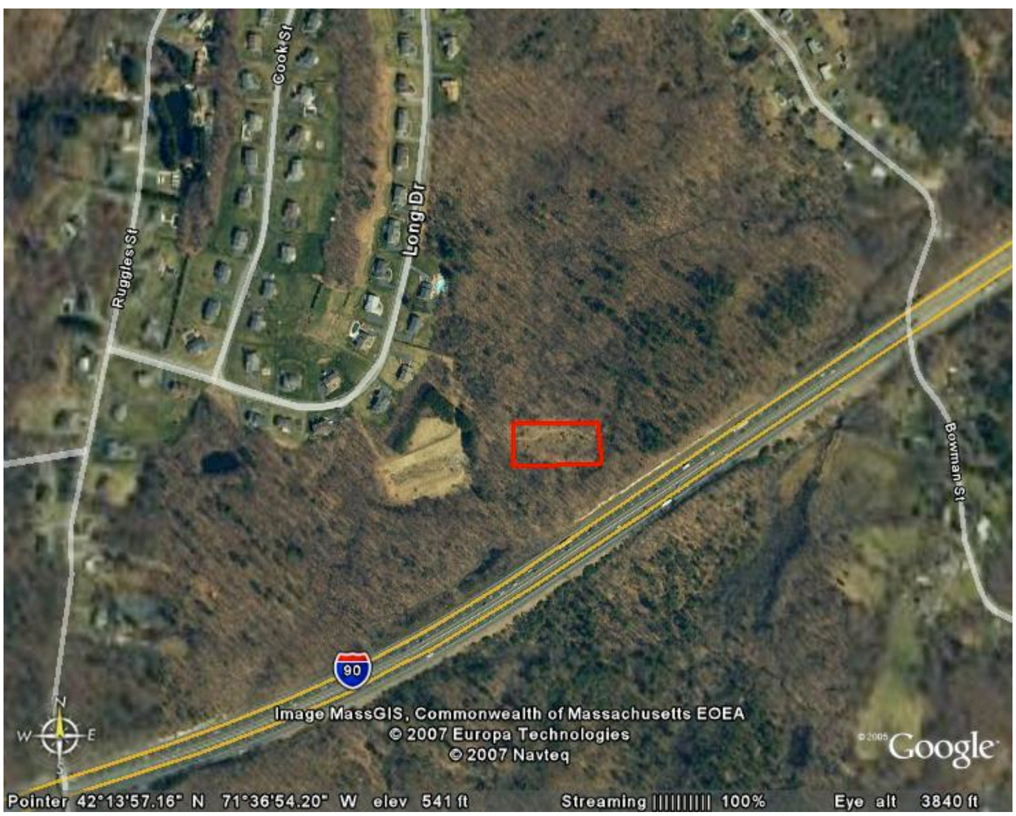

Figure 4. Aerial image of the Meadow Site (Google Earth, 2007). Approximate study area is outlined in red.

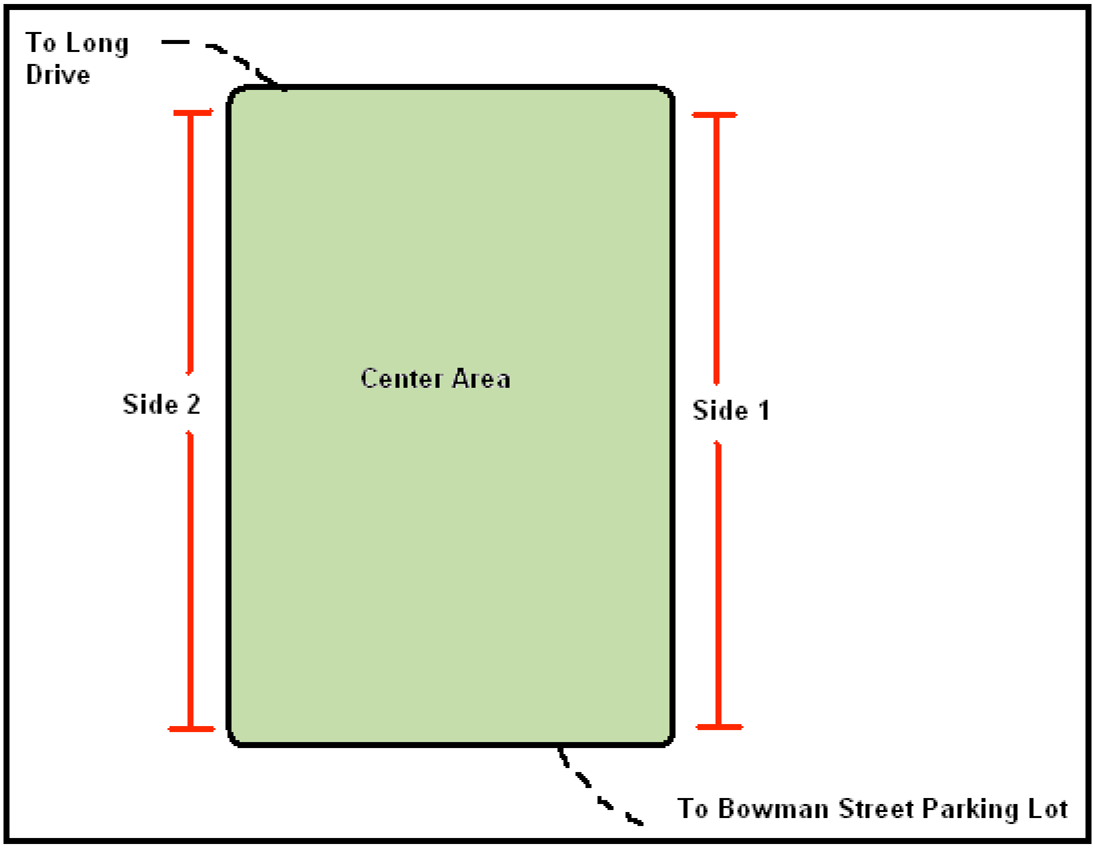

Figure 5. Diagram of study areas at the Meadow site.

3.3 SITE #3: Gravel Pit and its Headwaters Conservation Area ("Gravel pit")

This site, once an active gravel pit, is part of a larger 80 acre piece of property known as "Andrews-Nourse". The property is owned by the town of Westborough and is managed by the Westborough Community Land Trust. The land, which is part of the Assabet River headwaters, is bordered by the SUASCO Reservoir to the north and west. The western boundary of the property is marked by the Assabet Headwaters stream. The topography of the site slopes downward from south to north towards the reservoir. Because the entire property (also known as the Headwaters Conservation Area) is undeveloped, it protects the quality of 35% of the town of Westborough's water supply.

The site is accessed from the south by Andrews Street and contains many recreational trails (NEWFS, 2002).

The area of interest for this study is the sandy area next to the entrance (See Figures 6, 7, and 8). This area, in the northeastern portion of the Andrews-Nourse property, was formerly a gravel pit and was excavated for sand and gravel in the 1930's (NEWFS, 2002). The area is no longer used as a gravel pit and is currently in a very early successional state, composed of shrubland and grassy areas which include a lot of sandy ground. The northern and eastern parts of the Andrews-Nourse property (not part of this study) were once used by cattle and horses for pasture land. The forested parts of the property were logged for oak veneer around 20-30 years ago (NEWFS, 2002).

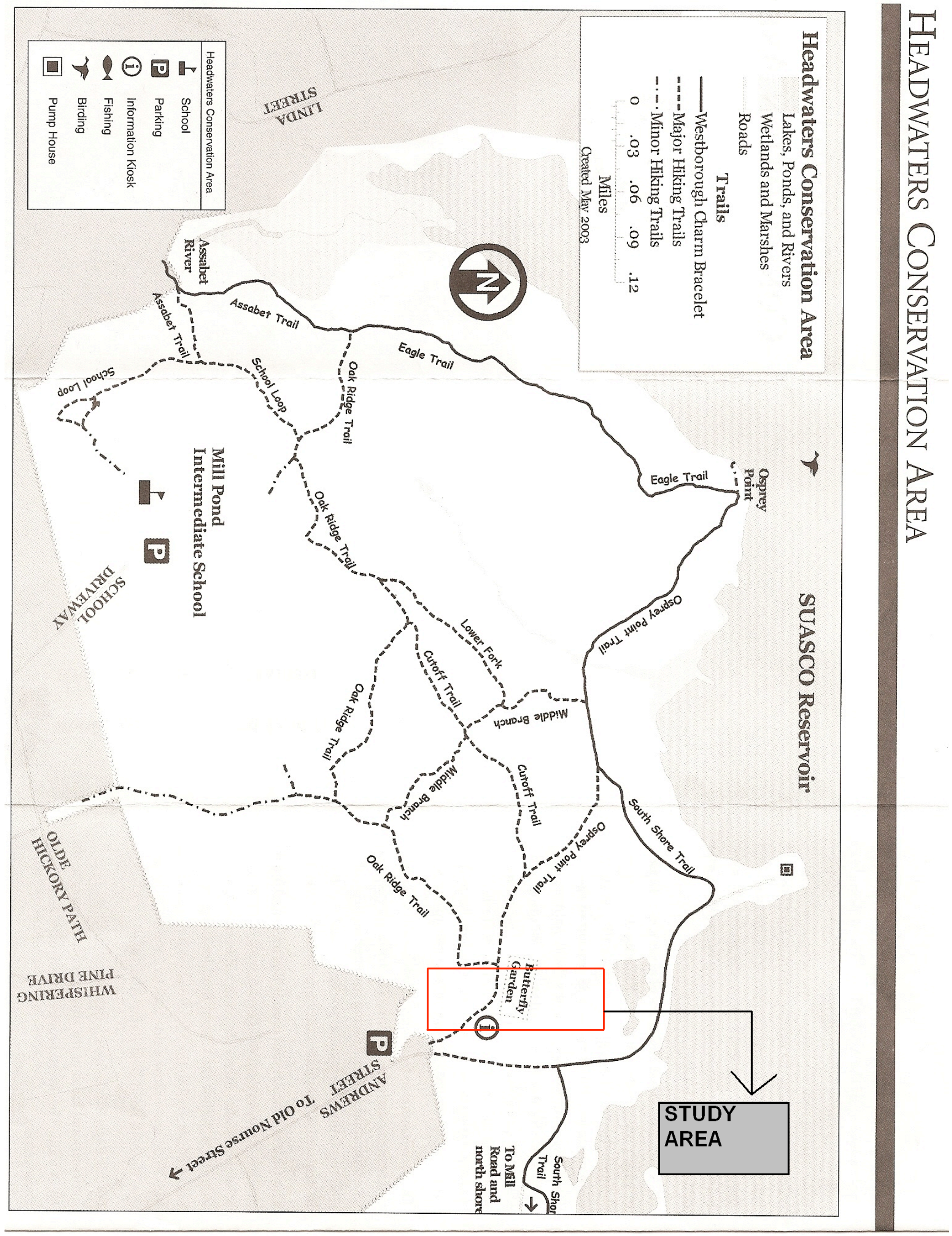

Figure 6. Map of the Headwaters Conservation Area showing general study area at the Gravel Pit outlined in red. Map from WCLT/Open Space Preservation Committee (2003).

Figure 7. Aerial image of the gravel pit site (Google Earth, 2007). Approximate study area is outlined in red.

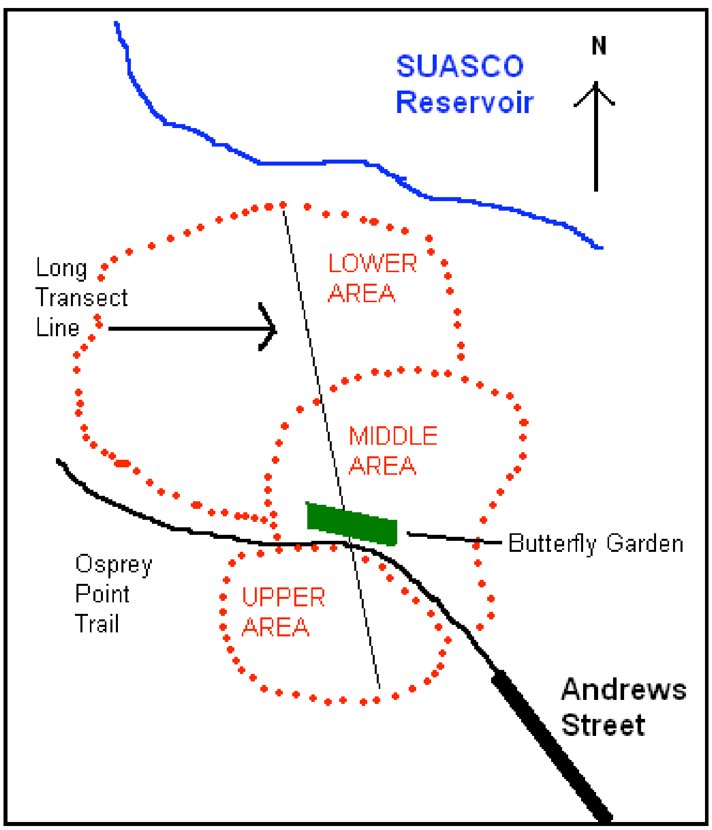

Figure 8. Diagram of study areas at the gravel pit.

3.4 SITE #4: Hemlock forest at Hero Property ("Hero property")

This site is a 6 acre piece of upland property located in the center of Orchard Swamp, which is part of the Assabet River watershed (See Figure 9) (WCLT). The site is accessed through the Greenleaf Canopy Trail, which starts behind the Haskell Street soccer fields. The trail is built upon an esker, which is a long ridge built by stream deposits from a stream which once flowed under a receding glacier. The forests in the Orchard Swamp area are severely disturbed by nearby baseball fields, a powerline right of way, and route 9. The remaining forests in the area are some of the least disturbed sites in Westborough. The stand I studied (around 6 acres) contains very old hemlock trees along with a mixture of beech trees surrounded by lower wetlands and potential vernal pools. This site does not have any vegetative invasive species present, but some of the hemlock trees are infected with the hemlock woolly adelgid. I chose to study this site to collect the "before" data on an invasion that we know is currently happening. I defined the plot I would study at this site by defining the wetlands as the outer boundaries. Currently, there are no management plans for this site, but the WCLT is trying to acquire the rest of the privately held open land in Orchard Swamp (D. Burn, personal communication, March 26, 2007).

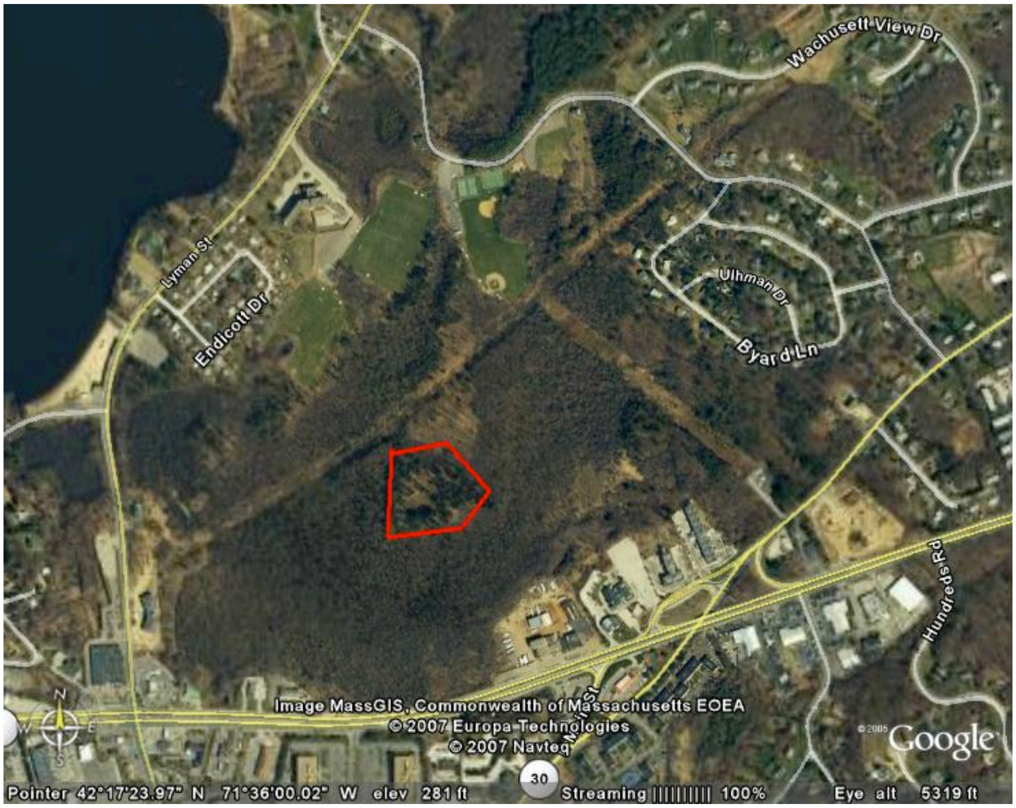

Figure 9. Aerial image of the Hero property (Google Earth, 2007). Approximate study area is outlined in red.

Chapter 4

Methods

This section describes the field work and data analysis methods conducted at each site. The results from these methods can be used in three ways: they can point out the need to manage a property in a certain way, they provide a valuable baseline set of data for future comparisons, and they offer a quantitative baseline for predicting what might happen to each site if no management is conducted.

4.1 Gilmore Pond

To determine the current ecological condition of this site, the prevalence of invasive species was monitored on land, in the water, and in the soil seed bank. The specific goals at the site were to:

1. Determine the relative abundance of species. This was done using the DAFOR scale (see description below) on October 22, 2006.
2. Determine the density of woody invasive species on land. This was done by sampling the most heavily infested land, the land on the western side of the pond, using the point-quarter sampling method (see description below) on October 29 and November 3, 2007.
3. Determine the prevalence of invasive species in the soil seed bank. This was done by sampling the soil seed bank (see description below) in two areas at the site – one heavily infested area close to the pond and trail, and a control area further away from the trail that was less infested with invasive species. The soil samples were collected from the site on December 8, 2006 and were spread out in the Wheaton College greenhouse on December 10, 2006.

4. Determine the prevalence of invasive aquatic species in the pond. This was done by taking samples of the aquatic vegetation at different points and depths in Gilmore pond on November 18, 2006.

4.1.a DAFOR SCALE

Relative abundance between species was measured using the DAFOR scale, which stands for dominant, abundant, frequent, occasional, and rare. These ratings apply to the entire area of a stand to describe the overall relative abundances of different species. The scale only relates species to each other, and not to a specific reference area. The terms can take on various definitions – for example, dominant can mean dominant in height, dominant in crown cover, dominant in basal area, or dominant in number. In this study, the definition dominant in both number and general percent cover was used. This method was completed after several walks through each site and after a list of all species present at each site had been composed. Using these observations, a rating of “D”, “A”, “F”, “O”, or “R” was assigned to each identified species.

4.1.b POINT-QUARTER SAMPLING

This method, also known as the point-centered quarter method, is ideal for sampling communities with widely spaced plants or communities where the dominant plants are woody shrubs (Kricher, n.d.). It is a plotless method, a sampling technique that does not require a prescribed area unit such as length and width (Bonham, 1989). The point-quarter method has been extensively used to study different vegetation types throughout the world, and is favored over the other plotless methods. Compared to the line-intercept method, it has been shown that this method provides the same accuracy level with only half the number of observations (Bonham, 1989). A limitation of the method in which counting becomes difficult, however, occurs if the vegetation cover exceeds 35% or if small shrubs/trees are obscured by larger plants.

In this method, random points within the stand were located by laying out flags along a series of parallel line transects. To choose the flag points randomly, a random number chart was consulted. Two numbers from the chart were read out, dictating how many steps along the rope transect were to be taken before each flag was put down. At Gilmore Pond, a total of 25 flags were placed down along two transect lines (12 flags along one line and 13 along the other). For an adequate sample, a minimum of 20 points is recommended (Bonham, 1989). At each sampling point, four 90 degree quarters were established using the transect line and by laying a perpendicular line down at the flag. In each quadrat, the nearest plant was located, the species identified, and the distance from the flag to the center of the root base was measured in meters (Kricher, n.d.). A minimum stem circumference of one inch was established so only the shrubby plants and trees would be counted.

Many plant species reproduce asexually underground by sending up shoots via underground rhizomes. Although these plants may appear to be different individuals when looking at them above ground, they are actually interconnected and are clones of the same plant. Individual stems in these kinds of populations are called ramets. It should be noted that the point quarter sampling method and all density methods used in this thesis assumed that individual plants separated from each other were indeed genetically distinct and were not ramets. Thus, this and the other density method described later (quadrat sampling) may have overestimated the number of genetically distinct plants.

To summarize the data, all of the distances from flag to plant were totaled for all the species and averaged to get the mean flag-to-plant distance. To calculate the mean area per plant, the average area of ground surface on which one plant occurs, this number was squared. To obtain the mean density for all species, the unit area (in this case 1 hectare) was divided by the calculated mean area per plant:

$$\text{Total density of all species} = \frac{\text{Unit area}}{(\text{Mean flag-to-plant distance})^2}$$

Once this total density of all species was calculated, the density of each species was then calculated. For example, using this data, the percent each species contributed to the total could be calculated. If 200 total plants were sampled and 50 were honeysuckle, honeysuckle would constitute 25% of the total. Furthermore, if the calculated total density of all species was calculated to be 20/ha, honeysuckle's density would be 5/ha.

4.1.c SOIL SEED BANK

Soil samples were collected from the Gilmore Pond site to investigate the prevalence of viable invasive species in the soil seed bank. The sampling methods follow a widely used soil sampling technique as described in Roberts (1981). Representative soil samples were taken at the site, spread out in suitable germination conditions in a greenhouse, and then the germinated plants were counted and identified.

The seeds of many plants require a cold treatment before they germinate. This built-in dormancy requirement protects them from germinating too early in the winter, in which the seeds might be killed by the cold temperatures. Different species have different requirements, but in general a 90 day cold treatment is adequate for most seeds in New England. Many invasive species, however, such as honeysuckle and bittersweet, do not require a cold treatment for their seeds to germinate. A study conducted by Sarah Riechard (1996) looked at 235 woody invaders and 114 non-invaders present in the United States. She found out that 49% of the invasive plants required a cold treatment to break dormancy while a higher 70% of native plants required a cold treatment. In my study, I did not perform a cold treatment on my samples; I spread them out in the greenhouse immediately after collection. Ideally, the seeds should have been given a cold treatment, but given time constraints, this was not done. Out of the three major invasive species at my sites (honeysuckle, bittersweet, and multiflora rose), multiflora rose is the only species that requires a cold treatment, so this is the only species out of the three that was affected by the decision.

4.1.c.i Field Soil Sampling

At Gilmore Pond, two sets of 25 soil samples were collected. A large number of samples were taken at each site because as a general principle, it is better to take a large number of small samples than a small number of larger samples (Roberts, 1981). One set of samples was taken next to the pond where the prevalence of invasive species (specifically honeysuckle and multiflora rose) was high, and the other set was taken 50 meters away from the pond in an area where no invasive species were visibly observed

(See Figure 3). During preliminary observation and point-quarter sampling, the majority of invasive species occurred along the trail next to the pond, with the density of invasive species generally decreasing away from the pond. Thus, the goal was to measure changes in the seed bank along a gradient, which made a transect approach with one close and one far sampling area optimal. Each individual soil sample was taken roughly 1-2 meters apart. To keep the two sets of samples as distant from each other as possible, the individual samples in each set (named "close" and "far" in reference to the distance from Gilmore pond) were collected in a rectangular area parallel to the pond. The close set of samples were taken from within two meters of the pond's edge to 12 meters of the pond's edge, and the far set of samples were taken from an area between 50 and 60 meters from the pond's edge. To collect each sample, a steel soil auger, 7 cm in diameter, was twisted 12 cm deep into the soil and removed. The total volume of each sample was 462 cubic centimeters. The leaf litter layer was included in each sample, because seeds are often present within it (Leck, Parker, and Simpson, 1989). The soil/leaf litter layer was then scraped out of the device and sealed in an individual labeled Ziploc bag for each sample.

4.1.c.ii Greenhouse Preparation

The samples were spread out and prepared in the Wheaton greenhouse on December 10, 2006. Initially, square flats 26 x 26 centimeters were prepared for the samples by separating each flat into two compartments with duct tape. A 1.5 inch layer of a soil and vermiculite mixture (4 to .5 ratio) was placed in the bottom of each flat. The square flats were then placed in larger rectangular flats with a thin layer of vermiculite on the bottom for proper water drainage. Two samples were randomly assigned to each square flat (one for each half of the separated flat) and then they were spread out on top of the prepared soil layer. Before they were spread out, any large leaves and rocks were removed from the samples. Any soil was scraped off of the leaves and they were visually inspected for seeds before they were removed. After the soil was spread out, the collected soil samples formed a roughly .5-1 inch layer on top of the bottom soil layer. The depth of each soil sample differed because some samples contained more leaves and rocks than others, which were removed before the soil was spread out. Each half flat was labeled with the sample it contained and the flats were placed randomly under a series of fluorescent 60 Watt Chromaso lamps in the greenhouse. To promote optimal germination conditions and to have as many seedlings as possible germinate, the flats were watered three times a week on Monday, Wednesday, and Friday, and they were placed under a 14 hour light regime (on at 6 am, off at 8 pm). Twice during the experiment, the flats were rotated randomly under the lamps.

4.1.c.iii Identification/ Data collection

To determine when the majority of seeds had germinated, every 2-3 weeks, the number of germinated plants was counted and recorded for each flat for a total of three times. The third time, no new plants had germinated, so it was assumed the majority of seeds had germinated and it was safe to begin quantifying and identifying the plants. To identify the invasive species, two methods were used. First, to identify oriental bittersweet, bittersweet seeds were taken off a known bittersweet plant and were spread out on a layer of soil and placed in the greenhouse as described above. This flat of only bittersweet seedlings was used as a reference to identify bittersweet plants in the other flats. To identify honeysuckle, a reference guide by the Ohio Agricultural Research and Development Center was used. The known species in the trays were identified on February 7 and 9, 2007. After being recorded, the known species were removed from the tray leaving the unknown/unidentifiable species behind to keep growing. During the week of April 9th, the remainder of the unknown species that could be identified were identified and the experiment was ended.

To analyze the seed bank results, the total number of times each species germinated was counted for each of the separate areas. This number was divided by 25 (the number of replicates) to obtain an average number of germinated seeds of each species per soil sample. For the conclusion, some of these numbers were converted to the number of germinated seeds per m^2. To convert, first, the area of ground the circular soil auger sampled was calculated. Then, 1 m^2 was divided by this number (.385 m^2) to determine how many samples there would be in 1 m^2.

4.1.d AQUATIC VEGETATION SAMPLING

Sampling of the aquatic vegetation in Gilmore Pond was conducted on November 18, 2006. Using a kayak, samples of the aquatic vegetation were taken from the pond at nine different sampling points. Samples were collected from the bottom, middle, and top of the pond using a long garden tool with curved metal pieces at the end. Samples could only be taken close to the edge of the pond and close to the island in the middle because the sampling tool could only reach down to a depth of around 8 feet. Samples from each sampling area were bagged and labeled in individual ziplock bags, brought back to the lab, and refrigerated overnight to prevent decay. They were identified in the lab the following day.

4.2 Meadow Site

To determine the current ecological condition of this site, the center of the meadow along with the two longer sides, named the right and left sides, were studied (See Figure 5). The right and left sides were studied separately because the dominant vegetation on either side differed. The right side was dominated by more woody and shrubby species, and the left side was dominated by more herbaceous species. The specific goals were to:

1. Determine the relative abundance of species at the site. This was done using the DAFOR scale (described above) on October 9 and 16, 2006.
2. Determine the density, percent cover, and frequency of invasive species. This was done by sampling the center, right, and left sides separately using quadrats (see description below).

4.2.a QUADRAT SAMPLING

The purpose of using quadrats is to count the number of individuals per some unit area, which is defined as the density. The quadrat delineates a measured area where species can be counted or vegetation cover can be estimated. In general, quadrats are best at quantifying the density of smaller herbaceous species versus larger woody species such as honeysuckle. The size of the quadrat used depends on what is being sampled – a smaller quadrat will usually be used in a grassy area compared to a larger quadrat in a more shrubby area. The quadrat needs to be large enough so that a significant number of the species in an area are included and small enough so that it is not too hard to count all of the plants accurately. To sample each quadrat, the number of each species encountered was recorded. When species were cut off by the edges of the quadrat, they were counted as "in" if the stem was rooted within the quadrat, and not in if simply the crown was overhanging the quadrat. Unknown species were keyed out in field identification handbooks or brought back to the lab for identification.

The middle area of the this site was sampled on October 3, 2006 using a total of 20 - .5 x .5 m^2 quadrats, and the two sides were sampled on October 6, 2006 using 7 - 1 x 1 m^2 quadrats on each side. The middle area was sampled with smaller quadrats because it was mostly grassy, while the sides were sampled with larger quadrats because they contained more woody shrubby species. The sides were sampled with fewer quadrats because of the larger quadrat size used. The center of the meadow site was divided into four quarters, and within each quarter, 5 quadrats were randomly placed down. To ensure that the placement was random, the quadrats were thrown, and they were left where they landed.

To determine the average density of each species, the total occurrence of each species (over all the quadrats) was divided by the number of quadrats sampled in an area. This gave the average density of each species per unit area of the quadrat size used. If the quadrat used was .25 m^2, the density results were multiplied by 4 to convert them to the average density per m^2. Frequency, the number of times a particular species occurs in a given number of sample plots (Mueller-Dombois and Ellenberg, 1974), was calculated for each species by dividing the number of quadrats in which the species occurred by the total number of quadrats sampled. In short, frequency measures the presence of a particular species at a site.

4.2.b PERCENT COVER USING QUADRATS

In each quadrat, the percent cover of the vegetation was also recorded. To estimate the percent cover, the Daubenmire method, also known as the canopy coverage method, was used (Daubenmire, 1959). Each individual species in the quadrat was assigned to one of six cover classes depending on its estimated percent cover in the quadrat (See Table 1).

Table 1. The Daubenmire Cover Scale.

Cover Class	Range of Cover (%)	Class Midpoints (%)
1	0-5	2.5
2	5-25	15.0
3	25-50	37.5
4	50-75	62.5
5	75-95	85.0
6	95-100	97.5

From Daubenmire (1959).

The intervals are uneven because the values allow for an easier estimation of cover than equal intervals would. In addition, it is necessary to break down the lower and higher values of the scale into finer values because the most and least abundant species can sometimes be significant (Mueller-Dombois and Ellenberg, 1974). If cover classes are broadly defined, as they are in the Daubenmire method, there is little chance of consistent human error when deciding on cover classes. To estimate the cover of a particular species, I first decided if it covered more or less than 50% of the quadrat. If it was less than 50%, next I decided if it covered more or less than 25% of the quadrat. If it covered less than 50% but more than 25%, I assigned it to cover class 3. If it covered less than 25%, I proceeded to determine if it covered very little area (0-5%) or more than this. If it covered very little area (Less than 5%), I assigned it to cover class 1. If it occupied more than this but less than 25%, I assigned it to cover class 2. This same method was used to determine the cover class of species that occupied more than 50% of the quadrat. The midpoints of each class are useful for statistical analysis of the data. With the use of midpoints, it is assumed that the actual values are symmetrically dispersed on either side (Bonham 1989). If the quadrat contains many species which have overlapping canopies, it is possible to have an estimate of over 100% cover.

To analyze the percent cover data, the class midpoints were used. For each species, first all of the midpoint numbers were added together. Then, this number was divided by the number of quadrats that were used in the area to obtain the average percent cover of the species.

4.3 Gravel Pit

I broke this site into three distinct study areas – an upper area, to the left of the walking trail, a middle grassy area, and a lower area, which is largely unvegetated (See Figure 8). The specific goals at this site were to:

1. Determine the relative abundance of species at the site. This was done using the DAFOR scale (as described above) in each of the three sections on October 9 and 11, 2006.

2. Determine the prevalence of invasive species in the soil seed bank in the upper area. Sampling was completed on December 12 using the same methods as described above for Gilmore Pond, with the differences described below.
3. Determine the density, percent cover, and frequency of invasive species in the upper area. The density was determined by using both the point-quarter (as described above with differences noted below) and quadrat sampling methods (as described above with differences noted below). In addition, the line intercept method (see description below) was utilized to determine the percent cover of bittersweet in this area because of its vine growth form. Point quarter sampling was conducted in this area to determine the density of the large honeysuckle bushes, and quadrat sampling was conducted to determine the density of the herbaceous grassy layer.
4. Determine the density, percent cover, and frequency of invasive species in the middle area. This was done by using quadrat sampling (as described above). Quadrat sampling was conducted in this area because the area is composed of primarily grassy species.
5. Determine the density, percent cover, and frequency of invasive species in the lower area. This was done by using both the point-quarter (as described above with the exceptions described below) and quadrat sampling methods (as described above). Point quarter sampling was conducted in this area to determine the density of the scattered small trees, and quadrat sampling was conducted to determine the density of the herbaceous species.

6. Determine the change in vegetation between the three areas. This was done on October 22, 2006 by using the line transect method (see description below).

4.3.a SOIL SAMPLING

At the Gravel Pit site, 25 soil samples were collected from the upper area to the left of the trail, which is the area of the site most heavily infested with invasive species, specifically honeysuckle and oriental bittersweet (See figure 8). Samples were taken throughout this area, each 1-2 meters apart using the same sampling techniques that were used at Gilmore Pond. The samples were spread out and prepared in the Wheaton greenhouse as described above on December 15, 2006.

4.3.b POINT-QUARTER SAMPLING

The same methods for point-quarter sampling described above for Gilmore Pond were used, except the layout of the transect lines and the number of flags used differed. In the lower area of the gravel pit site, 20 flags were placed down along five transect lines, and in the upper area of this site, 20 flags were placed down along seven transect lines.

4.3.c QUADRAT SAMPLING

At this site, sampled on October 7, 9, 10, and 11, 2006, the upper area was sampled using a total of 10 - 1 x 1 m^2 quadrats, the middle area was sampled using a total of 20 - .5 x .5 m^2 quadrats, and the lower area was sampled using a total of 20 - 1 x 1 m^2 quadrats. The middle area was sampled using a smaller quadrat size because it was mainly composed of grassy and small herbaceous species. The upper area was sampled using a larger quadrat size because it was composed of mostly larger woody species, and the back area was sampled using a larger quadrat size because there was not much vegetation present. Because of the larger quadrat size, a fewer number of quadrats were used in the upper area. In each area to ensure random placement, the quadrats were thrown and left where they landed.

4.3.d LINE TRANSECT SAMPLING

At this site, a transect line was used to sample the change in vegetation from the upper to the lower areas. A rope transect line 200 meters long was laid down from the top of the site to the back area of the site, making sure that the transect passed through each of the three distinct habitat types (See Figure 8). Every 15 meters, a circular quadrat, which encompassed an area of .25 acre, was laid down with the center at the meter mark on the transect line. A total of 14 quadrats were placed along the line starting at 0 meters. For each quadrat, species composition and percent cover data was recorded. To measure the species composition, a list was recorded of each species that was encountered in the quadrat, whether it occured once or multiple times. A plant was counted as in the quadrat if its stalked base was inside.

Percent cover was then estimated in each quadrat using cover classes along with the daubenmire cover scale method. The vegetation was broken into 5 vegetation types to demonstrate the change in vegetation across the study site.

The five vegetation types were defined as follows:

1. Mosses/ lichens
2. Grasses
3. Herbaceous Dicots
4. Shrubs
5. Trees

In this method, the cover class was estimated for each vegetation type rather than for each individual species. For example, in each quadrat, all of the present herbaceous dicots were grouped together and their cover was estimated as a whole. The advantage of this technique is that it is a rapid and simple way to describe and quantify changes in vegetation across a gradient.

To summarize the data, the transect line was broken down into the three distinct habitat areas of the site that it passed through – the upper, middle, and lower areas. The quadrats at 0, 15, and 30 meters were classified as in the upper area, the quadrats at 45, 60, 75, and 90 meters were classified as in the middle area, and the quadrats at 105, 120, 135, 150, 165, 180, and 195 meters were classified as in the lower area. For each of the three habitat types, the average cover class was calculated using class midpoints for each vegetation type.

4.3.e LINE INTERCEPT SAMPLING

Because of bittersweet's vine-like nature, a line intercept method (Bonham, 1989) was used to more accurately determine the percent cover of bittersweet in the upper area at the gravel pit site. To start out, three parallel lines were spread out along the top of the dense honeysuckle/bittersweet thicket. The lines were laid out from the beginning to the end of the thicket, which spanned a distance of 18 meters. Next, every two meters along each line, a half meter interval was marked. Along each of these half meter intervals, the percent cover of bittersweet underneath the interval was estimated using the same six cover classes described earlier. The percent cover was estimated by observing how many bittersweet vines, leaves, and berries intercepted the half meter interval.

To analyze these results, first, the percent cover data was converted to class midpoints as described before. Next, for each distance (0-18 m), the class midpoints for each line were averaged together to obtain an average percent cover of bittersweet at each distance. These results were then graphed in a line graph.

4.4 Hero Property

To determine the current ecological condition of this site, I first chose the plot I would study by defining the red maple swamp wetlands as the outer boundaries of the plot (See Figure 4). This site is not infested with a multitude of invasive plant species like the other sites, but Hemlock Wooly Adelgid has been spotted at the site. The site is not highly disturbed by humans, however there is some level of disturbance from the electrical wires running above the area. The specific goals at this site were:

1. Determine the extent of Hemlock Wooly Adelgid infestation on the hemlock trees. To determine this, I followed a Hemlock Wooly Adelgid sampling protocol described below.
2. Characterize the stand age. To determine the stand age, I counted growth rings (see method description below).
3. Characterize the stand tree size (see method description below).

4. Estimate the abundance of the major canopy tree species (See method description below).

4.4.a HEMLOCK WOOLY ADELGID SAMPLING

The hemlock trees at the Hero Property were monitored for Hemlock Wooly Adelgid on December 29, 2006 using methods described by Costa (2002) and Evans (2005). First, to determine the overall prevalence of Hemlock Woolly Adelgid in the stand, the lower branches of random hemlock trees were sampled (Costa, 2002). Costa's sampling plan is statistically based and allows for standardized detection and characterization of HWA infestations. Choosing a starting position, ten steps were taken in a random direction and the closest hemlock tree was located and its circumference was measured at standard breast height (1.5 meters above the ground). For analysis, the circumference measurements were converted to diameter at breast height (DBH). The only condition upon choosing a tree was that its lower branches be within reach. Very few trees had lower branches out of reach, so most trees in the stand could be sampled. One ground-level branch was then surveyed for the presence or absence of Hemlock Woolly Adelgid. To survey the branch, the undersides of the needles were searched for any white woolly masses, since in December the masses, or ovisacs, are readily visible. If woolly masses were found, the tree was marked as positive for HWA, and if no masses were found, a second branch on the opposite side of the tree was surveyed. If no HWA was found on either branch, the tree was marked negative for HWA. The sampling plan calls for between 8 and 100 trees to be sampled depending on the level of infestation (more for less infested areas). In this study, a total of 50 hemlock trees were sampled.

After the completion of surveying 50 trees, the percentage of trees infested was calculated.

To determine the current level of HWA infestation on the average tree, a randomized branch sampling method developed by Evans (2005) was used. This method is appropriate because it is unbiased and fits with the biology of HWA. The randomized branch sampling method (RBS) is useful because it generates unbiased estimates for the difficult to monitor HWA population. Before being used for HWA, the RBS method has been used to estimate fruit production, tree weight, needle mass, and tree biomass. To sample an infected tree, first a suitably small branch (15 cm in length) was clipped from the tree. Then, starting at the base of the branch, a random path to a terminal shoot was determined, i.e., at each fork in the branch, a direction was randomly chosen until the tip of the branch was reached. Along this path, the number of needles and the number of HWA ovisacs was counted and recorded. Later, the number of ovisacs to needles was converted to a standardized decimal of ovisacs/100 needles so the counts could be more easily compared across the stand. Because of the time consuming nature of this method, it was only conducted on approximately half of the trees that were marked positive for HWA. Approximately every other tree that was marked positive for HWA was sampled using this method for a total of 14 trees.

4.4.b GROWTH RING COUNTS

A tree ring is the layer of cells that are produced by a tree in the xylem or phloem over the duration of one year. The growth rate of a tree changes throughout the year, especially in temperate regions, resulting in visible tree rings in the trunk of the tree. A tree's growth rate is determined by two factors: the amount of glucose produced by photosynthesis and the rate at which the glucose is transformed into biomass (Fritts, Shashkin, and Downes, 1999). The inner part of the ring is formed early on in the spring and the outer part is formed later in the season (Wimmer and Vetter, 1999). Rings tend to be wider during years with favorable growing conditions (adequate water and sunlight) and narrower during years with unfavorable growing conditions, such as drought.

Tree ring patterns can provide a wealth of information about both individual trees and whole stands. In temperate regions, the age of a tree can be estimated by counting the number of rings in the xylem (Zhao et al., 1999). Tree ring patterns can also be used to determine past disturbances, climate, and stand factors such as competition level (Parish, Antos, and Hebda, 1999).

The age of the stand was estimated by counting tree rings in several large hemlock trees. Three dead trees were chosen (to avoid harming live trees) to sample because of their large size. The first tree appeared to have recently fallen to the ground because there was not much decomposition yet, and the second two trees were dead standing trees. To obtain an increment core from the three representative trees, increment borers were utilized.

Three borers with different lengths (20 cm, 30 cm, and 40 cm) were used. After assembling the borer, beeswax was applied to the borer bit to ease in removal. Methods for using the increment borers were obtained from a direction pamphlet provided by Forestry Suppliers, Inc. First, the borer was aligned towards the center of the tree and was screwed into the tree as far as it could go. After the borer was fully inserted, the handle was turned one turn counterclockwise to break the core from the tree. Next, the extractor was pulled from the circular borer bit and the resulting core was removed from the bit. Because of difficulties in using the 30 cm and 40 cm increment borers, only the 20 cm borer was used for the three trees. In addition to obtaining cores from each tree, the DBH was measured for each tree. The cores were brought back to the lab where the number of growth rings in each one was counted using a dissecting microscope.

Because the cores were not the full radius of the tree, the age of each tree was estimated using the cores available. Using the length of the core and the counted number of rings, the number of rings per centimeter could be determined for each core. To estimate the age for each tree, this number of rings per centimeter was multiplied by the radius in centimeters. It should be noted that this method is only an approximation of tree age, and does not provide as accurate an age estimate as taking a full core from the tree. The reason this method may not be accurate is that the rings may not be the same distance apart towards the center of the tree as they are towards the outside.

4.4.c TREE SIZE DISTRIBUTION

Tree size measurements (in circumference) for hemlock were taken at the same time the Hemlock Wooly Adelgid sampling took place. As described above, trees to sample were chosen by taking 10 steps in a random direction. The circumference of the closest tree was then measured and it was inspected for HWA. If the tree did not have lower branches within reach disqualifying it for HWA sampling, the circumference was still measured, thus the circumference of all encountered trees (a total of 53) were measured. Because the circumference of the hemlock trees was measured using standard measuring tape and not special DBH tape (which automatically converts circumference to diameter), the circumference measurements were converted to DBH using the formula: DBH = Circumference / 3.14. On April 20, 2007, the size distribution of beech trees was measured. A total of 53 random trees were measured using DBH tape.

4.4.d ESTIMATION OF CANOPY TREE ABUNDANCE

This method was utilized to estimate the relative abundance of the major canopy trees. 10 steps were taken in a random direction and the closest tree was chosen. The species of this tree was then identified and recorded. A total of 50 trees were sampled using this method. The number of times each species occurred was tallied up and then converted to a percentage of all trees.

CHAPTER 5

RESULTS

5.1 Gilmore Pond

A total of 35 species were found at this site, including 5 invasive species. Abundant species found include Morrow's honeysuckle, bramble, and red maple (See Table 2). The most abundant invasive species is morrow's honeysuckle (1,448/ha), along with frequent multiflora rose, occasional Japanese barberry, and rare Norway maple (See Table 3). While conducting point quarter sampling, it was noticed that the abundance of invasive species, particularly honeysuckle, decreased as the distance from the pond increased. Around halfway along the two transects, a stone wall was present after which very few honeysuckle plants were encountered. This observation is an indication of historical differences in land use on either side of the wall.

The only non-native species that germinated from the soil seed samples were common plantain and white clover (See Table 4). Surprisingly, no morrow's honeysuckle or multiflora rose plants germinated from the close soil samples since both plants were present at the site where the samples were taken.

Two species, coontail (*Ceratophyllum demersum*) and Nuttall's mudflower (*Mircranthemum micranthemoides*), were identified in Gilmore Pond from the aquatic vegetation sampling, both of which are native (See Table 5). Coontail was very abundant in the pond, as it was found in all but one of the sampling sites. Micranthemum was only found at one of the sites floating on the top of the water.

Overall, the main invasive species at this site is honeysuckle, which heavily infests the perimeter of the pond and the walking trail. Multiflora rose and Japanese barberry also occur at the site, but with less frequency.

Table 2. Relative abundance of all species at Gilmore Pond. Non-native species are in boldface.

DAFOR Results - Gilmore Pond		
Species		**Abundance Ranking**
Acer platanoides	**Norway maple**	R
Acer rubrum	Red maple	A
Acer saccharum	Sugar maple	O
Aster spp.	Aster	O
Berberis thunbergii	**Japanese barberry**	O
Betula alleghaniensis	Yellow birch	O
Betula lenta	Sweet birch	R
Carpinus caroliniana	American hornbeam	R
Carya ovata	Shagbark hickory	O
Castanea dentata	American chestnut	R
Equistum spp.	Horsetail	O
Fagus grandifolia	American beech	O
Fraxinus americana	White ash	R
Hamamelis spp.	Witch hazel	O
Hieracium pratense	**King devil**	R
Ilex verticilla	Common winterberry	F
Lonicera morrowii	**Morrow's honeysuckle**	D
Morus alba	White mulberry	R
Osmunda cinnamomea	Cinnamon fern	F
Pinus strobus	White pine	R
Populus grandidentata	Large toothed aspen	O
Potentilla simplex	Common cinquefoil	F
Prunus pennsylvanica	Pin cherry	O
Quercus alba	White oak	F
Quercus rubra	Red oak	O
Quercus velutina	Black oak	R
Rosa multiflora	**Multiflora rose**	F
Rubus spp	Bramble	A
Salix sepulcralis	Weeping willow	R
Solidago rugosa	Rough stemmed goldenrod	F
Thelypteris noveboracensis	New York fern	F
Toxicodendrum radicans	Poison ivy	O
Ulmus americana	American elm	R
Ulmus rubra	Slippery elm	R
Vaccinium corymbosum	Highbush blueberry	O
Viburnum acerifolium	Maple leaf viburnum	O
Total Invasive Species		5
Total Species		35

Table 3. Density of woody species surveyed using point quarter sampling at Gilmore Pond. Non-native species are in boldface.

Point Quarter Sampling Results - Gilmore Pond		
Species		**Density (#/ha)**
Acer platanoides	**Norway maple**	114
Acer rubrum	Red maple	800
Acer saccharum	Sugar maple	76
Carpinus caroliniana	American hornbeam	38
Carya ovata	Shagbark hickory	38
Fagus grandifolia	American beech	152
Fraxinus americana	White ash	38
Hamamelis spp.	Witch hazel	76
Ilex verticilla	Common winterberry	343
Lonicera morrowii	**Morrow's honeysuckle**	1448
Morus alba	White mulberry	38
Prunus pennsylvanica	Pin cherry	114
Quercus alba	White oak	152
Quercus velutina	Black oak	76
Ulmus americana	American elm	38
Ulmus rubra	Slippery elm	38
Vaccinium corymbosum	High bush blueberry	152
	Unknown #1	76
	Unknown #2	
Total density of all species		3810

Table 4. Density of viable seeds in soil at Gilmore Pond. Non-native species are in boldface.

Soil Sampling Results - Gilmore Pond			
		Average density of seeds per soil sample (462 cm^3)	
Species		**Gilmore Pond - Close**	**Gilmore Pond - Far**
Arisaema spp.	Jack in the pulpit	0.08	
Castanea dentana	American chesnut	0.12	0.04
Cyperaceae	Sedge	0.12	1.04
Hypericum mutilum	Dwarf St. Johnswort	0.04	0.32
Juncaceae	Rush		0.36
Ludwigia palustris	Water purslane	0.04	
Oxalis europaea	Yellow wood sorel	0.28	
Panicum clandestinum	Deer-tounge grass		0.16
Plantago major	**Common plantain**	0.08	
Poaceae	Grass	1.48	0.44
Potentilla canadensis	Dwarf cinquefoil	0.04	0.12
Potentilla simplex	Common cinquefoil		0.08
Pteridophyta	Fern sporophytes	9.48	32.36
Rubus spp.	Bramble	0.32	0.40
Solidago rugosa	Rough-stemmed goldenrod	0.08	
Toxicodendrum radicans	Poison ivy	0.04	
Trifolium repens	**White clover**	0.04	
Uvularia spp.	Bellwort	0.08	0.68
Viola spp.	Violet	0.00	0.16
	UK #1 (Leafy rosette)	0.04	0.04
	UK #2 (Leafy rosette)		0.08
Number of invasive species		2	0
Total number of species		16	14

Table 5. Plant species identified from the Gilmore Pond aquatic vegetation sampling.

Gilmore Pond Aquatic Vegetation Sampling Results			
Sample	**Location**	**Depth**	**Species**
1	B	Bottom	Unidentifiable (decayed)
2	B	Bottom	*Ceratophyllum demersum* (coontail)
3	D	Bottom	*Ceratophyllum demersum* (coontail)
4	D	Bottom	*Ceratophyllum demersum* (coontail)
5	F	Bottom	*Ceratophyllum demersum* (coontail)
6	G	Bottom	*Ceratophyllum demersum* (coontail)
7	H	Bottom	*Ceratophyllum demersum* (coontail)
8	H	Floating	*Mircranthemum micranthemoides* (Nuttall's mudflower)

5.2 Meadow Site

Center

In October when field work was conducted at this site, the grass had been recently cut and was no more than half a foot high, greatly hindering attempts to identify the species present. Along the edges of the meadow, there are several large brush piles that are overgrown with vegetation including invasive species. Dominant species in the center open field included grasses and abundant species included bramble, sweet fern, pussy toes, and rough-stemmed goldenrod (See Table 6). Rough stemmed goldenrod (10.4/m^2) and bramble (7.0/m^2) were the two most abundant and frequently found species during the quadrat sampling (See Table 7). Non-native species observed in this area include morrow's honeysuckle, field sorel, red clover, field hawkweed, queen Anne's lace, Oriental bittersweet, motherwort, and autumn olive. Morrow's honeysuckle was found at a density of 3.9/m^2 and a frequency of 40%, and oriental bittersweet was found at a density of 2.6/ m^2 and a frequency of 10%.

Table 6. Relative abundance of all species at the meadow site. Non-native species are in boldface.

DAFOR Results - Meadow Site				
		Abundance Ranking		
Species		Meadow - Center	Meadow - Right	Meadow - Left
Acer rubrum	Red maple	F	O	O
Ailanthus altissima	**Tree of heaven**			R
Antennaria spp.	Pussytoes	A	F	
Asclepias spp.	Milkweed	O		
Aster spp.	Aster	R		O
Betula populifolia	Gray birch	O	O	O
Bryophyta	Moss	F	O	O
Castanea dentata	American chesnut			R
Celastus orbiculatus	**Oriental bittersweet**	O	F	A
Comptonia peregrina	Sweet fern	A		F
Daucus carota	**Queen Anne's lace**	O		O
Eleaganus umbellata	**Autumn olive**	R		
Gnaphalium obtusifolium	Sweet everlasting	O		
Hamamelis spp.	Witch hazel		O	
Hieracium pratense	**Field hawkweed**	O		
Juncaceae	Rush	O		
Juniperus virginiana	Eastern red cedar	R		
Leonurus cardiaca	**Motherwort**	O		
Lonicera morrowii	**Morrow's honeysuckle**	F	A	F
Oxalis europaea	Yellow wood sorel	F		
Pinus strobus	White pine			R
Poaceae spp.	Grass	D	F	F
Populus tremuloides	Quaing aspen	R		
Potentilla canadensis	Dwarf cinquefoil			O
Potentilla simplex	Common cinquefoil	F	O	
Prunus spp.	Laurel	R		
Quercus alba	White oak	R	O	O
Quercus rubra	Red oak	O	F	O
Rhus typhina	Staghorn sumac	F	D	
Rosa multiflora	**Multiflora rose**	R	O	O
Rosa spp.	Rose	O		R
Rubus spp	Bramble	A	F	F
Rumex acetosella	**Field sorel**	F		O
Solidago gigantea	Late goldenrod	F	A	F
Solidago graminifolia	Lance-leaved goldenrod	O	O	F
Solidago juncea	Early goldenrod	F	A	F

Solidago rugosa	Rough stemmed goldenrod	A	D	A
Toxicodendrum radicans	Poison ivy	F		
Trifolium arvense	**Rabbit's foot clover**		O	
Trifolium pratense	**Red clover**	F		
Trifolium repens	White clover	F	O	
Vicia spp.	Vetch	F	O	O
Vitis labrusca	Fox grape	O	O	F
Total Invasive Species		9	4	6
Total Species		37	22	25

Table 7. Quadrat sampling results for the meadow site. Non-native species are in boldface. The + symbol means that the average percent cover is less than 1%.

Quadrat Results - Meadow Site										
		Meadow Site								
		Center			Right			Left		
Species		Density (#/m^2)	Frequency (%)	Avg % cover	Density (#/m^2)	Frequency (%)	Avg % cover	Density (#/m^2)	Frequency (%)	Avg % cover
Acer rubrum	Red maple	1.2	25	1	0.4	14	+	0.6	43	1
Antennaria spp.	Pussytoes	1.0	10	+						
Betula populifolia	Gray birch							0.1	14	+
Bryophyta	Moss						11			2.5
Celastus orbiculatus	**Oriental bittersweet**	2.6	10	3	2.4	14	2	3.3	43	10
Comptonia peregrina	Sweet fern	1.2	25	1	1.4	14	2	6.1	2	8
Eleaganus umbellata	**Autumn olive**	0.2	5	4						
Gnaphalium obtusifolium	Sweet everlasting	4.4	25	1						
Hieracium pratense	**Field hawkweed**	3.6	15	+						
Juncaceae	Rush							0.1	14	1
Leonurus cardiaca	**Motherwort**	1.0	5	1						
Lonicera morrowii	**Morrow's honeysuckle**	3.8	40	2	8.6	71	24	3.3	57	5
Oxalis europaea	Yellow wood sorel	3.0	30	1	1	14	+	0.3	14	+
Poaceae spp.	Grass								100	19
Potentilla simplex	Common cinquefoil	2.4	25	1	2.1	29	3	0.3	14	+
Prunus spp.	Cherry	0.8	10	+						
Quercus alba	White oak							0.3	29	1
Quercus rubra	Red oak				0.1	14	+			
Rhus typhina	Staghorn sumac	2.8	50	1	0.7	14	+			
Rosa multiflora	**Multiflora rose**				1.3	43	3	0.7	29	1
Rosa spp.	Rose							0.1	14	+
Rubus spp	Bramble	7.0	60	7	9.6	57	6	12.6	71	19
Rumex acetosella	**Field sorel**	4.4	20	1						
Solidago gigantea	Late goldenrod	1.0	20	1	0.3	14	+	1.4	29	1
Solidago graminifolia	Lance-leaved goldenrod	0.6	10	+	1.1	29	1	1.6	57	2
Solidago juncea	Early goldenrod	2.8	20	1	0.1	14	+	0.7	14	+
Solidago rugosa	Rough stemmed goldenrod	10.4	50	8	12.4	71	14	12.0	86	11
Toxicodendrum radicans	Poison ivy				1.4	14	5			
Trifolium pratense	**Red clover**	1.2	15	2	0.1	14	+			
Trifolium repens	White clover	2.8	25	1						
Vicia spp.	Vetch	2.4	15	1						
Vitis labrusca	Fox grape	0.8	10	2				0.4	29	1
	UK #1	0.6	5	+				0.4	14	1
	UK #2	5.4	15	1						
	UK #3 (Vine)				0.4	29	1			

	UK #4 (Green rosette)									
	Bare ground						18			16

Right Side

This side of the field contains more woody plants such as honeysuckle and sumac. There are several piles of discarded branches with honeysuckle and bittersweet growing on them, but there is less overall plant growth on these piles compared to the piles on the left side of the field. Dominant species in this area include staghorn sumac and rough-stemmed goldenrod, and abundant species include morrow's honeysuckle, late goldenrod, and early goldenrod (See Table 6). Major invasive species found include morrow's honeysuckle ($8.6/m^2$), oriental bittersweet ($2.4/m^2$), and multiflora rose ($1.3/m^2$) (See Table 7).

Left Side

This side of the field contained fewer woody plants than the right side. Abundant species include Oriental bittersweet and rough-stemmed goldenrod (See Table 6). Compared to the right side of the field, this side contains less honeysuckle ($3.3/m^2$) and more bittersweet ($3.3/m^2$) (See Table 7). However, there are more honeysuckle and bittersweet seedlings and runners creeping into the mowed field on this side. There is also a large autumn olive shrub present. The woody debris piles on this side are more overgrown with grasses and a dense mat of bittersweet than the woody debris on the right side of the field.

<u>5.3 Gravel Pit</u>

In general, this site is largely composed of open shrub and grassland and lacks an abundance of vegetation and a canopy. The soil is generally sandy and is exposed in several areas. To generalize the transition in vegetation between the three sub-areas of this site, a line transect method was conducted. Figure 10 summarizes the percent cover of the 5 different vegetation classes (mosses/lichen, grasses, herbaceous dicots, shrubs, and trees) in the three sub-areas.

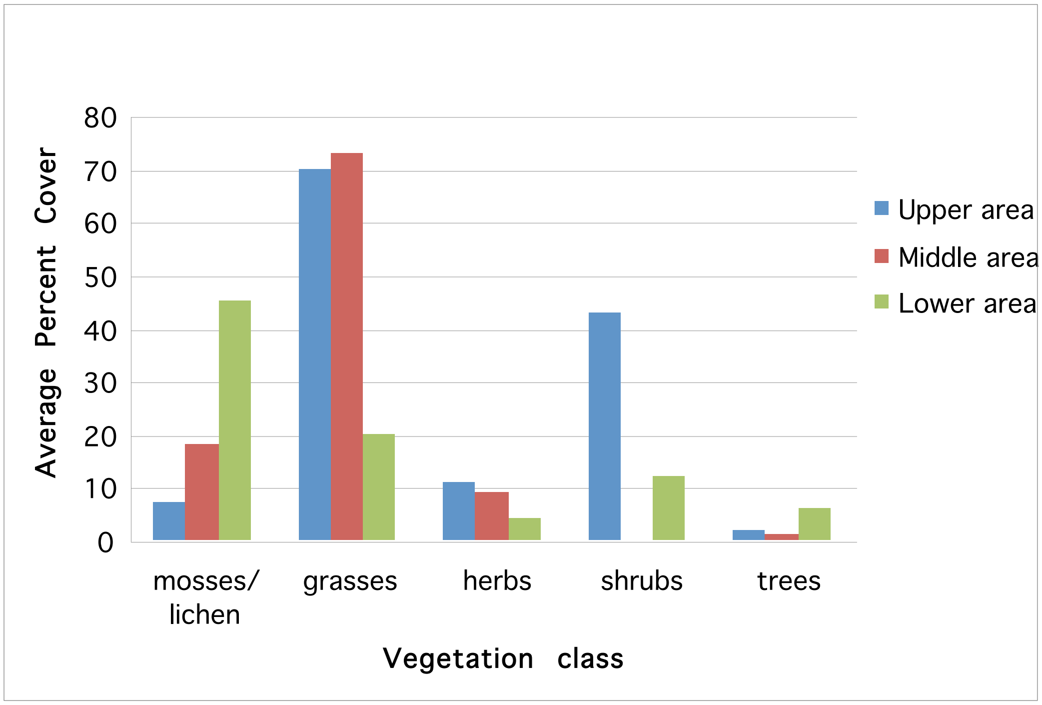

Figure 10. Differences in average percent cover of each vegetation class in the three areas of the gravel pit site.

The upper area is characterized by its high abundance of shrubs. In this area, it was found that shrubs including sweet fern, staghorn sumac, bittersweet, and honeysuckle, have an average percent cover of 43%. In the lower area, shrubs only had an average percent cover of 12% while they were not present at all in any of the middle area quadrats.

The middle area is characterized by its high abundance of grasses. In this area, grasses including little blue stem and downy chess have an average percent cover of 73%, which is higher than either of the other two sub-areas. This area is also characterized by its lack of shrubs and low percent cover of trees (1%)

The lower area is characterized by its high abundance of mosses and lichens. In this area, mosses and lichens have an average percent cover of 45%. In the upper area, mosses and lichens have a lower average percent cover of 6.7%, and in the middle area they have an average percent cover of 18%. This habitat also has the highest average percent cover of trees (6%) than either of the other two habitats.

Upper Area

Dominant species in this area include little blue stem grass and morrow's honeysuckle. Abundant species include Oriental bittersweet, round-headed bush clover, staghorn sumac, and rabbit's foot clover (See Table 8). Large honeysuckle bushes dominate about half of the area and form a dense thicket upon which the bittersweet is growing. Using quadrat data, honeysuckle plants comprise 14% and bittersweet plants comprise 4% of the total density of all species at the site. Little blue stem grass comprises 51% of the total density of all species.

Morrow's honeysuckle is the most abundant invasive species with a density of 5,375 plants per hectare while Oriental bittersweet was found at a density of 375 plants per hectare using the point-quarter method (See Table 9). There is a high abundance of honeysuckle seedlings surrounding and underneath the honeysuckle thicket. Using the quadrat method, honeysuckle was found at a density of 4.5 plants/m^2 while oriental bittersweet was found at a density of 1.1 plants/m^2 (See Table 10). The quadrat and point-quarter data cannot be directly compared to each other because the quadrat method is able to pick up the high number of seedlings on the ground in addition to larger shrubs while the point quarter method only picks up only larger plants. Other non-native species found in this area include downy chess grass, Queen Anne's lace, king devil, poor man's pepper, common mullein, and rabbit's foot clover.

Two major invasive species, Morrow's honeysuckle and Oriental bittersweet, germinated from the soil samples taken at this site (See Table 11). Either honeysuckle or bittersweet were found in 44% of the samples. Honeysuckle germinated at a density of 0.4 plants/soil sample while bittersweet had a higher density of 1.04 plants/soil sample. Other invasive species which were abundant include catnip and henbit. Six species of invasive plants germinated from the soil samples out of a total of 19 species found. Compared to Gilmore Pond, more species of invasive plants germinated from the soil samples in this area.

To more accurately describe the percent cover of the bittersweet growing over the honeysuckle thicket in this area, a line intercept method was used. The results from the average of the three transect lines are graphed in Figure 11. In general, the percent cover of bittersweet was low towards the periphery of the honeysuckle thicket and was greater towards the center.

Table 8. Relative abundance of all species at the Gravel Pit site. Non-native species are in boldface.

DAFOR Results - Gravel Pit				
		Abundance Ranking		
Species		**Gravel Pit - Upper**	**Gravel Pit - Middle**	**Gravel Pit - Lower**
Ambrosia spp.	Ragweed	O	A	
Andropogon scoparius	Little bluestem grass	D	D	D
Antennaria spp.	Pussytoes	F	A	
Aster spp.	Aster	R		
Betula papyrifera	Paper birch	R		
Betula populifolia	Gray birch	R	R	A
Bromus tectorum	**Downy chess grass**	R	O	A
Bryophyta	Moss		D	A
Celastus orbiculatus	**Oriental bittersweet**	A		
Comptonia peregrina	Sweet fern	F	O	F
Daucus carota	**Queen Anne's lace**	O	O	
Eleaganus umbellata	**Autumn olive**		R	
Equistum spp.	Horsetail	R	R	
Eragrostis reptans	Purple lovegrass	O	O	
Erigeron canadensis	Horseweed		R	
Gaylussacia baccata	Huckleberry			R
Gnaphalium obtusifolium	Sweet everlasting	O	O	R
Hieracium pratense	**King devil**	R		R
Juncus tenuis	Path rush	O	O	R
Lepidium virginicum	**Poor man's pepper**	O	R	
Lespedeza capitata	Round-headed bush clover	A	A	A
Linaria canadensis	Blue toadflax		R	
Lonicera morrowii	**Morrow's honeysuckle**	D	R	
Oenothera cruciata	Evening primrose		R	
Oenothera fruticosa	Sundrops		O	
Pinus strobus	White pine		R	O
Poaceae spp.	Grass			O
Polygonella articulata	Sand joint weed	O	A	O
Populus grandidentata	Large toothed aspen	R		R

Populus tremuloides	Quaing aspen			A
Potentilla canadensis	Dwarf cinquefoil	O	A	
Potentilla recta	**Rough-fruited cinquefoil**		R	
Prunus spp.	Laurel			R
Quercus alba	White oak	R	R	
Rhus glabra	Smooth sumac	O	R	
Rhus typhina	Staghorn sumac	A		
Rubus spp	Bramble	O	O	O
Salix spp.	Willow		R	
Solidago erecta	Erect goldenrod			O
Solidago gigantea	Late goldenrod	R	R	
Solidago nemoralis	Gray goldenrod	O	R	O
Solidago odora	Sweet goldenrod	R		
Solidago rugosa	Rough stemmed goldenrod	R		
Solidago speciosa	Showy goldenrod			O
Solidago tenuifolia	Slender goldenrod			O
Solidago ulmifolia	Elm-leaved goldenrod			O
Trichostema dichotomum	Blue curls		R	
Trifolium arvense	**Rabbit's foot clover**	A	A	
Vaccinium angustifolium	Early low blueberry			R
Verbascum thapsus	**Common mullein**	R	O	
Total Invasive Species		8	8	2
Total Species		30	33	23

Table 9. Density of woody species at the Gravel Pit site. Non-native species are in boldface.

Point Quarter Sampling Results - Gravel Pit			
		Density (#/ha)	
Species		**Gravel Pit - Upper**	**Gravel Pit - Lower**
Betula papyrifera	Paper birch	125	
Betula populifolia	Gray birch		703
Celastrus orbiculatus	**Oriental bittersweet**	375	
Comptonia peregrina	Sweet fern	250	
Comptonia peregrina	Sweet fern		108
Gaylussacia baccata	Huckleberry		108
Lonicera morrowii	**Morrow's honeysuckle**	5375	
Pinus strobus	White pine		27
Populus grandidentata	Large toothed aspen	125	
Populus grandidentata	Large toothed aspen		108
Populus tremuloides	Quaking aspen		1082
Rhus typhina	Staghorn sumack	3500	
Rubus spp.	Bramble	125	
Vaccinium angustifolium	Early low blueberry		27
	Unknown #2	125	
Total density of all species		10000	2165

Table 10. Quadrat sampling results for the gravel pit site. Non-native species are in boldface. The + symbol means the average percent cover is less than 1%.

Quadrat Results - Gravel Pit										
		Gravel Pit								
		Upper			Middle			Lower		
Species		**Density (#/m²)**	**Frequency (%)**	**Avg % cover**	**Density (#/m²)**	**Frequency (%)**	**Avg % cover**	**Density (#/m²)**	**Frequency (%)**	**Avg % cover**
Ambrosia spp.	Ragweed				0.6	5	+			
Andropogon scoparius	Little bluestem grass	16.3	100	23	28.0	95	40	4.3	90	9
Antennaria spp.	Pussytoes	1.6	30	1	2.8	40	1			
Aster spp.	Aster	0.1	10	+						
Betula populifolia	Gray birch							0.3	10	+
Bromus tectorum	**Downy chess grass**				1.2	5	1	2.5	55	1
Bryophyta	Moss			3		75	9			
Celastus orbiculatus	**Oriental bittersweet**	1.1	20	9						
Comptonia peregrina	Sweet fern	0.5	30	2	1.2	10	1			
Daucus carota	**Queen Anne's lace**	0.3	20	1	0.2	5	+			
Equistum spp.	Horsetail	0.2	20	1						
Eragrostis reptans	Purple lovegrass	0.2	10	+	1.0	5	2			
Gnaphalium obtusifolium	Sweet everlasting				0.4	5	+			
Juncus tenuis	Path rush				4.2	20	1	0.1	5	+
Lepidium virginicum	**Poor man's pepper**	0.1	10	+	0.2	5	+			
Lespedeza capitata	Round-headed bush clover	0.5	30	1	3.0	40	1	3.0	45	+
Lonicera morrowii	**Morrow's honeysuckle**	4.5	90	24						
Oenothera fruticosa	Sundrops				2.8	10	+	0.2	5	+
Oxalis europaea	Yellow wood sorel	3.6	20	1				0.1	5	+
Poaceae spp.	Grass							0.9	30	1
Polygonella articulata	Sand joint weed				1.4	15	+	0.7	25	+
Populus tremuloides	Quaing aspen							0.4	25	1
Potentilla canadensis	Dwarf cinquefoil	0.2	10	+	4.0	20	1			
Potentilla recta	**Rough-fruited cinquefoil**				0.2	5	+			
Rhus glabra	Smooth sumac	0.3	30	1						
Rubus spp	Bramble	0.7	30	2	0.2	5	+			
Solidago erecta	Erect goldenrod							0.5	5	+
Solidago gigantea	Late goldenrod	0.4	30	1						
Solidago nemoralis	Gray goldenrod	0.5	20	1				0.3	5	+
Solidago odora	Sweet goldenrod	0.3	20	1						

Solidago rugosa	Rough stemmed goldenrod	0.3	10	+						
Solidago speciosa	Showy goldenrod							0.4	20	+
Solidago tenuifolia	Slender goldenrod							0.2	5	+
Solidago ulmifolia	Elm-leaved goldenrod							1.1	40	+
Trifolium arvense	**Rabbit's foot clover**	0.8	10	3	9.6	50	6	1.8	15	2
Verbascum thapsus	**Common mullein**	0.4	20	1	0.2	5	+			
	UK #1 (Green rosette)							0.2	15	+
	Lichen						3			77
	Bare ground			8		95	14			

Table 11. Density of viable seeds in soil at the gravel pit site. Non-native species are in boldface.

Soil Sampling Results - Gravel Pit		
Species		**Density of seeds per soil sample (462 cm^3)**
Celastrus orbiculatus	**Oriental bittersweet**	1.04
Chaenorrhinum minus	**Dwarf snapdragon**	0.04
Digitaria sanguinalis	Crabgrass	0.16
Erigeron canadensis	Horseweed	0.92
Lamium amplexicaule	**Henbit**	1.20
Linum usitatissimun	**Common flax**	0.32
Lonicera morrowi	**Morrow's Honeysuckle**	0.40
Nepeta cataria	**Catnip**	0.80
Oxalis europaea	Yellow wood sorel	0.08
Panicum clandestinum	Deer-tounge grass	0.04
Poaceae	Grass	0.28
Rubus spp.	Bramble	0.08
Solidago rugosa	Rough-stemmed goldenrod	0.04
Toxicodendrum radicans	Poison ivy	0.04
Verbascaum thapsus	Common mullein	0.72
Verbena simplex	Narrow-leaved vervain	0.04
Verbena urticifolia	White vervain	0.04
	UK #1 (Leafy rosette)	0.12
	UK #2 (Dicot)	0.12
Number of invasive species		6
Total number of species		19

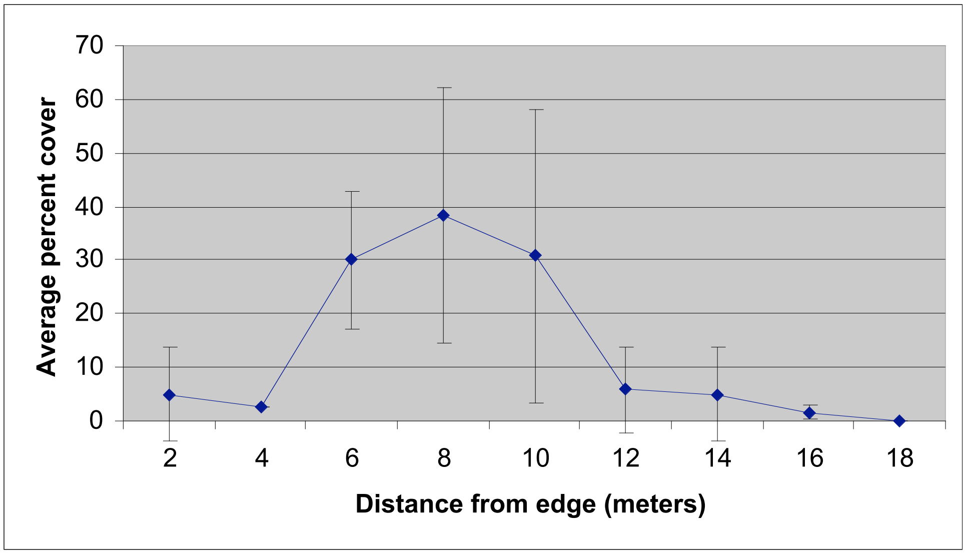

Figure 11. Average percent cover of bittersweet in the upper area of the gravel pit site based on line intersect sampling. Bars represent standard deviation.

Middle Area

Dominant species in this area include little blue stem grass (28.0/m^2) and moss. Abundant species include ragweed, pussytoes (2.8/m^2), round headed bush clover (3.0/m^2), sand joint weed, dwarf cinquefoil, and rabbit's foot clover (9.6/m^2) (See Tables 8 and 10). There are few invasive species in the majority of this area, except one large clump of autumn olive and two smaller clumps of multiflora rose, neither of which was sampled with the random quadrat sampling. The right edge of the meadow, however, contains a moderate amount of oriental bittersweet and honeysuckle seedlings creeping in from the forested edge.

Lower Area

This area is sparsely vegetated and is dominated by quaking aspen (.4/m^2) and gray birch (.3/m^2) in the shrub layer and little blue stem, downy chess, and round headed bush clover in the herbaceous layer (See Tables 8 and 10). The soil is covered by a thin layer of various lichen species (Average percent cover of 77% from the quadrat sampling). The area has a very distinctive feel when you are walking over it because you can hear the crunching under your feet with every step you take. This area also shows signs of erosion, as there are deep, eroded, parallel lines running downhill parallel to each other. In most of the erosion lines, mosses are growing, and many of the trees are also concentrated in these lines. The other dominant feature of this area is the multiple clumps of sweet fern. This area appears to be an important turtle nesting area, as it is adjacent to a lake and 18 predated turtle nests were found in an area approximately two acres in size. There are also many deer trails and tracks throughout the site.

Surrounding Forest

From observations, the canopy of the surrounding forest is mainly composed of white pine, white oak, red oak, red maple, gray birch, and shagbark hickory. The understory is composed of maple leaf viburnum, New York ferns, red maple, princess pine, low brush blueberry, American chestnut, and a few sassafras trees. Honeysuckle shrubs are dense along the beginning of the trail entering the woods, and become sparser as you walk further in. Multiflora rose is also thickest along the Osprey Point walking trail entering the woods.

5.4 Hero Property

This site contains mostly a mixture of beech and hemlock trees of varying ages with some scattered red and white oak and red maples. Red maples are more abundant in the lower wetland areas. After sampling 50 trees, it was found that 50% of them were hemlock, 30% were beech, 12% were oak, and 8% were maple. The forest has little understory as the canopy is well developed and the ground is relatively dark. No vegetative invasive species such as honeysuckle, bittersweet, or multiflora rose were found in the plot, but many of the hemlock trees are infested with the hemlock wooly adelgid disease.

The smallest measured hemlock tree in the stand had a DBH of 2 cm and the largest measured hemlock tree in the stand had a DBH of 92 cm. The average DBH of 53 trees measured was 24.8 cm. Out of the 53 beech trees measured, the smallest tree in the stand had a DBH of 5 cm and the largest tree in the stand had a DBH of 35.2. The average DBH of the beech trees was 16.0 cm. Figure 12 graphs the size distribution of hemlock and beech trees in the stand. In general, the beech trees are smaller in size than the hemlock trees. The majority of the beech trees (47%) have a DBH of 11-20 cm., with only 6% having a DBH of 31-40, and none having a DBH above 40. In contrast, although the majority of hemlock trees (34%) have a DBH between 0-10, the sizes are more evenly spread out and are larger than the beech trees. 24% of the hemlock trees are larger than 40 cm in diameter.

After sampling for hemlock woolly adelgid, a surprising number of trees at the site were infected. In general, the insect was mainly found only at the very tips of branches. Out of a total of 50 trees sampled for the adelgid, 72% were infected with hemlock woolly adelgid. Out of the 14 infected trees more closely sampled, the average severity of infection was 9.6 ovisacs per 100 needles. The average DBH of the infected trees was higher (35.8 cm) than the non-infected trees (19.1 cm).

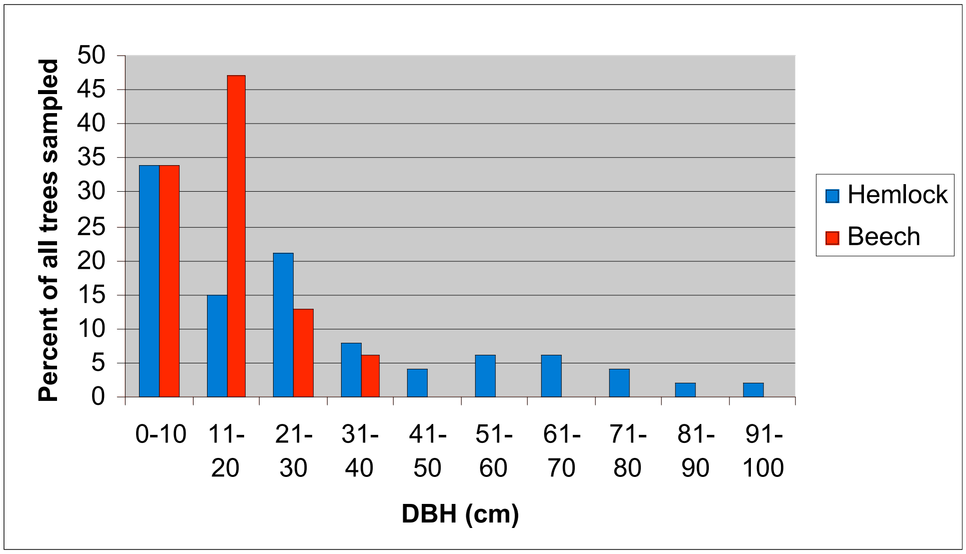

Figure 12. The size distribution for hemlock and beech trees sampled at the Hero Property. A total of 53 hemlock and 53 beech trees were sampled.

The ages of three hemlock trees were estimated using tree ring analysis. Between the trees, the average number of rings per cm ranged from 4-5, and the ages ranged from 86-159 years old (See Table 12). Using these data, the average age of the hemlock trees in the stand and the age of the largest hemlock tree in the stand were also estimated. The average number of rings per cm of the three sampled trees (4.65) was multiplied by the average radius of hemlock trees in the stand (12.4 cm) to obtain an average age estimate of 58 years. The radius of the largest tree in the stand (46 cm) was multiplied by 4.65 to obtain an estimated age of 214 years.

Table 12. Estimated ages of three hemlock trees at the Hero property.

Tree Ring Analysis - Estimated Ages of Hemlock Trees			
Tree	**DBH (cm)**	**Avg. rings/cm**	**Estimated age (years)**
1 (fallen)	42.8	4.00	86
2 (standing dead)	55.6	4.95	138
3 (standing dead)	63.5	5.00	159

Evidence of wildlife activity was also seen at this site. On March 24, 2007, at least three distinct deer tracks were seen in the soil at the site along with at least two distinct wild turkey tracks. In addition, there is one certified vernal pool at the site (and others pools that may be vernal pools but are not certified). Vernal pools are the home to many animal species such as spotted salamanders, wood frogs, and spring peepers.

CHAPTER 6

MANAGEMENT RECOMMENDATIONS

As stated before, the results reported above can be used in three ways: they can point out the need to manage a property in a certain way, they provide a valuable baseline set of data for future comparisons, and they offer a quantitative baseline for predicting what might happen to each site if no management is conducted. In this section, I describe the ecological importance of each of the four sites and present several different management options. The organization of each section is as follows:

I. Assessment of site
II. Ecological importance of the site
III. Current management of the site (if any)
IV. Previous ecological studies at the site (if any)
V. What will happen if nothing is done to the site?
VI. Management options
    a. The desired outcome and goals of management
    b. The means by which this management can be achieved
    c. A follow-up assessment of the success of the management effort

6.1 Gilmore Pond

6.1.a Assessment of Site

This site is heavily infested with honeysuckle – there are 1,448 plants per hectare in the study area. Honeysuckle was the dominant plant found during point quarter sampling, comprising 38% of all plants sampled. The areas near the trail circling the pond are most affected, however thick patches also occur further into the woods in some areas. Multiflora rose and Japanese barberry also occur at the site, but at a lesser density and frequency. No invasive species were found in Gilmore Pond, and no invasive species grew from soil samples taken at the site.

6.1.b Ecological Importance

This property is ecologically important for several reasons. First, Jackstraw Brook, which flows out of Gilmore Pond, is classified as an "Outstanding Resource Water," which is defined by the EPA as "a surface water of the Commonwealth so designated in the Massachusetts Surface Water Quality Standards." These waters constitute an outstanding resource as determined by their outstanding socioeconomic, recreational, ecological, and/or aesthetic values (Mass DEP, 2007). Jackstraw Brook flows into the cedar swamp in Westborough, which is classified as an "Area of Critical Environmental Concern (DCR, 2006)." These are places which receive special recognition because of the quality, uniqueness and significance of their natural and cultural resources. Native brook trout have been found in Jackstraw Brook before, and it was once a high quality cold water fishery. However, low flows and heavy inputs of sediments from upstream developments have degraded the habitat (Riverways Program, 2007). Thus, because of these designations and the stream's ecological importance, this stream and its surrounding upland habitat are important to protect from further environmental degradation.

Another ecological importance of this site is its use by forest wildlife species. Examples of species that use mixed deciduous forests in New England include the white tailed deer, wild turkeys, ruffed grouse, barred owl, black-capped chickadee, red-eyed vireo, ovenbird, pileated woodpecker, blue jay, little brown bat, tufted titmouse, snowshoe hare, gray squirrel, eastern chipmunk, raccoon, gray fox, red fox, coyotes, red-backed vole, red-spotted newt, and the gray tree frog (Wernert, 2004). During a visit to the site in September, an abundance of frogs were observed along the edge of the pond. This study did not determine the exact wildlife species that use this piece of land, however, which is one drawback. In addition to these wildlife benefits, this site is also important aesthetically because it serves as a popular walking and hiking trail for the residents of Westborough.

6.1.c Current Management

This site is not presently being managed, however, plans are being developed by Waterman Design Associates, Inc. and may be implemented within the year. The main goal of management is to remove the invasive species (mainly honeysuckle, with bittersweet and multiflora rose as encountered) to prevent them from overgrowing and killing the native species. A large area of honeysuckle to the north of the pond will be targeted, however, efforts will be undertaken around the entire perimeter of the pond. In addition, the plan states that some removal may take place on abutting properties with the permission of the abutting land owners.

The invasives will be removed mechanically with a brush hog along with smaller hand tools. A brush hog is a heavily built rotary mower that can attach to the back of a tractor. It has the ability to cut through thick shrubbery. After cutting, the stems will be treated with glyphosphate. Mechanical removal of honeysuckle will occur in late fall, while removal of bittersweet may begin earlier in the season by hand pruning. Following the removal and glyphosphate treatment, a seed mixture of native species will be planted in the disturbed areas to prevent the invasives from re-establishing. The exact seed mixture has not been picked out yet, but it will probably be a buffer zone seed mixture of New England wetland plants supplemented with arrowwood and dogwood. According to New England Wetland Plants, Inc., their wetland seed mix contains a "variety of native seeds that are suitable for most wetland restoration sites that are not permanently inundated. All species are best suited to moist disturbed ground as found in most wet meadows, scrub shrub, or forested wetland restoration areas" This mixture contains: Fox Sedge (*Carex vulpinoidea*), Bearded Sedge (*Carex comosa*), Lurid Sedge (*Carex lurida*), Soft Rush (*Juncus effusus*), Grass-leaved Goldenrod (*Euthamia graminifolia*), Boneset (*Eupatorium perfoliatum*), Hop Sedge (*Carex lupulina*), Blue Vervain (*Verbena hastata*), Nodding Sedge (*Carex gynandra*), Green Bulrush (*Scirpus atrovirens*), Sensitive Fern (*Onoclea sensibilis*), Blue Flag Iris (*Iris versicolor*), Woolgrass (*Scirpus cyperinus*), Spotted Joe Pye weed (*Eupatorium maculatum*), Swamp Milkweed (*Asclepias incarnata*), Monkey Flower (*Mimulus ringens*), Soft-Stem Bulrush (*Shoenoplectus tabernaemontani*) (ex- *S. validus*), Hardstem Bulrush (*Schoenoplectus acutus*) (ex- *Scirpus acutus*), Nodding Bur Marigold (*Bidens cernua*), and Flat-top Aster (*Aster umbellatus*). The mixture will likely be an overwintering seed mixture, which is spread out before first snow and begins to come up the following spring, but this has not been decided for certain yet (B. Waterman, personal communication, April 24, 2007).

6.1.d Previous ecological studies at the site

There have been no other ecological studies of the upland area surrounding Gilmore Pond, however, in 2005, Aquatic Control Technology, Inc. conducted a biological survey of Gilmore Pond. The purpose of this study was to document the water quality and vegetation distribution of the pond. The study found that the overall occurrence of aquatic vegetation in the pond was low and consisted mostly of coontail (*Ceratophyllum demersum*) and a small amount of aquatic moss. They did not find any non-native, invasive plants in the pond, however, they did find several plants of purple loosestrife near the concrete structure in the southeast area of the pond. Water quality sampling found elevated levels of nitrogen and phosphorous in the pond. These results back up my findings, as I also did not find any invasive species in the pond and found mostly coontail. I did not, however, find any purple loosestrife during my sampling.

Wesley Buckalew also studied the macroinvertebrates and water chemistry of Gilmore Pond for his senior honors project at Westborough High school.

6.1.e What will happen if nothing is done?

The land surrounding Gilmore pond is heavily invaded with invasive species, particularly honeysuckle, along with smaller amounts of multiflora rose and Japanese barberry. If no management is conducted at this site, the woody herbaceous invasive species will likely continue to spread in area and increase their density, displacing the native understory species. Once established in an area, honeysuckle can rapidly spread via seed production and/or asexual reproduction, and grow aggressively. Because of its dense growth and early leaf-out, it will continue to compete with native shrubs, and can also inhibit forest floor wildflowers. In addition to these changes, it has been shown that birds which nest in honeysuckle experience higher predation rates (Schmidt and Whelan, 1999). Lastly, the aesthetic value of the land may decrease if a monoculture of honeysuckle takes over.

6.1.f Management options

The goal of management at this site is to control the invasive species present. The current proposed management plan developed by Waterman Design Associates, Inc. is well designed and thought out. The plan calls for seasonal cutting of honeysuckle and bittersweet followed by treatment with glyphosate, which is a widely used and effective method for controlling woody invasive species. I agree that the main cutting should be done in the fall, because this is the ideal time of year to cut honeysuckle to minimize resprouting. Bittersweet can begin to be hand pulled earlier than fall, as it does not have the same resprouting ability as honeysuckle. When removing Oriental bittersweet, it is important to bag the vines if seeds are present to prevent their further spread. It is important that clipping or hand removal be performed every year, because when honeysuckle is cut and then abandoned, populations develop that are more dense and productive than before clipping (Luken and Mattimiro, 1990).

The plan does not call for a specific concentration of glyphosate, but I propose that a 25% solution be used on the cut stems since this was proven effective in controlling woody invasive species in forest interiors (Hartman and McCarthy, 2004). The herbicide should be applied in late fall, when the risk to surrounding vegetation is lowest. To minimize the risk of the herbicide to Gilmore Pond and the surrounding vegetation, it should only be applied to cut stems (by painting it on) rather than applied as a foliar spray.

Herbicide application methods are regulated by state and federal laws. Landowners can apply unrestricted herbicides on their own properties (unless it is within a wetland buffer zone), however, a pesticide applicator's license is required to apply pesticides on land owned by another person (Umass Pesticide Education Program, 2005). People who apply herbicide on these lands are required to obtain a Massachusetts applicators license and certification by the Massachusetts Pesticide Bureau within the Department of Food and Agriculture. According to Brad Mitchell, Director of Biosecurity and Regulatory Services for the Massachusetts Department of Agricultural Resources, at this time, members of a land trust still do need a license to apply herbicide to properties owned by the land trust. However, IPANE (Invasive Plants Atlas of New England) is currently discussing trying to change licensing laws by removing the need for liability insurance for land trusts, which would make it easier for them to manage their land.

The seed bank dynamics of a particular area are important to study because they are part of the natural flora, even if they are not readily visible. The seed bank is critical in maintaining floral diversity and its composition must be taken into account during the development of management plans (Roberts, 1981). Surprisingly, none of the major invasive species germinated from soil samples taken at this site. Some species, such as multiflora rose, do not germinate without a cold dormancy period, and thus would not be expected to germinate from the soil samples taken in the fall. Honeysuckle, however, does not need a dormancy period (Luken and Thieret, 1996), so its absence from the soil samples is surprising. Because the species is prevalent at the site, perhaps if more samples were taken from different areas it would have been found. Soil samples were taken from this site in autumn because of time constraints of this project, however, one drawback to this method is that samples taken at the end of winter sometimes yield more seedlings than samples taken in autumn (Raynal and Bazzaz, 1973). Thus, if soil samples were taken at the end of the winter, they may have yielded different results.

In terms of management, knowing whether a species has seeds which can persist in the seed bank is important because control programs that only kill the plants may stop the dispersal of new seeds, but this does not ensure that the dormant seeds already in the seed bank won't germinate (Ellsworth, Harrington, and Fownes, 2004). In general, persistent seeds have the ability to remain dormant in the soil or litter for more than a year (Leck, Parker, and Simpson, 1989). Neither honeysuckle nor bittersweet have seeds which remain persistent in the soil seed bank for more than 1-2 years (Luken and Mattimiro, 1991). Thus, because the seeds are not long lived in the soil, once the larger adult plants are controlled, the seed bank will not be a persistent source of new colonists. The seeds of multiflora rose, however, remain viable in the seed bank for up to 20 years, and can be a constant source of new seedlings in an area that has been previously cleared of adult plants. Management of this site should focus on eliminating the adult plants followed in subsequent years by monitoring and removing any seedlings sighted (Luen and Mattimiro, 1990).

I believe that planting a seed mixture in the areas that will be disturbed by mechanical removal of invasives is a good idea. It may help prevent new invasive seedlings from becoming established, and it will look pleasing aesthetically. The wetland seed mixture seems appropriate, but a good alternative to it might be the "New England erosion control/Restoration mix for detention basins and moist sites. This mix contains a selection of native grasses and wildlflowers designed to colonize moist, recently disturbed sites and is an excellent mixture for restorations on moist sites that require quick stabilization as well as long term establishment of native vegetation (New England Wetland Plants, Inc)". The mix contains: Switchgrass (*Panicum virgatum*), Virginia Wild Rye (*Elymus virginicus*), Creeping Red Fescue (*Festuca rubra*), Fox Sedge (*Carex vulpinoidea*), Creeping Bentgrass (*Agrostis stolonifera*), Soft Rush (*Juncus effusus*), New England Aster (*Aster novae-angliae*), Grass-leaved Goldenrod (*Euthamia graminifolia*), Nodding Bur Marigold (*Bidens cernua*), Green Bulrush (*Scirpus atrovirens*), Joe-Pye Weed (*Eupatorium maculatum*), Boneset (*Eupatorium perfoliatum*), and Blue Vervain (*Verbena hastata*).

Evaluation of the success of this management plan can be accomplished by carefully repeating the point-quarter sampling and DAFOR methods I performed at this site and comparing the results to my baseline data.

6.2 Meadow Site

6.2.a Assessment of Site

For the meadow site as a whole, honeysuckle and oriental bittersweet are the invasive species most prevalent. In the center of the field, honeysuckle grows mainly as stump sprouts from plants that had been cut and bittersweet mainly creeps from the forest edges, but on either side of the field, there are large honeysuckle shrubs and thick vines of bittersweet. Multiflora rose and autumn olive are also present at the site, but in more contained patches and at a lower density.

6.2.b Ecological Importance

Prior to European Settlement, although most areas were forested, there were scattered large grasslands throughout North America. When European settlers came to New England, they cleared vast areas of forest in the 1800's to provide land for agriculture. By the mid 1800's, 60-80% of the land in New England had been cleared by settlers for agricultural purposes (Mass Wildlife, 2005). These farms were soon abandoned because of their rocky soil and hilly landscape for more desirable farmland in the Midwest. Because of this large migration of farmers to the Midwest, many farms in New England were abandoned beginning in the late 1800's. Once the former farms became abandoned, they soon began to succeed into shrub and then woodland habitat. Today, grassland area has declined by more than 60% since the 1930's in New England and New York (Norment, 2002).

As the once open grasslands and fields began the succession process during the first 10-20 years, they provided excellent habitat for early successional species. Forest succession continued, though, and most areas gradually developed into young forests, providing optimal habitat for New England forest species such as ovenbirds, scarlet tangers, and banded hairstreak butterflies (Mass Wildlife, 2005). Today, most of Massachusetts's landscape is dominated by maturing forests along with residential and commercial developments, which are all taking a toll on the survival of early successional species.

Grassland habitats are imperative to protect because they provide essential breeding, feeding, and resting sites for a variety of wildlife, insect, and especially avian species. These openings are dominated by plants that thrive in full sunlight and contain grasses, herbaceous plants, wildflowers, and legumes (Mass Audubon, 2007). Many species of early-successional birds including the American goldfinch, upland sandpiper, vesper sparrow, grasshopper sparrow, savannah sparrow, eastern meadowlark, and the bobolink rely on grasslands for feeding and nesting purposes. This site may be too small for most of these species to nest in it, however, it is still important to protect because it can serve as a stop-over site for migrating birds, or as a feeding site for birds. Birds of prey, such as American kestrels, red-tailed hawks, and broad-winged hawks, also rely on these grasslands to hunt small mammals. In addition to providing habitat for bird species, grasslands provide habitat to many small mammals (meadow voles, meadow jumping mice, cottontail rabbits and chipmunks), larger mammals (white-tailed deer, red foxes, and turkeys), and butterflies (tiger swallowtails, monarchs, and fritillaries) (Mass Audubon, 2007).

Many of the species listed above are undergoing large declines across much of their historic ranges because of the loss of grassland habitat. Three early successional bird species, the upland sandpiper, vesper sparrow, and grasshopper sparrow, are classified as either endangered or threatened by MassWildlife and are currently undergoing major declines. The regal fritillary butterfly, once very common, is no longer believed to occur in Massachusetts. The New England cottontail rabbit, which is the only native cottontail species in Massachusetts, was also once common, but not it only occurs sporadically (MassWildlife, 2005).

Although grassland was not always common in New England, this fact should not be used as an argument against protecting this valuable habitat. The protection of early-successional habitats is critical as they are quickly becoming less common in the New

England Landscape. This type of early successional land continues to decline not only in the Northeast - habitat is also being lost in the Midwest because of development (Norment, 2002). Thus, this type of habitat may become rare and its protection is critical.

6.2.c Current Management

Currently, the WCLT is managing this site to preserve it as grassland habitat for small mammals and invertebrates. Besides these ecological motivators, they are also preserving the grassland for its scenic value as a contrast for hikers coming out of the woods on either end of the meadow. Brush piles were left along the edge of the meadow for habitat and because the trust did not want to carry the brush out with them or burn it on site. It is reported that the piles have decreased in volume over the past few years (M. Fox, personal communication, March 26, 2007).

The meadow was last cut in August with a DR brush mower. The land trust is considering building an entrance for a small tractor in the future to ease in mowing. This past fall, the tree stumps were cut and rocks were removed to make mowing easier. Invasive species have been periodically removed from the meadow for the past three years. The current management plan calls for yearly cutting in mid-to-late summer and the clearing of invasive species around the border of the meadow indefinitely (M. Fox, personal communication, March 26, 2007).

The current management plan is based on information Mark Fox (from the WCLT) obtained from a conference sponsored by the Trustees of the Reservations, a personal site walk with Jeff Collins from Mass Audubon, and literature from a conference session on managing grasslands (M. Fox, personal communication, March 26, 2007).

Massachusetts Fish and Wildlife own a piece of property in Westborough, Massachusetts similar to the meadow site named the "Westborough Wildlife Management Area." This 428 acre piece of property, although much larger, is comparable to the meadow site because parts of it are being managed for early successional habitat, specifically a mixture of shrub and grassland. The site is being managed through Massachusetts Fish and Wildlife's Upland Habitat Management Program. The entire property consists mostly of a mixed hardwood and conifer forest interspersed with agricultural and brushy fields. An 80 acre area of the site is being managed to maintain mostly an early successional shrub habitat. The main goal of management is to attract shrubland birds such as the willow flycatcher, common yellowthroat, and indigo bunting, which are experiencing documented long-term population declines (J. Liske-Clark – Upland Program Coordinator, MA Fish and Wildlife, personal communication, April 18, 2007).

To manage the early successional scrub shrub habitat, the area is mowed on a 5-6 year rotation in late summer. The year following mowing, herbicides are applied to control invasive species. The major invasive species at the site include multiflora rose, autumn olive, common buckthorn, exotic honeysuckles, and Asiatic bittersweet, along with less common invasive species such as brown knapweed (*Centaurea jacea*) and whitetop (*Lepidium draba*). Herbicide spraying occurs in late summer and is contracted out to licensed applicators. The application method is a foliar application and is applied using a motorized blowing backpack. The applicators grid out the entire mowed area and walk across it spraying the herbicide when they encounter any invasive species. Using a motorized backpack is considered a targeted application and is somewhat selective (J. Liske-Clark, personal communication, April 18, 2007).

To date, this management strategy has been very effective at eradicating invasive species. To monitor the effectiveness of the mowing and herbicide use, a vegetation survey is conducted every 2-3 years. This survey is not specific for invasive species, rather it is more general. MA Fish and Wildlife require a 95% control rate when they license out each job to a contractor, and so far, they have achieved this success rate at the Westborough Wildlife Management Area. Because there are so many seed sources for invasive species nearby, the managers realize that the major invasive species will never be completely eradicated from the site, but they are optimistic that the densities are currently going down (J. Liske-Clark, personal communication, April 18, 2007).

6.2.d. Previous Ecological Studies

There have been no previous ecological studies at this site.

6.2.e What will happen if nothing is done?

If nothing is done to manage this site and it remains undisturbed, it will quickly begin to revert into a field dominated by late season perennial herbs and shrubs (Norment, 2002). The abundant invasive species at the edges of the meadow, particularly honeysuckle and bittersweet, will continue to grow and creep into the central meadow, and the honeysuckle seedlings already growing in the central meadow will continue to grow. The field will likely become dominated by woody invasive species such as honeysuckle which could shade out the area and prevent the establishment of successional trees. These invasive species will likely begin to dominate, lowering the biodiversity of the habitat, because of their superior growth and reproduction capabilities. Because open-grown thickets of honeysuckle are more productive than forest-grown populations, it will likely grow and spread at a very fast rate (Luken and Thieret, 1996). The value of this habitat to early successional birds as well as small mammals and butterflies will likely decrease if this scenario occurs. In addition, the aesthetic value of this habitat as a field in the woods will decrease if it is allowed to become overgrown with shrubby invasive species.

6.2.f Management options

The goal of management at this site should be to: 1) maintain the early successional grassland so as to attract a diversity of birds, mammals, and insects, such as those listed above and 2) reduce the extent and abundance of invasive shrubs and vines. This site should just be managed as grassland, because it is too small of an area to also incorporate shrubland in. It is important to preserve grassland habitats because as explained above, a variety of species, some of which are declining in Massachusetts, depend on them for food and reproduction. As stated above, even if the site is too small for birds to nest in, it is still important to protect because it can provide a critical stop-over feeding habitat. In addition to this ecological goal, another goal should be to preserve the site for aesthetic and recreational purposes, as a walking trail enters the meadow from either side. This habitat provides a pleasant change in scenery for hikers walking on the wooded trail, and provides opportunities for the public to bird watch.

This site provides diversity at the landscape level because it is distinct from the surrounding wooded vegetation.

The current informal management plan for this site developed by the WCLT is a good start for management. Mowing the site is certainly necessary to prevent the establishment of invasive species and shrubs in the field, however the frequency and timing of mowing is critical. The current plan calls for mowing in mid-to-late summer, however, mowing in early and mid summer (June and July) is not advised because early cutting can destroy the ground nests and young of some species of birds. In particular, the young of savannah sparrows and eastern meadowlarks don't fledge until late July (Mass Audubon, 2007). In addition, it is not necessary to mow every year to attract grassland birds. Mowing less frequently, such as every 2 years, will allow for the development of late-blooming wildflowers and butterflies (Oenler, Covell, Capel, and Long, 2006). When mowing, blades should be raised to at least 6 inches off the ground in order to prevent nest destruction (Mass Audubon, 2007).

One concern of mine at this site is the piles of woody brush left along the edges of the field. Although they may provide some nest material for birds and habitat for small mammals, they also provide a habitat easily invaded by invasive species. The piles are densely overgrown, especially with bittersweet vines, which are creeping into the meadow. The piles should be removed so as to get rid of this easily invaded habitat. Because removing the piles during the nesting season may disrupt birds' nests, they should be removed during the fall.

The invasive species along the edge of the field (honeysuckle, bittersweet, and autumn olive) should also be managed. While the site does have a lot of invasive species, their populations are not out of control yet. Thus, it is advisable to control these species as soon as possible because it is best to control invasive plants when they are small and in their initial stages of invasion before they become unmanageable. The goal should be complete eradication while the plants are still easy to remove, however, this may not be attainable because birds will bring in new seeds from invasive species on nearby lands. Because the invasives are contained in a relatively small area at this site, they can be removed mechanically. Smaller plants can be removed using a Weed Wrench, which pulls the plant and roots out of the ground. The stems of larger plants may have to be cut using a chain saw. Because species such as honeysuckle vigorously resprout after cutting, painting the cut stems with a 50% solution of glyphosphate may be desirable to prevent re-establishment (Hartman and McCarthy, 2004). The best time of year to apply this treatment is during early fall so impacts to native plants and animals are minimized. When removing bittersweet, care should be taken to avoid spreading the seeds, which is accomplished by bagging the vines (PCA, 2006). The invasive species in the center of the meadow can be individually hand pulled, which is time-intensive, or they can be cut and brushed with herbicide as described above.

Although honeysuckle and bittersweet seeds do not remain viable in the seed bank for a long time, the seeds of multiflora rose can last up to 20 years (Amrine, 2002). Thus, it is important to continually monitor for new seedlings and remove them even after the main initial removal effort is conducted.

One last part of the management plan for this site should include control of the tree of heaven (*Ailanthus altissima*) spotted on the left side of the meadow. The tree of heaven is an invasive deciduous tree native to central China. The species rapidly grows up to 80 feet high, and has large compound leaves 1-4 feet in length which are composed of 11-25 smaller leaflets along the stems (PCA, 2006). The tree is a prolific seed producer, can form impenetrable thickets overrunning native vegetation, and produces toxins that prevent the establishment of other plants. It can reproduce either sexually through seeds or asexually through vegetative sprouts. One method of controlling this species is through girdling, in which a strip of bark 2 inches wide is cut away from the tree. The benefits of girdling are that it is inexpensive and only kills the targeted plant. However, because the tree can vigorously resprout, girdling can only be used on this species if it is accompanied by applying 100% triclopyr herbicide to the cut (Mass Audubon, 2007).

Evaluation of the success of this management plan can be accomplished in two ways. To evaluate the goal of eradicating invasive species, the methods I performed at this site can be carefully repeated and compared to the results of my baseline data. Methods I conducted at this site include the DAFOR scale and quadrat sampling. To evaluate the goal of promoting the habitat for animals, wildlife surveys can be conducted. The presence of larger mammals at the site can be detected by using a game camera, and the presence of birds at the site can be monitored by conducting yearly bird surveys.

6.3 Gravel Pit

6.3.a Assessment of Site

The upper area of this site is dominated by honeysuckle with a density of 5,375 plants/hectare and Oriental bittersweet with a density of 375 plants/hectare. The bittersweet is growing over the honeysuckle, making an impenetrable thicket in places.

In addition, both honeysuckle and Oriental bittersweet seedlings germinated from soil samples taken in this area. Honeysuckle germinated at a rate of 1.04 plants/m^2 while Oriental bittersweet germinated at a higher rate of 2.7 plants/m^2. There are few invasive species in the majority of the middle area, except one large clump of autumn olive and two smaller clumps of multiflora rose, neither of which was sampled with the random quadrat sampling. The right edge of the meadow, however, contains a moderate amount of oriental bittersweet and honeysuckle seedlings creeping in from the forested edge. The lower area does not have a large invasive species problem at the present time.

6.3.b Ecological Importance

This site is ecologically important for four reasons: it lays in a zone 2 Aquifer Protection Area, it is unique from the surrounding forested area, it is a breeding site for snapping and painted turtles, and it is a recreation area for the residents of Westborough.

First, this site lays in a Zone 2 Aquifer Protection Area (Town of Westborough, 2003), which is defined as the land around a well where protection activities should be focused. Each well has a zone 1 protective radius and a zone 2 protection area. Zone 1 is the area closest to the well and consists of a 100-400 foot radius proportional to the well's pumping rate. Zone 2 is the primary recharge area for the aquifer and its radius varies (Massachusetts Department of Environmental Protection, 2002). These areas are important to focus on because they protect the quality of the water pumped from the well.

Second, this site is unique from the forested area that composes the rest of the property and it supports many species that would be unable to grow in a forested area. This added diversity of plant species is desirable. There are three different types of diversity – alpha, beta, and gamma. Alpha diversity is the diversity within a particular area, and is measured by counting the number of taxa within the community. Beta diversity compares the diversity between different ecosystems or along gradients, and is measured by comparing the number of taxa that are unique to each of the ecosystems. Gamma diversity is the total diversity across a large region composed of different habitat types. From a larger perspective, it is important to have gamma diversity across a large region, and preserving the gravel pit in an early successional state would help accomplish this.

Third, because 18 predated turtle nests were found at this site, it is an important nesting site for turtles. After describing the site and showing the eggs found to herpetologist Dr. Peter Auger, he believed that two species of turtle, the snapping turtle (*Chelydra serpentina*) and the painted turtle (*Chrysemys picata*) likely use the site for nesting. Both of these turtles are common in Massachusetts and use sandy, elevated, and well drained soils as nesting sites (P. Auger, personal communication, April 24, 2007).

The snapping turtle is a large freshwater turtle with a range including most of the central and eastern United States. It prefers slow-moving water and areas with a soft mud bottom and abundant aquatic vegetation. It has a 3 week nesting period between May 15 and June 15, where the females dig out a nest and lay eggs to a depth of 7-18 cm (Ernst, Lovich, and Barbour, 1994). The females sometimes travel long distances (more than 1 kilometer) over land and water to find a nest site. The snapping turtle has temperature dependent sex determination, i.e., the incubation temperature of the eggs during development triggers the gonadal development leading to the sex of the hatchling. In this species, males are produced at high and low temperatures and females are produced at intermediate temperatures (29-31 degrees Celsius). The hatchlings emerge from the nests in mid August to early October (Ernst, Lovich, and Barbour, 1994).

The painted turtle is a small turtle with red markings on its shell. It has a large range across the North American continent and is common throughout the eastern United States. It nests from late May until mid July and hatches in August. It also has temperature dependent sex determination, except that in this species, cooler temperatures (22-27 degrees Celsius) produce mostly males and warmer temperatures (30-32 degrees Celsius) produce mostly females. The females do not pick a particular nest site to influence the sex ratio of their clutch, rather, they select a nest site that maximizes the probability that their eggs will be able to successfully complete development and hatch (Ernst, Lovich, and Barbour, 1994).

This site is important to protect because edge habitats in wetland areas are under pressure and are declining across Massachusetts. Turtles such as the snapping and painted turtles depend upon these sites as nesting habitats. Even though both of these species are not currently on the endangered species list in Massachusetts, it is still important to protect their nesting areas because they could become endangered in the future if nesting sites are not preserved. Under natural conditions, such as conditions that would result from a fire for example, there would be a variety of successional stages present. However, because humans rapidly put out any fires that start, areas with early successional stages are becoming increasingly rare to find (P. Auger, personal communication, April 24, 2007). Thus, there is a current need to re-establish these "natural conditions" in protected areas.

Another important feature of this site is the layer of cryptogamic crust that is present over much of the soil in the middle and lower areas. Cryptogamic, or biological, soil crusts are formed by a combination of lichens, bryophytes (mosses and liverworts), cyanobacteria, green algae and fungi, and the uppermost layer of the soil (Leys and Eldridge, 1998). These crusts are important to the soil surface because they provide protection against wind and water erosion. The crusts have been shown to be able to reduce soil erosion by binding sand particles together, providing a habitat for soil invertebrates, improving water penetration and retention, and are useful indicators of environmental health (Leys and Eldridge, 1998 and Lesica and Shelly, 1992). In habitats with a cryptogamic crust, the soil particles are physically stabilized by the action of cyanobacteria and other crust organisms. These organisms bind together small soil particles into larger ones either through the process of entangling their filaments together or adhering the soil particles to their filaments by excreting a mucilaginous sheath (Eldridge and Leys, 2003). The importance of crusts should not be underestimated, because when crusts are destroyed (such as by trampling, grazing, or fire), results include surface instability, reduced infiltration, and the unfavorable conditions for the germination of plants (Leys and Eldridge, 1998). These crusts are critical at this site because they stabilize the soil and keep the hillside from washing away into the reservoir.

Soils generally possess soil horizons, or distinctive horizontal layers, that differ in physical composition, chemical composition, or organic content. The gravel site lacks the rich, organic upper layers of the soil horizon because it was once mostly bare rock and is now in an early successional state. The succession at this site can be described as primary succession, because the succession occurs on substrates without previous plant cover or developed soil layers (Sven-Olov, 1990). This is in contrast to secondary succession, where a developed soil layer is already present. The substrate at primary succession sites is often deficient in nutrients and water, and thus for plants to establish, access to nitrogen is critical (Sven-Olov, 1990).

At the gravel pit site, the cryptogamic crust is critical to help develop the upper soil horizons that are lacking because it has the ability to fix atmospheric nitrogen. Because of the crust's ability to fix nitrogen, it makes the soil more available for plants to grow on. During succession in gravel pits, the accumulation of organic matter from plants growing and eventually decomposing leads to an increase in nitrogen content, water holding capacity, in addition to helping develop the upper organic layers of the soil profile. Developing the upper organic layers of the soil profile is important to support the growth of larger shrubs and eventually trees (Sven-Olov, 1990).

At the gravel pit site, the most common tree growing in the lower area is aspen. Aspen, a common tree in North America, commonly exists as an early successional species because it can reproduce both sexually and asexually. To reproduce asexually, its stems send out lateral roots that can send up other erect stems. The collection of stems forms a single genetically identical individual called a clone (Mitton and Grant, 1996).

6.3.c Current Management

The Westborough Community Land Trust has a stewardship agreement with the town for this site. In addition, a trail runs through the site and is maintained by WCLT.

6.3.d Previous ecological studies at the site

In 2002, Applied Ecological Services conducted a Breeding Bird Survey at the Headwaters Conservation Area (HCA). On June 13, 2002, they gathered baseline documentation of birds present at the HCA in addition to collecting information about the natural communities at the site. One of their stations was in the gravel pit, and between the hours of dawn and 8:30 a.m., they observed 14 bird species at the site: Canada goose, mallard, mourning dove, red-eyed vireo, blue jay, American crow, black-capped chickadee, gray catbird, brown thrasher, eastern towhee, northern cardinal, red-winged blackbird, common grackle, and American goldfinch.

A previous study by the New England Wildflower Society in 1992 inventoried the plant communities throughout the HCA property. The study found that the majority of the property is composed of a dry woodland community. This community occupies much of the central and southern portions of the property. The community is very homogeneous and there is not a high diversity of plant species in any layer (tree, shrub, or herbaceous layer). The species that defines the community type is huckleberry (*Gaylussacia baccata*), which is found throughout the herbaceous and shrub layers. Huckleberry grows well in thin, well drained soils, which is the case over much of the property since it gently slopes downward towards the reservoir. The forest community is also dominated by oak and pine in the canopy, with portions of pure pine trees throughout. The survey did not find any endangered or threatened species on the property or any outstanding natural communities. They wrote that the lack of rare species or outstanding natural communities does not lessen the value of the property and that it is well suited as an educational and recreational resource for the local community.

The study also points out the problem of invasive species on the property, particularly in the gravel pit area. In my own observations, I noticed as well that the invasive species are spreading into the surrounding woodland and even further into the woods along the trail. They predict that without action, honeysuckle and bittersweet have the potential to become dominant species throughout the property. Action should be taken before the problem gets worse and while the invasives are mainly contained in one area. They also point out the value in keeping the gravel pit area in an early successional stage, both for the water view of the reservoir as you enter the property and because it adds to the overall diversity of the HCA property by supporting a number of species that are not found elsewhere at the site (such ad the bird's foot violet, *Viola pedata*).

In addition, the study noted that the property also supports a variety of wildlife. They observed actual individuals or evidence of raccoons, deer, coyote, turtles, hawks, osprey, heron, owls, gray squirrels, chipmunks, fox, salamanders, newts, frogs, toads, and a variety of songbirds.

6.3.e What will happen if nothing is done?

Gravel pit succession

If nothing is done at this site, succession will continue in the gravel pit. Olov-Sven (1990) studied 68 abandoned gravel pits and their surroundings and found that the surrounding vegetation type strongly affects pit vegetation, and old pits show more resemblance to the surrounding vegetation than younger pits. However, he adds that because exploitation has changed the environment of the pits, it cannot be expected that the vegetation in the pits will become exactly identical to the vegetation in the surrounding forest. As the pit succeeds, species number may increase in some areas, because species number in pits are much lower than those in the surrounding vegetation generally (Olov-Sven, 1990). Bare areas in the pit may remain even 100 years after abandonment (Olov-Sven, 1990). A study done by Klara and Karel (2006) found that generally in sand and gravel pits, open dry grasslands are present during early stages of succession (4-10 years after abandonment), perennial grasses and forbs show up during middle stages of succession (11-25 years after abandonment), and in late successional stages (25+ years after abandonment), trees and shrubs become dominant and grasslands decrease.

Predicted changes in vegetation

In the upper area of the gravel pit, honeysuckle and bittersweet are already well established, and will probably continue to spread into the forest and surrounding areas if nothing is done. In this area, the honeysuckle and bittersweet will likely decrease the species richness, and it could even turn into a honeysuckle and bittersweet monoculture.

The middle area currently is grassland, but if nothing is done at the site, it will continue to succeed and will eventually develop shrubs and trees. Another possibility is that the honeysuckle will spread from the upper area into the middle area and the middle area could become a honeysuckle monoculture. Later successional species, like trees, cannot become established under a thicket of honeysuckle very well because they become shaded out. After surveying 93 forest stands in Ohio, Hutchinson and Vankat (1977) found that honeysuckle cover was inversely correlated with the density and species richness of tree seedlings and with the cover of herbs. Gorchov and Trisel (2003) found that removing honeysuckle shoots increased native tree seedling's survival.

The lower area is currently mostly bare except for a few shrubs and trees. If nothing is done, grasses, shrubs, and trees will continue to establish in this area. The establishment of a denser canopy layer may make the area unsuitable for turtles to nest, as more shaded areas could change the sex ratio of turtle hatchings.

6.3.f Management options

The gravel pit area at HCA should be kept in its present early successional state, especially as lands around it are becoming increasingly developed. In addition, there are not other areas around the reservoir that are protected and in a similar stage of succession. There are benefits to keeping the area at its current state as an early successional area. First, the site is used by a variety of wildlife and bird species as described in the past ecological studies section above. The site is also frequented by walkers and hikers, and currently there is a great view of the reservoir from the trail between the upper and middle areas of the gravel pit.

Upper area

The invasive species in the upper area of this site should be removed because they are a threat to the surrounding areas of the gravel pit and woodlands. Honeysuckle and bittersweet may spread and become dominant in the forest and other areas of the site, threatening to prevent the establishment of native vegetation and reduce species diversity.

As described above, this site is in a Zone 2 Aquifer Protection Area. While herbicide use in a Zone 2 Aquifer Protection Area is not banned outright, it should be avoided because of the potential to contaminate the aquifer. Thus, control of invasive species at this site should be purely mechanical. Because the invasives form a large thicket in the upper area, the initial removal effort should be performed by a brush hog or similar mowing machine. Some of the bushes may have to be cut down manually if they are too large for the brush hog. If possible, the roots should also be removed to prevent re-sprouting. If the roots cannot be easily removed, the area should be mowed twice a year to control the honeysuckle and bittersweet. While repeated mowing has been shown to help control honeysuckle, it is more effective in shaded than open areas (Hartman and McCarthy, 2004). Thus, hand-pulling of plants in between mowing treatments may be necessary to help control the species.

Both honeysuckle and Oriental bittersweet germinated from soil samples taken in this area. However, if the large adult plants are removed, it will eliminate the source of seeds into the seed bank. Because both honeysuckle and oriental bittersweet seeds are not long-lived in the soil, once adult plants are controlled, the seed bank will not continue to be a source of new colonists (Luken and Mattimiro, 1991). On the other hand, because existing trees serve as a perch site for birds which might disperse seeds into the area from other areas outside of the gravel pit, it is possible that invasive seeds will still enter the seed bank. Thus, it is critical that yearly hand-pulling is conducted to keep up with any new seedlings that grow.

Middle area

Invasive species should also be removed from the middle area of this site. Presently, they are only present along the edges of the meadow, and so hand-pulling efforts should be conducted to control the invasives before they get out of control and become a larger problem. I believe that the middle area should be maintained as an open grassland because of the benefits of grassland areas to birds and mammals described in the above meadow site section. 14 species of songbirds were found at this site during a breeding bird survey, and they likely utilize the grassland for cover and feeding purposes. There are currently no trees or shrubs growing in the majority of the area, but if succession is allowed to continue, they may start to establish. Thus, yearly monitoring should be conducted at the site to determine if tree or shrub species are becoming established in the middle area. Such species should be removed if they are detected.

Lower area

The lower area should be kept in an early successional state also. This area should be preserved in its current state, as it is currently a nesting site for turtles. Selected trees that begin to invade the lower area should be cut back. I propose to maintain the level of trees currently existing in this area, since this level is functioning as a good nesting site for turtles presently. While the main purpose of the tree pruning is for the turtles, a secondary benefit is that it keeps the aesthetically pleasing view of the reservoir open from the hiking trail. The area should be sampled every 3-4 years to determine the density of trees and shrubs at the site. This data can be compared to the baseline density data that I gathered from point-quarter sampling in this report. In the lower area, I found a total of 4 tree species at the following densities (See Table 9): quaking aspen – 1,082/ha; gray birch – 703/ha; large toothed aspen – 108/ha; white pine – 27/ha. After sampling is completed, the numbers should be compared to determine how many trees should be cut down. All of the trees should not be cut down because sparse trees increase the habitat heterogeneity, which increases the health of the ecosystem overall (P. Auger, personal communication, April 24, 2007). The trees should be cut down manually with a hand saw (equipment such as large trucks or chippers should not be brought in). While as large of an area as possible should be preserved to allow for variation in the thermal regime, the current size of the lower area is adequate to protect the site for nesting turtles, and this size should be maintained (P. Auger, personal communication, April 24, 2007).

As described above, the cryptogamic crust is important to maintain at this site because it provides a variety of benefits to early successional areas. In general, these crusts maintain themselves and it does not need a specific management regime at this site to remain functional (P. Auger, personal communication, April 24, 2007). However, the crust will become damaged if it is overly trampled by humans or machines, and so it is important to reduce trampling of the crust as much as possible during sampling and tree removal events (Eldridge and Leys, 2003). One possible way to reduce human trampling of the crust is to utilize the information kiosk located on the hiking trail between the upper and middle areas. A short note about the importance of the crusts can be written in a brochure about the site, and it can ask that people stick to the designated trails so they do not harm the crust.

Evaluation of the success of this management plan can be accomplished in the following way: For the upper area, quadrat sampling can be repeated as described in the methods section to determine if the density of honeysuckle and Oriental bittersweet is kept low. Quadrat sampling can also be conducted in the middle area to detect the presence of any invasive species. For the lower area, point quarter sampling should be conducted every 3-4 years to determine the current density of trees and shrubs present.

<u>6.4 Hero Property</u>

6.4.a Assessment of site

Seventy-two percent of hemlock trees at this site are infected with hemlock woolly adelgid. The average severity of infection is 9.6 ovisacs (white fuzzy egg masses) per 100 needles. In a study of 15 forest stands throughout Connecticut and Massachusetts, the average infestation of hemlock trees with HWA was similar to what was found in this study (Evans, 2005). Unlike the other three sites studied, invasive plant species are not an issue at the Hero property.

6.4.b Ecological Importance

Hemlock has been present and abundant for more than 8,000 years in New England (Foster, 2000). Hemlock is an ecologically important late-successional species and provides habitat for many species of wildlife which depend on the tree's dense canopy layer for shelter, food, and breeding sites. The species is also associated with riparian areas and plays an important role in preventing erosion along river and stream banks and maintaining cool water temperatures. In these habitats the tree is a very important shelter to wildlife as it can moderate temperatures in both the colder winter and warmer summer (USDA Forest Service). Hemlocks are also important aesthetically and are valued in recreational areas (USDA Forest Service).

6.4.c Current Management

There are no current management plans at this site.

6.4.d Previous ecological studies at the site

There have been no previous ecological studies at this site.

6.4.e What will happen if nothing is done?

If nothing is done at this site, hemlock health will dramatically decline, and the hemlocks will begin dying from HWA infestation. The remaining unaffected trees in the stand will likely become infected with HWA because of their close proximity to infected trees. All size classes of hemlock trees can become infected with HWA, so it is unlikely that many trees will remain unaffected. HWA is currently widespread across the Northeastern United States and is continuing to spread. So far, no infected forest has shown any sign of recovery.

The major consequence of HWA is that widespread hemlock die-back will greatly change the structure and composition of the forest habitat, which can alter the use of this site as wildlife habitat (Foster, 2000). Once hemlock trees are gone from a stand, other species will eventually replace them. Because hemlock forests provide a lot of shade and prevent species which are not shade-tolerant from growing in the understory, if this hemlock canopy is lost, more sun will be let in which will allow a different set of species to grow. Studies in the literature predict that opportunistic herbaceous species as well as black birch, red maple, and oak will recolonize New England following hemlock dieback. Orwig and Foster (1998) state that in stands where hemlock trees have died, black birch, red oak, and red maple are present in the overstory and are beginning to also become established in the understory. They found that the seed bank does still contain a high level of hemlock seedlings, but once they germinate, they are quickly infested with HWA, and the hemlock seeds do not remain viable for more than 2 years. Thus, they predict that HWA will eventually cause a shift from a hemlock-dominated habitat to hardwood-dominated forests across a wide area.

If hemlocks begin to die in the Hero property, I predict that beech trees will begin to dominate the canopy level. I sampled hemlock and beech trees to determine their size distributions because they are the two dominant tree species at the site (See Figure 12). In general, a high percentage of beech trees are small, and if more sunlight hits the stand because of hemlock death, I predict these beech trees would likely grow larger.

The hemlock decline will also impact the nearby wetlands. Hemlock is an important riparian species and is commonly found around wooded swamps such as are found at the Hero property. A decline in the abundance of hemlock trees can dramatically alter the physical, chemical, and biological conditions in these wetlands (Colburn and Orwig, 2003). In general, wetlands in watersheds dominated by hemlocks have higher levels of dissolved organic carbon and lower levels of dissolved nutrients than wetlands in watersheds dominated by hardwoods. In addition, wetlands associated with hemlock forests have low year round evapotranspiration because they are more shaded and they generally have stable hydrology regimes. Wetlands associated with deciduous forests have higher evapotransiration rates, and a higher hydrologic variability (Ellison et al., 2005). This change can reorganize food webs in these wetlands (Colburn and Orwig, 2003).

Vernal pools might also be impacted by a hemlock decline. A certified vernal pool exists in the middle of my study site at this property, and other vernal pools are located at the peripheries of the swamp and are similarly surrounded by hemlocks. Vernal pools found in hemlock forests have lower light levels and temperatures than pools in open areas or pools found in forests with deciduous trees (Colburn, 2004). Changes in a pool's hydrology or temperature can affect the species composition living in the pool. A pool's flooding regime can also be altered from hemlock decline because sunlight can increase evapotranspiration rates in a pool. If the flooding regime of a pool is altered, it can change the timing of the life cycles of vernal pool animals and insects (Colburn, 2004).

6.4.f Management options

In general, there are no practical means currently available for managing HWA in forested environments as the tools that are available are limited and inadequate. First, there are no natural enemies in North America to keep its population in check, and second, only trees that are readily accessible can be managed for the insect. Trees can be sprayed with a horticultural oil, however, this product is difficult to spray on tall trees and in forested areas. One management option is possible, but it would likely be time consuming and expensive. Pesticides can be injected into shallow holes drilled into each tree's root base via pressurized plastic capsules. The insecticide moves up into the tree where it is fed upon by the adelgids. The technique works best when applied in mid-May, and needs to be reapplied every 6 months (McClure, 1998). However, this method is only useful in trees that have been recently affected, which may rule out the majority of trees at the Hero Property. The best hope for forested environments infected with HWA is biocontrol by the coccinellid beetle, however this treatment is still being researched.

Conclusion

The sound management of properties with invasive species can be a daunting and costly task. Effective control and prevention of invasives first requires the development of a long term management plan. Research into the biology of the invasives present, the site characteristics, the desired goals of management, and the effectiveness of control strategies are all necessary before a management plan can be drafted. After a management plan is drafted, it is also very important to develop a plan for appropriate follow up studies to access the success of the management effort. Although managing invasives can be difficult, if done correctly with sound principles of management in mind, the payoff can be huge.

The results of this study will be presented to the Westborough Community Land Trust and the Westborough Conservation Commission to guide their management of these four sites in the future.

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REFERENCES

Applied Ecological Sciences (2002). *Breeding Bird Survey of the Headwaters Conservation Area, Westborough, Massachusetts.*

Amrine, J.W. Jr. (2002). Multiflora rose. In Van Driesche, R., *Biological control of invasive plants in the Eastern United States*, USDA Forest Service Publication FHTET-2002-04. Retrieved March 28, 2007 from: http://www.invasive.org/eastern/biocontrol/22MultifloraRose.html.

Aquatic Control Technology, Inc. (2005). *Report on the baseline biological survey of Gilmore Pond, Westborough, MA.*

Bauman, D. (1999). Mehrhoff tackes invasive alien plants. UCONN Advance. Retrieved April 25, 2007, from: http://advance.uconn.edu.

Bonham, C.D. (1989). *Measurements for Terrestrial Vegetation*. New York: John Wiley & Sons.

Blossey, B., Skinner, L.C., and Taylor, J. (2001). Impact and management of purple loosestrife (*Lythrum salicaria*) in North America. *Biodiversity and Conservation,* 10: 1787-1807.

Bryan, W.B. (1994). Mechanical control of the Multiflora rose. Retrieved March 28, 2007 from: http://www.caf.edu.

Bryan, W.B. and Milles, T.A. (1988). Effect of frequency and method of defoliation and plant size on survival of multiflora rose. *Biological Agriculture and Horticulture,* 5: 209-214.

Collier, M.H., Vankat, J.L., and Hughes, M.H. (2002). Diminished plant richness and abundance below *Lonicera maackii*, an invasive shrub. *The American Midland Naturalist,* 147(1), 60-71.

Carlton, J.T. (2001). Introduced species in U.S. coastal waters: Environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia.

Colburn, E.A. (2004). *Vernal Pools: Natural history and conservation*. Blacksburg, Virginia: The McDonald & Woodward Publishing Company.

Costa, S.D. (2002). Sampling for detection and monitoring of Hemlock Woolly Adelgid within Hemlock stands. In: *Proceedings of the Third Symposium on Hemlock Wooly Adelgid in the Eastern United States.* Asheville, NC: Forest Health Technology Enterprise Team, USDA, and US Forest Service.

Daubenmire, R.F. (1959). Canopy coverage method of vegetation analysis. *Northwest Science,* 33: 43-64.

D'Antonio, C. and Meyerson, L.A. (2002). Exotic plant species as problems and solutions in ecological restoration: A synthesis. *Restoration Ecology,* 10(4): 703-713.

DCR (2006). DCR Areas of Critical Environmental Concern (ACEC) Viewer. Retrieved May 2, 2007, from: http://maps.massgis.state.ma.us/acecs/pages/main.jsp.

Deering, R.H. and Vankat, J.L. (1999). Forest colonization and developmental growth of the invasive shrub *Lonicera maackkii*. *The American Midland Naturalist,* 141(1), 43-50.

Derrickson, K. C. and Breitwisch, R. (1992). Northern Mockingbird. *In* The Birds of North America, No. 7 (A. Poole, P. Stettenheim, and F. Gill, Eds.). Philadelphia: The Academy of Natural Sciences; Washington, DC.: The American Ornithologists' Union.

Doll, J.D. Biology of Multiflora rose. (2006). *Proceedings of North Central Weed Science Society,* 61:239.

Dreyer, G.D., Baird, L.M., and Fickler, C. (1987). *Celastrus scandens* and *Celastrus orbiculatus*: Comparisons of Reproductive Potential between a Native and an Introduced Woody Vine. *Bulletin of the Torrey Botanical Club,* 114(3): 260-264.

Eldridge, D.J. and Leys, J.F. (2003). Exploring some relationships between biological soil crusts, soil aggregation and wind erosion. *Journal of Arid Environments,* 53: 457-466.

Ellison, A.M., Bank, M.S., Clinton, B.D., Colburn, E.A., Elliot, K., Ford, C.R. et al. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment,* 3(9): 479-486.

Ellsworth, J.W., Harrington, R.A., and Fownes, J.H. (2004). Survival, growth and gas exchange of *Celastrus orbiculatus* seedlings in sun and shade. *American Midland Naturalist,* 151: 233-240.

Ellsworth, J.W., Harrington, R.A., and Fownes, J.H. (2003). Seedling emergence, growth, and allocation of Oriental bittersweet: effects of seed input, seed bank, and forest floor litter. *Forest Ecology and Management,* 190: 255-264.

Ernst, C.H., Lovich, J.E., and Barbour, R.W. (1994). *Turtles of the United States and Canada*. Washington, D.C.: Smithsonian Institution Press.

Evans, A. (2005). A randomized branch sampling method for Hemlock Woolly Adelgid. In: *Proceedings of the Third Symposium on Hemlock Wooly Adelgid in the Eastern United States.* Asheville, NC: Forest Health Technology Enterprise Team, USDA, and US Forest Service.

Evans, J.E. (1983). A literature review of management practices for multiflora rose (*Rosa multiflora*). *Natural Areas Journal,* 3:6-15.

Foster, D.R. (2000). Hemlock's future in the context of its history: An ecological perspective. In: Sustainable management of hemlock ecosystems in Eastern North America. USDA GRT-NE, Symposium Proceedings.

Fritts, H.C., Shashkin, A., and Downes, G.M. (1999). A simulation model of conifer ring growth and cell structure. In R. Wimmer and R.E. Vetter (Eds.), *Tree-Ring Analysis* (pp. 3-32). Cambridge, England: CABI Publishing.

Gorchov, D.L. and Trisel, D.E. (2003). Competitive effects of the invasive shrub, *Lonicera maacii* (Rupr.) Herder (Caprifoliacae), on the growth and survival of native tree seedlings. *Plant Ecology,* 166(1), 13-24.

Gould, A.M. and Gorchov, D.L. (2000). Effects of the exotic invasive shrub *Lonicera maacii* on the survival and fecundity of three species of native annuals. *The American Midland Naturalist,* 144(1), 36-50.

Hartman, K.M. and McCarthy B.C. (2004). Restoration of a forest understory after the removal of an invasive shrub, Amur honeysuckle (*Lonicera maackii). Restoration Ecology,* 12(2), 154-165.

Hartzler, R.G. and Owen, M.D.K. (1992). Multiflora rose and its control. Retrieved March 28, 2007 from: http://www.extension.iastate.edu.

Hutchinson, T.F. and Vankat, J.L. (1997). Invasibility and effects of Amur honeysuckle in southwestern Ohio forests. *Conservation Biology*, 11(5), 1117-1124.

Ingold, J.I. and Craycraft, M.J. (1983). Avian frugivory on honeysuckle (*Lonicera*) in southwestern Ohio in fall. *Ohio Journal of Science,* 83(5), 256-258.

Invasive Plant Species Assessment Working Group (IPSAWG). (2005).*Oriental Bittersweet Fact Sheet*. Retrieved March 28, 2007 from: www.invasivespecies.IN.gov.

Klara, R. and Karel, P. (2006). Spontaneous vegetation succession in disused gravel-sand pits: Role of local site and landscape factors. *Journal of Vegetation Science,* 17: 583-590.

Kricher, J. *Vegetative Analysis: Plotless Sampling Techniques*. Laboratory Handout.

Leck, M.A., Parker, V.T., and Simpson, R.L.

Leicht, S.A. and Silander, J.A. Jr. (2006). Differential responses of invasive *Celastrus orbiculatus* (Celastraceae) and native *C. scandens* to changes in light quality. *American Journal of Botany,* 93(7): 972-977.

Lenox, A.T. (2001). Fact sheet – invasive insects: Hemlock woolly adelgid. The Pennsylvania State University, University Park, PA.

Lesica, P. and Shelly, J.S. (1992). Effects of cryptogamic soil crust on the population dynamics of *Arabis fecunda* (Brassicaceae). *American Midland Naturalist,* 128: 53-60.

Leys, J.F. and Eldridge, D.J. (1998). Influence of cryptogamic crust disturbance to wind erosion on sand and loam rangeland soils. *Earth Surface Processes and Landforms,* 23: 963-974.

Luken, J.O., Kuddes, L.M., and Tholemeier, T.C. (1997a). Response of understory species to gap formation and soil disturbance in *Lonicera maackii* thickets. *Restoration Ecology,* 5(3), 229-235.

Luken, J.O., Kuddes, L.M., Tholemeier, T.C., and Haller, D.M. (1997b). Comparative responses of *Lonicera maacii* (Amur honeysuckle) and *Lindera benzoin* (Spicebush) to increased light. *The American Midland Naturalist,* 138(2), 331-343.

Luken, J.O. and Mattimiro, D.T. (1991). Habitat-specific resilience of the invasive shrub Amur honeysuckle (*Lonicera maackkii)* during repeated clipping. *Ecological Applications,* 1(1), 104-109.

Luken, J.O. and Thieret, J.W. (1996). Amur honeysuckle, it's fall from grace. *BioScience,* 46(1), 18-24.

Luken, J.O., Tholemeier, T.C., Kunkel, B.A., and Kuddes, L.M. (1995). Branch architecture plasticity of Amur honeysuckle (*Lonicera maackii* (Rupr.) Herder): initial response in extreme light environments. *Bulletin of the Torrey Botanical Club,* 122(3), 190-195.

Ma, J. and Moore, G. (2003). Brooklyn Botanic Gardens: *Celastrus orbiculatus* Thunb. Retrieved March 28, 2007 from: http://www.fs.fed.us/

Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., and Bazzaz, F. Biotic invasions: Causes, epidemiology, global consequences and control. *Issues in Ecology,* 5: 1-20.

Malinoski, M.K. Hemlock Woolly Adelgid. The University of Maryland. Retrieved March 30, 2007 from: http://www.hgic.umd.edu.

Massachusetts Audubon Society. (2007). Managing small grasslands for grassland birds. Retrieved April 17, 2007, from: http://www.massaudubon.org/Birds_&_Beyond/grassland/small.php.

Massachusetts DEM Lakes and Ponds Program (2006). *A Guide to Selected Invasive Non-native Aquatic Species in Massachusetts*.

Massachusetts Department of Environmental Protection (2002). Source water protection and assessment report. Retrieved April 25, 2007, from: http://www.mass.gov/dep/water/drinking/2115000.pdf.

Mass DEP (2007). 314 CMR 4.00: Massachusetts Surface Water Quality Standards. Retreived May 2, 2007, from: http://www.mass.gov/dep/water/laws/314cmr4.htm.

MassWildlife. (2005). Biodiversity Initiative. Retrieved April 19, 2007, from: http://www.mass.gov/dfwele/dfw/bdi/bdihome.htm.

Mattei, L. (2006). Lecture invasive species removal projects currently being conducted by the Sudbury Valley Trustees. Wheaton College, Norton, MA. November 28, 2006.

McClure, M.S. and Cheah, C.A.S.-J. (1999). Reshaping the ecology of invading populations of hemlock woolly adelgid, *Adelges tsugae* (homoptera: Adelgidae), in eastern North America. *Biological Invasions,* 1: 247-254.

McNab, W.H. and Loftis, D.L. (2002). Probability of occurrence and habitat features for oriental bittersweet in an oak forest in the southern Appalachian mountains, USA. *Forest Ecology and Management,* 155: 45-54.

Meyer, S.E. (2006). Rosa L. Retrieved March 30, 2007, from: www.nsl.fs.fed.us/wpsm/Rosa.pdf.

Mitton, J.B. and Grant, M.C. (1996). Genetic variation and the natural history of quaking aspen. *Bioscience,* 46(1): 25-31.

Mueller-Dombois, D. and Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology.* New York: John Wiley & Sons.

National Park Service. (2006). Great Smoky Mountains National Park – Hemlock Woolly Adelgid. Retrieved March 29, 2007, from: http://www.nps.gov.

New England Wetland Plants, Inc. Catalog. Retrieved May 2, 2007 from: http://www.newp.com/catalog.htm.

New England Wildflower Society (NEWFS). (2002). *Plant Inventory of the Headwaters Conservation Area, Westborough, Massachusetts.*

Norment, C. (2002). On grassland bird conservation in the Northeast. *The Auk,* 119(1): 271-279.

Oehler, J.D., Covell, D.F., Capel, S.C., and Long, B.L. (2006). Managing grasslands, shrublands, and young forests for wildlife: A guide for the Northeast. Published by the Northeast Upland Habitat Technical Committee, MA Division of Fisheries and Wildlife.

Ohio Agricultural Research and Development Center. *Ohio Perennial and Biennial Weed Guide,* From: http://www.oardc.ohio-state.edu/weedguide/.

Ohio Department of Natural Resources (DNR) (2005). Amur, Morrow and Tatarian Honeysuckle. Retrieved November 26, 2006, from http://www.ohiodnr.com/dnap/invasive/1amurhoneysuck.htm.

Orwig, D.A. and Foster, D.R. (1998a). Stand, landscape, and ecosystem analyses of hemlock woolly adelgid outbreaks in southern New England: An overview. In: Proceedings: Symposium on sustainable management of hemlock ecosystems in eastern North America.

Orwig, D.A. and Foster, D.R. (1998b). Forest response to the introduced hemlock woolly adelgid in southern New England, USA. *Journal of the Torrey Botanical Society,* 125(1): 60-73.

Parish, R., Antos, J.A., and Hebda, R.J. (1999). Tree-ring patterns in an old-growth, subalpine forest in southern interior British Columbia. In R. Wimmer and R.E. Vetter (Eds.), *Tree-Ring Analysis* (pp. 231-248). Cambridge, England: CABI Publishing.

Plant Conservation Alliance's Alien Plant Working Group (PCA). (2006). Fact Sheets: Alien plant invaders of natural areas. Retrieved March 28, 2007 from: http://www.nps.gov/plants/alien/

Raynal, J.D. and Bazzaz, R.A. (1973). Establishment of early successional plant populations on forest and prairie soils. *Ecology,* 54: 1335-1341.

Reichard, S.H. (1996). California Exotic Pest Control Council, 1996 Symposium Proceedings.

Rhoades, A.F. and Block, T.A. (2002a). *Morrow's honeysuckle and Amur honeysuckle.* Retrieved November 26, 2006, from http://www.paflora.org.

Rhoads, A.F. and Block. T.A. (2002b). *Multiflora rose fact sheet*. Retrieved March 28, 2007 from: http://www.paflora.org.

Richburg, J.A., Dibble, A.C., and Patterson, W.A. III. (2002). Woody invasive species and their role in altering fire regimes of the Northeast and Mid-Atlantic states. Pages 104-111 *in* K.E.M. Galley and T.P. Wilson (eds.). Proceedings of the Invasive Species Workshop: the role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL.

Riverways Program (2007). River Instream Flow Stewards – Low flow inventory – Suasco River Basin. Retrieved May 2, 2007 from, http://www.mass.gov/dfwele/river/programs/rifls/lf_suasco.htm.

Roberts, H.A. (1981). Seed banks in soils. *Advances in Applied Biology*, 6: 1-55.

Rooney, T.P. and Waller, D.M. (2003). Direct and indirect effects of white tailed deer in forest ecosystems. *Forest Ecology and Management,* 181: 165-176.

Save our Hemlocks. (2005). Retrieved February 26, 2007, from: www.saveourhemlocks.org.

Schery, R. (1977). The curious double life of *Rosa multiflora. Horticulture,* 55:56-61.

Schmidt , K.A. and Whelan, C.J. (1999). Effects of exotic *Lonicera* and *Rhamnus* on songbird nest predation. *Conservation Biology,* 13(6), 1502-1506.

Smith-Fiola, D. (2004). The hemlock woolly adelgid: Life cycle, monitoring, and pest management in New Jersey. Rutgers Cooperative Research and Extension, New Brunswick, NJ. Retrieved March 30, 2007 from: www.rce.rutgers.edu.

Steneck, R.S. and Carlton, J.T. (2001). Human alterations of marine communities – students beware! In *Marine Community Ecology*, eds. M.D. Bertness, S.D. Gaines, and M.E. Hay. Sinauder Associates, Inc, Sunderland, Massachusetts.

Sven-Olov, B. (1990). Vegetation development in abandoned gravel pits: Effects of surrounding vegetation, substrate, and regionality. *Journal of Vegetation Science,* 1(5): 675-682.

Szafoni, B. (1990). Vegetation management guideline – Multiflora Rose (*Rosa multiflora* Thunb.). Illinois Nature Preserves Commission. Retrieved March 28, 2007 from: http://www.inhs.uiuc.edu.

The Nature Conservency (TNC). (2003). Element Stewardship Abstract for Celastrus Orbiculata. Retrieved April 25, 2007, from: http://tncweeds.ucdavis.edu.

Town of Westborough, MA (2003). Open space and recreation plan. Retrieved April 18, 2007, from http://www.town.westborough.ma.us/Public_Documents/WestboroughMA_BComm/openspacereport/OSRP.html.

UMASS Pesticide Education Program (2005). Retrieved April 18, 2007, from: http://www.umass.edu/pested/.

USDA Forest Service (2006). *Bell's Honeysuckle.* Retrieved November 26, 2006, from http://www.na.fs.fed.us/fhp/invasive_plants.

USDA Forest Service. An exotic pest threat to Eastern Hemlock: An initiative for management of hemlock woolly adelgid. Retrieved March 30, 2007 from: http://www.na.fs.fed.us/fhp/hwa/pub/hwa_mgt_plan.pdf.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., and Melillo, J.M. (1997). Human domination of Earth's ecosystems. *Science,* 277: 494-499.

Vitousek, P.M. and Walker, L.R. (1989). Biological invasion by Myrica faya in Hawai'i: Plant demography, nitrogen fixation, ecosystem effects. *Ecological Monographs,* 59(3): 247-265.

Waterman Design Associates, Inc. (2007). *Proposed Trail/Pond Enhancement Plan for Gilmore Farm Road.* Westborough, MA.

Weatherbee, P.B., Somers, P., and Simmons, T. (1998). *A Guide to Invasive Plants in Massachusetts*. Massachusetts Division of Fisheries and Wildlife publication.

Weed Wrench Co. (2005). Weed wrench – woody plant puller. Retrieved April 25, 2007, from www.weedwrench.com.

Wernert, S.J. (Ed.). (2004). *North American Wildlife.* China: Reader's Digest.

Westborough Community Land Trust (WCLT). *Properties*. Retrieved January 12, 2007, from http://www.westboroughlandtrust.org.

WCLT and Westborough Open Space Preservation Committee (2003). Trail Maps: Headwaters Conservation area and Bowman Conservation area to Gilmore Pond.

Wimmer, R. and Vetter, R.E. (Eds.). (1999). *Tree-Ring Analysis*. Cambridge, England: CABI Publishing.

Woods, K.D. (1993). Effects of invasion by *Lonicera tatarica* L. on herbs and tree seedlings in four New England forests. *American Midland Naturalist* 130: 62-74.

Zavelata, E.S., Hobbs, R.J., and Mooney, H.A. (2001). Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology and Evolution,* 16(8).

Zhao, Z., Hu, M., Sashida, Y., Tang, X., Shimomura, H., and Tokumoto, H. (1999). Practical application of annual rings in the bark of *Magnolia*. In R. Wimmer and R.E. Vetter (Eds.), *Tree-Ring Analysis* (pp. 119-138). Cambridge, England: CABI Publishing.

FIELD GUIDES:

Brown, L. (1979). *Grasses: An Identification Guide*. Boston: Houghton Mifflin Company.

Fassett, N.C. (1940). *A manual of aquatic plants.* New York: McGraw-Hill Book Company, Inc.

Fernald, M.L. (1987). *Gray's manual of botany* (8^{th} ed.). Portland, Oregon: Dioscorides Press.

Knobel, E. (1980). *Field Guide to the Grasses, Sedges, and Rushes of the United States*. New York: Dover Publications, Inc.

Little, E.L. (1980). *National Audubon Society Field Guide to Trees – Eastern Region*. New York: Alfred A. Knopf, Inc.

Muenscher, W.C. (1944). *Aquatic plants of the United States.* New York: Comstoc Publishing Company, Inc.

Newcomb, L. (1977). *Newcomb's Wildflower Guide*. Boston, Massachusetts: Little, Brown and Company.

Peterson, R.T. and McKenny, M. (1968). *Wildflowers*. Boston, Massachusetts: Houghton Mifflin Company.

Royer, F. and Dickinson, R. (1999). *Weeds of the Northern U.S. and Canada*. Canada: The University of Alberta Press.

Rushforth, K. (2004). *The Easy Tree Guide*. Guilford, Connecticut: The Globe Pequot Press, Inc.

Hotchkiss, N. (1967). *Underwater and floating-leaved plants of the United States and Canada.* Washington, D.C: Bureau of Sport Fisheries and Wildlife, U.S. Fish and Wildlife Service.

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