Treatment of Hemlock Woolly Adelgid (*Adelges tsugae* Annand) infestation on Eastern Hemlock (*Tsuga canadensis*) stands in Weston, MA

**Introduction**

Eastern hemlock (*Tsuga canadensis*) is a tree species native to eastern North America and is characteristic of the New England forest. Hemlocks are highly valued for their ecological importance (Cowles 2009). For instance, they are extremely shade tolerant, grow in riparian areas, keep stream temperatures steady, provide homes to many different types of wildlife, maintain soil quality and forest hydrology, and provide thermal protection in the winter for certain forest species (Small *et al.* 2005). Not only are hemlocks vital for ecosystem services, their wood is also harvested for use as pulp, paper, and saw logs (McWilliams & Schmidt, No date). Overall, hemlocks are one of the most important and most highly regarded species of the upland forests in central and Northern New England. Therefore is essential to keep this forest species intact for future generations especially during a time when many ecosystems are forced to face growing threats from changing climate, unforeseen weather-related disturbances, and invasive species.
In particular, the introduction of an invasive insect species, the hemlock woolly adelgid (*Adelgis tsugae* Annand; HWA) has severely impacted the eastern hemlock forests across southern New England at a devastating rate. The combination of this invasive species with the hemlock’s characteristic slow growth and regeneration rates, low viability of seeds, shallow root system, and thin bark makes the species extremely sensitive to disturbances, diseases, and pest infestations (Small *et al.* 2005). Within the town of Weston, MA, HWA has caused damage on hemlocks in several stands that are located on conservation land. In response, the Weston Conservation Commission has appropriated money towards effective tree treatment and subsequent monitoring. This case study focuses on preparing the selected stands for future management and protection against the HWA epidemic through mapping and establishing long-term monitoring plots to compare effectiveness of treatment to non-treatment. Furthermore, the success and safety of applying a chemical insecticide, Imidacloprid, in the face of HWA’s resilience to cold and changing climate will also be investigated in this study. The foundation laid down by this project will serve as a stepping-stone towards exploring the possibilities of HWA best care management within forest settings and will implement ways to monitor the treatment’s progress.
Background

History

HWA is originally from Japan where the species of ornamental hemlock there (*Tsuga diversifolia*) is unaffected to its predatory behavior, due to a combination of predators and natural resistance (McClure *et al.* 2001). It first came to the western part of North America around 1920 near British Columbia. After 30 years, it spread to the eastern part of the United States and was first spotted in Virginia around 1950. HWA then spread to Massachusetts in 1988 through Connecticut (University of Massachusetts Extension, *Hemlock Woolly Adelgid*). The range of eastern hemlocks begins north in Quebec, Canada, as far west as the Lake States, and with southern limits as far as Georgia and Alabama (See Figure 1). Unlike Western hemlock, Eastern hemlock shows very little resistance to this exotic species, which has allowed it to grow and spread rapidly. The rate at which HWA has spread in the last 10 years has been 20-30 km annually.

Although currently only a small portion of this hemlock range has been affected by HWA, the increasing rate of infestation due to changing climate and ease of transportation puts eastern hemlocks at higher risk. Common modes of transport include wind travel and
transmission by birds, deer, and humans (McClure et al., 2001). The sticky ovisacs that surround the adelgid eggs make it very easy for forest dwelling animals to transport HWA (United States Forest Service, Pest Alert, 2005). Most recently, however, human transport of infested hemlock stock is the growing reason behind localized HWA infestations and long distance infiltration as well. Its adaptation to high elevations and low temperatures (showing resistance to temperatures as low as -20°C) has made HWA extremely resilient to the cold winters in the Northeast (Paradis et al., 2007). For this reason, there are predictions that HWA will overwhelm the majority of the eastern hemlock range (McClure et al., 2001).
**Figure 1.** The U.S. Forest Service documented which counties in the Northeast that have been infested by HWA and that had been newly infested in the year 2008. As can be seen, the whole state of Massachusetts has been infested with HWA. (Image courtesy of the U.S. Forest Service’s HWA Distribution maps collection, adjusted by author)

**Biology**

HWA is a close relative of aphids, in the family Adelgidae, which consists of insects that are commonly associated with feeding on conifer species and producing growths, such as woolly
masses and galls, on them (University of Massachusetts Extension, *Hemlock Woolly Adelgid*).

Unlike other members of this family, however, the HWA feeds on stored starches in the needles of the hemlock instead of sap (United States Forest Service, *Pest Alert*). These starches are essential to long-term growth and health of the tree and depletion of this nutrient is detrimental to eastern hemlocks.

There are two generations of HWA per year that have coexisting life stages. The overwintering generation of HWA lay their eggs between late February through March (Stadler *et al.*, 2005). The eggs are a reddish brown color and remain in this stage until April when they hatch (See Figure 2). Dispersal of this generation is most frequent during their nymph phase in which they favor settling on the ends of hemlock branches at the base of needles. There are two types of phenotypes within this generation: wingless and winged. Those that are wingless lay the second generation of offspring on hemlocks while those that are winged lay their eggs on spruce. Since the type of spruce species that is necessary for HWA to reproduce is not present in eastern North America, HWA does not pose a risk to spruce species in this area. The wingless adelgids lay their eggs after becoming adults around June, and the nymphs that hatch are dormant until October (See Figure 2). Only in late autumn do they feed and use their sucking mouthparts to drain plant sap from the hemlock twigs, and mature in late February.
Since HWA feeds on the base of hemlock needles the host tree becomes very vulnerable to desiccation and the leaf takes on a gray hue (McClure et al., 2001). A toxin it secretes may also be injected into the tree while feeding takes place, thereby exacerbating the damage it inflicts upon the tree (Maryland Cooperative Extension, *Hemlock Woolly Adelgid*, p. 1). Due to
drying out, the needles fall off of the trees and new apical buds are kept from growing. The hindrance of new bud production keeps the growth on branches at a minimum, and effects on major limbs could be observed within two years. Damage usually occurs from the bottom of the tree initially and moves up toward the canopy even though distribution of HWA throughout the tree is generally uniform. The movement of damage towards the canopy is most likely a result of HWA targeting regrowth at the crown since previously infested branches are unlikely to produce new growth. Death to infested trees ranges from 4 to more than 10 years (McClure et al., 2001).

HWA populations are dependent on the nutritional quality of the hemlock stands, which means that densities tend to fluctuate on an annual basis (McClure et al., Hemlock Woolly Adelgid, p.11). Usually there is a high peak in population of HWA during the first year of infestation and then a severe drop in population during the following year. As a result of a decreased volume of adelgids, tree growth could occur and influence growth in HWA density once again. This pattern of growth and drop in HWA densities continues until the tree is unable to sustain HWA populations.
Management

Although some sources say that management is less necessary in forest settings because trees have been shown to withstand infestations of HWA for longer periods of time, there are measures that can be taken to keep infestation levels in control and prevent future HWA outbreaks (University of Massachusetts Extension, *Hemlock Woolly Adelgid*). There are different measures that could be taken depending on what setting the trees are in, but the primary focus of this study is to find treatment plans suitable for forests. Integrating aspects of biological control, chemical control, and monitoring projects would be ideal for the stands in Weston.

Integrated management

Integrated management is encouraged when assessing a complex challenge like that posed by infested eastern hemlock stands. Within a forested setting, a solid understanding of the HWA population densities in a stand is required (McClure et al., *Hemlock Woolly Adelgid*, p.13). Sampling techniques need to be developed in order to adequately address the necessary treatment and the cost of treatment that will occur. Studies have shown that there is a correlation between population density of HWA on a tree and the percentage of infested twigs. These values vary from site to site and between generations of HWA. With prediction models like these,
comprehensive plans can be made to accommodate future changes in HWA densities. Even though the application of imidacloprid will be the primary form of treatment for these stands in Weston, future use of integrated management could be incorporated to reduce the required dosage or frequency of chemical treatment by introducing less invasive methods.

**Horticultural Oil**

Horticultural oil, containing the active ingredient paraffinic oil, is a way for HWA to be controlled if it is applied in February or early March prior to when females lay eggs (Maryland Cooperative Extension, *Hemlock Woolly Adelgid*, p. 1). This is a product made from petroleum, which suffocates the pest (Dilling *et al.* 2009). Another application of oil is necessary after eggs have hatched in mid-summer in order to maintain control over population density (Maryland Cooperative Extension, *Hemlock Woolly Adelgid*, p. 1). Spraying more of the tree will increase the amount of pest control. However, this type of treatment is less viable in forest settings because the high density of trees located near one another makes branches less accessible for spraying. In nursery settings or when treating ornamental hemlocks that are not in high-density stands, this method would be worth considering for Weston hemlocks.
Natural Predators

Native predators like chrysopid and hemerobiid lacewings, syrphid flies, and cecidomyiid flies have been less effective at controlling HWA populations since they are mostly generalists (McClure, *Biological control of Hemlock Woolly Adelgid in the eastern United States*, 4; Flowers *et al.* 2006). Predators from China and Japan are being studied for their potential as biological control for HWA (McClure *et al.*, *Hemlock Woolly Adelgid*, p.13). For example, the adult and larval forms of the lady beetle or coccinellid (*Pseudoscymnus tsugae Sasaji*), a Japanese species, preys on all life stages of HWA. They appear to favor HWA over other forms of prey and prefer to feed on HWA eggs the most. *P. tsugae* seems to be one of the most viable candidates for population control of HWA because it can adapt to many types of climates, favors feeding on adelgids, has a similar life cycle to HWA, and is able to disperse and locate its prey efficiently. Studies have been performed in 10 northeastern states with *P. tsugae* and it has successfully overwintered and established itself at many sites in addition to being cold hardy. More than one million beetles have been released in hemlock stands in the eastern part of the United States, and various collections performed in Pennsylvania Connecticut suggest that it has established itself in these regions (Flowers *et al.* 2006). Its effectiveness, however, is dependent on annual climate changes and it seems to be too early in research findings to establish whether
or not it is completely effective as a form of biological control. It has not yet been made available commercially but would be a suitable candidate for study in the future monitoring program.

A beetle that is native to the western United States and Canada (*Laricobius nigrinus*) has been used in Virginia on HWA and is another viable option for biological control (McClure, *Biological control of Hemlock Woolly Adelgid in the eastern United States*, 4). The eggs of this species are cold hardy and larvae feed on HWA when other predators are not active (Mausel *et al*. 2008). Its stages of feeding are synchronized with HWA egg and nymph life stages (sistentes that are present from summer to the following spring and progredientes that are present during the winter months) and it shows a preference to feeding on HWA when faced with eating other types of insects in the adelgid family. *L. nigrinus* oviposition and larval development coincide with the egg-laying of overwintering HWA generations which indicates good synchrony (Zilahi-Balogh *et al*. 2002). This predator developed fully to adulthood when feeding on HWA, but did not reach this level of development when feeding on other species in the adelgid family. In addition, a study performed by Zilahi-Balogh *et al.*, *L nigrinus* had a strong host specificity for HWA (2002). The results of this study made it possible for *L. nigrinus* to be cleared for release by the USDA APHIS program
In a study that Mausel et al. did on determining whether a field insectary was effective for harvesting *L. nigrinus* in an HWA infested hemlock field, their results strongly recommended the use of insectaries to rear populations of this HWA predator (2008). Not only did this method enhance the biological control of HWA, it successfully acclimated *L. nigrinus* to its new environment and made it healthier and more effective than beetles raised in a laboratory. Using infested trees in more public areas like city parks, golf courses, campuses, or cemeteries are other options for rearing this predator if planting hemlocks is not a viable option. In a field insectary setting, *L. nigrinus* would potentially be self-sustaining and be a source of predators used to release in infested hemlock stands. Exploring this field insectary option could be a project that the Weston Conservation Commission may want to invest in for the future monitoring of the hemlock stands on their land.

At this point in research, however, a variety of predators may be needed to control HWA populations as opposed to just biological control species. Flowers et al. investigated the possibility of using several HWA predators in conjunction to combat infestations to determine the overall impact and the competitive interactions between the species. They used two specialist predators, *Laricobius nigrinus* and *Sasajiscymnus (Pseudoscymnus) tsugae* and a generalist predator *Harmonia axyridis* Pallas. Although these studies were done in the
Southeastern part of the nation, all three species were able to survive low temperatures and there was no direct negative impact on populations due to competition. *L. nigrinus* was more tolerant of cold temperatures (as low as 5.8°C) than *S. tsugae* or *H. axyridis* (as low as 7.5°C). In the spring, *L. nigrinus* had the most effect on controlling HWA populations and during the summer months, *H. axyridis* preyed the most upon progrediens. The combination of these two predators had more of an impact than did *S. tsugae*, which seemed to have more limitations to the experimental frame of this experiment. Although competition between conspecifics negatively impacted predator numbers, heterospecific interference was low. Flower *et al.* recommended using treatments that include multiple predators because of the low interspecific competition. Releasing low concentrations of predators is also recommended to prevent negative impacts of intraspecific interference.

**Chemical Pesticide treatment using imidacloprid**

**General information**

A common and effective chemical pesticide, imidacloprid, has been used to control HWA populations in hemlock stands throughout the Northeastern United States (University of Massachusetts Extension, *Hemlock Woolly Adelgid*). Imidacloprid was registered by the EPA in
the U.S. in 1994 and was made for the purpose of commercial pesticide use (Northwest Coalition for Alternatives to Pesticides (NCAP) 2001; Silcox, *Using imidacloprid to control hemlock woolly adelgid*). It works systemically which means that it is taken up by the plant and kills the insects that feed on it. It is used on many crops, and used to control cockroaches as well as termites. The way it kills insects is by mimicking a nervous system receptor that normally receives acetylcholine, thereby blocking nerve impulses. Insect receptors are more sensitive to this chemical than those found in mammals, but imidacloprid effects receptors in the same manner. This means that in high enough concentrations, negative effects of imidacloprid could be found in larger organisms than insects.

The Bayer Corporation has three products that can be applied on the leaves of hemlocks or on the soil (Merit 75WP, Merit 75WSP, and Merit 2F) and two treatments can be used for trunk injections (Imicide and Pointer Insecticide; Silcox, *Using imidacloprid to control hemlock woolly adelgid*). This pesticide can only be applied to trees by a licensed professional, and is usually done through and injection into the soil or the trunk or soil drenching (University of Massachusetts Extension, *Hemlock Woolly Adelgid*). Imidacloprid can be used as a preventative measure for stands that are at risk of being infested if low doses are applied or may require several applications if the damage to a stand is severe. Although application is performed on an
individual basis and is time consuming, a well-planned application used in Weston appeared to be the most suitable treatment to keep the infestation of HWA at bay.

**Toxicity**

Imidacloprid is absorbed by the xylem through the roots of the tree and diffused into areas within the twigs to target where the insects with piercing or sucking mouthparts feed (Dilling *et al.* 2009). After 24-48 hours of feeding on the infused tree, HWA usually dies. Since imidacloprid affects acetylcholine in parasitoid hymenoptera, and subsequently their behavior, the question exists whether or not this chemical has a negative effect on native insect species and other organisms that benefit forest ecology. Dosages between 2 and 4 ppm had negative effects on an enzyme (cellulae) - that facilitates breakdown of organic matter in the gut of the earthworm species, *Eisenia fetida*. With dosages of 0.2ppm, levels of cellulae were found to be reduced (Northwest Coalition for Alternatives to Pesticides (NCAP) 2001). Additionally, a study done by Capowiez and Bérard (2005) investigated whether or not imidacloprid application influenced the behavior of two species of earthworms (*Aporrectodea noceurn* and *Allolobophoria icterica*). In past experiments, sperm counts of earthworms were lowered and cast production decreased when specimens were exposed to imidacloprid. Also Capowiez and Bérard found that
the application of imidacloprid shortened burrow length, decreased the rate of reusing burrows, and reduced the distance that the earthworms covered. The experiments done used levels of imidacloprid that were under the lethal levels at approximately 0.33 ppm. The use of imidacloprid on soil also limited the areas that earthworms chose to explore. This could mean that soil that has been treated for HWA outbreaks could possibly be less oxygenated due to the avoidance of earthworms to those areas. The depth that the earthworms burrowed was also negatively affected, which would have an impact on how far water is transferred in the soil since borrows allow surface water to penetrate far into soil. Although these studies were done in controlled soil terrariums, similar effects would probably be observed in forest ecosystems. Thus far, no experiments have been found that investigate the ecological effects of imidacloprid treatment over several years on whole forest stands.

On a larger scale of organisms, forest wildlife is also put at risk when in the presence of imidacloprid (National Pesticide Information Center (NCIP) 1998). It was found that imidacloprid increased the chances of genetic damage to DNA by five times (Northwest Coalition for Alternatives to Pesticides (NCAP) 2001). When the chemical degrades, its metabolites have been found to have even more toxic effects on insects than the original chemical. Its negative effects on birds includes lack of coordination, less responsiveness, and in
serious cases, inability to fly. Thinning eggshells, decrease in egg production, and lower rate of successful hatching are also side effects of exposure as well as reduced egg production and hatching success when concentrations of 234 ppm were found in food (U.S. EPA 1992). High concentrations of imidacloprid can be lethal to adult fish at concentrations exceeding 80 ppm, but juvenile fish are at higher risk to its toxicity.

Of more importance to this case study is imidacloprid’s toxicity to aquatic invertebrates since many of the stands in Weston are located very closely to freshwater streams. A study done on a freshwater crustacean (*Hyalella azteca*) found imidacloprid to be toxic at 55 ppb, which is a concentration below the accepted dosage level of treatment. In a study done on artificial ponds, with a 5 ppb dosage of imidacloprid, the species number and concentration of invertebrates was reduced (Northwest Coalition for Alternatives to Pesticides (NCAP) 2001). Genetic mutations and damaged DNA were found to occur at concentrations as low as 0.05 ppm as well. However, during a soil injection treatment of imidacloprid in the Southern Applications, only trace amount of imidacloprid was found to enter streams during a time period of two years (Churchel *et al.*, Environmental Fate of Imidaclorpid). There was not enough of the chemical present to negatively impact the aquatic organisms in the stream. With this being said, it is unlikely that
the hemlocks treated near streams in Weston will have a significant negative impact on organisms in those areas.

This pesticide also has negative impacts on beneficial insects that could be an asset to forest ecology, such as honeybees (Northwest Coalition for Alternatives to Pesticides (NCAP) 2001). Tests have also shown that imidacloprid could be lethal to predatory insects like lady beetles and lacewings (Smith & Krischik 1999). Spider mite occurrences on hemlock trees after being treated with the highest allowed dosage of imidacloprid were found in an experiment performed by Cowles et al. (2009) Increased frequency of spider mite outbreaks could also pose a threat to hemlocks and the organisms that they sustain (Cowles 2009). A study done by Kreutweiser et al. on the effects of imidacloprid treated foliage effecting the litter breakdown of non-target invertebrates showed that there was reduced organic litter breakdown when organisms were exposed to imidacloprid (2008). Although these effects occurred sub-lethally, if the level of imidacloprid is high where there is a large density of fallen foliage, negative ecological impacts could occur. This would be of concern especially in cases where large areas of treated hemlock stands are infested, die, and are cut down to prevent the spread of an HWA infestation. Water contamination is also a concern since imidacloprid was shown to have leached through
soil faster than many other registered pesticides like diuron, diazinon, and chlorpyrifos. EPA, however, did not list it as a restricted use product under water quality protection regulations.

The strongest effect of imidacloprid lasts for approximately three months, which is long enough to ward off pests that attack plants during early growth. However, because it is a systemic pesticide, the chemical can be leached easily between roots and plant matter to soil and also into groundwater. According to Richard Cowles, as stated in Connecticut Agricultural Experiment Station’s Best Management Practices, low concentrations of the pesticide bind tightly to organic matter but in saturated concentrations it can move through organic soil very quickly. According to Cowles, a buffer zone of approximately 50 feet has been chosen as the appropriate distance by managers when treating trees that are located near streams. The strongest suggestion made by Cowles, however, was to choose dosages of imidacloprid that would maximize its binding strength to organic matter which would not only prevent its mobility through soil but would also facilitate its absorption into tree roots. Injections should be shallow and spread out around the base of the tree. The lowest dosage that is marked as effective on the label should be used and the soil should not be saturated with the chemical. If it is in a solution of water, it breaks down quickly in sunlight with a half-life between 4 hours and 1.4 days. It would also dilute quickly into nontoxic concentrations if it were to mix with uncontaminated
water. The risk of imidacloprid contamination comes from a concern of the chemical being bound to organic matter and entering a stream, sinking to the bottom away from sunlight, and persisting for a longer period of time. This is why it is important to ensure that runoff from the surface of applications does not occur since this could lead to pollution of aquatic ecosystems.

In a study performed by Dilling and her colleagues on the impact of different methods of imidacloprid application (soil drenching, soil injection, and tree injection), soil-drenched applications were found to have the most significant effect on other nontarget forest species in terms of species density and richness (Dilling et al. 2009). Injections of imidacloprid into the tree showed the least impact on the observed species most likely because it left very little residual material after application. This study also looked at the effect of the pesticide on individual species of nontarget insects. The methods of soil injection and soil drenching appeared to be the treatments that had the most impact on the studied species. Species that were studied included lepidopteran species, that were more prone to being affected, were able to feed on other tree species and the psocopterans fed on several hosts as detritivores, which meant that these populations would be able to find other non-contaminated food sources if necessary. There was a reduction of phytophaga insects, which could alter the rate of nutrient production and other
ecological processes. This reduction could also negatively affect the number of predators and parasitoids that live on hemlocks and decrease the variety of preferred prey of these species.

**Recommended uses**

There have been studies that have shown that using lower dosages of the chemical imidacloprid can not only maintain HWA levels, but will also avoid degrading surrounding ecosystems. The study that Cowles and his colleagues did on optimizing imidacloprid effectiveness while trying to uphold aquatic ecosystem health found that there are specific dosage levels that can effectively treat certain densities of pests (2009). A strategy suggested was to achieve maintenance of tree health over a wide area by treating with 0.5g a.i. per 2.5cm DBH. This strategy would reduce costs and keep dosage levels low in addition to protecting the environment and allowing integrated pest management strategies to be used. With this type of treatment, low levels of HWA could be maintained in order to promote predator introduction and other biological control agents. A different approach would be to use higher dosage levels in order to execute high control treatment that would isolate and exterminate new, first generation HWA infestations. This dosage level would be 1g a.i. per 2.5 cm DBH and could result in 99% mortality; however the application process and speed at which imidacloprid works is somewhat
slow and such a plan would need to be done in conjunction with another type of control method, like biological control, or a different chemical insecticide. Their research also found that if the treatment was based on a specified dosage of chemicals for each DBH centimeter, a larger amount of dilution would occur for treatment of large trees. This would mean that trees of larger size would require larger concentrations of these chemicals in their tissue.

Appropriate dosages can be approximated by using the biomass of trees to figure out the quantity of imidacloprid necessary (Cowles 2009). It was found that the log of the biomass of the tree above the ground has a relationship that is directly proportional to log(DBH). Cowles also discovered that there was a relationship between the water use of a tree and the dilution of the insecticide. Due to the fact that the log of the amount of water used by a tree has a directly proportional relationship to its DBH, the log of the minimum effective dosage must have the same type of relationship with the tree’s DBH. This relationship allows for treatment plans to be made specific for each individual tree. The assessment process would undoubtedly would take more time, but the money saved from using less chemical and the ecological preservation that would result would likely outweigh the need for intensive tree assessment. Cowles made a recommendation to increase dosages by increments based on DBH measurement, which is what the Weston Conservation Commission plans to implement.
Different forms of imidacloprid may have more effectiveness in binding to organic matter. For instance, tablets and gel treatments leached less chemicals into soil than the powder form of the pesticide. The tablets made it possible to apply imidacloprid where it was gradually released into the soil and absorbed efficiently by the roots. Studies showed that there was an improvement in adelgid suppression as time passed with the use of tablets, although results were slow to begin with. Both tablet formulations and shallow soil injections are viable options for treating hemlocks outside of the buffer zone of aquatic ecosystems because of the reduced amount of leaching that is associated with these treatment methods. Tablets, registered as CoreTect, contain 20% imidacloprid and appear to be available commercially through the Bayer Corporation. This tablet option may be a viable treatment method for the hemlocks in Weston through a partnership with Bayer Environmental Science (Bayer Environmental Science 2008).

Cold hardness

The ability of the HWA to withstand cold temperatures during overwintering is an aspect of their biology that has made them so resilient during the winters in the Northeastern part of North America. The lowest temperature that this insect could survive is between -35°C and -
30°C (Costa et al. 2004). Additional studies have shown that the limits of HWA spread are in areas where the lowest temperatures range from -28.8°C to -26.5°C (Skinner et al. 2003). This is why their movement northward is slow because it is not resilient to these colder temperatures in the winter. The overall results concluded that HWA cold hardiness varied with the geographical location as well as with the time of year. In the winter, the adelgids at the varying geographical locations of the test sites began with relatively similar levels of cold hardiness, and gradually lost cold tolerance as the winter went by. Climate change also plays a role in HWA’s range and distribution due to warming temperatures over the next century (Paradis et al. 2006). Due to this fact, it is possible, however, that a combination of warming temperatures over time and cold hardiness would allow the HWA to eventually spread further north.

Case study in Weston

Methods

Infestation of the hemlock woolly adelgid was found in several stands under the ownership of the Weston Conservation Commission. In order to hinder the spread of HWA and the concurrent destruction of hemlock forests, the commission made the decision to fund an HWA treatment program. In the fall of 2008, $5,000 was spent on the treatment of a portion of
conservation land, named the Highland Forest stand. The Commission was granted another $25,000 in Community Preservation Act funds to treat the hemlock stands in the spring of 2009. Treatment costs about $2.50 per inch of tree diameter, so careful decision-making was necessary in order to select which trees in Weston were worth treating. There was not only the issue of not being able to treat all stands, but there was also the limitation of not being able to treat every tree in each stand. Preliminary counts were executed in several stands given the names, of Church Street, Cliff Road, Pinecroft, Hemlock Pond, Highland Core South, and Ogilvie and basic cost projections were made to get an idea of how the funds would be distributed amongst the various stands (Refer to Table 1 in the Appendix).

Based on the data provided by the preliminary counts, the Weston Conservation Commission voted on which stands needed treatment. The Conservation Commission decided to proceed with treatment on Cliff, Church, Highland Core South, Pinecroft, Hemlock Pond, and part of what remained to be treated of the Highland stand (See Figure 3). The large Highland stand was divided into a core area that would definitely be treated, and the remaining area surrounding the core that will be treated based on how much money remains after treating all other authorized stands. After this decision was made, we returned to the chosen stands and
performed more detailed mapping for monitoring the effectiveness of the treatment and tagged individual trees (trees that averaged 12 inches or larger in DBH were assessed).
Figure 3. This map displays the five major stands that the Conservation Commission authorized for HWA treatment. These include Pinicroft Road, Church Street, Highland Forest, Hemlock Pond, and Cliff Road. (Image courtesy of Emily Silver).
Upon tagging the hemlocks, decisions were made whether or not to treat each tree. The decisions were based on general aspects such as crown condition, which was rated on a scale of 1-5. 1 indicates that the foliage of the crown is 100% present, 2 indicates 75% foliage, 3 indicates 50% foliage, 5 indicates 25% foliage, and 5 signifies a dead tree (Refer to Figure 4). Determining the vigor of the tree, such as looking at whether or not it had been scarred or currently was damaged or diseased, also influenced the decision as to whether or not to treat the tree. The location of the tree in relation to other hemlocks or other species of trees was an influential factor in deciding whether or not treatment would be best. For example, if there was a large chance that the tree was going to be heavily suppressed in the future or if an old tree was projected to fall and damage a hemlock it would not be a strong candidate for treatment. Also, if a stand was very densely populated with hemlocks, there could be opportunity to thin those trees out; choosing fewer would save money that could go towards treatment in other stands.
Figure 4. a. Displays the crown rating of a 1 (100% crown foliage) b. Displays the crown rating of a 2 (75% crown foliage) c. Displays the crown rating of a 3 (50% crown foliage) d. Displays the crown rating of a 4 (25% crown foliage) Images taken by author.
These stands were mapped after finalized counts were executed to accurately document which trees should be treated. This was not only an ideal documentation technique for present and future treatment monitoring, but it also will serve as a guide for the treatment professionals to use during pesticide application. Additional data that was collected in addition to crown condition was DBH (diameter at breast height) measurements, tree tag number, and whether or not the tree was going to be treated.

The Church Street stand is the second largest stand that was chosen to be treated. It had a final count of 217 trees and 168 of them were chosen to be treated. The average DBH of the trees was 24 inches, and the estimated cost of treatment is $10,080 (see Figure A-1 in Appendix). Also, in the Church Street stand, a transect line was used during counting since the stand was large and was along a slope. In addition to the information previously mentioned, the distance each tree was located from the transect line was also documented in order to give the professionals treating the trees a good idea of where each tree is located (See Figure 5).
Figure 5. Emily Silver (left) is recording data about hemlock tree’s location, tag number, crown health, and treatment and Brian Donahue (right) is assessing the tree’s health and tagging it.

The Cliff Road stand is located in the southern part of Weston and is the smallest area of land that is going to be treated. It contains 174 trees and 118 of them will be treated. The average DBH of the trees was 16 inches and it is estimated to cost about $4,720 to treat (See Figure A-2 in Appendix).

The Hemlock Pond stand is the eastern most stand in Weston and contains 74 trees. All of these trees will be treated. The average DBH was 13 inches and the estimated cost of treatment is $2,405 (See Figure A-4 in Appendix).
The Highland stand, the largest treated stand in Weston, was already tagged and assessed Fall of 2008, but only the north half of it was treated with imidacloprid. The south half will be treated in the spring of 2009 along with the other stands that were assessed in this study. Areas outside of the Highland stand that contain hemlock trees were assessed, but there was enough money in the budget to save 160 trees in this buffer zone. Trees in this area were chosen in order to meet an overall goal of having an even distribution of trees treated around the whole area of the Highland stand in order to give equal amounts of buffering to the stand itself. Within the Highland stand, the North Core contains 120 trees and 100 of them were treated in fall of 2008, which cost $5,000. The average DBH of these trees was 20 inches. In the south core area of the stand, there were 108 trees counted and 88 of them will be treated. The average DBH of the trees was 16 inches and the cost is about $3,520. In the area around the core, there were 370 trees counted and 160 trees could possibly be treated. The average DBH is 16 inches and the cost would amount to about $6,400.

The Pinecroft stand contained trees mostly located on private land. There were 8 trees found on conservation land and all of them will be treated. This would cost $340. Some of the private landowners are planning on treating the trees on their land or are willing to treat at least some of them in order to aid conservation efforts.
Future Work

The application of the insecticide, imidacloprid, will occur in the spring of 2009. There are also going to be installments of monitoring plots within the Highland and Ogilvie stands. Since there will be untreated areas of these stands, control plots will be placed in these sections in order to compare treated hemlock trees to untreated hemlock trees. Future monitoring of these plots will clarify whether or not the imidacloprid treatment is effective in warding off HWA and how the chemical insecticide affects the overall health of the tree. Also, these plots can be used to monitor the development of the stands and to compare trees that have been treated to those that remain untreated. Establishment of these control plots will make it possible to answer questions that pertain to the length of time these treatments will last, how the application of these chemicals alter the health of the forest past the two to three year expected life of imidacloprid (Cowles 2006), whether or not the HWA is kept at bay for longer periods of time after one application, and if the chemical treatment is much more beneficial and cost effective than not treating trees at all. Such plots can also be beneficial towards answering questions about how HWA population densities change annually along with climate. Relevant data could lead to breakthroughs pertaining to how climate change could possibly play a role in the HWA outbreaks.
In addition to looking at the overall picture of treated trees in the stand in relation to the untreated control plot, comparisons can also be made between trees that are located within the treated stand that were chosen to be treated or untreated. Aspects that could be considered for further study include whether or not having an untreated tree located near a treated tree would promote eventual HWA infestation after the initial treatment or whether or not the injection treatment has an advantage or impact on neighboring untreated trees. Having substantial answers to these questions will give more guidelines to how treatment methods should be revised to give the most benefit to the health of the entire stand. With such evidence, additional funding can be sought for future projects and studies to take place.

Besides looking at how trees are affected in the long-term, stream ecology studies could also be a useful topic of study to consider for the future. With wetlands and streams located near hemlock stands, knowing how imidacloprid interacts with these biological systems could give more of a reason for future application to either cease or continue.

Identifying these stands and carefully documenting them has established a firm baseline from which further studies can take place. This case study will allow for the eastern hemlock forests of Weston to be conserved in efforts to preserve the native forest ecology and ecosystem functions that are characteristic of the Northeast. With the studies that will take place after
application of imidacloprid and after the establishment of monitoring plots in Weston, deeper conclusions will be found and used to combat the damage caused by HWA on a nationwide level.
### Appendix

**Table 1.** Hemlock Counts for Highland, Cliff Road, Church Street, Pinecroft, & Ogilvie stands

<table>
<thead>
<tr>
<th>Weston Conservation Land – Hemlock Trees -- 2009</th>
<th>Selected 2009 Stands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stand</strong></td>
<td><strong># Trees</strong></td>
</tr>
<tr>
<td>Highland Core -- North</td>
<td>120</td>
</tr>
<tr>
<td>Highland Core -- South</td>
<td>108</td>
</tr>
<tr>
<td>Highland -- outside core</td>
<td>370</td>
</tr>
<tr>
<td>Cliff Road</td>
<td>174</td>
</tr>
<tr>
<td>Church Street</td>
<td>217</td>
</tr>
<tr>
<td>Pinecroft</td>
<td>8</td>
</tr>
<tr>
<td>Ogilvie -- Intersection X</td>
<td>25</td>
</tr>
<tr>
<td>Ogilvie -- Intersection 3 - 4</td>
<td>30</td>
</tr>
<tr>
<td>Ogilvie -- S of intersection 4</td>
<td>24</td>
</tr>
<tr>
<td>Hemlock Pond</td>
<td>74</td>
</tr>
<tr>
<td>Elliston Woods</td>
<td>40</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1190</td>
</tr>
</tbody>
</table>
Maps

**Church Street Hemlocks**

Data courtesy of the Town of Weston. Hemlocks based on mapping March-April 2009. Emily Silver, Suburban Ecology Project (413) 320-2396. Hemlock_mapping.mxd

*Figure A-1.* Church Street stand map. Image courtesy of Emily Silver.
Figure A-2. Cliff Road stand. Image courtesy of Emily Silver.
Figure A-3. Highland Forest stand map. Image courtesy of Perry Erlitz and Alex Melman.
Figure A-4. Hemlock Pond stand map. Image courtesy of Emily Silver.
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