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Site characterization of hemlock stands at Allegheny National Forest

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Site characterization of hemlock stands at Allegheny National Forest

Daniel Farcas

Thesis submitted to College of Agriculture, Natural Resources and
Design at West Virginia University in partial fulfillment for the
requirements for the degree of

Master of Science
In
Forestry

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Morgantown, West Virginia

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soil cycle, immobilization, mineralization

ABSTRACT

Site characterization of hemlock stands at Allegheny National Forest

Daniel Farcas

Eastern Hemlock *Tsuga canadensis* is a coniferous tree native to eastern North America. It ranges from northeastern Minnesota eastward through southern Quebec, and from the southern Appalachian Mountains to northern Georgia and Alabama.

This majestic tree is threatened with elimination by an invasive species Hemlock Woolly Adelgid (HWA) *Adelges tsugae* introduced in the USA in 1924, which is believed to be a native of Asia. HWA reduces shoot growth, provokes branch dieback, and eventually tree death.

One strategy to help mitigate the fast spread of HWA is to determine what may cause host potential resistance to HWA and how to use this information to develop HWA-resistant management program. This project was initiated to....

To do that, randomly selected trees have been studied in Allegheny National Forest in 2006 with monthly data collection by hand-held soil probe instruments measuring temperature and water content noting the time of sampling and also some of them have been instrumented with station recording equipment called Hobo with recorders inserted at 15 cm soil depth and collecting temperature and water content data continuously. Net N mineralization and net nitrification were calculated using the in situ incubation technique, in this method the values of extractable nitrate-N and ammonium-N in incubated soil are compared to the initial. Exchangeable ammonia was extracted from air-dried soil samples that were sieved through a 2 mm sieve, using 2 M KCl in a 10:1 solution:soil ratio.

Statistical analysis was conducted using SAS with data collected, the main effects were thinning treatment (reference, thinning), soil pH, soil organic matter percentage, tree DBH, soil temperature, sampling months.

The thinning (treatment) is statistically significant ($p = 0.053$). The thinned plots mineralize more total nitrogen, almost 10 mg/kg of soil, approximately 50% than the reference plots. Thus, the observed N mineralization rate for the growing season was 21.7 mg/kg to 30 cm soil depth in control plots, or 65.8 kg N/ha. The estimated rate of N mineralization in HWA-infested stands was 30 times the observed rate, reaching 1973 kg/ha.

A series of spatial prediction maps of the landscape Nitrogen levels were created by using ArcGIS 9.2 software that helped acquire a spatial perspective of the soil N mineralization rates in forest ecosystems at a large scale. These spatial prediction maps will become increasingly important once the HWA infests the study site and will be visible impacts of N mineralization rates change in forest soil.

By creating a data base before HWA infestation of the stand and continuing gathering data after HWA infestation, with the help of the nitrogen mineralization model we will be able to elucidate the stand nutrient vs. HWA cause and effect relationship.

Nitrogen forms are an important water quality parameter, but in excess, it can be detrimental to waterways and their ecosystems. Enriched nutrient loads to streams may alter surface water quality and disrupt management of watersheds used by municipal treatment water. Nitrate and cations diffusion into the surface water can reduce its drinking quality. Blue-baby syndrome (Methemoglobinemia) can be caused by high nitrate found in drinking waters.

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Introduction

Pennsylvania has 17 millions acres of forestland, of which approximately 29 percent is state owned and is estimated that \$5 billion of timber products are produced annually. According to Pennsylvania Department of Conservation and Natural Resources based on a tree mortality survey made in 1997, 180,000 acres of forest are impacted by defoliation due to different pests such as elm spanworm, gypsy moth, HWA, fall cankerworm, beech bark disease, and forest tent caterpillar.

Allegheny National Forest (ANF) is located in northwestern Pennsylvania. It covers 512,998 acres of land and it has one of the oldest old-growth forests of eastern hemlock in the U.S. ANF is known mostly for the extensive recreational area that offers endless trails, camping, hiking, hunting, canoeing, snowmobiling and ATV, fishing and wildlife watching opportunities.

Home to over 70 species of fish and more than 300 species of mammals, ANF is the result of two historical periods: first the exploitation of timber till 1923, that left few pockets of old growth, and second, seventy-seven years of scientific and sustainable management (Cogbill, 2002). The presettlement forests of the ANF consisted mainly of hemlock (*Tsuga canadensis*) and beech (*Fagus grandifolia*), but later on heavy cutting favored mostly hardwoods. Sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), yellow and black birch (*Picea glauca* and *Picea mariana*), white ash (*Fraxinus americana*), and black cherry (*Prunus seratina*) are now also found in significant percentage in the ANF (Whitney, 1990).

On June 23, 1931, eastern hemlock was designated the official state tree of Pennsylvania, by then most of the old growth forests in Allegheny National Forest that had once been the most important states attraction had been converted to slash and burn operations.

Known also as the Canadian Hemlock, Prucher de Canada, or by its scientific name *Tsuga Canadensis*, eastern hemlock is a coniferous tree native to eastern North America. It ranges all the way from northeastern Minnesota eastward through southern Quebec, and from the southern Appalachian Mountains to northern Georgia and Alabama. It prefers cooler areas and humid climates, grows well in shade and it has a long life, the recorded specimen reached up to 554 years old (Gove, 1988). In its range, January temperatures are about -12°C, increasing in July to an average of 16°C or higher (Godman, 1965). Eastern hemlock is a shallow-rooted tree, and even tall trees have roots in only the upper 30 cm of the soil. Hemlock seeds do not necessitate a mineral soil to germinate well and grow (Collingwood, 1964).

Eastern hemlocks start producing seed when they are between 20 to 30 years old, the small winged seeds are dispersed by wind and gravity. Hemlocks do not sprout and layer only rarely (Godman, 1965). As dominant overstory tree species, hemlocks have few or no other trees in the understory. Hemlock is very susceptible to fire but usually escapes fires because it grows in moist habitats. (Rogers, 1978)

Because it provides a unique niche for a diversity of flora and fauna, eastern hemlocks are important to the ecology of the region and are also vital to local and regional economies. Hemlock creates an irreplaceable habitat because it modifies the

environment of wetlands, streams, and creeks on whose banks hemlock commonly grows abundantly.

One of the few evergreens that affect stream temperatures, the decline of eastern hemlock will also affect trout and other fish species. In winter time white-tailed deer gather together beneath hemlocks for valuable cover and winter food (Lishawa, 2007).

This majestic tree is threatened with elimination by an invasive species introduced in the USA in 1924, called Hemlock Woolly Adelgid (HWA) or by its scientific name *Adelges tsugae* which is believed to be a native of Asia (USDA- Forest Service Northeastern Area State & Private Forestry Downloaded August 15, 2008 from: <http://www.na.fs.fed.us>).

Because eastern hemlock is highly sensitive to insect defoliation, mortality also occurs with or other pests like hemlock looper (*Lambdina fiscellaria*) or gypsy moth (*Lymantria dispar*). Although gypsy moth and hemlock looper may dramatically erupt and collapse, several years may pass among outbreaks allowing hemlocks to recuperate, while HWA is a chronic stressor and it never leaves the stand (Dennis, 1999).

Discovered in 1936 in Honshu, Japan, HWA was thought in the beginning to be a harmless hemlock inhabitant. Birds, mammals, humans and wind are the known factors that help spreading HWA; HWA may survive up to two weeks without feeding (McClure, 1999).

Two generations of HWA are produced each year, starting with March and April when the females lay an average 280 eggs in small cotton-like clusters in concealed places on hemlock foliage, buds, cones, and stem crevices. These eggs hatch into larvae in April and May (Cheah, 1996). The eggs hatch in response to temperature and the

larvae feed on young hemlock twigs sap until maturity when they become adults by the middle of June (Cheah, 1996). The new generation has 2 types of adults: adults that are winged and they can only reproduce on a special Japanese spruce found in Asia, and that is why they die off, and the other wingless adults that stay on the hemlock tree, feed on the twigs from July through the early fall when they become dormant, resume feeding by mid-October, and grow into the adult stage that they will stay in during the winter time. (Jenkins, 1999).

The destructive power of this exotic pest depends on feeding on the sap at the base of hemlock needles, restricting nutrients flowing to the foliage; this leads to the death of the infested hemlock within 4-5 years of the invasion. Hemlocks infested with HWA gradually lose needles and create overstory canopies that allow more light to reach the understory vegetation and the forest floor. Dying hemlocks lose the role in plant nutrient uptake and evapotranspiration.

HWA in the eastern United States is spreading at a rate of about 20-30 km/year (Chowdhury, 2002). At the moment, the hemlock stands in the southeast US are at the leading edge of the infestation. (Figure1)

Figure1: HWA infestation range in Northeastern United States, where green is the natural hemlock range and pink the HWA observed presence.

1.0. Literature review

1.1. HWA impact on the eastern forest ecosystem

It is estimated that the Adelgids have damaged or killed over half of the eastern hemlocks in the forests of Virginia and New Jersey and have been identified and reported in 15 other states. Infestation with HWA has been found through different parts of the Allegheny National Forest and has been reported in 29 counties in Pennsylvania (Danoff-Burg, 2002).

The spreading of HWA takes place from East to West. HWA invasion front is currently about 4 to 8 years from the thinning site in ANF (Figure 2).

Figure 2: HWA invasion map in the state of Pennsylvania, and the study site in Warren County

The only remaining forest refuge of eastern hemlock which is untouched by the HWA is an area of about 35,000 hectares in the southern Appalachians, but this too is in danger of being infested by natural or human factors with HWA (Lambdin, 2006).

The decline of the hemlock forests will have an ecological, cultural, and economic impact. Eastern hemlock has been exploited in Allegheny National Forest for the last 200 years for construction timber and as a source of tannic acid used in leather tanning. Hemlock trees are used for different products, mostly for paper and mulch, subflooring, light framing, sheathing, roofing and boxes and crates (Herrick, 1980).

Although Hemlock is not a preferred source of lumber source because it has the tendency to splinter, is brittle and is abundant in knots, it is still used in landscaping for its ability of keeping its lowest branches live throughout its life and also for its characteristic to grow in the shade (Harlow, 1957).

Ornamental nursery trade may be responsible for the adelgid's sudden spreading south, since people imported nursery stock from infested areas for their landscape decorative value.

One of the most visible forms of HWA impact will be the decrease in the aesthetic beauty in many of our forests and also in loss of the habitat diversity. When the hemlock dies what comes underneath is not hemlock but hardwood species such as black birch (*Betula lenta*) and red maple (*Acer rubrum*) (Jenkins, 1999).

Thick stands of eastern hemlock offer outstanding wildlife habitat, important cavity value for wildlife, cover to wild turkey and ruffed grouse, outstanding thermal shield and snowfall interception for white-tailed deer and moose in winter time (Frelich, 1985).

One other negative factor related to the loss of the hemlocks is the change in forest ecosystems. It was found that the death of hemlock is related to the disturbance of six species of birds: black-throated green warbler, ovenbird, hermit thrush, blue-headed vireo, acadian flycatcher and blackburnian warbler the death of hemlock trees causing significant changes in the avian population and distribution (Tingley, 2002).

Hemlock trees, because they grow close to ravines, help maintains aquatic habitat integrity and diversity by regulating stream flow and lowering water temperature in the summer days (Evans, 2002). Hemlock trees also create buffer zones around in riparian areas that absorb impacts of factors like increased runoff from urbanization (Welsch, 1991).

1.2. Potential soil impact of HWA

The decline of eastern hemlock may alter the water ecosystems and lead to nutrient and mineral loss of the infested stand. It has been observed that nitrogen (ammonia and nitrate) and Cations (Ca^{2+} , Al^{3+} , and Mg^{2+}) are lost with soil water and stream surface waters in the watershed in time of hemlock decline and its mortality (Yorks, 1999).

The Eastern hemlock mortality that leads to nitrogen losses may cause a major reduction in site nutrient capital and may alter the future forest productivity by diminishing the available nitrogen in the soil.

The rapid decline of hemlock under HWA also results in the higher needle inputs to O horizon, the layer of leaf litter covering many heavily vegetated areas (Nuckolls, 2009).

Foliar nitrogen concentration of infested hemlocks was found to be 20 to 40 % higher than in a regular hemlock stand. This may be one of the reasons why throughfall beneath infested trees contains higher quantities of nitrogen compounds, dissolved organic carbons and cations (Evans, 2006).

In another study, in which stands of hemlock trees were girdled to simulate mortality attributed to HWA, soil water chemistry showed high concentrations of NO_3^- and the majority of cations two to three months later. These elevated concentrations were attributed to increased rates of mineralization and nitrification and fine root mortality (Yorks, 1999). N mineralization and nitrification rates in soil have been found to be higher in HWA infested stands, but whether the increase in soil N turnover rates is a result of or cause for HWA damage has not yet been determined (Yorks, 1999).

Without human intervention, the eastern hemlock forests are probably destined to the loss of the site nutrient capital (Woodsen, 2002).

1.3. Forest soil Nitrogen cycling

Any living organisms, like plants, animals or microbial populations necessitate a constant source of Nitrogen. A vital element, Nitrogen, is required for the synthesis of proteins that make up the cell materials and plant tissue (Eldor, 2007).

Microorganisms in general and plants acquire Nitrogen from the adjacent soil and water, and then animals get the bound form of N from the food they eat (Figure 3).

Figure 3: Forest soil N cycle

Some specialized organisms may attain nitrogen straight from the pool of nitrogen gas in the air, but this requires the organisms to expend more energy, this is because most of the nitrogen in soils is collected within the soil humus in forms that plants cannot use.

Fermentative bacteria breaks down the proteins using protease enzyme into amino acids that acetogens bacteria decompose into acetic acid, hydrogen gas, nitrogen gas released into the air, and carbon dioxide gas.

Although decomposition of organic matter by microorganisms that help recycle nutrients like nitrogen back into the environment takes place somewhat quickly, most of the organic plant-available nitrogen takes years to form.

Plants suffering from deficiency in nitrogen exhibit stunted growth and yellowish leaves. 'Nitrogen robbery' phenomenon happens because of soil organisms that utilise any nitrogen in order to break this down.

A large amount of N may also cause harm to plants, animals, humans and the environment. N accumulation in the edible fruits and foliage of plants may pose potential health risks for animals and humans.

Nitrate and cations diffusion into the surface water can reduce its drinking quality. Blue-baby syndrome (Methemoglobinemia) can be caused by high nitrate found in drinking waters. An environmentally-caused illness in children, methemoglobinemia, arises when infant's blood is not capable to transport sufficient oxygen to body cells and tissue. The excessive nitrates in drinking water are changed to nitrite in the digestive system; the nitrites interact with hemoglobin forming elevated amounts of methemoglobin that is unable to carry oxygen to body cells and tissue. Deprived of oxygen the infant develops a bluish color and later may result in long-term digestive and respiratory problems (Majumdar, 2003).

For the environment the threats imposed by the excess of N in soils is that may be taken away with surface runoff and water moving through soils. The largest part of this N is in soluble forms, such as nitrate and ammonium. The enriched nutrients load into the streams and deteriorate the surface water quality and disrupt the normal standards of the watersheds used for municipal water treatment stations and can cause eutrophication in lakes.

1.4. HWA management strategies

In the last 20 years several strategies have been formulated to stop the spread of the HWA, including: biological control through using releases of the Japanese lady beetle (*Sasajiscymnus tsugae*), whose primary prey is HWA (McClure, 1999).

Insect-killing fungi have also the potential to be used as biological control management strategies because they can penetrate directly through the body wall of an insect and after fungus-induced death, large number of fungus spore are released from the decomposing body to continue the infection cycle. Collected HWA bodies with fungal infection signs from hemlock forest in U.S. and China were culture and resulted in 79 fungal HWA killing isolates, some of the more virulent species isolates were selected and under on-going research (Reid, 2002).

Various treatments have been used in an effort to control HWA spreading including: pesticide injection, horticultural oil, insecticidal soap. These treatments work well on each individual tree treated but are difficult to use or nearly impossible to apply on large backwoods stands (Wallace 2000).

Another strategy is to determine what may cause host potential resistance to HWA and how to use this information to develop HWA-resistant management program. Looking at host resistance will help develop strategies to identify and forecast tree and stand vulnerability. Development of HWA-resistant hemlock stands may be done by analysis of influence of site factors and host plant chemistry on tree resistance.

Thinning of tree stands allow the remaining trees to grow strong and healthy. Thinning contributes to the growth of remaining individual trees within the stand by eliminating natural competition for resources like water, sunlight, and soil nutrients.

Cold winter temperature seems to be one of the nature's management strategies. In northern Connecticut in January 2000, a series of sub-zero nights that followed a period of moderately mild temperatures caused high mortality up to 90% of the overwintering sistens nymphs of HWA (McClure, 1999). It was hypothesized that rain may help reduce limit the HWA invasion by dislocating crawling individuals that will fall on the soil liter where eventually will be prey upon by other insects (McClure, 1999).

Hemlocks are also in danger of heavy defoliation throughout gypsy moth outbreaks and are more likely to be killed than other hardwoods. Complete defoliation may kill up to 90% of the mature hemlocks (McClure, 1995).

Defoliation reduces the photosynthetic area of the tree, and impedes transpiration and translocation within the tree.

The recovery of hemlocks from defoliation is a slow process that may take 3-4 years and it starts with the new foliage growth that has a characteristic golden-green color. Hemlocks weakened by defoliation are vulnerable to other pest attack and especially drought.

1.5. Soil nitrogen mineralization models

Models represent attempts at mathematical characterization of a natural phenomenon that can be fitted to the experimental results. The level of complexity of a

model is determined by the understanding of the natural system to be modeled, by the accessibility of the data and by the way the model will be applied (Sharpe, 1990)

The most important drawback of models that seek to estimate the mineralization of organic nitrogen is that the organic nitrogen pool is large compared to the inorganic nitrogen pool, causing significant errors when estimating the quantity of organic nitrogen available in soil (Adams, 1984).

Several mathematical models for soil nitrogen mineralization were developed in the last 40 years. Most studies evaluated the effects of environmental factors such as soil water content, soil temperature, soil aeration, soil organic matter decomposition rate (Table 1).

Model	Equation	Description	Reference
a) Simple Exponential	$N_m = N_o(1 - \exp^{-kt})$	Considers that N-mineralization is described by only one pool, N_o , which defines the potentially mineralizable N as a function of t and a rate, k.	STANFORD & SMITH (1972)
b) Simple Exponential	$N_m = N_o(1 - \exp^{-kt^b})$	Similar to that described by STANFORD & SMITH (1972), introducing a time exponent (b).	MARION <i>et al.</i> (1981)
c) Simple Exponential	$N_m = N_1 + N_2 - (N_2 \exp^{-k_2 t})$	This model considers the presence of an initial flush of mineralization (N_1) and of the active fraction (N_2) as a function of t and a rate k_2 .	JONES (1984)
d) Simple Exponential	$N_m = N_1(1 - \exp^{-k_1 t}) + k_o t$	The model describes two pools, k_o being the mineralization rate of the most stable pool.	CABRERA (1993)
e) Double Exponential	$N_m = N_o S(1 - \exp^{-ht}) + N_o(1 - S)(1 - \exp^{-kt})$	Considers two pools, where S and (1-S) represent the labile fraction and recalcitrant fraction of N_o , decomposing at a specific rate of h and k, respectively.	MOLINA <i>et al.</i> (1980)
f) Double Exponential	$N_m = N_{oq}(1 - \exp^{-k_q t}) + N_{os}(1 - \exp^{-k_s t})$	The first term describes the readily mineralizable and the second the less readily mineralizable N, decomposing at a specific rate of k_q and k_s , respectively.	INOBUCHI <i>et al.</i> (1985)
g) Hyperbolic	$N_m = N_o t / (t^{1/2} + t)$	Gives an estimate of the half-life of mineralization ($t^{1/2}$).	JUMA <i>et al.</i> (1984)
h) Parabolic	$N_m = At^b$	Used by STANFORD & SMITH to give a pre-estimate of N_o by a non-linear model.	BROADBENT (1986)

Table 1. Eight mathematical models described in the literature for estimating organic N mineralization from: Empirical models to predict soil nitrogen mineralization (Camargo, 2002)

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STUDY 1

2. Soil Nitrogen mineralization model for hemlock stands at the Allegheny National Forest

2.1. Introduction

The first part of the project focused on a Nitrogen flow cycle model for the site in Allegheny National Forest (ANF). My supporting objective of this research is to find out whether selected soil environmental or chemical characteristics determine soil nitrogen mineralization and nitrification rates. The rationale was that by creating a data base before HWA infestation of the stand and continuing gathering data after HWA infestation, with the help of the nitrogen mineralization model overview we can elucidate the stand nutrient vs. HWA cause and effect relationship (Piatek, 2007). The hypothesis driving the rationale is that soils experience a significant increase in net N mineralization in HWA affected stands because of the nutrient-enriched throughfall due to higher foliar N content of infested trees; and higher soil temperature due to increased light from thinning canopies and decomposition in the same time (Figure 4). Further, bacteria are also significantly more abundant on hemlock litter under HWA infested trees, mostly because of progressively higher needle loss and changes in needle chemistry (Stadler, 2006). Nitrogen concentration in litter is the most important factor that also indicates that tree species control spatial N mineralization rates in forest soils (Weihong, 1998).

This study is limited to the modeling of Nitrate and Ammonia pre-HWA as they may help in understanding the environmental risk posed by the invasive Hemlock Woolly Adelgid.

Although applying fertilizers may help the growth and health of uninfected trees, fertilizing with nitrogen may in fact support HWA survival (McClure, 1999). Fertilized hemlock stands become rapidly heavily infested than the ones unfertilized (Hale, 2006).

It was found that high concentrations of Phosphorus and low concentration of Nitrogen in resistant hemlock species sustain the idea that fertilizing with Nitrogen weakens the hemlock own defense. Even further higher concentrations of Nitrogen and Potassium were strongly associated with higher infestation of the tree stands (Pontius, 2006).

Changes in nutrient cycling because of hemlock mortality should be significant, mainly because the increase in nutrient losses that may lead to site nutrient capital reduction should translate by increases nutrient loadings to surface stream water and acidification of soil and stream water.

Hemlock has a preference towards growing close to streams and ravines, which will require minimum effort for future data collection that will look for significantly water degradation of surrounding stream in the proximity of the study site.

Figure 4: Hypothesized relation between hemlock mortality and N and cations leaching

2.2. Methods

2.2.1. Study site

The study was conducted in the Allegheny National Forest, near Warren, Pennsylvania. Part of the Allegheny High Plateau, the area is characterized by high hills, sharp ridges, and narrow valleys with dendritic drainage. Soils in the Allegheny High Plateau are composed primarily from sandstone with rock fragments, mostly well drained with important erosion potential due to steep slopes. The water capacity of the soil is low because of the coarse texture. The climate is cool and humid with an average precipitation of 900 to 1,020 mm, somewhat higher in spring and early summer and lower in winter time. Average annual temperature is around 10 C⁰ (Pennsylvania Department of Conservation and Natural Resources State Forest Resource Management Plan. Water Resources. <http://www.dcnr.state.pa.us/forestry/sfrmp/water.htm>. Accessed 2010 Apr 11).

In Allegheny National Forest there are 57 native trees species and 5 introduced trees that are here organized by leaf shape and arrangement. Wide and Flat: Alternate Arrangement: Cucumbertree Magnolia (*Magnolia acuminata* L.), Black Gum (*Nyssa sylvatica*), RedBud (*Cercis canadensis* L.), Common Sassafras (*Sassafras albidum*), Bigtooth Aspen (*Populus grandidentata* Michx.), Quaking Aspen (*Populus tremuloides*), American Beech (*Fagus grandifolia*), Paper Birch (*Betula papyrifera*), Sweet Birch (*Betula lenta* L.), Yellow Birch (*Betula alleghaniensis*), Black Cherry (*Prunus serotina*), Choke Cherry (*Prunus virginiana* L.), Fire Cherry (*Prunus pensylvanica* L.), Serviceberries (*Amelanchier species*), American Elm (*Ulmus americana* L.), Slippery Elm (*Ulmus rubra*), Common Hackberry (*Celtis occidentalis* L.),

American Linden (*Tilia americana* L.), Red Mulberry (*Morus rubra* L.), Black Oak (*Quercus velutina* L.), Northern Red Oak (*Quercus rubra* L.), Pin Oak (*Quercus palustris*), Scarlet Oak (*Quercus coccinea*.), Chestnut Oak (*Quercus montana*), White Oak (*Quercus alba* L.), American Chestnut (*Castanea dentata*), Sycamore (*Platanus occidentalis* L.), Tulip Tree (*Liriodendron tulipifera* L.), Black Willow (*Salix nigra*), Witch Hazel (*Hamamelis virginiana* L.), Black Locust (*Robinia pseudoacacia* L.), Common Honeylocust (*Gleditsia triacanthos* L.), Bitternut Hickory (*Carya cordiformis*, K.Koch), Mockernut Hickory (*Carya tomentosa*), Pignut Hickory (*Carya glabra*), Shagbark Hickory (*Carya ovata*), Shellbark Hickory (*Carya laciniosa*), Tree Of Heaven (*Ailanthus altissima*), Butternut (*Juglans cinerea* L.) and Black Walnut (*Juglans nigra* L.).

Wide and Flat, Opposite Arrangement: Flowering Dogwood (*Cornus florida* L.), Catalpa (*Catalpa bignonioides*), Norway Maple (*Acer platanoides* L.), Red Maple (*Acer rubrum* L.), Silver Maple (*Acer saccharinum* L.), Striped Maple (*Acer pensylvanicum* L.), Sugar Maple (*Acer saccharum*), Box Elder (*Acer negundo* L.), White Ash (*Fraxinus americana* L.), Black Ash (*Fraxinus nigra*) and Buckeyes (*Aesculus species*).

Needle-shaped or Linear: Eastern Hemlock (*Tsuga canadensis*), Eastern Red Cedar (*Juniperus virginiana* L.), Colorado Blue Spruce (*Picea pungens*), Norway Spruce (*Picea abies* L.), Red Pine (*Pinus resinosa*), Scots Pine (*Pinus sylvestris* L.), Table Mountain Pine (*Pinus pungens*), Virginia Pine (*Pinus virginiana*), Pitch Pine (*Pinus rigida*), Eastern White Pine (*Pinus strobus* L.) and American Larch (*Larix laricina*).

In the experimental design the study area was divided in three blocks, each block contained a number of plots and within each plot there were trees sampled and a tree sister within every 20 feet.

To understand if thinning mixed hemlock-hardwood-white pine stands will help increase the vigor of hemlock trees and also will augment the survivability of hemlock when HWA enters the stand, 6 plots have been thinned and 6 plots have been kept as reference in 2007. Thinning will be referred as treatment (Figure 5).

In this project, randomly selected trees in each plot were studied in 2006 and 2007 with monthly data collection by hand-held soil probe instruments measuring temperature and water content noting the time of sampling and also some of them have been instrumented with station recording equipment called Hobo with recorders inserted at 15 cm soil depth and collecting temperature and water content data continuously (Piatek, 2007).

Distribution of the treatment and reference plots in ANF

Figure 5: Working site near Warren, PA with treatment and reference plots.

2.2.2. Soil sample collection and preparation

Net N mineralization and net nitrification were calculated using the in situ incubation technique, in this method the values of extractable nitrate-N and ammonium-N in incubated soil are compared to the initial (Brye, 2002). Incubations occurred in situ for around one month, starting with May 14, 2007, ending with October 20, 2007 (May-June,

June-July, July-August, August-September and September-October). Soil cores were incubated in the experimental plot in polyvinyl chloride capped tubes, 7 cm in diameter by 30 cm long. The tubes were sharpened to the outside at the bottom to minimize soil compaction in the core throughout installation. Capping the tube successfully prevents rain from leaching nitrogen mineralized inside the tube; enclosing a volume of soil also prevents roots from uptake of mineralized nitrogen.

Samples for the soil ammonia and nitrate concentration were taken at 30 cm soil depth because nitrogen concentrations are different among soil horizons with greatest concentrations originated in the litter layer and diminishing with growing depth and the nitrogen found deeper than 30 cm usually is not significant or available to plants. (Strahm, 2005).

Two samples were taken per tree and there were 4 trees chosen in the reference plots and 6 trees in thinned plots, each block contain 4 plots. There were 3 blocks containing 12 plots. Both samples: incubated and initial have been transported on ice to the laboratory. The two samples from each tree were mixed in the field.

Soil subsamples were taken for soil water content determination; these were initially weighed and then oven-incubated for 72 hours at 70⁰C (Piatek, 2007).

The soil temperature and humidity measurements were also taken from all 4 cardinals' points at each experimental tree at north, south, west, and east at the middle crown point and at the edge of the crown. The DBH of each tree has been measured during early experiment establishment.

2.2.3. Soil Nitrogen laboratory analysis method

2.2.3.1. Determination of Ammonia

Exchangeable ammonia was extracted from air-dried soil samples that were sieved through a 2 mm sieve, using 2 M KCl in a 10:1 solution:soil ratio.

The KCl extract was then filtered and analyzed to find the ammonia concentration using the phenate method that is based on the Berthelot reaction, in which ammonia reacts with alkaline phenol, then with sodium hypochlorite to form indophenol blue. To enhance sensitivity sodium nitroprusside is added and the absorbance is measured at 630 nm and is directly proportional to the ammonia concentration of the sample (Sparks, 1996).

2.2.3.2. Determination of Nitrate

The inorganic nitrate was extracted from the soil samples using 2 M KCl solution in the same time for ammonia and nitrate.

The nitrate was quantitatively reduced to nitrite by passage of the sample through a copperized cadmium column. The reduced nitrate into nitrite plus the original was then determined by diazotizing with sulfanilamide followed by coupling with N-(1-naphthyl) ethylenediamine dihydrochloride resulting a magenta color liquid that its absorbance is read at 520 nm (Sparks, 1996).

2.2.3.3. Soil Nitrogen laboratory analysis method

The apparatus used in ammonia and nitrate soil determination was Lachat QuickChem 8000 Flow Injection Analyzer with AIM-250 Autosampler.

Each sample was run twice, first for nitrate-nitrite and then for ammonia, test showed high reproducibility. Five standards were used to create a standard curve from which the unknown sample concentration was determined.

2.2.3.4. Mineralization rate calculation

The mineralization rate for each month was obtained through the difference between incubated and initial sample both for ammonia and nitrate. The growing season total for ammonia and nitrate was obtained as a difference between the incubated and initial concentration of the soil sample.

Soil water content was calculated as the difference between the soil subsample weight and the weight after oven drying, the average value between two subsamples was taken as the final value.

2.2.3.5. Calculation of the Soil Nitrogen Content

The calculation of soil nitrogen content was done based on: soil nitrogen concentration, horizon thickness, bulk density, percent coarse fragment (% >2mm).

$$M = (T) (Db) (1-G)(10^5) \\ = (T, \text{ cm})(Db, \text{ g x cm}^{-3})(1-G)(F1, 10^{-3} \text{ kg g}^{-1})(F2, 108 \text{ cm}^2 \text{ x ha}^{-1})$$

Where:

M = Soil Mass (kg ha⁻¹)

T = Thickness of horizon (cm)

Db = Bulk density (g cm⁻³)

G = Fraction greater than 2mm (coarse fraction)
F1 and F2 are conversion factors

2.2.4. Statistical Analysis

2.2.4.1. ANOVA

Statistical analysis was conducted using SAS (SAS Institute, 1990), the main effects were thinning treatment (reference, thinning), soil pH, soil organic matter percentage, tree DBH, soil temperature, sampling months. The statistical analysis was carried out based on the hypothesis that there is no significant difference between reference and thinned plots, soil pH, organic matter, DBH, soil temperature, sampling months. A significance level of $\alpha = 0.05$ was considered. Pair-wise comparisons for significant differences between main effects and interaction effects were calculated using Tukey's test.

A significant difference at α level < 0.05 between reference plots and thinning plots would suggest that there is a treatment impact.

2.2.4.2. Multiple regressions

Multiple regression method was used to calculate the rate of nitrogen mineralization. Tree DBH and soil water content, soil temperature, soil organic matter and soil pH are in this study the independent variables, and ammonia and nitrate concentration are the dependent variables.

The regression equation has the form $Y = b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_4 \cdot x_4 + b_5 \cdot x_5 + c + e$, where Y is season total N mineralization rate. The b's are the regression coefficients for the corresponding x (independent variables) terms, c is the constant or intercept, and e is the error term found in the residuals.

2.3. Results

2.3.1. Monthly Ammonia Concentration

The average ammonia concentration by month follows the same pattern for each block (Figure 2, 3, 4). Ammonia concentration has a steady value above zero starting from May-June for the next three months till August-September when a significant decrease can be seen, followed by a return to positive values.

2.3.2. Monthly Nitrate Concentration

The average nitrate concentration by month follows the same pattern for each block (Figure 2, 3, 4). A decrease in nitrate concentration was observed starting from May-June for the next three months till August-September when it increased.

2.3.3. Total Mineralization Rate

Total mineralization rate reflects the same trend as the monthly ammonia and nitrate concentrations (Figure 5).

2.3.4. Total Season Mineralization Rate

Total soil nitrogen concentration for the entire season is 24 mg/kg with 23.7 mg/kg soil ammonia concentration and 0.3 mg/kg nitrate concentration.

2.3.5. ANOVA

The thinning (treatment) is statistically significant ($p= 0.053$). The thinned plots mineralize more total nitrogen, almost 10 mg/kg of soil, approximately 50% than the reference plots (Table 6). The reference plots in block 1 have the lowest seasonal total nitrogen concentration that is significantly different from all thinned plots in all blocks.

2.3.6. Regression

Soil water content, soil temperature, tree diameter at breast height, soil organic matter, soil pH used in this multiple regressions helped obtain a total N mineralization rate for thinned (N_{thinned}) and reference (N_{control}).

$$N_{\text{thinned}} = 3.98 - 0.46 \times \text{DBH} - 2.10 \times \text{O.M.} + 1.88 \times \text{pH} + 0.66 \times \text{H}_2\text{O} + 1.89 \times t$$

and,

$$N_{\text{control}} = 3.75 - 0.47 \times \text{DBH} - 3.44 \times \text{O.M.} + 2.05 \times \text{pH} + 0.37 \times \text{H}_2\text{O} + 2.03 \times t$$

where;

N = Total N Mineralization Rate [mg/kg]

DBH = Tree Diameter at Breast Height [cm]

O.M. = Soil Organic Matter [Percentage]

H_2O = Soil Water Content [Percentage]

t = Soil Temperature [Celsius]

The overall goodness-of-fit measures can be found in Table 8.

R , the measure of association between the observed value and the predicted value shows that is a stronger the linear association for the control model than for thinned

model. The Coefficient of Multiple Determinations, R^2 shows that 60% of the variation for the control model can be explained by the soil water content, soil temperature, DBH, O.M. and pH, while only 43% for the thinned model can be explained by the same variables. Adjusted R^2 also is better for the control model than for thinned model.

2.3.7. Calculation of the Soil Nitrogen Content

$$\begin{aligned} \text{A horizon mass (kg ha}^{-1}\text{)} &= (10 \text{ cm}) (0.9 \text{ g cm}^{-3}) (1-0.15) (10^5) \\ &= 765,000 \text{ kg/ha} \end{aligned}$$

$$\begin{aligned} \text{B horizon mass (kg ha}^{-1}\text{)} &= (20 \text{ cm}) (1.3 \text{ g cm}^{-3}) (1-0.17) (10^5) \\ &= 2265,900 \text{ kg/ha} \end{aligned}$$

$$\begin{aligned} \text{A horizon + B horizon soil nitrogen} &= (765,000 \text{ kg/ha} + 2265,900 \text{ kg/ha}) (21.7 \text{ mg/kg}) \\ &= (3030900 \text{ kg/ha}) (21.7 \text{ mg/kg}) \\ &= 65.77 \text{ kg/ha} \end{aligned}$$

2.3.8. Correlations of growing season total N mineralization rate.

Total N mineralization rate for the growing season grow is higher for soil water content for the reference plots than the thinned ones (figure 12). Growing season total N mineralization rate is diminished for the thinned plots with increasing tree DBH while that relationship is inverse in the reference plots (Figure 13). Soil growing season total N mineralization rate decreases with soil organic matter content both for reference and thinned plots but the decrease is steeper for reference plots (Figure 14).

While for soil pH growing season total N mineralization rate is increasing with a pH in the thinned plots, growing season total N mineralization rate is decreasing with a pH in the reference plots (Figure 15).

Figure 16 shows that growing season total N mineralization rate behave differently with increase soil temperature, for thinned grows and for reference declines.

2.4. List of tables and figures

Table 2: ANOVA table for pH

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between plots	1.626	8	0.203	3.784	0.0009	2.067
Within plots	3.922	73	0.053			
Total	5.549	81				

Table 3: ANOVA table for O.M.

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between plots	27.030	8	3.378	1.001	0.442	2.067
Within plots	246.333	73	3.374			
Total	273.363	81				

Table 4: ANOVA table for DBH.

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between plots	2589.010	11	235.364	2.962	0.001	1.878
Within plots	8581.027	108	79.453			
Total	11170.04	119				

Table 5: ANOVA table for H₂O %

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>Df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Among H ₂ O% within Month	1036.676	28	37.024	2.412	0.0006	1.576
Among Months	185.507	4	46.376	3.022	0.0207	2.452
Error	1718.7	112	15.345			
Total	2940.884	144				

Table 6: ANOVA table for t⁰

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Among t ⁰ within Month	161.541	29	5.570	2.057	0.003	1.565
Among Months	5918.489	4	1479.622	546.536	>0.001	2.449
Error	314.043	116	2.707			
Total	6394.073	149				

Table 7: ANOVA table for average N mineralization

ANOVA						
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1279.53	5	255.906	2.483	0.053	2.533554
Within Groups	3091.83	30	103.061			
Total	4371.37	35				

Table 8: Average N mineralization rate mg/kg for treatment, block and plot sum for season

Treatment / N	Block.Plot	Average N mineralization (mg/kg)	Average block N mineralization $\pm$ SE (mg/kg)	Average treatment N mineralization (mg/kg)
Thinned	1.2	25.6	33.4 $\pm$ 2.0	
	1.3	41.1		
	2.2	27.7	29.7 $\pm$ 3.4	
	2.3	31.7		31.3 mg/kg
	3.1	35.3	30.7 $\pm$ 1.6	
	3.2	26.1		
Control	1.4	18.8	13.6 $\pm$ 2.2	
	1.5	8.5		
	2.5	32.1	30.0 $\pm$ 3.8	
	2.6	27.9		21.7 mg/kg
	3.7	25.0	21.4 $\pm$ 1.6	
	3.8	17.8		

Table 9: Summary statistics output for treatment and control for multiple regression analysis.

Parameter/ Treatment	Thinned	Control
Multiple R	0.3532	0.7545
R Square	0.4311	0.6058
Adjusted R Square	0.3683	0.5856
Standard Error	1.3227	1.0467
P-value	0.023	0.044

Figure 6: Average ammonia and nitrate concentrations for each block, thinned (T) and reference (C) with bars representing $\pm$ S.D.

Figure 7: Total average ammonia and nitrate concentration for Block 1.

Figure 8: Total average ammonia and nitrate concentration for Block 2.

Figure 9: Total average ammonia and nitrate concentration for Block 3.

Figure 10: Total ammonia and nitrate concentration by months with standard deviation

Figure 11: Correlation between soil water content and growing season total N mineralization rate.

Figure 12: Correlation between tree DBH and growing season total N mineralization rate.

Figure 13: Correlation between soil organic matter and growing season total N mineralization rate.

Figure 14: Correlation between soil pH and growing season total N mineralization rate.

Figure 15: Correlation between soil temperature and growing season total N mineralization rate.

2.5. Discussion

In this study we found total nitrogen mineralization rates to be 65.8 kg/ha from May to October for the study site at Allegheny National Forest.

Other studies found nitrogen mineralization rates, exceeding 120 kg/ha/yr in deciduous forest soils of southern Illinois, Indiana, and Ohio. Lower N mineralization rates at 20 kg/ha/yr were found in the coniferous forest soils of northern and eastern Michigan. Wisconsin's forest soils have a close value to the findings in this study, predominantly 40–90 kg/ha/yr, in a coniferous- deciduous forest (Weihong, 1998).

The multiple regression model shows that current rates of mineralization are related to soil water content, soil temperature, tree DBH, soil organic matter, soil pH and will help see the difference between what the normal N mineralization should be and the N mineralization rate after HWA moves in the studied area.

Another important benefit of this study will be, once the HWA moves in, is the knowledge of the efficiency of thinning treatments in augmenting the vigor of eastern hemlock. Ultimately, increased health and vigor of eastern hemlock will help diminish the mortality in stands infested with HWA.

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STUDY 2

3. Soil Nitrogen mineralization prediction maps for hemlock stands at Allegheny National Forest

3.1 Introduction

Estimated prediction of soil total N concentration is one of the most important on-going researches in soil science, recent studies based on sample points and validation showed high prediction accuracy using kriging and cokriging method (Chunfa, 2009).

The supporting objective for this second part of the project is to create maps overlays of the soil nitrogen mineralization rates in the hemlock stands before the infestation. The rationale is that by creating soil nitrogen mineralization prediction maps before HWA infestation of the stand and continuing creating soil nitrogen mineralization prediction maps after HWA infestation we can observe if there is any pattern to the nitrogen concentrations or if they can be associated with any other elements.

In the second part of my thesis I have continued with a series of Nitrogen soil mineralization rates prediction maps by using ArcGIS 9.2 software that will help in detecting the nitrogen loss once the insect invades the site.

3.2. Methods and Data collection

The fitting of the mathematical Ammonia and Nitrate models was done using the GIS software ArcGIS 9.2. with the help of the geostatistical wizard tool. Geostatistics used by ArcGIS software is based on a branch of statistics focusing on spatiotemporal datasets developed to predict probable distributions (Champigny, 1992)

Geostatistics assume that adjoining points are spatially related, based on spatial autocorrelation. Geostatistical Wizard employs the cross-validation technique that removes one or more data locations and then predicts their associated data using the data at the rest of the locations. The prediction maps were made with ARCGIS 9.2 software, using Geostatistical Analyst Extension with Ordinary Kriging Method optimized with Anisotropy.

All the spatial data were obtained from the Pennsylvania Spatial Data Access the layer used are: Pennsylvania county boundaries, Pennsylvania state roads, Pennsylvania Digital Elevation Model - 10-meter, all from U.S. Geological Survey (PASDA, <http://www.pasda.psu.edu/>).

The Digital Prediction Model for Ammonia and Nitrate was manual reclassified in 8 different classes, based on the range of the lowest to the highest concentration of the five months of study.

The maps depict a prediction of the ammonia and nitrate outcomes concentration based on known ammonia and nitrate sample concentrations.

The maps overlays are the elevations contour lines every 10 ft, local country roads and sampling points.

3.2.1. Statistical Analysis

3.2.1.1. Data Analysis

Calculating nearest neighbor index based on the average distance from each feature to its nearest neighboring feature with Spatial Statistics Tools from Arc Toolbox

with Average Nearest Neighbor for each block we found that the pattern of the blocks is random, with the Z values found in table 10.

The Z values describe how many standard deviations above or below the mean our data value is. Positive Z values are above the mean and negative Z values are below the mean.

Trent analysis is providing a 3D perspective of the studied data that helps seeing trends in the dataset, the sample points are plotted on an X-Y plane and the value is given by the height in the Z dimension. Also the value are projected on the X-Z, showed here with the green line and Y-Z plane, showed with the blue line as scattered plots and a polynomial curve is fit through the points of projected planes.

In our study X axes represents North-South, with the positive value being North, and Y axes represents East-West with the positive value being East.

A semivariogram is a statistic that evaluates the average decrease in similarity among two random variable as the distance between those two variable increases (Olea, 1999).

“The Semivariogram or the Covariance cloud shows the empirical semivariogram and covariance for all pairs of locations within a dataset and plots them as a function of the distance between the two locations. Each red dot is the empirical semivariogram (the difference squared plotted relative to the separation distance) between a pair of locations in the dataset.” From ArcGIS 9.2.Desktop Help: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Semivariogram/Covariance_cloud, last modified August 7, 2007

3.2.1.2. Prediction Maps

“Kriging method analyzes the statistical variation in values over different distances and in different directions to determine the shape and size of the point selection area as well as the set of weighting factors that will produce the minimum error in the elevation estimate.” (Cressie, 1991).

“Anisotropy is a descriptor of one aspect of an affine transformation. In two dimensions, this is the ratio of the axes of the ellipse into which a circle is transformed by an affine transformation.” (Slice, 2001)

3.3. Prediction maps results

A significant part of the results is showed as N rates mineralization prediction maps by month and total. Prediction maps were generated for Ammonia and Nitrate.

3.3.1. Data Analysis and Prediction Maps

Figure 16: Trent analysis and Semivariogram for ammonia for May-June.

Figure 17: Trent analysis and Semivariogram for nitrate for May-June.

Figure 18: Trent analysis and Semivariogram for ammonia for June-July.

Figure 19: Trent analysis and Semivariogram for nitrate June-July.

Figure 20: Trent analysis and Semivariogram for ammonia for July-August.

Figure 21: Trent analysis and Semivariogram for nitrate for July-August.

Figure 22: Trent analysis and Semivariogram for ammonia for August-September.

Figure 23: Trent analysis and Semivariogram for nitrate for August-September..

Figure 24: Trent analysis and Semivariogram for ammonia for September-October.

Figure 25: Trent analysis and Semivariogram for nitrate for September-October.

Figure 26: Trent analysis and Semivariogram for total ammonia for season.

Figure 27: Trent analysis and Semivariogram for total nitrate for season.

Figure 28: Trent analysis and Semivariogram for season total nitrogen.

Table 11: Z value and Observed Mean / Expected Mean Distance by block with observation

Block #	Z value (standard deviations)	Observed Mean Distance / Expected Mean Distance	Observations
Block 1	-0.71	0.88	The pattern is neither clustered nor dispersed.
Block 2	1.22	1.21	While somewhat dispersed, the pattern may be due to random chance.
Block 3	1.07	1.17	While somewhat dispersed, the pattern may be due to random chance.

Frequent and widely disperse sampling points create better geostatistical models, because it is possible to find the fine inflexion of patterns. In our study block 1, seems to be the most biased one, while block 2 and 3 value is over the mean, thus more dispersed.

Ammonia prediction map for MAY-JUNE

Figure 29: Ammonia prediction map for May-June

Ammonia prediction map for JUNE-JULY

Figure 30: Ammonia prediction map for June-July

Ammonia prediction map for JULY-AUGUST

Figure 31: Ammonia prediction map for July-August

Ammonia prediction map for AUGUST-SEPTEMBER

Figure 32: Ammonia prediction map for August-September

Ammonia prediction map for SEPTEMBER-OCTOBER

Figure 33: Ammonia prediction map for September-October

Total ammonia prediction map

Figure 34: Total ammonia prediction map

Nitrate prediction map for MAY-JUNE

Figure 35: Nitrate prediction map for May-June

Nitrate prediction map for JUNE-JULY

Figure 36: Nitrate prediction map for June-July

Nitrate prediction map for JULY-AUGUST

Figure 37: Nitrate prediction map for July-August

Nitrate prediction map for AUGUST-SEPTEMBER

Figure 38: Nitrate prediction map for August-September

Nitrate prediction map for SEPTEMBER-OCTOBER

Figure 39: Nitrate prediction map for September-October

Total nitrate concentration from may to october

Figure 40: Total nitrate prediction map

Figure 41: Total Nitrogen prediction map with sampling points. Where the first number represents the block, the second number the plot and the third the tree.

3.3.2. Prediction Maps Results

The spatial prediction maps of total Ammonia concentration show that the highest concentration spread over a wide area that covers: thinned and reference plots, high and low elevations, road proximity but also remote surfaces. Ammonia concentration doesn't seem to be influenced by these factors (Figures 29 through 41).

The concentration prediction map for May-June time period indicates increased levels of ammonia in all sampled points from 6 mg/kg to 14 mg/kg, while the concentration nitrate prediction map tends to be close to zero, with two areas in close proximity showing a contrast in nitrate mineralization rate, in one area we can see an increase in the other a decrease (Figure 29 and 35).

In June-July there are three levels of ammonia concentration, all above zero, with a gradual decrease towards the center of the studied area, the lowest concentration are on the left side of the Henry's Mill road. For nitrate prediction map we can also see that the lowest concentrations are found on the left side of the Henry's Mill road (Figure 30 and 36).

During July-August we can see the highest ammonia concentration, which reaches close to 25 mg/kg. For nitrate prediction map we can see again two areas in close proximity to the road where nitrate concentration is diminished (Figure 31 and 37).

August-September is the month with the highest drop in ammonia concentration, while the ammonia values tend to remain close to zero in the center of the studied area, the edges come close to values of -14 mg/kg. Nitrate prediction map shows a gradual decrease in concentration from East to West (Figure 32 and 38).

In the last sampled time period of 2007, September-October, we can see a rejuvenation of the ammonia concentration with the highest concentration on the North side of the studied area and with the lowest value in the center. The highest nitrate concentration is in the center of the studied area. (Figure 33 and 39).

Total ammonia concentration prediction map shows high concentrations towards the south part where it has values close to 38 mg/kg and gradually diminishes to 2 mg/kg towards the north-east (Figure 34).

For the total nitrate concentration prediction map it can be seen that there are two main peaks whose values are close to 20 mg/kg, low concentration of nitrate in the proximity of these two peaks are as low as -12 mg/kg (Figure 40).

3.4. Discussion

The prediction values concur with the findings in the first study, showing a large decrease in ammonia levels during the time period of August-September at a spatial scale. We can see that the total rate of mineralization for the season reaches close to 40 mg/kg (Figure 41) and there are positive values for the total season ammonia, but the values for nitrate concentration are in great proportion negative meaning that nitrate is lost faster than is produced.

There was no clear association with roads, contour lines or other geographical factors.

Although at this point no spatial correlation or pattern was clearly established in month by month analysis both for ammonia and nitrate concentration, future investigation may reveal the studied area nitrogen mineralization blueprint. Prediction maps will

become increasingly important once the HWA infests the study site and will be visible impacts of N mineralization rates change in forest soil.

3.5. List of tables and figures

Table 11: Mean Error and Root Mean Square Error for ammonia prediction map

PERIOD	ME	RMSE
MAY-JUNE	0.06094	2.641
JUNE-JULY	0.09477	2.974
JULY-AUGUST	0.1556	3.672
AUGUST- SEPTEMBER	-0.2053	4.61
SEPTEMBER-OCTOBER	0.3329	3.984

Table 12: Sampling points with there geographical data reference

POINT	X	Y	ALTITUDE
B1-2-1	-79.03912905600	41.64917386230	536.537
B1-2-2	-79.03968854810	41.64919523620	537.258
B1-2-3	-79.04001711870	41.64878083490	537.258
B1-2-4	-79.04087785630	41.64885199720	536.537
B1-3-5	-79.04042850250	41.65007734760	537.979
B1-3-6	-79.04032037590	41.65051974450	537.979
B1-3-7	-79.04077350160	41.65029150530	537.739
B1-4-5	-79.03863041660	41.65285167380	538.220
B1-5-4	-79.03706467710	41.65266542790	537.018
B1-5-6	-79.03807905500	41.65211515590	537.258
B1-5-7	-79.03792248110	41.65250910540	538.220
B2-2-2	-79.04448458920	41.65600544870	543.507
B2-2-3	-79.04510032390	41.65631700400	544.468
B2-2-8	-79.04418728310	41.65659830070	544.949
B2-2-9	-79.04385745530	41.65614500740	543.267
B2-5-6	-79.04269371180	41.65637433620	537.739
B2-5-7	-79.04245843180	41.65592221640	536.778
B2-6-7	-79.03996179810	41.65367888380	543.747
B2-6-8	-79.03965778650	41.65408280770	537.739
B2-6-9	-79.03940490450	41.65368148220	537.979
B3-2-10	-79.04410036280	41.64229072720	537.739
B3-2-3	-79.04461140740	41.64264997560	534.855
B3-2-9	-79.04356375340	41.64239441140	536.778
B3-7-1	-79.04452658260	41.64812184960	536.537
B3-7-2	-79.04499756170	41.64830943660	534.615
B3-7-3	-79.04580239210	41.64830415600	537.018
B3-7-6	-79.04655676340	41.64848235530	534.375
B3-8-1	-79.04607949780	41.65046199320	538.700
B3-8-2	-79.04583499770	41.65087740030	534.855

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4. Discussion

4.1. Study overview

This study was conducted to assess the nitrogen cycle prior to HWA infestation with the objective to compare and to determine later on the impact of HWA by looking at changes in nitrogen cycle.

The research combined different sampling techniques, statistic analysis and soil chemistry and microbiology to estimate the possible future Nitrogen loss due to the Hemlock Woolly Adelgid infestation.

Although other studies demonstrated that temperature and soil water content significantly affected net soil nitrogen mineralization they were still unable to have good fit of the model, other factors may also influence nitrogen mineralization rates measured in the laboratory and in situ (Knoepp, 2002).

Other aspects that may influence the nitrogen mineralization rates may be the forest composition, tree species and age and the pedology of the area.

While the mineralization rates in this study had increases and decreases in ammonia concentration, other studies on forest soil cycles found a constant ammonia mineralization rate through the same months we studied (Toda, 2000). You never even mention mineralization vs. immobilization. Now is the time.

4.2. HWA disturbance

We also looked if there is a significant impact on the biotic and abiotic components of the Nitrogen loss due to HWA disturbance in the eastern hemlock. Because of the intricate organizational levels of the natural ecosystem the Nitrogen cycle disturbances followed by loss of N may reflect as disarray in soil N outputs, microhabitats environments down to aquatic communities (Snyder 1998).

Because hemlocks are found usually close by riparian zones the problem of N leaching is the main concern. More and more studies on HWA discover an enrichment in ammonium-N availability in the hemlock infected stands mostly because of the augmented needle loss (Jenkins, 1999).

Because nitrogen deposition is expected to increase and surpass the forests soils capacity to take in the overload nitrogen, the significant enhancement in nitrogen will flow from watersheds into streams, rivers and ultimately into the ocean. Recent findings showed that HWA nitrogen loading in rivers and streams raised rapidly (Soehn et al. 1999).

4.3. Nitrogen loss dimensions

Nitrogen forms are an important water quality parameter, but in excess, it can be detrimental to waterways and their ecosystems.

Enriched nutrient loads to streams may alter surface water quality and disrupt management of watersheds used by municipal treatment water (Jenkins, 1999).

A study by Jenkins and others showed nitrification rates over 30 times as high in HWA infested forests than healthy hemlock stands (Jenkins, 1999).

In the U.S., HWA presence was positively identified in 321 counties from 17 states: Connecticut, Delaware, Georgia, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia, West Virginia covering 338,140.24 km² or 33814000 ha.

In this study, the normal output for total nitrogen mineralization in our mixed hemlock-hardwood stands was found to be 65.8 kg N/ha for control. If we look at 30 times this normal nitrogen output we will have 1973.1 kg N/ha, and for the surface of the reported HWA area 66,718,403,400 kg or 66.7 megatons instead of 2,223,946,780 kg or 2.22 megatons.

Further studies will be necessary to confirm these findings and estimates.

4.4. Local impact

Hundreds of miles of streams flow through the Allegheny National Forest and an easy access to river front make a great destination for local anglers.

Tionesta Creek, bordering the study site, is a tributary of the Allegheny River that flows generally south in Forest, Clarion, Warren, McKean, and Elk Counties in Pennsylvania may also be under a potential threat of eutrophication and the first visible signs in watershed of the HWA invasion.

4.5. HWA soil disturbance

Soil ammonium concentrations normally exceeded nitrate concentrations ten times in undisturbed and thinned hemlock stands at the Alleghany National Forest. This indicates that ammonium is not usually limiting nitrification.

The low nitrate concentration in soils can be explained through three principal pathways: denitrification, leaching, and surface volatilization.

Denitrification takes place when nitrate (NO_3^-) is found in the soil and there isn't enough oxygen (O_2) in the soil to supply the needs of bacteria and microorganisms living in the soil. When O_2 concentrations are low, bacteria and microorganisms use the oxygen found in the nitrate and the result is the production of N gas (N_2) or nitrous oxide (N_2O), that in the end will volatilizes from the soil (Garten, 2004). The 3 conditions that generate an environment that promotes denitrification are high temperatures for high activity of soil microorganisms, wet soils and compaction. Most of these conditions can be found at the ANF in the months of August-September, when high temperatures and high activity of are soil microorganisms due to leaves falling and considerable precipitation.

Further more, soil leaching N losses occur when soil moisture is higher than the soil can actually hold. When water moves through the soil, nitrates (NO_3^-) in the soil solution is moved along with the water, while ammonia (NH_4^+) and other close forms of N have a positive charge and are retained by the clay in the soil which has negative sites (Eldor, 2007).

Also the rate of surface volatilization depends on moisture level and temperature, when the soil surface is moist, the water evaporates into the air and ammonia taken in the water vapor and lost. That is why on dry soil surfaces, less ammonia is lost.

Soil N leaching begins to take place when the hemlocks start defoliating losing N into the soil that ends up in streams and rivers, and finally into the oceans.

5. Conclusion

Biocontrol does not appear successful in stopping the HWA spreading and it might take several approaches to impacting the HWA to the level where it can be controlled.

It is necessary to further research to understand the exact biology and specific physiological characteristics of the exotic invaders on their hosts and the related ecosystem processes so we can demystify the direction of habitat change, temporal dynamics, and long time consequences. Mortality in hemlocks already increased siltation, erosion and stream temperatures in riparian zones.

A better understanding of the tree interaction with HWA is paramount to the development of stand management practices to alleviate damages from HWA (Piatek, 2007).

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