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Mapping Hemlock Stand Distribution and Structure in Otsego County, NY to Develop Site-specific Mitigation of Hemlock Woolly Adelgid

Emma Drake
Union College - Schenectady, NY

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ABSTRACT

The invasive hemlock woolly adelgid insect (*Adelges tsugae*, HWA) threatens eastern hemlock trees (*Tsuga canadensis*) throughout eastern North America and is an increasing threat in Otsego County, NY. Different management strategies can mitigate the spread and effect of HWA, but landowners need information on the distribution and characteristics of hemlock stands to inform their decision-making process. We used field sampling of stand structure combined with remotely sensed data to a) map eastern hemlock in Otsego County and b) model stand structural characteristics of these stands. This information will be used to develop and disseminate site-specific recommendations on mitigation options to land owners. During the summer of 2022 we used point sampling (n= 5-10 per stand) to measure basal area and density of all tree species from 21 hemlock dominated stands distributed across the county. Stand total basal areas were between 24 and 54 m^2/ha with relative basal area of hemlock between 37 to 88 %. The majority of the stands were west to north facing and were at elevations ranging from 362m to 557m. Supervised classification was employed with the Semi-Automatic Classification Plugin in QGIS using Sentinel-2 imagery Level 1C ((09/02/2022) and Level 2A (11/06/2021)) on a training set of 81 plots. This classified the vegetation into categories of Cultivated Field, Hay Field, Deciduous Forest, Pine Stands, Spruce Stands and Eastern Hemlock Stands. We were able to map areas of majority eastern hemlock with 97% accuracy. Stepwise multiple regression results showed that Sentinel-2 bands can be used to estimate percent eastern hemlock, total basal area and total density all with more than 70% accuracy. Together a map of land cover classification and hemlock stand structural characteristics can inform land owner's decisions on mitigation of hemlock woolly adelgid either by cultural, chemical, silviculture and/or biological controls.

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INTRODUCTION

Invasive species are one of the greatest threats to the integrity of eastern forests in North America. They can alter species composition, ecosystem function, aesthetic appearance and economic quality of forests (Ayres, Lombardero, 2000). Crystal et al. (2021) estimated that invasive species have cost North America over $26 billion per year since 2010 and an overall cost of $1.26 trillion from 1960 to 2017. One invasive species, hemlock woolly adelgid (*Adelges tsugae*, HWA), is a main threat to eastern hemlock trees (*Tsuga canadensis*) throughout the eastern forests of North America. HWA has caused and is continuing to cause widespread mortality of eastern hemlock (Pontius et al., 2010 and Cornell University). It is imperative that efforts be made to mitigate the effects of HWA with management techniques since eastern hemlocks hold such important ecological and socioeconomic roles.

The rise of HWA is a threat to the important ecological, economic and aesthetic values that eastern hemlocks hold. HWA is a small, aphid-like insect that was first introduced into Virginia from Asia during the 1950's (McClure, 1991). Since then, it has spread to the southern range of eastern hemlocks in northern Georgia and to the northern range in southern Maine. It has not yet spread to northern New York, Vermont, New Hampshire or Maine. In Canada it has only spread to the southern part of Nova Scotia. Its main ways of spreading are from wind, birds, deer and humans (McClure, 1991).

HWA was first identified in New York throughout the lower Hudson Valley and Long Island in 1995 (NYS DEC). HWA has the ability to spread at a rate of 20-30 km per year (Foster, 2000). Since its introduction to New York, it has continued to expand throughout the capital region and westward toward the Catskills and Finger Lakes with the front of infestation running west to east along the midline of the state (NYS DEC).

Once an eastern hemlock is infested, HWA poses a great threat as they feed on the xylem parenchyma cells (water storing cells), which disrupts the storage and transfer of nutrients (Young et al., 1995). Persistent feeding damages the hemlocks (needle loss) and mortality (of buds, branches and tree) usually occurs within 4 to 10 years following infestation (McClur., 1991).

Efforts to mitigate the effects of HWA with management techniques are variable. There are four main ways of managing HWA, cultural controls, silviculture practices, chemical controls and biological controls. It is for the land managers to decide which type of control will be most effective. A combination of these three types of population controls will most likely be needed to significantly reduce populations of HWA but for most situations this will not be practical. Land managers will need to make decisions on treatment based on the conditions of the hemlocks, conditions of the site, the location of the hemlocks and the risk of hemlock mortality (Pontius et al., 2010).

But, before land managers can make this decision, they need to have information on where exactly hemlocks are and where HWA has been detected. Plot based field sampling is the traditional way to obtain this information but as technology has grown scientists are now able to create a landscape-scale coverage of hemlocks and its conditions with the use of remote sensing. Jennifer Pontuis and others have been at the forefront of this research specifically in the Catskills region of New York (Pontius et al., 2005 and Pontius et al., 2010 and Hanavan et al., 2015). Using Pontius's work as a guiding tool, we have worked to use plot based data and remotely sensed data to a) map eastern hemlock distribution in Otsego County, NY, and b) model the structural characteristics of these stands. Together a map of land cover classification and

hemlock stand structural characteristics can inform landowner's decisions on mitigation of hemlock woolly adelgid either by cultural, silvicultural, chemical or biological controls.

Background

The eastern hemlock is a staple tree of eastern forests in North America. Within the United States, they are naturally found throughout New England, New York and Pennsylvania, reaching westwards to the Appalachian Mountains and southwards to northern Georgia and Alabama (Godman & Lancaster, n.d). Beyond the United States they extend north into Canada where they are found in south-central Ontario to southern Quebec and extending through New Brunswick to Nova Scotia (Godman & Lancaster, n.d).

Within their range in North America, eastern hemlock inhibits a range of different sites, soil types and climatic conditions. Eastern hemlock can be found in areas of very moist soils such as swamp and stream borders, as well as areas of drier soils such as steep slopes, ridgetops and ravines. Depending on the location, they can grow at elevations varying from sea level to 730 m (2,400 ft) in their northern zone, from 300 and 910 m (1,000 and 3,000 ft) in New York and Pennsylvania and from 610 to 1520 m (2,000 to 5,000 ft) in the Appalacians (Godman & Lancaster, n.d). When regarding micro-climate, eastern hemlock reside in cool and humid conditions. The northern and southern regions differ in winter temperatures and precipitation levels with northern regions having colder winters and less precipitation than southern regions (Godman & Lancaster, n.d).

Eastern hemlock creates unique environmental conditions in their stands. They are a long-lived and shade tolerant species. Their stands are distinct because eastern hemlock foliage is able to photosynthesize in dense shade which in turn allows them to keep leaves on their lower

branches (Rosenthal & Wildova, 2017). This significantly limits the amount of solar radiation that is able to reach the forest floor which results in little understory and herbaceous vegetation (Mathewson, 2009). These characteristics create a unique microclimate in eastern hemlock stands. Stands are generally cool, dimly-lit and contain moist soils. The microclimate in the summer months is cooler with understory air temperatures being 3 to 4 degrees celsius lower than air temperatures outside of the stand (Hadley, 2000). The microclimate in the winter months is warmer in the understory as the foliage acts as an insulator (Rosenthal & Wildova, 2017). The soils in these stands are low in pH and also have low levels of nitrogen, first because eastern hemlock thrives in these conditions and second because the needles of hemlock are acidic (Mathewson, 2009).

These stand characteristics create a unique habitat for wildlife species (Orwig & Foster, 1998 and Ellison, 2014). Many avian, mammalian, arthropod and amphibian species are associated with eastern hemlock in their regions in the United States (Yamasaki et al., 2000 and Ellison, 2014). Aquatic invertebrates and fish species that live in streams which flow through hemlock stands are also associated with eastern hemlock because of hemlock's ability to keep streams cool (Ellison, 2014 and Snyder et al., 2002). One of the most well known species that is associated with eastern hemlock stands is the white tailed deer (*Odocoileus virginianus*). White tailed deer reside in hemlock stands during the winter due to the low amount of snow cover. Along with the white tailed deer, there are many other species that call eastern hemlock stands home. When it comes to birds, eastern hemlock stands pose as important areas for breeding of black-throated green warbler (*Setophaga virens*), winter wren (*Troglodytes hiemalis*), ovenbird (*Seiurus aurocapilla*) and blackburnian warbler (*Setophaga fusca*) (Yamasaki et al., 2000). During the non breeding season eastern hemlock acts as an important seed source for american

goldfinch (*Spinus tristis*), red crossbill (*Loxia curvirostra*), white-winged crossbill (*Loxia leucoptera*) and evening grosbeak (*Coccothraustes vespertinus*) (Yamasaki et al., 2000). Other species like ruffed grouse (*Bonasa umbellus*), yellow-belliedsapsucker (*Sphyrapicus varius*), great horned owl (*Bubo virginianus*), and overwintering forest birds also rely on eastern hemlock stands (Yamasaki et al., 2000). Twenty-three out of the 32 species of insectivores, hares, and rodents that inhabit northeastern forest habitat use the hemlock forest type (Yamasaki et al., 2000). There are five species that have hemlock as a main preference; snowshoe hare (*Lepus americanus*), red squirrel (*Sciurus vulgaris*), deer mouse (*Peromyscus maniculatus*), southern red-backed vole (*Myodes gapperi*), and porcupine (*Erethizon dorsatum*). Thirteen out of the 14 carnivorous species that inhabit forest habitats in New England also use the hemlock type (Yamasaki et al., 2000). There are 4 species that have a seasonal preference with hemlock; red fox (*Vulpes vulpes*), black bear (*Ursus americanus*), marten (*Martes*), and bobcat (*Lynx rufus*) (Yamasaki et al., 2000). Red-backed salamanders (*Plethodon cinereus*) and red-spotted newts (*Notophthalmus viridescens*) have also been found to have important habitat connections to hemlock stands (Mathewson, 2009). Snyder et al., 2002 showed that streams draining from hemlock stands supported more total taxa of aquatic invertebrates than those draining hardwood from stands. They also found that over 7% of the taxa showed strong associations with hemlock with three taxa found exclusively in hemlock streams. It can be seen that eastern hemlock plays an important role in the lives of wildlife species.

Due to eastern hemlocks' wide range and abundance, distinct stand characteristics and unique associated fauna, this species is considered a foundation species. A foundation species is one that creates and defines particular ecosystems; controls the distribution and abundance of associated flora and fauna; and modulates core ecosystem processes, including energy flux and

biogeochemical cycles (Ellison, 2014). Since eastern hemlock is a foundation species is it important that we do everything we can to conserve this ecosystem.

Along with being a foundation species, eastern hemlock also play an aesthetic and economic role. Hemlock stands are beautiful areas which have been commented on by some of the most famous writers such as Henry David Thoreau, Emily Dickinson and Ernest Hemingway (Rosenthal & Wildova, 2017). These areas are an important part of recreational activities as people just simply like the beauty of hemlocks. Economically, hemlocks have an interesting history. Hemlock bark was previously used during the processing of leather since its bark contains high concentrations of tannin. The tannin was used to make tannic acid which was needed to tan hides (Canham, n.d.). This became a big business and hemlock stands in New York State were devastated, but by the early 20th century eastern hemlock was no longer used for the tanning of hides as tanneries would either import bark or use synthetics, allowing regeneration of stands. Currently, eastern hemlock has moderate usage for wood pulp and lumber.

The loss of eastern hemlock will impact ecological, aesthetic and economic values. As HWA damages more hemlock, the canopies of these stands will begin to open up and let more light in. Orwig and Foster (1998), found an increase in light rapidly supports understory vegetation such as black birch (*Betula lenta*) and red maple (*Acer rubrum*). Consequently, hemlock forests are expected to diminish while deciduous hardwoods increase. This change will have significant ecological impacts especially on the lives of species who depended on hemlock stands. Areas that have hemlocks along streams could also be significantly impacted. A study done by Jenkins and others found that inorganic nitrogen availability and nitrification rates increased with HWA infestation and hemlock mortality which suggests that nitrate leaching is likely to occur in regions experiencing hemlock mortality. This could significantly impact the

productivity of streams and the quality of the water (Ward et al., 2004). The mortality of hemlocks will change the iconic look of eastern forests. Once beautiful hemlock forests will be damaged and forever changed.

HWA is very tiny (less than 1.5 millimeters) and is a dark reddish-brown to purplish black color (Ward et al., 2004). It gets its woolly name because of its wool-like wax filaments which protects the insect and its eggs from desiccation and natural enemies (Ward et al., 2004). This woolly appearance is visible from late fall to early summer. HWA is unique because it goes through two complete parthenogenetic (all-female) generations a year (Young et al., 1995). There are the sistens (winter generation) and the progrediens (spring generation;McClure, 1989). The winter generations development lasts from early summer all the way to mid spring while the spring generations development lasts from spring to early summer (Ward et al., 2004). The spring generation adults produce offspring midsummer, which hatch in late summer. At this point the offspring enters a summer dormancy period which lasts from late summer to mid fall, this is why no woolly appearance is seen during this time frame. A portion of the spring generation adults don't produce offspring right away, instead they develop into winged adults that leave the hemlock tree and search for spruce trees to begin sexual reproduction. However, in North America, the right species of spruce does not exist, therefore the winged adult offspring are not able to survive (McClure, 1989). But, the other offspring does survive and breaks dormancy in late fall to early winter and completes the life cycle. The two-all female generations a year and absence of a natural enemy allows the HWA to greatly increase in population every year and become more threatening to eastern hemlocks across their range.

There are four main ways to control HWA: cultural, silvicultural, chemical and biological control. Cultural control methods can vary. A reduction in the chance for invasion by HWA is the

first cultural control. An example of this would be the decision made by states to quarantine their hemlock products such as logs, firewood and seedlings (Ward et al., 2004). This requirement can help limit the spread of HWA to areas that have not been infested yet, like Wisconsin and south-central Ontario to southern Quebec. Another example would be the removal of bird feeders in areas where hemlocks live. This can help lessen the spread of HWA since birds are known to spread HWA (Ward et al., 2004). Another cultural control would be the attempt to improve tree health. Examples of this would be the pruning trees or silvicultural intervention. One misconception is that Nitrogen fertilizer would help hemlocks to fight against HWA. This has proven to be untrue as this type of fertilization actually increases the abundance of HWA as it helps them to survive and reproduce (McClure, 1991). A third cultural control would be the mechanical removal of adelgids. This could be done with the use of a high water pressure system or by cutting heavily infested twigs from branches (McClure, 1995). The final cultural control could be the planting of resistant hemlock species. Other species of hemlock are much more resistant to HWA compared to the eastern hemlock (McClure, 1995). Though, the long term success of these different species is unknown in the north eastern regions (McClure, 1995). This option would be put more towards an ornamental landscape (McClure, 1995). Cultural controls vary and may only have small impacts on control of HWA. But cultural controls include simple tasks that homeowners can do independently.

Silviculture practices includes the initiation of regeneration to another native coniferous species. This regeneration could possibly mitigate the negative impacts from loss of eastern hemlock. This option would be best in areas where eastern hemlock is declining severely. Some native coniferous options would be Red Spruce (*Picea rubens*) and White Spruce (*Picea glauca*).

Chemical controls are another way to control the populations of HWA. Chemical control is the use of pesticides to limit or diminish populations of pests. Pesticides have been known to be effective in controlling HWA but high costs, the need for frequent applications and impacts on other organisms and the environment can limit the use of this type of control. The availability of this method varies; some insecticides can be used by homeowners while others can only be used by a licensed arborist (McClure, 1995). Neonicotinoids, a type of insecticide, is known to successfully control HWA by means of soil drench, soil injection and trunk injection Havill et al., (2014). It is important that they only be applied to trees that are still relatively healthy since these treatments rely on the flow of sap (McClure, 1995). The more damaged the tree, the longer it will take for the insecticide to transport through the tree.

Chemical controls are not a practical solution when it comes to hard to access forests and forests which are very large in size. The cost of repeated insecticide application and the potential environmental consequences need to be thoroughly thought about before the decision to use insecticides is made. One consequence that needs to be thought about is the impact the insecticide could have on bodies of water. Since many hemlocks are found along streams, there is a viable concern for leaching.

Biological controls are the final method of controlling HWA and are continually being studied. Biological control is the use of natural enemies such as predators, parasites or pathogens to control the population of pests. Since HWA is a non-native species to North America, it does not face any natural enemies. Efforts began in 1992 as biological control agents from Japan, Canada and China have been studied to see if they can 1) survive in regions of need and 2) control populations of HWA (Cheah et al., 2004).

So far there are three main biological control agents along with a range of pathogens. One of the first potential biological agents was a lady beetle (*Sasajiscymnus tsugae*) which was found in Japan in 1992 (Sasaji, & McClure, 1997). *S.tsugae* was imported, evaluated, mass reared and then cleared for release in 1995. Field release observations in Connecticut have shown that the long-term impact of *S.tsugae* on hemlocks is variable based on site to site.

More exploration for biological control agents occurred from 1995 to 1997 in China. During this period three more lady beetles were deemed potential biological control agents of HWA. These beetles were previously unknown species of *Scymnus (Neopullus)* (Coleoptera: Coccinellidae) and were identified as *Scymnus camptodromus*, *Scymnus sinuanodulus*, and *Scymnus ningshanensis* (Cheah et al., 2004). These three biological control agents were imported and evaluated. There were difficulties with mass rearing so release of *S. ningshanensis* and *S. sinuanodulus* was delayed until 2004 but there were no recoveries of these two species (Havill et al., 2014). Mass rearing of *S. camptodromus* continues with hope of a release (Havill et al., 2014).

The third potential biological control agent was found in 1997 in British Columbia; a small beetle, *Laricobius nigrinus* Fender (Coleoptera: Derodontidae). *L.nigrinus* was evaluated and mass reared with a release in 2003. Studies done by Salom show that establishment of *L.nigrinus* is possible and that it does indeed decrease the population of HWA (Mausel et al., 2010). Two other species of *Laricobius* have also been reported as being predators of HWA, *Laricobius rubidus* and *Laricobius osakensis*. Large scale releases are continuing to be worked on for these beetles.

Overall these methods of control can work together to mitigate the effects of HWA on eastern forests. It is important to know the structure and environmental characteristics of eastern

hemlock stands when determining which method to use. A combination of multiple methods will most likely provide the best results.

METHODS

Using plot based field procedures and remotely sensed data, GIS was used to map the eastern hemlock distribution in Otsego County, NY, which can inform homeowners and land managers in making decisions about mitigation of HWA.

Data Collection/Field Work

Over the summer of 2022 we collected data that would was analyzed in the fall and winter term of 2022/2023. Field work efforts began on June 21st, 2022 and lasted for four weeks. We visited six County Forests, two New York State Forests, six Private Properties, three Clark Foundation properties and two SUNY Oneonta properties which were distributed throughout the county. We visited a total of 21 hemlock dominated stands and took measurements from 130 plots. Within each stand we had a different number of plots depending on the total acreage of the stand (Table 1) following sampling procedures of Zimmerman (2020).

Table 1. Ratio chart of plots in a stand (Zimmerman, 2020)

Hectares	# of Plots
0 - 1.6	3
2 - 2.8	4
2.8 - 4	5
4 - 6	7
6 - 10	10
10.5 - 12	14
16+	15

Plots were placed evenly across a stand prior to on-ground visit using the Gaia GPS app (Version v2023.3). At each plot the date and field team were recorded as well as the GPS waypoint number from the Garmin GPSMAP 64 series device. We also collected the latitude, longitude, elevation, slope, aspect, position (streambeds and flats = 1, benches and toe slopes =

2, gentle midslopes = 3, moderate midslopes = 4, severe upper slopes= 5, and summit and shoulder positions = 6) and health class (Table 2), the latter two follow Pontius (2010).

Table 2. Health classes of eastern hemlock tree

Class	Overall decline status	New growth	Canopy transparency	Fine twig dieback	Live crown
		Percent			
0	Perfect health	> 98	0 to 3	0	> 97
1	Very healthy	96 to 98	2 to 5	-	91 to 96
2	Healthy	94 to 96	4 to 7	5	78 to 90
3	Pre-visual decline	86 to 94	6 to 9		64 to 77
4	Decline first visible	69 to 86	8 to 12	10	52 to 63
5	Early decline	48 to 69	11 to 18	15	42 to 51
6	Moderate decline	23 to 48	17 to 26	20 to 30	30 to 41
7	Severe decline	4 to 23	25 to 40	35 to 45	20 to 29
8	Extremely unhealthy	2 to 4	39 to 64	50 to 60	10 to 19
9	Death imminent	1 to 2	63 to 67	65 to 80	1 to 10
10	Dead	0	> 67	85 to 100	0

Prism sampling was conducted at each plot to measure the basal area and density of all tree species. At the center of the plot a 10 degree prism was used to determine which trees were in our plot and which trees were not in our plot. There were some trees that were border trees and not discernable in the field. Inclusion of these trees would be determined afterwards based on their distance to the plot center and their diameter following the procedure in the US Army Corps of Engineers prism sampling guide. After the trees were determined to be in, out or border, the diameter at breast height (DBH) was measured with a biltmore stick to the nearest 2.5 cm. Height was measured for three canopy trees at each plot and averaged. In addition, canopy cover was measured using a densiometer at the plot center.

Data Analysis

During our data analysis we completed a number of calculations, coding and statistical models. Data was averaged by stand since each stand had multiple plots within it. We used the Density Management Field Exercise from Forest Silviculturist Umatilla National Forest (Powell,

D. C., 2012) to calculate if border trees were in or out. We also conducted a number of calculations to determine basal area, relative basal area, density and relative density with the help of the Prism Sampling Paper (Mitchell et al., 1995). We created a non-metric multidimensional scaling (NMDS) plot in R (version 2022.07.2). We also conducted a stepwise multiple regression analysis in JMP Pro (Version 16.0.0).

GIS/Remote Sensing

We used Sentinel-2 (Level 1C (09/02/2022) and Level 2A (11/06/2021)) images from the Copernicus Open Access Hub (Copernicus n.d.) to complete our analysis in QGIS (Version 3.22 Bialowieza).

With the use of the Semi-Automatic Classification plugin (SCP plugin) we were able to conduct a classification of Otsego County, NY (Congedo, 2021). Using the SCP plugin we clipped and converted our data to surface reflectance before running our classification. We also removed all bodies of water from our data. Our classification was based off of drive by data of pine, spruce and hemlock stands. Drive by data was data that was collected while in a vehicle. Pine, spruce and eastern hemlock stands were identified from the road and were later entered into Gaia. We also used areas of mowed fields, grass fields and deciduous forests. In total there were 81 areas that were used for the classification.

Once these areas are entered into the classification, the plugin completes the land cover classification. The classification was validated by comparing back to the 21 stands that we visited in the summer. 20 out of our 21 stands were classified as hemlock dominated, 95% of our hemlock stands were classified as dominant eastern hemlock.

RESULTS

Field Plots to Characterize Hemlock Stands

Hemlock stands varied considerably in size and structure. Average stand size was 5 ha with relative basal area ranging from 0.37 to 0.88 (Table 4a, b). On average, our stands were composed of 61% eastern hemlock, 10% red maple (*Acer rubrum*), 7% Sugar Maple (*Acer saccharum*), 3% Yellow Birch (*Betula alleghaniensis*), 3% American Beech (*Fagus grandifolia*), 4% white pine (*Pinus strobus*), 4% red oak (*Quercus rubra*) and the last 8% was composed of species that were seen sporadically. Stand 14 had the highest relative basal area of hemlock (0.88), it also is the stand with the largest relative density of hemlock (0.51). The average number of species per stand was 8 with 12 species being the maximum (Stand 6) and 5 species being the minimum (Stand 14 & 21). The stand with the least amount of diversity also happened to be the stand with the largest relative basal area and relative density of eastern hemlock (Stand 14). We can see a trend in the data that stands with less diversity had larger relative basal area of eastern hemlock while stands with more diversity had smaller relative basal area of eastern hemlock.

Table 3. All species that were seen in our 21 eastern hemlock stands.

Species	Scientific name	Code
Eastern Hemlock	Tsuga canadensis	TSUCAN
Red Maple	Acer rubrum	ACERUB
Sugar Maple	Acer saccharum	ACESAC
White Pine	Pinus strobus	PINSTR
Northern Red Oak	Quercus rubra	QUERUB
Yellow Birch	Betula alleghaniensis	BETALL
American Beech	Fagus grandifolia	FAGGRA
White Ash	Fraxinus americana	FRAAME
Black Cherry	Prunus serotina	PRUSER
Black Birch	Betula lenta	BETLEN
American Basswood	Tilia americana	TILAME
Ironwood/Hophornbeam	Ostrya virginiana	OSTVIR
Paper Birch	Betula papyrifera	BETPAP
Norway Spruce	Picea abies	PICABI
White Oak	Quercus alba	QUEALB
American Hornbeam	Carpinus carolinia	CARCAR
Quaking Aspen	Populus tremuloides	POPTRE
Red Pine	Pinus resinosa	PINRUB
Bigtooth Aspen	Populus grandidentata	POPGRA
Shagbark Hickory	Carya ovata	CAROVA
Striped Pine	Acer pensylvanicum	ACEPEN

Table 4a. Relative basal area of each species in each stand with total basal area (m^2/hectare)

Species	ST14	ST17	ST16	ST21	ST22	ST12	ST11	ST8	ST13	ST5
TSUCAN	0.88	0.84	0.84	0.80	0.80	0.78	0.69	0.64	0.64	0.61
ACERUB		0.05		0.07	0.14	0.14	0.12	0.04	0.14	0.22
ACESAC	0.07	0.05	0.01		0.02	0.01	0.02	0.15	0.04	
PINSTR	0.02		0.02		0.004	0.03				0.01
QUERUB			0.04		0.01				0.09	0.01
BETALL		0.03	0.01	0.01		0.02	0.05	0.02		0.06
FAGGRA	0.03	0.01	0.02		0.004		0.08	0.10	0.02	0.04
FRAAME		0.01			0.01	0.01			0.01	
PRUSER		0.01		0.11	0.004	0.02	0.03			0.02
BETLEN			0.05						0.03	0.01
TILAME	0.01			0.01				0.05	0.01	
OSTVIR										
BETPAP									0.03	
PICABI										
QUEALB					0.01					
CARCAR										
POPTRE			0.01							0.01
PINRUB										
POPGRA										
CAROVA										
ACEPEN										
Total BA	44	48	45	47	54	47	42	39	47	39

Table 4b. Relative basal area of each species in each stand with total basal area (m^2/hectare)

Species	ST6	ST10	ST19	ST20	ST18	ST9	ST1	ST7	ST3	ST4	ST2
TSUCAN	0.56	0.55	0.51	0.51	0.49	0.47	0.47	0.47	0.45	0.43	0.37
ACERUB	0.11	0.12	0.18	0.26	0.09		0.02	0.10	0.08	0.17	0.02
ACESAC	0.09			0.07	0.03	0.19	0.19	0.02	0.18		0.23
PINSTR	0.01	0.03	0.09		0.01			0.23	0.16	0.29	
QUERUB		0.26	0.06	0.04	0.08	0.06	0.02	0.06	0.02	0.04	
BETALL	0.07		0.01	0.02	0.08	0.04	0.05		0.02	0.03	0.19
FAGGRA		0.02		0.09	0.03	0.03	0.02	0.03			0.17
FRAAME	0.03		0.02		0.15	0.06	0.11		0.01		
PRUSER	0.01		0.01	0.01				0.01	0.05	0.03	0.01
BETLEN			0.07		0.03	0.01	0.03	0.02			0.01
TILAME	0.03	0.01			0.01		0.08		0.03		
OSTVIR	0.03		0.01			0.14	0.01				
BETPAP	0.02								0.01	0.01	
PICABI								0.06			
QUEALB		0.01	0.03								
CARCAR	0.01				0.01			0.01			
POPTRE	0.01										
PINRUB									0.01	0.01	
POPGRA											0.01
CAROVA						0.01					
ACEPEN										0.01	
Total BA	41	39	50	41	36	35	39	46	39	52	24

Table 5a. Relative density of each species in each stand with total density (trees/hectare)

Species	ST14	ST17	ST16	ST21	ST22	ST12	ST11	ST8	ST13	ST5
TSUCAN	0.51	0.15	0.13	0.27	0.10	0.08	0.18	0.28	0.12	0.14
ACERUB		0.28		0.21	0.07	0.08	0.06	0.11	0.08	0.12
ACESAC	0.15	0.16	0.02		0.60	0.21	0.06	0.05	0.09	
PINSTR	0.04		0.04		0.03	0.02				0.03
QUERUB			0.05		0.03				0.04	0.02
BETALL		0.22	0.34	0.16		0.41	0.09	0.08		0.08
FAGGRA	0.16	0.10	0.11		0.07		0.56	0.42	0.06	0.39
FRAAME		0.06			0.04	0.14			0.04	
PRUSER		0.02		0.24	0.03	0.06	0.05			0.06
BETLEN			0.17						0.10	0.11
TILAME	0.13			0.12				0.05	0.03	
OSTVIR										
BETPAP									0.43	
PICABI										
QUEALB					0.03					
CARCAR										
POPTRE			0.13							0.05
PINRUB										
POPGRA										
CAROVA										
ACEPEN										
Total Density	14	30	45	18	40	54	32	49	52	62

Table 5b. Relative density of each species in each stand with total density (trees/hectare)

Species	ST6	ST10	ST19	ST20	ST18	ST9	ST1	ST7	ST3	ST4	ST2
TSUCAN	0.08	0.13	0.11	0.23	0.06	0.20	0.11	0.04	0.09	0.06	0.14
ACERUB	0.05	0.09	0.05	0.13	0.05		0.05	0.03	0.08	0.04	0.08
ACESAC	0.07			0.22	0.03	0.04	0.1	0.01	0.07		0.10
PINSTR	0.01	0.03	0.02		0.01			0.02	0.03	0.02	
QUERUB		0.08	0.08	0.07	0.05	0.04	0.03	0.08	0.06	0.03	
BETALL	0.04		0.02	0.17	0.07	0.05	0.19		0.33	0.03	0.09
FAGGRA		0.57		0.15	0.05	0.04	0.12	0.02			0.41
FRAAME	0.07		0.49		0.02	0.04	0.07		0.04		
PRUSER	0.03		0.05	0.04				0.05	0.06	0.03	0.04
BETLEN			0.04		0.02	0.14	0.1	0.10			0.06
TILAME	0.05	0.03			0.03		0.06		0.04		
OSTVIR	0.11		0.09			0.39	0.18				
BETPAP	0.04								0.03	0.03	
PICABI								0.04			
QUEALB		0.06	0.04								
CARCAR	0.46				0.61			0.61			
POPTRE	0.01										
PINRUB									0.17	0.05	
POPGRA											0.09
CAROVA						0.06					
ACEPEN										0.70	
Total Density	133	62	125	23	136	65	94	160	77	117	59

Stands also differed in their environmental characteristics (Table 6). We had seven north facing, one east facing, six south-west facing and seven north-west facing stands. Nine of the stands had no to low slope, 1% - 5%, 10 of the stands had a medium slope, 8% - 15% and two stands were severely sloped, 21% - 27%. Stands with a position of 2, which are benches or toe slopes, were the stands that were characterized as being in relatively swampy areas. The rest of

our stands were on midslopes that varied in severity. These stands were characterized as being in ravines or hilly regions. Elevations of stands ranged between 362 m to 557m with only two stands (Stands 20 and 18) being above 609 m. All of the hemlock stands we visited were either perfectly healthy or very healthy (Table 5). Only one stand (Stand 13) was known to have a presence of HWA but no obvious signs were detected.

Table 6. Environmental characteristics of eastern hemlock stands in Otsego County

Stand	Latitude	Longitude	Position	Aspect	Slope	Elevation	Health	Tree Height	Canopy
ST14	42.79	-74.91	3	289	2	500	1	19.3	2
ST17	42.85	-74.85	3	288	5	541	0	21.5	2
ST16	42.52	-75.25	3	305	15	390	0	22.2	1
ST21	42.65	-75.11	2	340	4	503	0	20.5	0
ST22	42.80	-74.91	6	358	5	457	0	24	1
ST12	42.68	-74.91	2	355	3	416	0	26.3	1
ST11	42.69	-74.93	2	331	3	362	1	26.8	1
ST8	42.76	-74.95	3	351	9	528	0	19.4	0
ST13	42.74	-74.89	4	316	15	477	0	18.4	1
ST5	42.60	-75.22	3	84	1	515	1	22.7	1
ST6	42.76	-75.21	3	21	8	505	0	21	1
ST10	42.82	-74.98	4	313	27	541	0	19	0
ST19	42.48	-75.04	3	287	9	478	0	19.5	0
ST20	42.69	-74.68	4	305	15	642	0	21.7	0
ST18	42.69	-74.68	2	299	2	623	0	20	0
ST9	42.80	-74.93	4	12	21	534	1	23	1
ST1	42.64	-74.93	3	314	13	493	1	20.8	0
ST7	42.64	-74.98	2	239	8	518	0	24.7	1
ST3	42.62	-75.02	3	5	10	558	0	23.1	2
ST4	42.62	-75.02	3	216	4	547	0	25	1
ST2	42.62	-74.94	3	227	10	439	0	21.7	2

NMDS plots were used to understand the variation within eastern hemlock stands. Environmental characteristics were added to the NMDS. The length of the arrow shows the strength of association between stands and environmental characteristics.

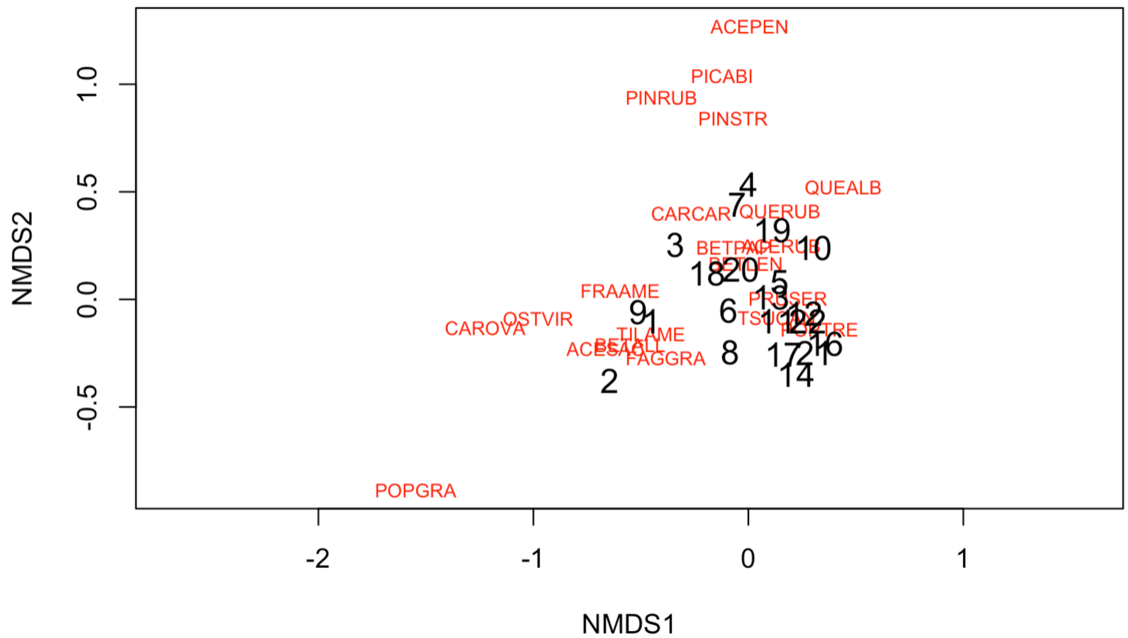

Figure 1. NMDS ordination of the relative basal area of all woody tree species within hemlock stands. The 21 hemlock stands are shown by stand numbers (see tables 4a,b). Species names are shown in table 3. Differences along the first axis are associated with differences in hardwood species. Differences along the second axis are associated with other coniferous species. The high association of ACEPEN with the second axis is due to its presence in a single stand.

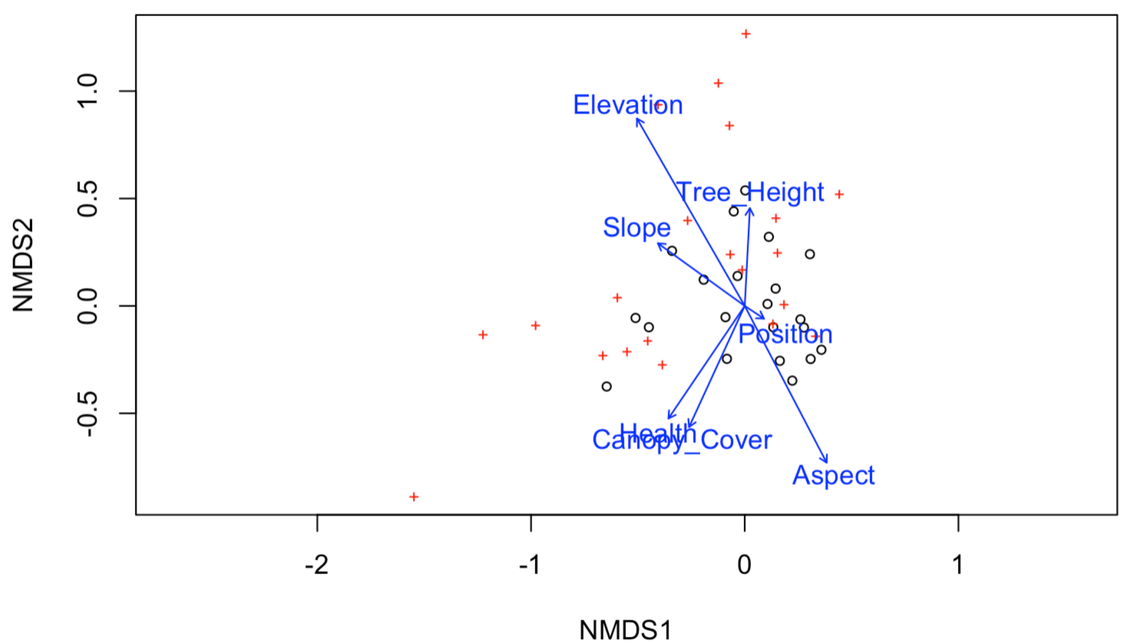

Figure 2. NMDS ordination of the relative basal area showing associations with environmental and tree canopy variables. The black circles and red crosses represent the stand number and tree species from Figure 1. The first axis does not have a strong association with any of the

environmental or tree canopy variables. The second axis shows most association with elevation and aspect.

The NMDS ordination for relative basal area gave us information that hemlock stands vary either because they have more hardwood species or because they have more coniferous species. Elevation and aspect have the strongest association with hemlock stands when it comes to relative basal area.

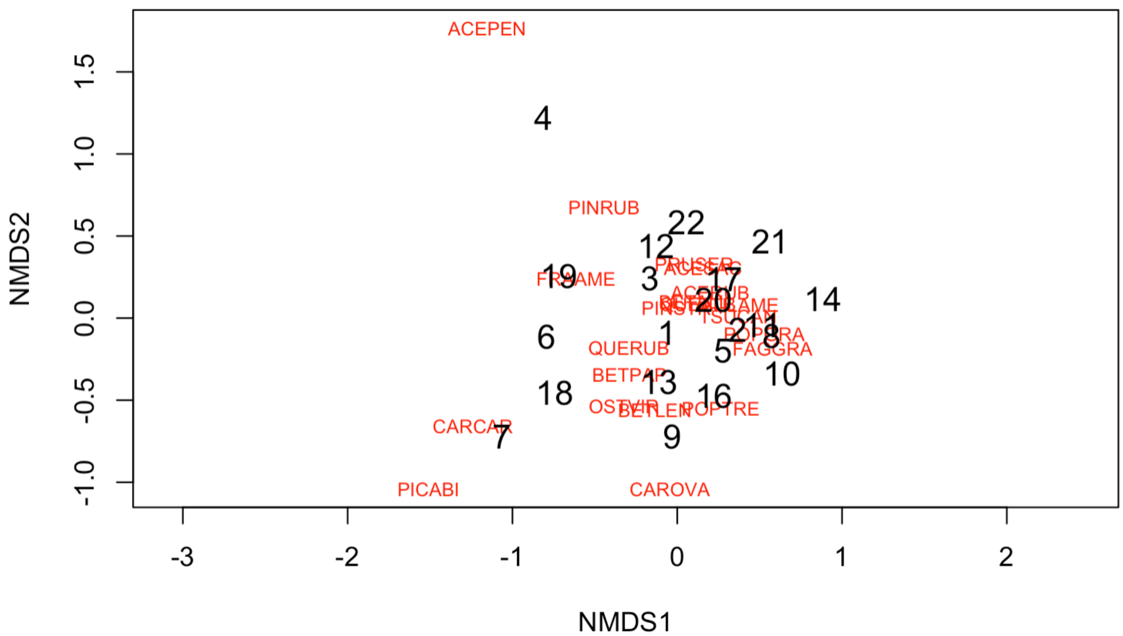

Figure 3. NMDS ordination of the relative density of all woody tree species within hemlock stands. The 21 hemlock stands are shown by stand numbers (see tables 4a,b). Species names are shown in table 3. There are no significant differences along the first axis or the second axis.

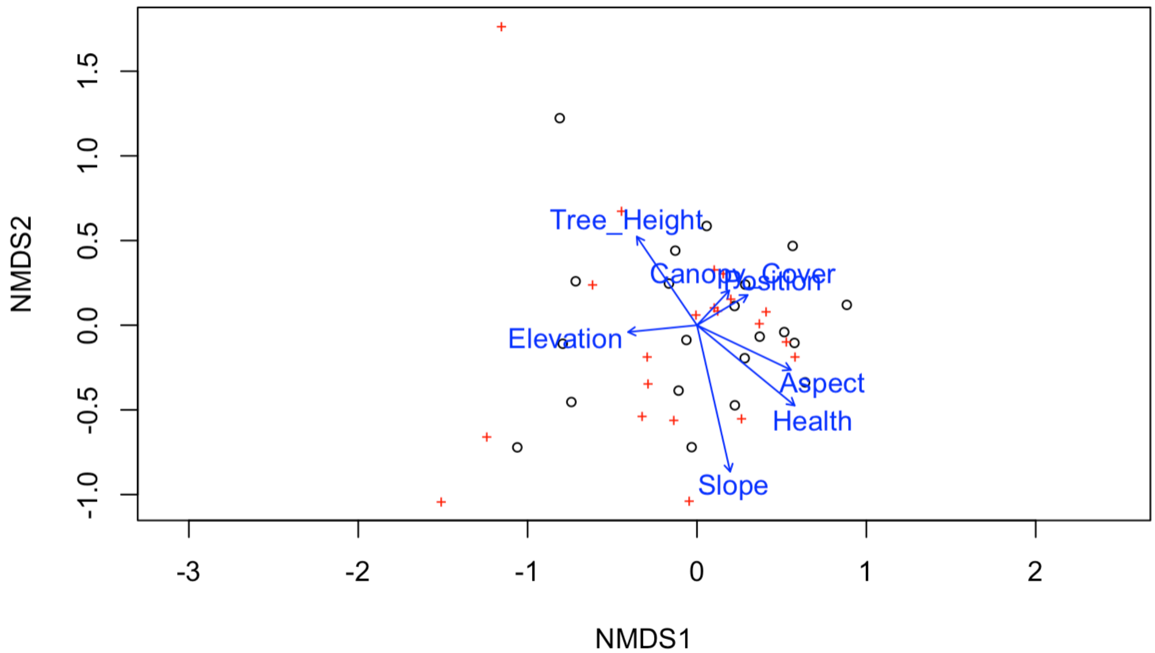

Figure 4. NMDS ordination of the relative density showing associations with environmental and tree canopy variables. The black circles and red crosses represent the stand number and tree species from Figure 3. The first axis does not have a strong association with any of the environmental and tree canopy variables. The second axis shows most association with tree height and slope.

The NMDS ordination for relative density didn't really give us too much information. This could be because density is an ever changing variable and depends on many factors. So it would be difficult to recognize a significant pattern. Tree height and slope have the strongest association with hemlock stands when it comes to relative density.

QGIS SCP Land Cover Classification

Of stands that were >37% hemlock (21 stands), classification shows 20 out of 21 of them are hemlock dominated. The classification classified areas that are majority eastern hemlock in Otsego County with 95% accuracy.

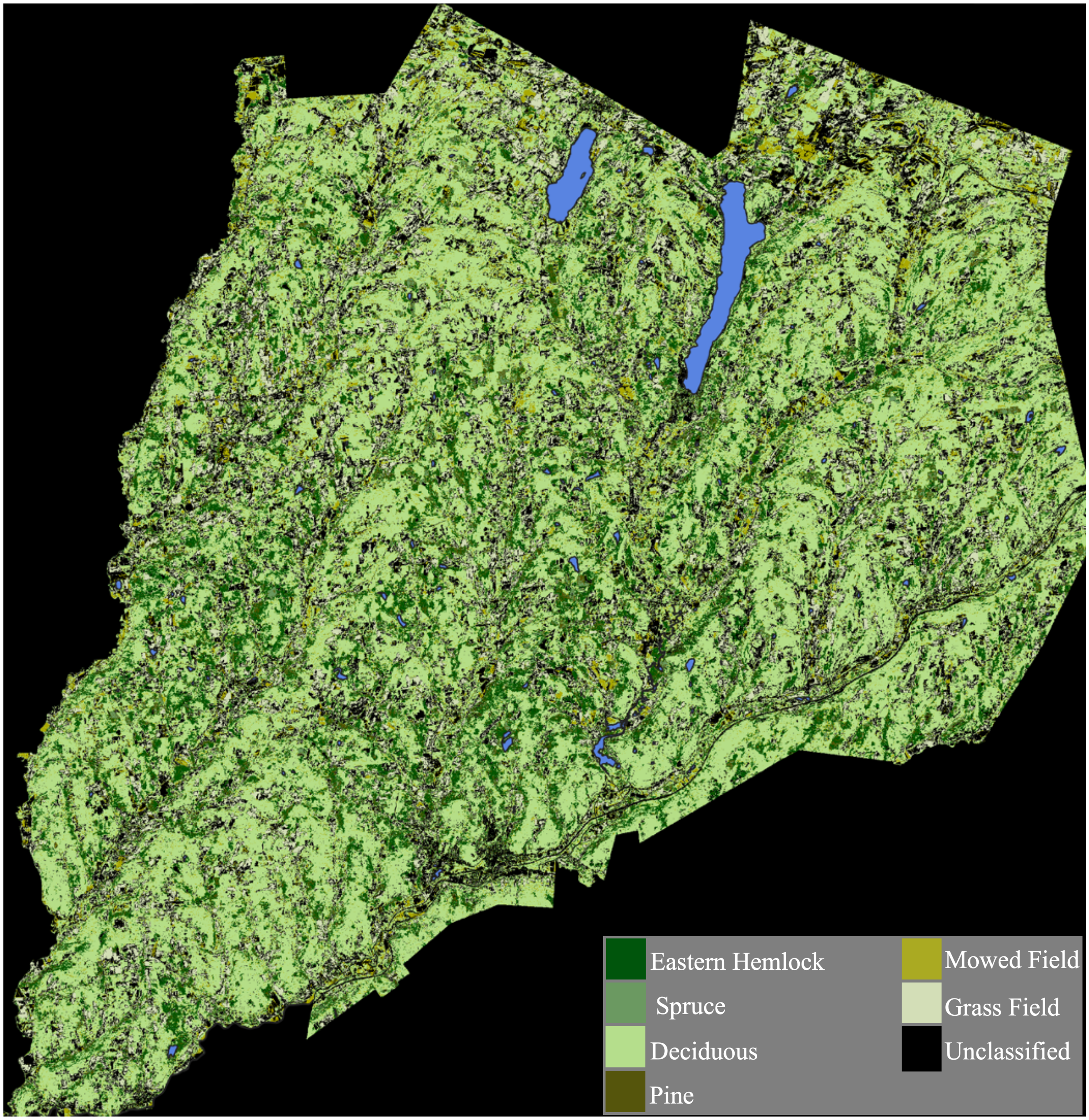

Figure 5. Land cover classification of Otsego County, NY produced in QGIS with the use of the SCP plugin. Eastern hemlock stands (dark green) comprise 7% of the county land area.

The classification shows that eastern hemlocks are predominantly along the valleys but are also seen in other regions. Deciduous forests make up the majority of forested land in Otsego County with 30%.

Table 7. Percentage of each class in the classification. Blue water bodies are included in the unclassified percentage.

Class	Percentage (%)
Eastern Hemlock	6.98
Spruce	1.25
Pine	2.14
Deciduous	29.58
Mowed Field	4.05
Grass Field	5.17
Unclassified	50.82

From Figure 6 it can be seen that the classification did an accurate job at classifying coniferous areas, deciduous areas and areas of grass field.

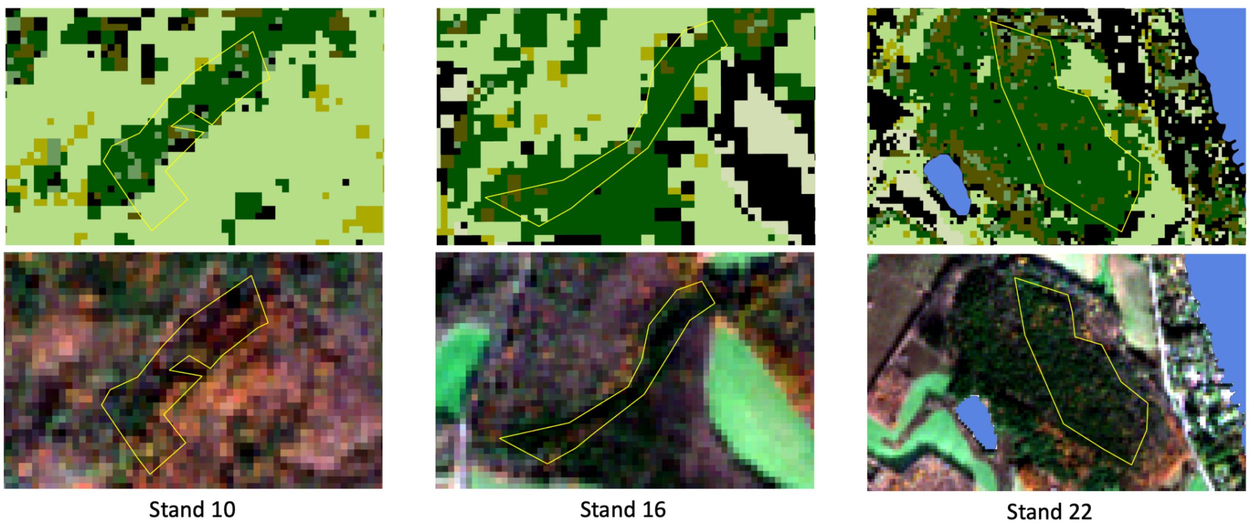

Figure 6. Natural color images of stand 10, stand 16 and stand 22 with their respective land cover classification

Modeling Eastern Hemlock Stand Characteristics

Multiple Regression analysis was conducted to see if eastern hemlock stand structural characteristics are predictable with the use of Sentinel imagery. Multiple regression results showed us that we can use Sentinel band 2 from september ($p = 0.0002$), band 5 september ($p = 0.0004$), band 4 november ($p = 0.0007$), band 12 november ($p = 0.0788$) and band 8A november ($p = 0.0076$) to predict percent of eastern hemlock with 87% accuracy (Table 8). We can also predict total basal area with 71% accuracy and total density with 81 % accuracy (Table 8).

Table 8. Predicted Stand Structural Characteristics. Multiple Regression results from the September and November Sentinel bands which were used for the land cover classification

Characteristic	Model		Predictor Variables		
	P Value	R^2	Variable	Estimate	P Value
NMDS1 relBA	0.0004	0.71	band8Asept_mean	-3.45991	0.0807
			band8nov_mean	-51.41346	0.0172
			band12nov_mean	-18.81107	0.0006
			band8Anov_mean	61.053542	0.0086
			Intercept	0.7333643	0.2348
NMDS2 relBA	0.1064	0.13	band5sept_mean	22.591101	0.1064
			Intercept	-1.33541	0.1071
NMDS1 relDen	<.0001	0.94	band3sept_mean	135.18375	0.0004
			band5sept_mean	-200.6818	<.0001
			band7sept_mean	-253.6867	<.0001
			band8sept_mean	241.81641	<.0001
			band8Asept_mean	16.242584	0.5576
			band2nov_mean	433.94472	<.0001
			band3nov_mean	-390.0157	<.0001
			band8Anov_mean	32.039069	0.0005
			Intercept	3.2940514	0.0024
NMDS2 relDen	0.0795	0.15	band4nov_mean	-29.34228	0.0795
			Intercept	0.9580013	0.0842
Percent TSUCAN	<.0001	0.87	band2sept_mean	68.763322	0.0002
			band5sept_mean	-21.22194	0.0004
			band4nov_mean	-29.07607	0.0007
			band12nov_mean	7.4651931	0.0788
			band8Anov_mean	4.542495	0.0076
			Intercept	0.3264248	0.3823
Total BA	0.0003	0.71	band6nov_mean	9313.3976	0.0045
			band8nov_mean	-6727.972	0.0111
			band11nov_mean	4975.8978	0.0617
			band12nov_mean	-7269.499	0.0259
Total Den	<.0001	0.81	band2sept_mean	-21500.42	0.0732
			band5sept_mean	35854.041	<.0001
			band8sept_mean	-4019.114	0.0013
			band3nov_mean	-20980.02	0.0358
			band5nov_mean	15170.193	0.0025
			Intercept	-644.612	0.0223

DISCUSSION

The combination of field and remote sensing assessments have given us important information on eastern hemlock stands in Otsego County, NY. We now know about the distribution of hemlock in Otsego County, NY. We have also learned about predicting eastern hemlock stand characteristics such as percent eastern hemlock and relative basal area. This information informs landowners and managers about mitigation options for HWA and how to go about choosing the best option for individual sites.

From the field assessment we know that there is variation in eastern hemlock stands. We can compare our results with those found in New England following initial HWA infestation (Orwig and Foster 2002). They found variation among their eastern hemlock stands, which was due to disturbance history such as logging and, also, because of environmental conditions. In the present study, primary compositional variation in stands may have been, in part, due to logging history as two stands that separate along the first axis in the NMDS analysis are both county forests which have been logged in the recent past (Figure 1, stands 1 and 2). Stand 9 is also in this cluster. That could be because stand 9 is an area that has also been logged/cleared as it is used for recreational activities. Orwig and Foster (2002) also observed variation in the historical use of the eastern hemlock stands they visited. Variation along the second axis in the NMDS could be because of environmental factors such as aspect. Some stands are south-west facing (4 and 7) while some stands are north-west/north facing (14, 16 and 21; Figure 1). We did not come across any stands that were east facing Orwig and Foster (2002) also found minimal amounts of eastern hemlock stands on east facing slopes. Eastern hemlocks are not usually found on eastern slopes because they prefer moist conditions. Since the sun rises in the east, eastern slopes are more dry. Our stands had hemlock basal area ranging from 9 to 43 $m^2 ha^{-1}$ while Orwig and

Foster (2002) had hemlock basal area ranging from 19 to 75 $m^2 ha^{-1}$. The variation we found in the eastern hemlock stands of Otsego County, NY present the same types of variation that are seen within other eastern hemlock stands in the New England region.

From the remote sensing we were able to determine where the areas of majority eastern hemlock are in Otsego County, NY. Vegetation and other land covers have unique spectral features such as reflectance, which can be identified from remotely sensed imagery. When conducting our classification we tested two different remote sensing image sources, Landsat 8-9 and Sentinel-2. Our classification ended up using the Sentinel-2 imagery due to it providing better species-level resolution. Initially, Landsat 8-9 OLI/TIRS Collection 2 Level-1 data was used to perform the land classification. Landsat 8-9 consists of 11 spectral bands with a spatial resolution of 30 meters for bands 1-7 and bands 9-11 and 15-meters for band 8. This type of imagery is known to be limited in spatial resolution and is therefore usually used to map broad land cover classes and vegetation at the community level (Xie, 2008). It can be a challenge to use Landsat imagery for mapping at the species level, especially in a heterogeneous environment like a coniferous forest (Xie, 2008). Because of Landsat's coarser resolution (30 meters), it became too difficult to map on a species level to distinguish spruce, pine and hemlock.

Given the limitations of Landsat imagery, we used Sentinel-2 imagery, which has been shown to discriminate vegetation classes better (Phiri, 2020). Sentinel-2 consists of 13 spectral bands with a spatial resolution of 10 meters for bands 2-4 and 8, 20 meters for bands 5-8A and 11-12 and 60 meters for bands 1 and 9-10. Sentinel-2’s finer resolution and additional bands allowed us to map at a species level in a heterogeneous environments with more accuracy than Landsat 8-9. The land cover classification using the Sentinel-2 imagery was able to map areas of

majority eastern hemlock with 97% accuracy. From our classification, 7% of Otsego County is composed of eastern hemlock (Table 7).

Together, the field assessments and the remote sensing can work together to give us important information on eastern hemlock stands in Otsego County. Using both forms of data, a predictive model was created to give us even more information on these stands. By employing a stepwise multiple regression analysis were able to predict three measures with more than 70% accuracy. We are able to predict percent eastern hemlock, total basal area and total density with 87%, 71% and 81% accuracy, respectively. Knowing these measures can be important when it comes to making decisions on mitigation of HWA.

Although these results are promising, we have not yet been able to apply them to our classification. To apply this model to our classification, an equation must be created and then be applied to our classification with the use of a band calculator tool. We would then be able to predict percent eastern hemlock, total basal area and total density for a specific area of eastern hemlock.

Information on hemlock stand distribution and structure can work together to provide landowners with information to inform HWA mitigation options. Landowners can see where areas of majority eastern hemlock are and will soon know other specifications such as percent eastern hemlock, total basal area and total density. Landowners will be able to use the information provided in this report along with information on HWA treatment options from the Cornell University NYS Hemlock Initiative to decide on mitigation of HWA that is appropriate for their stands.

The Cornell University NYS Hemlock Initiative has great tools when it comes to the point of deciding what mitigation option to use for the different eastern hemlock sites. Chemical

controls will most likely want to be used on individual, large hemlock trees. An example of this would be a landowners backyard where there are a few large trees. Chemical controls are not feasible for areas that have a large basal area and large density because this is a costly control. Although biological controls are still in the early stages of research, they are being released only on public lands at the present. In Otsego County, the county forests and NYS forests we visited could qualify to have biological controls released with those of greater extent having priority. Silvicultural practices could be used in a wide range of eastern hemlock stands. These entail thinning or removing hemlock, potentially planting desirable species, in effect, accelerating successional processes. It would probably be most feasible in the county and state forests since these are already areas that are managed on a regular basis. These are just some of the general suggestions when it comes to mitigation of HWA.

Some more specific examples of mitigation of HWA in eastern hemlock stands can come by exploring a few of the stands in our sample. Looking at Stand 2 it has the smallest relative basal area of eastern hemlock, 0.37, as well a low total density, 59 trees/ha^{-1}. This stand is also a stand that has been logged numerous times. If this stand became infested with HWA I would recommend that this stand undergo silviculture practices to either transition the forest to deciduous species like sugar maple or black birch or to initiate regeneration of another native coniferous species such as red spruce. I recommend this because there is already a small relative basal area of hemlock along with a small total density. The likelihood of hemlock trees in this stand surviving infestation is low.

Another stand to consider is Stand 17. This stand has a high relative basal area of eastern hemlock, 0.84, as well a small total density, 30 trees/ha^{-1}. This stand is on private property and is 5.8 ha^{-1} in size but it is part of a larger stand that is 20 ha^{-1} in size. If this stand became infested

with HWA I would recommend that if biological control agents are available, they should be used here. I recommend this because this stand has alot of eastern hemlock so the loss of this species could have profound ecological effects. This stand also has a relatively low density especially of eastern hemlock, 0.15, so HWA would not spread as quickly allowing time for the biological agents to work well.

The last stand to consider is Stand 13. This stand has a high relative basal area of eastern hemlock, 0.64, as well as a relatively high total density, 52 trees/ha^{-1}. This stand is on Clark Foundation property and is 4 ha^{-1} in size. This is the only stand that we visited that is infested with HWA. This stand is located along the edge of Otsego Lake. Because of this stands location, size and low relative density especially of eastern hemlock, 0.12, I think either initiation of regeneration of other coniferous species or release of biological agents would be the best option. This stand is along the lake and is probably providing important ecological services such as cooling streams that may be flowing into the lake and providing habitat for species that may live along the lake. The loss of this stand could have impacts on the lake and the surrounding area. Initiation of regeneration of other coniferous species could help replace the ecosystem services that eastern hemlocks provide. Biological agents could help the hemlocks persist through infestation and allow them to keep providing the important ecological services that they provide.

The results of this study have provided us with valuable information that can be passed on to landowners in Otsego County. It is the hope that landowners in Otsego County will use this map to help them identify areas of majority eastern hemlock. Once landowners see where the majority eastern hemlock is, they can use tools from the Cornell University NYS Hemlock Initiative to choose which stands should be prioritized for mitigation. This report can hopefully

give landowners a glimpse into the mitigation options for HWA. Landowners can use this report as a tool when they are working with land managers to plan the mitigation strategies of HWA.

Although infestation of HWA is inevitable, Otsego County can be well prepared for infestation. The percentage of eastern hemlock in the county is the highest compared to the other coniferous species. This species holds significance in the county and should be managed with care. The mitigation of HWA must occur in Otsego County or a foundation species will surely be lost. There are many resources available to landowners when it comes to making a well informed decision on mitigation of HWA.

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