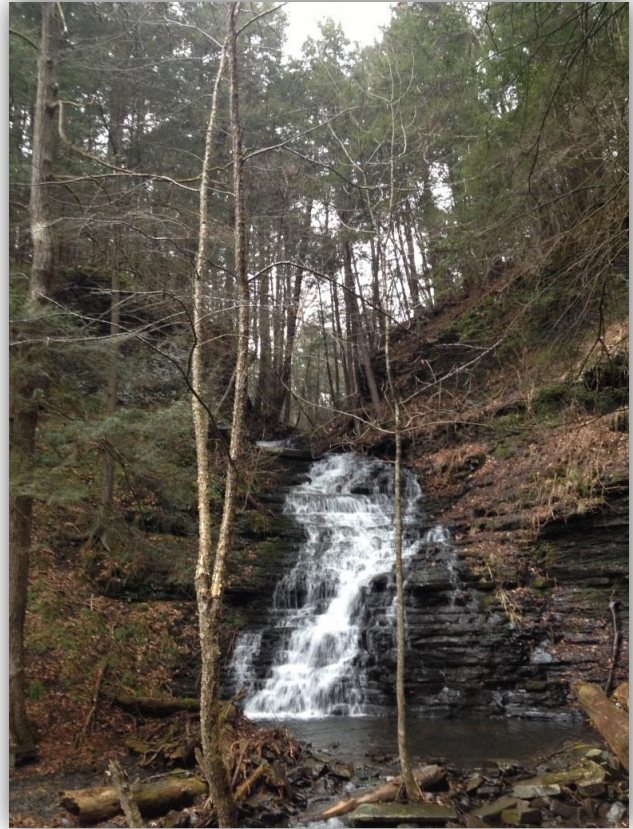


# Facilitating Management of Hemlock Woolly Adelgid in the Catskill Mountains



November 2014



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**November, 2014**

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## Executive Summary

Hemlock woolly adelgid (HWA) is an invasive insect that has caused widespread hemlock mortality in states south of New York and is likely to impact forest and aquatic resources in the Catskill region over the next decade. To facilitate the management of HWA and guide hemlock conservation efforts in the Catskills, this project aimed to map the distribution of hemlock dominated forest in a ~ 700,000 acre study area in the core of the Catskill Park as well as assess the health of 35 hemlock sample stands and determine HWA distribution across the Catskills. HWA bio-control release criteria were also developed and applied to the sample stands.

The study area contained ~ 40,900 acres of hemlock dominated forest (>50% basal area), which is ~ 7% of the forest cover. A disproportionately large amount of the hemlock dominated forest is in stream buffer areas. Thirty three percent of the total hemlock-dominated forest fell in stream buffers (300 feet wide). The East Branch of the Neversink River/ Neversink Reservoir Watersheds had the highest percentage of hemlock dominated forest in the stream buffer at 20% (1,575 acres). A majority (68%) of the hemlock dominated forest is in private ownership. Twenty-two percent (9,231 acres) of the hemlock forest is on land owned by New York State Department of Environmental Conservation (DEC), while 9% (3,777) is on land owned by New York City Department of Environmental Protection (NYC DEP).

Hemlock woolly adelgid was found in 89% of the sample stands and is believed to be widespread in the Catskills. Sample stands in the eastern portion of the Catskills had a higher percentage of sampled hemlock branches infested with HWA. Hemlock elongated scale was found in 40% of the sample stands, primarily in the eastern portion of the Catskills, infecting a high percentage of the trees. Forty-nine percent of the hemlock sample stands were in a “moderate to healthy condition”, while 51% were in “moderately severe to severe decline”. Two stands were found to have high mortality. The “moderate to healthy” stands are primarily found in the East Branch of the Delaware River Watershed.

Hemlock forests in the East Branch of the Delaware River Watershed (western portion of the study area) appear to be healthier and will likely persist longer than the stands to the east, therefore this area may be considered a high priority for hemlock conservation over the long-term. Currently, none of the hemlock forest stands surveyed in the spring of 2014 were suitable for bio-control release. The majority of declining hemlock sample stands are located in the Esopus Watershed, with ~80% stands sampled in the watershed in a declining state (15 of 19). It is likely that severely declining stands will experience substantial hemlock mortality within five to ten years, which may have impacts to ecosystem functions, aesthetic values and recreation.

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## Introduction

Hemlock woolly adelgid (HWA) is an invasive insect that has caused widespread hemlock mortality in states south of New York and is likely to impact forest and aquatic resources in the Catskill region over the next decade. Hemlock is a dominant tree species along riparian areas in the New York City (NYC) watershed and Catskill Park, and is the second most abundant tree species (% of total basal area) on Department of Environmental Protection (DEP) owned lands in the Catskill/Delaware portion of the NYC watershed (NYC FMP 2011). Hemlock-dominated forests have dense shade and acidic soil conditions that create a unique habitat affecting plant and animal species composition, productivity, nutrient cycling, and decomposition. Hemlock forests mitigate water temperature, retain sediments, and mediate hydrology, which influence fish species assemblages and water quality. A study in the Delaware Water Gap National Recreation Area (NRA) found that brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) were two to three times as prevalent in hemlock stands when compared to hardwood streams (Ross et al. 2003). A study in southern Appalachia found that the effect of hemlock die-off and replacement with deciduous species will have a significant impact on the hydrologic flux of forest transpiration, especially in winter (Brantley et al. 2013). Hemlock is also important for recreation, with some of the most unique habitat in the Catskills (i.e. waterfalls, etc.) found in hemlock groves.

HWA was originally detected in the Catskills in the late 1980s and has since spread throughout the region, and as far north as Albany County. HWA is found in all the counties in the Catskill region, but information on its distribution at the landscape scale is lacking. The decline of hemlock stands can take decades after the initial infestation with multiple factors—such as winter temperatures and site conditions—affecting the rate of decline.

Information on the distribution and condition of hemlock stands and their level of HWA infestation is required to guide a comprehensive HWA management approach in the Catskills. Data on the distribution of hemlock forests and status of decline has been limited in the Catskills until recently, when the USFS published numerous GIS datasets for a 700,000 acre area in the heart of the Catskill Park (Pontius et al. 2005). At the same time, the development of biological-control-agents for HWA has been progressing. The Catskill Regional Invasive Species Partnership (CRISP) has expressed interest in the status of the hemlocks in the Catskills and opportunities for biological-control-agent releases. Agencies and organizations need the location and condition of hemlock at the stand scale by ownership, watershed, and distance to streams in order to prioritize management efforts. To facilitate the management of HWA and guide hemlock conservation efforts in Catskills this project aimed to:

1. Summarize the abundance of hemlock dominated forest by watershed, primary landowner and in stream buffers in a ~ 700,000 acre study area in the core of the Catskill Park;
2. Assess the health of 35 hemlock dominated forest stands and determine the distribution of HWA in the Esopus, East Branch of Delaware and Neversink Watersheds;
3. Develop and apply HWA bio-control release criteria; and
4. Discuss implications to conservation and management.

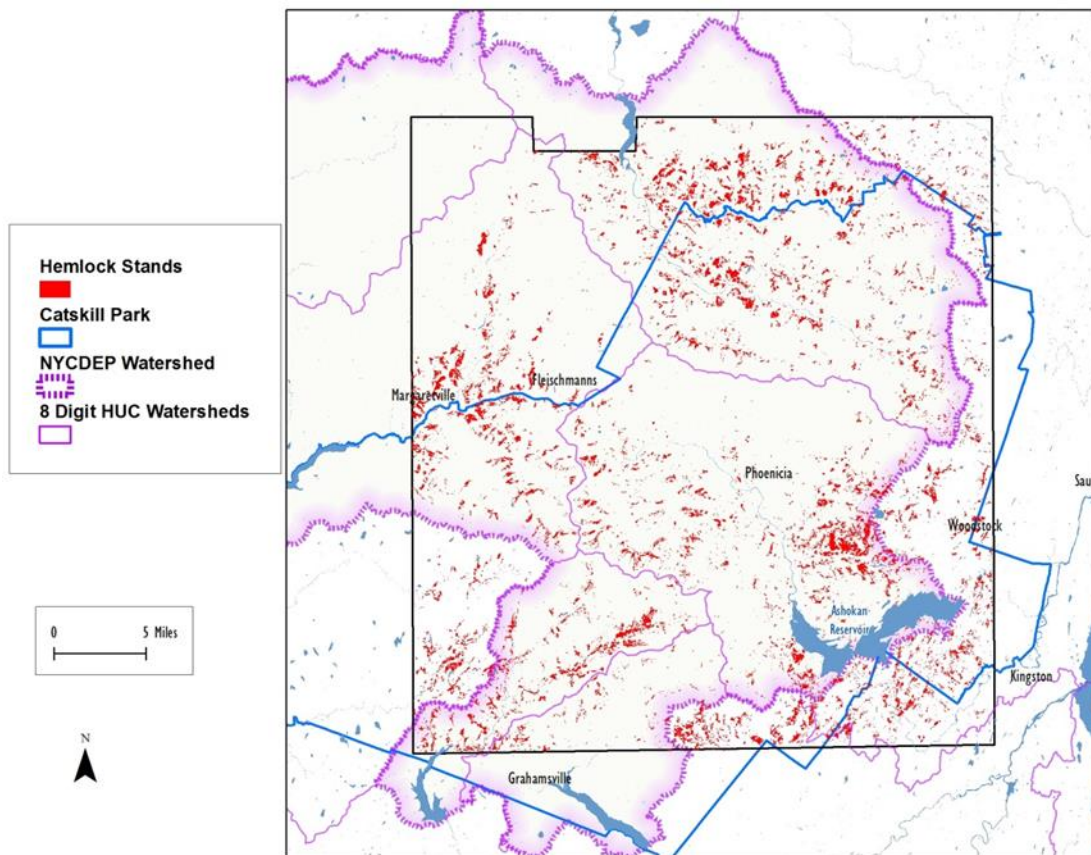
The sections in this report follow the four project goals outlined above.

## 1.0 Abundance and Distribution of Hemlock

Information on the abundance and distribution of hemlock dominated forest is needed to guide hemlock conservation and management efforts in the Catskills. The following section identifies areas with high concentration of hemlock forest and its ownership.

### 1.1 Study Area

In 2001, the USDA Forest Service Northern Research Station (NRS), working with NASA, captured aerial imagery for a 687,273 acre area with Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (Pontius et al. 2005) in the Catskill Mountains. The 2001 study area covers 71% of the Catskill Park (492,655 acres) and 54% of the West of Hudson New York City Watershed (546,433 acres) (Figure 1).



**Figure 1.** Location of the hemlock dominated forest stands in relation to the AVIRIS boundary study area, Catskill Park and NYC watershed.

### 1.2 Methods

The USFS Forest Service-NRS processed the raw AVIRIS imagery to create percent hemlock basal area and decline raster grids (Pontius et al. 2005). Hemlock dominated areas (>40% basal area) were correctly identified with 83% accuracy (Pontius et al. 2005). The Nature Conservancy (TNC) acquired the percent hemlock basal area and decline prediction raster grids from the USFS Forest Service-NRS.

We developed a hemlock dominated forest stand data layer to assess the distribution of hemlock in relation to watershed and ownership boundaries in order to guide field survey and management efforts. A threshold of >50% hemlock basal area (BA) was established for this analysis. From the percent hemlock basal area raster grid, in ArcGIS Spatial Analyst we extracted pixels predicted to have >50% hemlock BA and then reclassified the raster grid to a single value. We then used the low pass filter in Spatial Analyst to smooth the data, removing isolated pixels. Finally, we converted the raster grid to polygons to create a hemlock-dominant forest stand layer.

The predicted decline of hemlock dominated forest stands was summarized using the raster grid, a decline rating developed by Pontius et al. (2005) and the hemlock dominated forest stand datalayer. Decline rating for each hemlock stand and 12 digit hydrologic unit code (HUC) watersheds was summarized using the Zonal Statistic function in ArcGIS. The majority decline value was used to assign a single decline rating for the stand. The mean decline rating was also calculated for each watershed.

To determine the abundance of hemlock in stream riparian areas, a 300 foot stream buffer layer was created in ArcGIS using a hydrography layer acquired from NYC DEP. A stream buffer layer was created only for 12 digit HUC watersheds in the NYC Watershed and had their centroid in the AVIRIS study area.

## 1.3 Results

### Abundance Hemlock Dominated Forest

The study area contains 40,900 acres of hemlock dominated forest (>50% BA), which is 7% of the forest cover (Figure 1, Table 1). There are 29,981 acres of hemlock dominated forest in the portion of the Catskill Park covered by the study area and 30,136 acres in the NYC watershed, which is ~ 7% of the forest cover.

**Table 1.** Abundance of hemlock (acres) in and surrounding 300 ft. stream buffers by ownership and 8 digit Hydrological Unit Code (HUC) Watersheds.

HUC 8 Watersheds	Hemlock (ac)	% Watershed Hemlock	% Hemlock on DEC	% Hemlock on DEP	Hemlock in Stream Buffer (ac)	Stream Buffer (ac)	% Stream Buffer Hemlock
East Branch Delaware River	8,052	5.1	24.9	6.2	2,078	30,074	6.9
Mid -Delaware River/Neversink	3,670	7.5	31.0	7.4	2,098	14,790	14.2
Mid-Hudson River/Esopus	15,262	5.9	26.1	10.0	2,789	41,150	6.8
Rondout - Wallkill Rivers	3,032	7.0	44.8	0.8	264	6,590	4.0
Schoharie Creek	10,876	6.6	6.8	13.4	2,980	43,223	6.9
<b>Grand Total</b>	<b>40,900</b>	<b>7.0</b>	<b>22.6</b>	<b>9.2</b>	<b>10,211</b>	<b>135,827</b>	

## **Distribution of Hemlock Dominated Forest**

Hemlock dominated forest is relatively evenly distributed within the larger 8 digit HUC watersheds in the study area (Table 1). There are, however, differences in the abundance of hemlock dominated forest in smaller 12 digit HUC watersheds (Figure 2, See Appendix 1). For example, 14% of the Lewis Creek-Batavia Kill watershed (Schoharie Creek) is hemlock-dominated forest. Similarly, ~ 11-12% of the Huckleberry Brook, Neversink Reservoir and Beaver Kill-Esopus Creek watersheds are hemlock dominated forest. Eight watersheds in the study area have >10% hemlock dominated forest.

The variation in the concentration of hemlock forest can also be seen by summarizing it by a 1<sup>2</sup> mile grid overlaid onto the study area (Figure 3). There were 89 square miles in the grid with > 100 acres of hemlock dominated forest (> 15% of the grid cell) and 23 square miles in the grid with > 160 acres (>25% of the grid cell). These high concentration areas could be hemlock conservation focal areas.

## **Hemlock Forest in Stream Buffers**

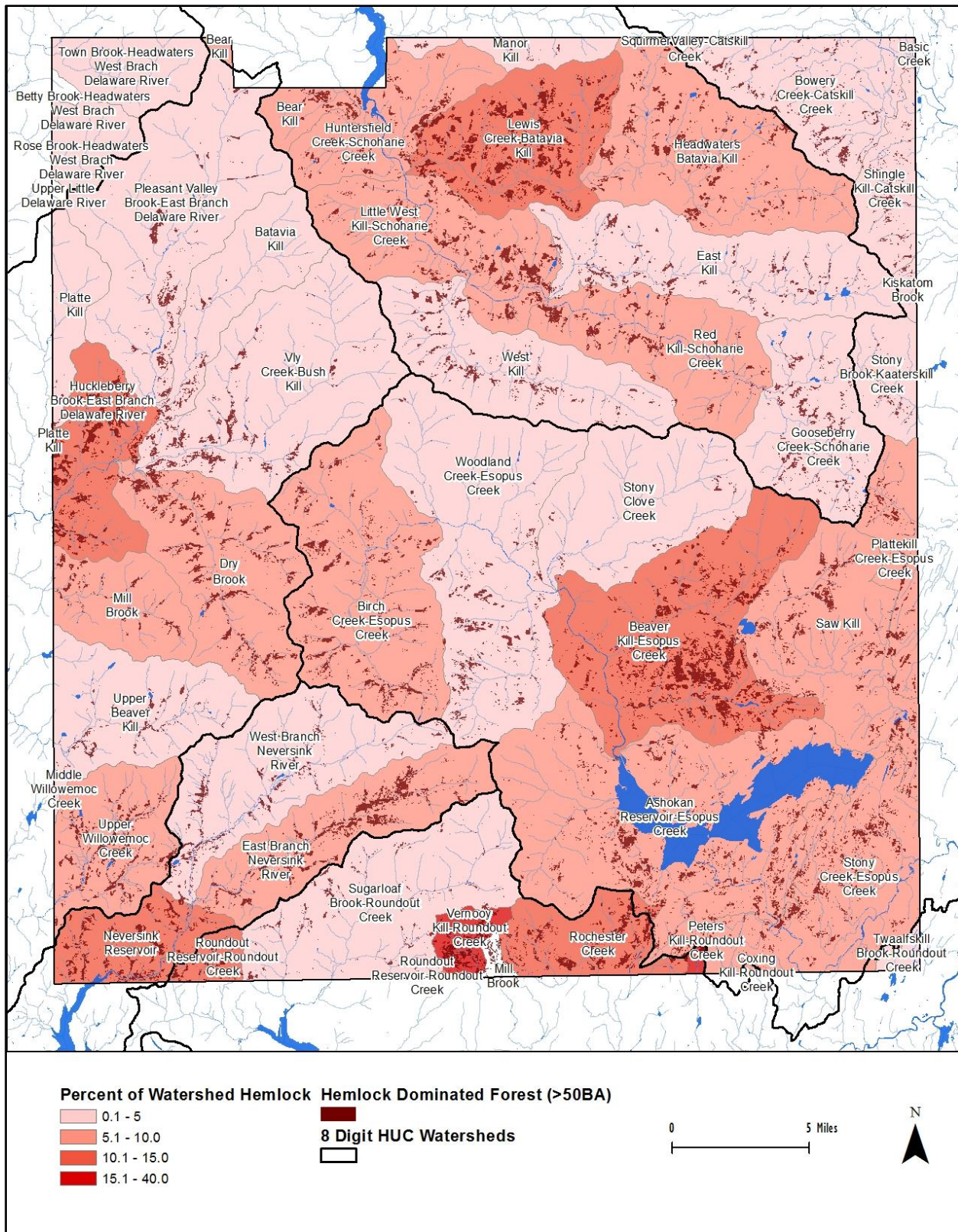
A disproportionately large amount of the hemlock-dominated forest falls in stream riparian buffers. Thirty three percent of the total hemlock dominated forest fell in 300 ft. stream riparian buffers (Figure 3, See Appendix 1). Overall, there were 10,210 acres of hemlock dominated forest in stream riparian buffers, which is ~ 7.5% of total riparian area (135,827 acres). The East Branch of the Neversink River/ Neversink Reservoir Watersheds had the highest percentage of hemlock dominated forest in the riparian buffer at 20% (1,575 acres). The Beaver Kill-Esopus Creek watershed also had a notable amount of hemlock-dominated forest at 1,329 acres (12.7%). Additionally, Dry Brook, Huckleberry Brook, Lewis Creek-Batavia Kill and Little West Kill-Schoharie Creek watersheds had >10% of the riparian area in hemlock dominated forest.

## **Hemlock Forest Ownership**

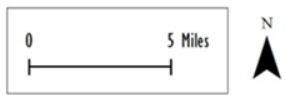
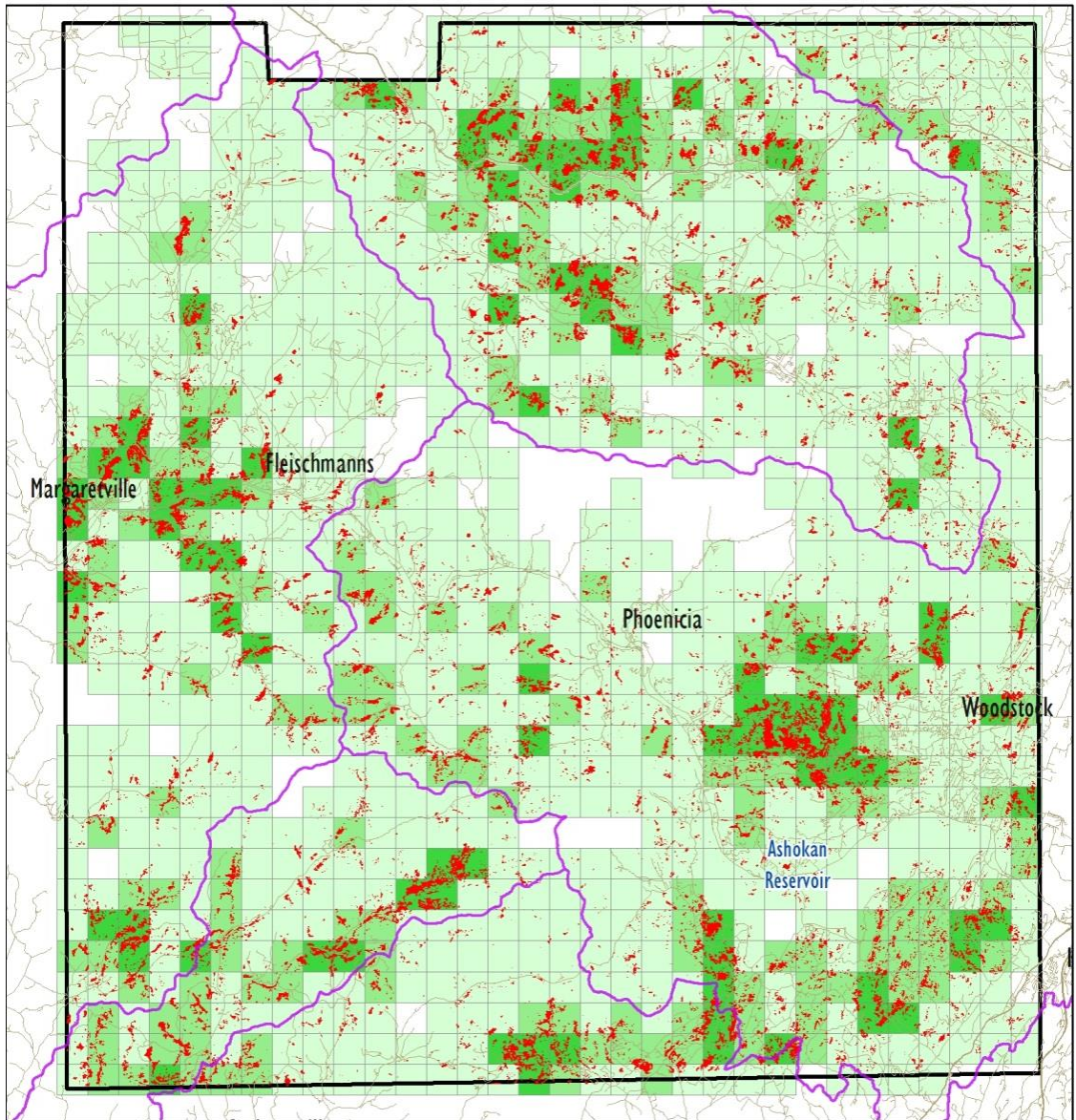
Hemlock woolly adelgid management efforts in the Catskills will be influenced by policies of the agencies and interests of private landowners that own hemlock forests. A majority (68%) of the hemlock dominated forest is in private ownership (Table 1, Figure 5). The Schoharie Watershed had the highest proportion and total amount of the hemlock in private ownership at 80% and 8,679 acres respectively. Twenty-two percent (9,231 acres) of hemlock forest is on land owned by DEC, while 9% (3,777) is on land owned by NYC DEP. The greatest abundance of hemlock dominated forest on NYC DEP lands occurs in the Beaver Kill-Esopus Creek watershed (877 acres, 22% of total area) and Lewis Creek-Batavia Kill (509 acres, 18% of total area). Greater than 70% of the hemlock-dominated forest in the Birch Creek-Esopus Creek, Woodland Creek-Esopus Creek, Upper Willowemoc Creek and Vernooy Kill-Roundout Creek watersheds fall on DEC property, totaling 3,581 acres.

## **Hemlock Decline in 2001**

In 2001, 69% of hemlock dominated stands were predicted to be in the earliest decline stage; with 23% healthy, and 9% in light decline (See Appendix II). There was some variation in hemlock decline among the 12 digit HUC watersheds. Stony Creek-Esopus Creek watershed in the eastern portion of the study area had a high proportion (32%) of hemlock forest area in light decline, while 64% of hemlock forest in Birch Creek-Esopus Creek was healthy (See Appendix II).



**Figure 2.** Percent of 12 digit HUC watersheds containing hemlock dominated forest.



**Figure 3.** Abundance of hemlock dominated forest summarized by a 1 mile square grid in the Catskills.

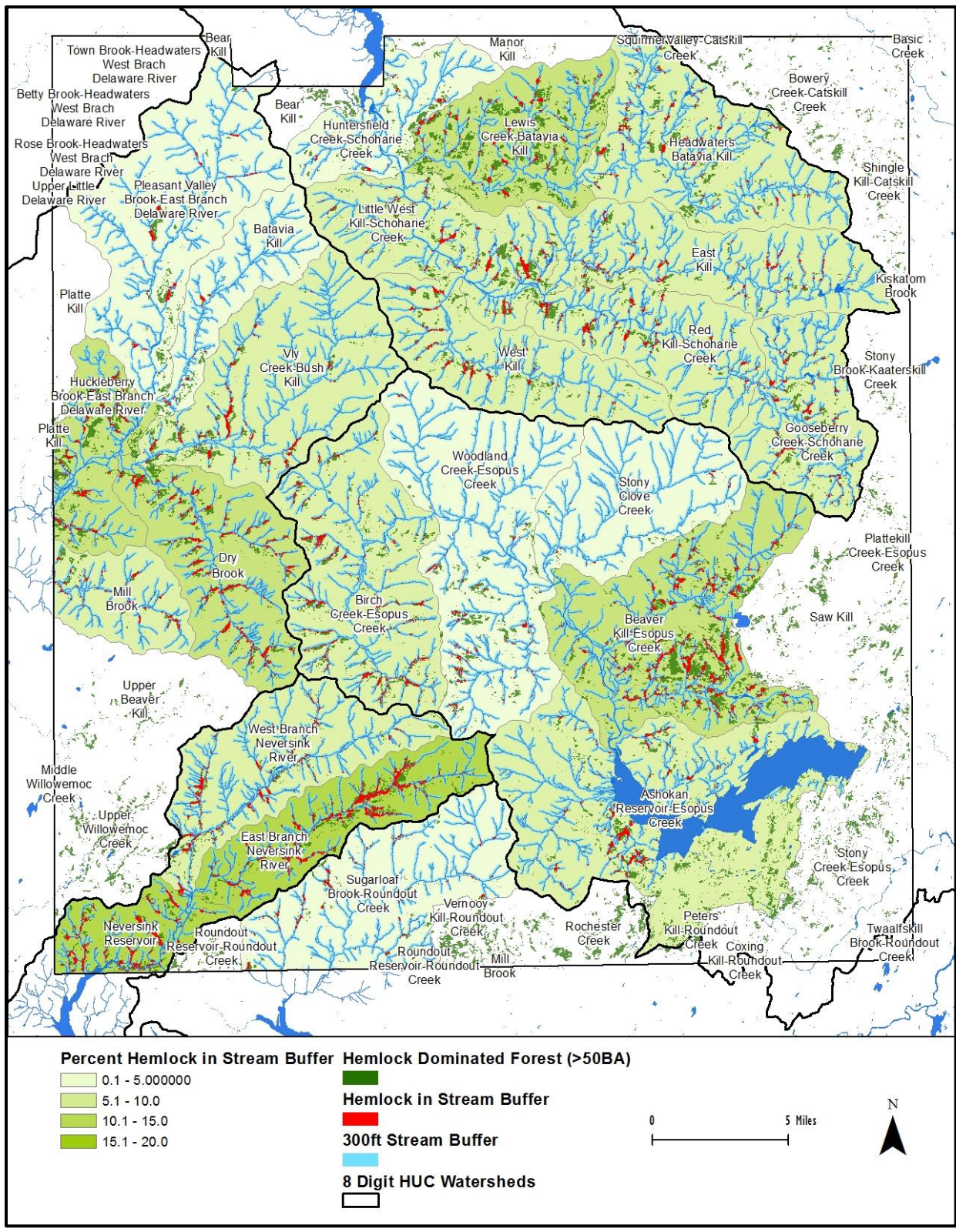


Figure 4. Percent of stream riparian buffers containing hemlock dominated forest by 12 digit HUC watersheds.



## 2.0 Hemlock Forest Stand Survey

We surveyed 35 hemlock dominated stands in the spring of 2014 (April to June) to gain a greater understanding of the status of hemlock forest health and distribution of HWA in the Catskills.

### 2.1 Methods

#### Sample Stand Selection

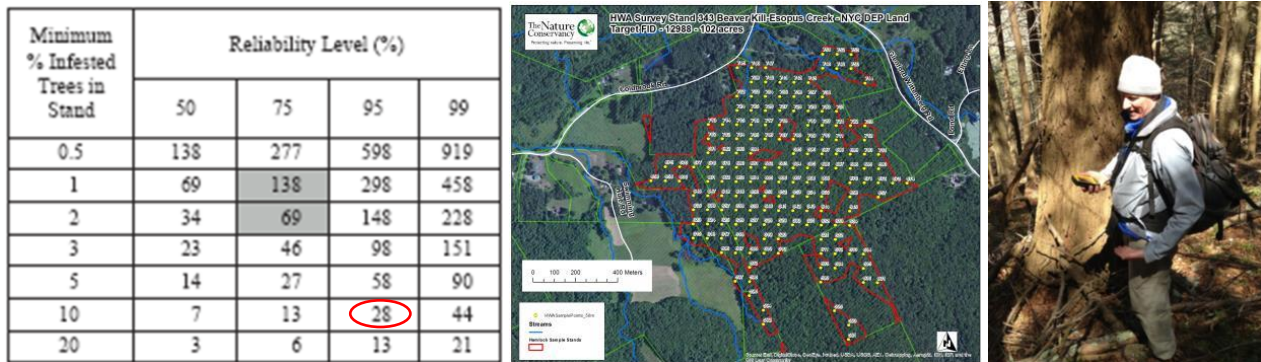
We sampled 35 hemlock forest stands in three watersheds (Esopus, East Branch of Delaware and Neversink) within the larger study area (Table 2, Figure 7). Hemlock stands in the Schoharie watershed were not sampled due to travel expense and the large proportion of hemlock on private property. Hemlock sample stands were selected if they were located on NYC DEP or NYS DEC property, > 25 acres, and < 1 mile from a road. The number of sample stands in each watershed is relatively proportionate to the amount of hemlock forest (Table 1 and 2).

**Table 2.** Number of sample stands by watershed and ownership.

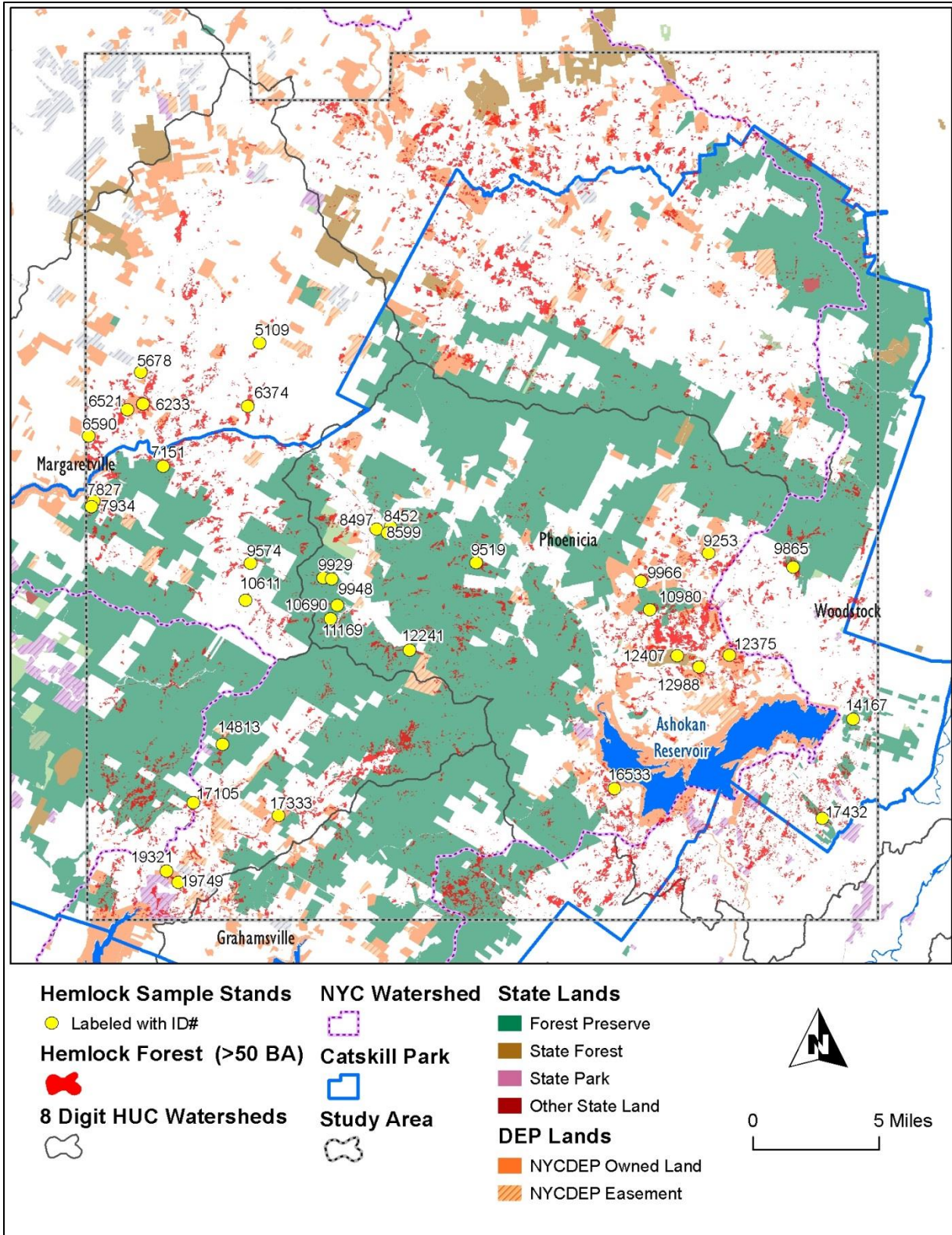
Watershed	NYS DEC	NYC DEP	Private	Total
Esopus	13	5	0	18
East Branch of Delaware	3	7	2	12
Neversink	2	3	0	5

#### Sample design

We modified a sample design developed by the U.S. Forest Service to determine the presence of HWA and assess hemlock health (Costa and Onken 2006). Using the Repeat Shapes extension in ArcGIS we overlaid a 50 meter point grid onto the hemlock-dominated forest stand data layer (Figure 6). In the field, we selected 10 to 20 points to uniformly cover the sample stand. We navigated to the points using a Trimble Juno GPS unit and inspected three understory trees for HWA, totaling 30 to 45 sample trees per stand. With this sample size we had a 95% reliability of detecting HWA in stands with 10% of the tree infested (Figure 6).



**Figure 6.** The table above from Costa and Onken (2006) shows the number of trees that must be searched to detect an infested tree by minimum detection threshold (minimum percent of infested trees) and reliability level (probability of finding a single infested tree). Also depicted is the 50 meter grid overlaid onto a sample stand.



**Figure 7.** Location of 35 hemlock forest sample stands labeled with unique identification number.

## Field Methods

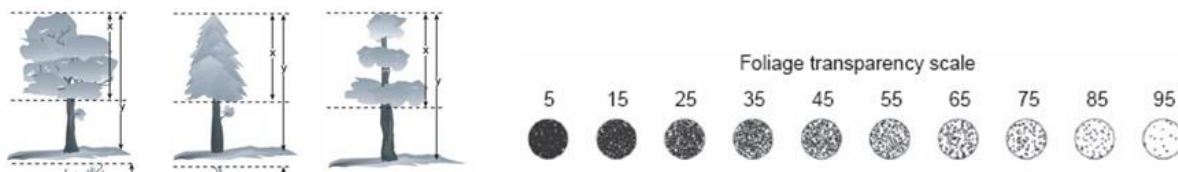
At each sample point we measured hemlock basal area, recorded presence of HWA and elongated scale, and assessed hemlock tree health. We tallied the presence of hemlock, dead hemlock, and other tree species using a 10-factor wedge prism to calculate the % hemlock at each variable radius plot.

To determine the presence of HWA and elongated scale, we selected the three closest hemlocks to the point center that had foliage accessible. On each sample hemlock, the first meter of one branch was inspected for white woolly masses distinct to hemlock woolly adelgid egg sacs. If adelgid was detected, we counted the amount of adelgid egg sacs on the first five lateral branchlets of the branch and assigned the value to one of three abundance classes: Low (1- 19), Moderate (20-39) and High (> 40) (Figure 8). We also searched for the presence of hemlock elongate scale within the first meter of the same branch we looked for HWA.



**Figure 8.** High density of hemlock woolly adelgid egg sacs on the five terminal branchlets and hemlock elongated scale.

To assess hemlock health, we measured uncompact live crown ratio (LCR) and canopy transparency of the two closest canopy forming hemlocks to the center point. LCR was recorded as the percent of the tree height that had foliated branches in five percent increments (Schomaker et al. 2007) (Figure 9). Foliage transparency is the amount of skylight visible through the live, normally foliated portion of the crown. Higher transparency ratings have greater sunlight visible through the crown (Figure 9 and 10). Transparency was measured in five percent increments using a foliage transparency card (Schomaker et al. 2007). Diameter at breast height was also measured for the two canopy forming hemlocks.



**Figure 9.** Figure adapted from USFS (2007) diagram showing how uncompact live crown ratio is measured as a percentage of actual tree length and how foliage transparency scale was used in this project.

### Hemlock Decline Class Rating

To rate the health of hemlock trees and forest stands, we adapted methods developed by Pontius et al. (2004 and 2005). LCR and transparency were normalized from 1–10 (Table 3), then averaged and assigned one of four health class ratings for each tree sampled (Table 4). A hemlock forest stand health class rating was then assigned based on the percent of individuals in one of the four tree health classes (Table 5). For example, 66% of the trees in the stand would need to be rated as “Healthy” for the stand to be classified as “Healthy”.

**Table 3.** Assigned values for transparency and live crown ratio based on Pontius et al. (2004 and 2005).

Value	Transparency	LCR
0	5	95
1	10	90
2	15	85 - 80
3	20	75 - 65
4	25	65 - 55
5	30	50 - 45
6	35	40 - 35
7	40	30 - 25
8	45 - 60	20 - 15
9	65 - 95	10 - 5

**Table 4.** Hemlock health class rating and associated average value of live crown ratio and transparency.

Average	Tree Health Class Rating
1 - 4	Healthy
4.5 - 6	Moderate
6.5 - 8	Severe Decline
8.5 - 9	Near death



**Figure 10.** Hemlock trees in the background with high transparency and rated as near death.

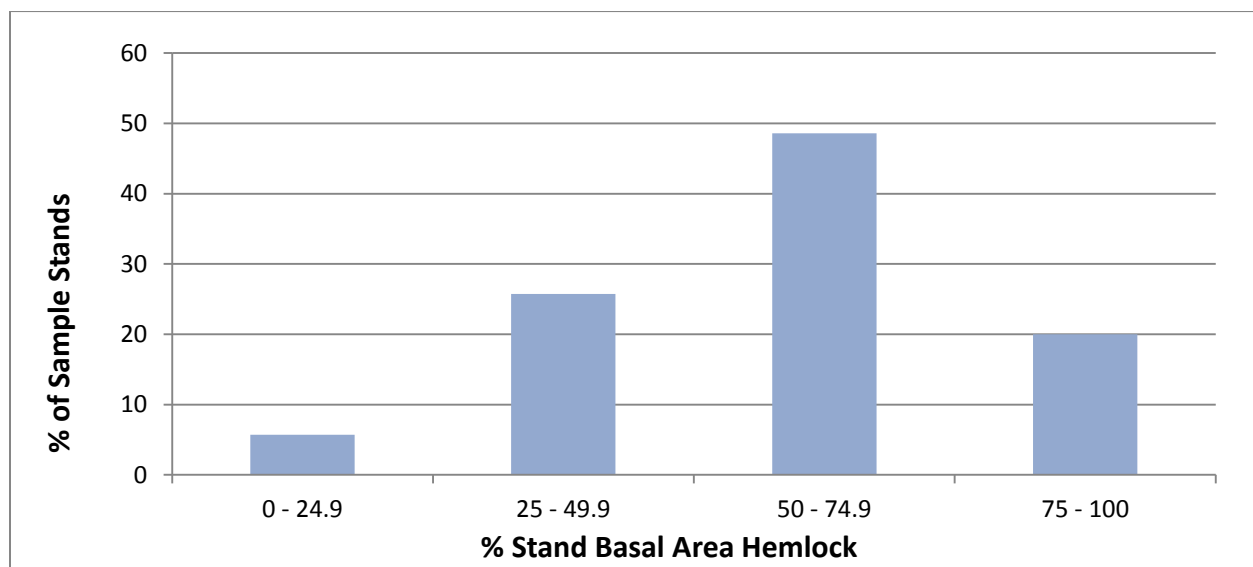
**Table 5.** Hemlock forests stand health class rating criteria.

Stand Health Rating	Criteria
Healthy	> 66% Trees Healthy (~ 2/3 trees sampled)
Healthy to Moderate	> 33% Trees Healthy and > 33% Trees Moderate
Moderate	> 10% Healthy Trees and Health Trees + Moderate = >50%
Moderate to Severe Decline	>33% Trees Moderate
Severe Decline	> 66% Trees in Severe Decline or Near Death
Severe Decline and High Mortality	> 10% Hemlock Sampled Dead

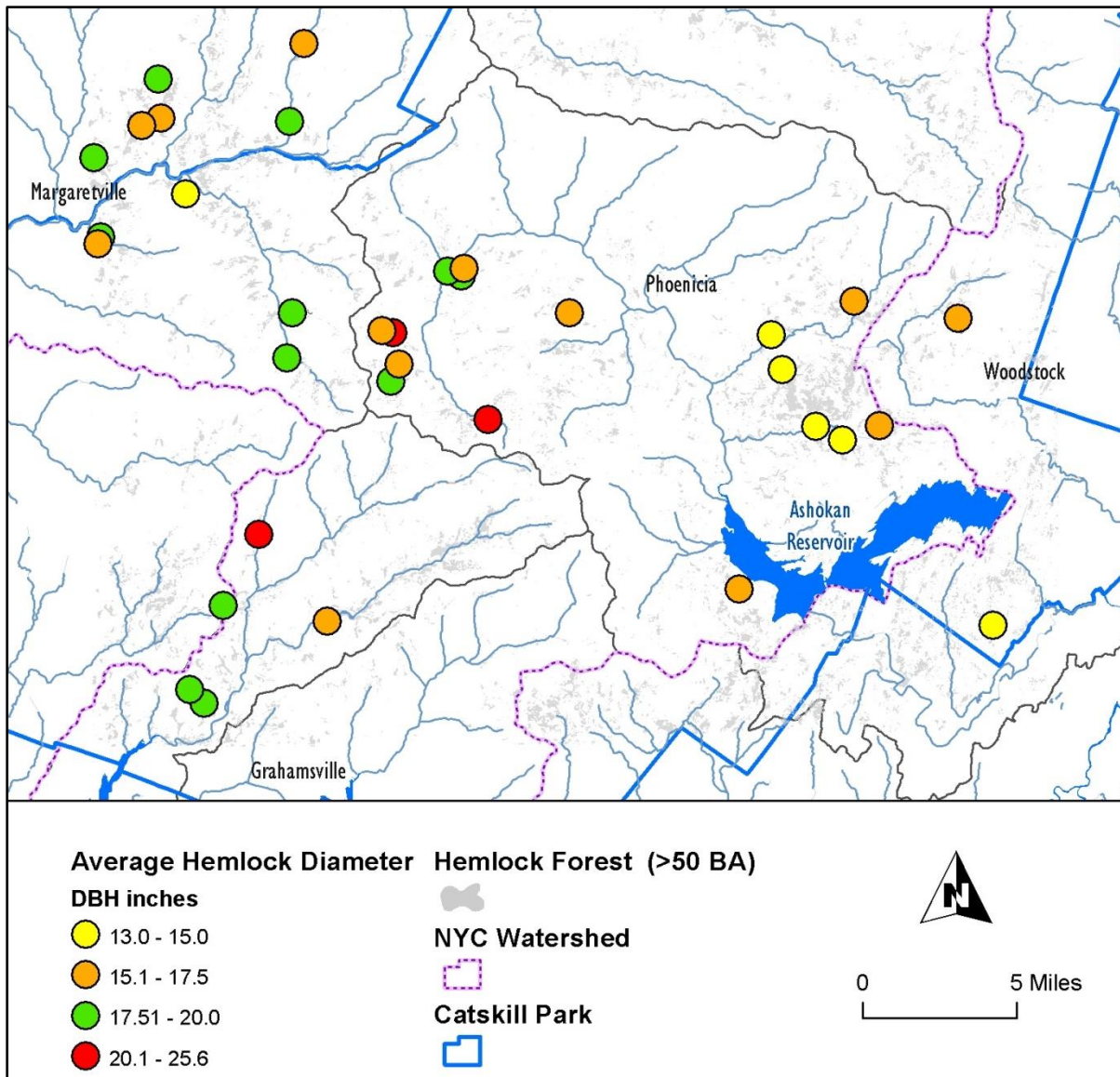
## 2.2 Results

### Hemlock Forest Stand Composition and Structure

The 35 sample stands had an average hemlock basal area of 59% and ranged from 19% to 97% hemlock basal area. Sixty-nine percent of sample stands (24 of 35) had > 50% hemlock basal area (Figure 11). Average diameter of the canopy forming trees was  $17.1 \pm 0.4$  inches diameter breast height (DBH) for 34 stands (DBH was not recorded at one stand). Three stands had an average DBH over 20.0 inches, two in the Birch Creek/Esopus watershed and one in the West Branch Neversink River watershed (Figure 12). Seventy-four percent of the stands had an average DBH between 15.0 and 20.0 inches. Stands with high hemlock basal area had little sunlight reaching the forest understory (Figure 13).



**Figure 11.** Percent of 35 sample stands by the percent of the basal area hemlock.



**Figure 12.** Average diameter of hemlock at the 35 sample stands.



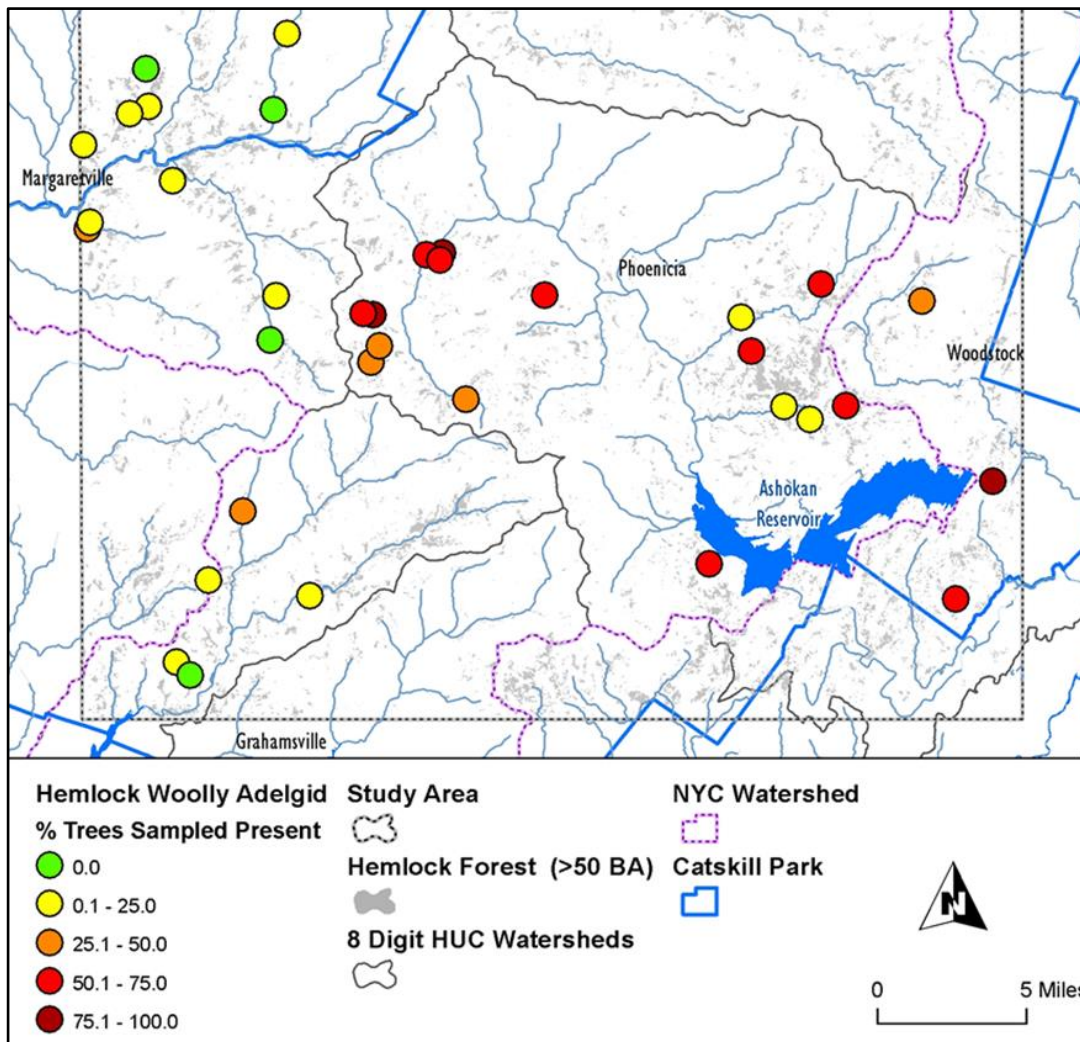
**Figure 13.** Forest stand dominated by hemlock with little light reaching the understory.

## Distribution of Hemlock Woolly Adelgid and Elongated Scaled

Hemlock woolly adelgid was found in 89% of the sample stands and is believed to be widespread in the Catskills (Table 6). Sample stands in the eastern portion of the Catskills had a higher percentage of sampled hemlock branches infested with HWA (Figure 14). Thirty-five percent of the sample stands had >50% of the hemlocks infested with HWA. HWA egg sack density was relatively low, with 43% of the sample stands in the “low” category. We found moderate and high egg sack density in 57% of the stands, but this condition was only found in one understory hemlock branch in each stand (Table 7).

**Table 6.** Percent of sample stands by percent of hemlocks with woolly adelgid present.

% of Trees	# of Stands	% of Stands
Absent	4	11
0 - 25 %	13	37
25 - 50%	6	17
50 - 75%	9	26
75 - 100%	3	9

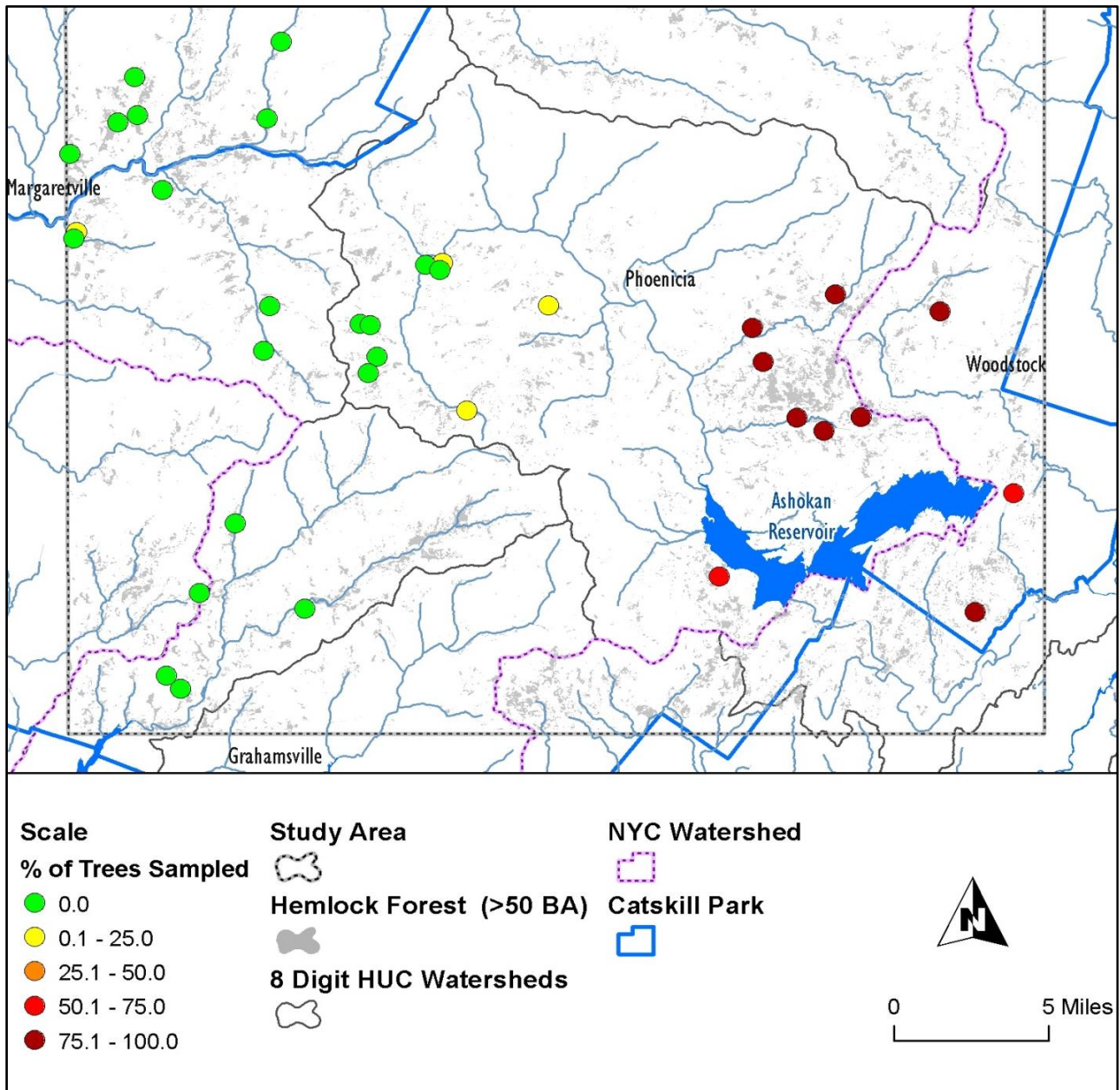


**Figure 14.** Distribution and abundance of hemlock woolly adelgid in the Catskills.

Hemlock elongated scale was found in 40% of the sample stands, but only in the Esopus Watershed in the eastern portion of the Catskills, infesting a high percentage of the trees (Figure 15). The ten stands furthest to the east had >50% of the sampled hemlock branches infested.

**Table 7.** The number of stands that had at least one branch meeting the hemlock woolly adelgid egg sack density category classes.

Category	Egg Sack Density Classes	# of Stands	% of Stands
Low	< 20	15	43
Medium	20 - 39	13	37
High	> 40	7	20



**Figure 15.** Distribution and abundance of hemlock elongated scale at the 35 sample stands.

## Hemlock Forest Stand Health Rating

A range of health conditions were found in the 35 hemlock forest sample stands (Figure 16). Forty-nine percent (17) of the hemlock sample stands were in a “moderate to healthy condition”, while 51% were in “moderately severe to severe decline”. Two stands were found to have high mortality. The “moderate to healthy” stands are not evenly distributed across the study area (Table 8, Figure 17). A majority of the “moderate to healthy” hemlock sample stands (11 of 17) were found in the East Branch of the Delaware River Watershed, while 15 of the 19 declining stands were located in the Esopus Watershed. The health of the sample stand in the Neversink was mixed.

**Table 8.** Number of hemlock sample stands by health rating and watershed.

Health Stand Rating	Esopus	E.B. Delaware	Neversink	Total
Healthy		2	1	3
Moderate to Healthy	3	3		6
Moderate	1	6	1	8
Moderate to Severe	5		2	7
Severe	8		1	9
Severe and High Mortality	2			2



**Figure 16.** A wide range of hemlock health conditions were found in the 35 survey stands. The first photo shows a stand with a high amount of hemlock mortality and decline, while the second photo depicts a relatively healthy stand with little sunlight reaching the forest floor.

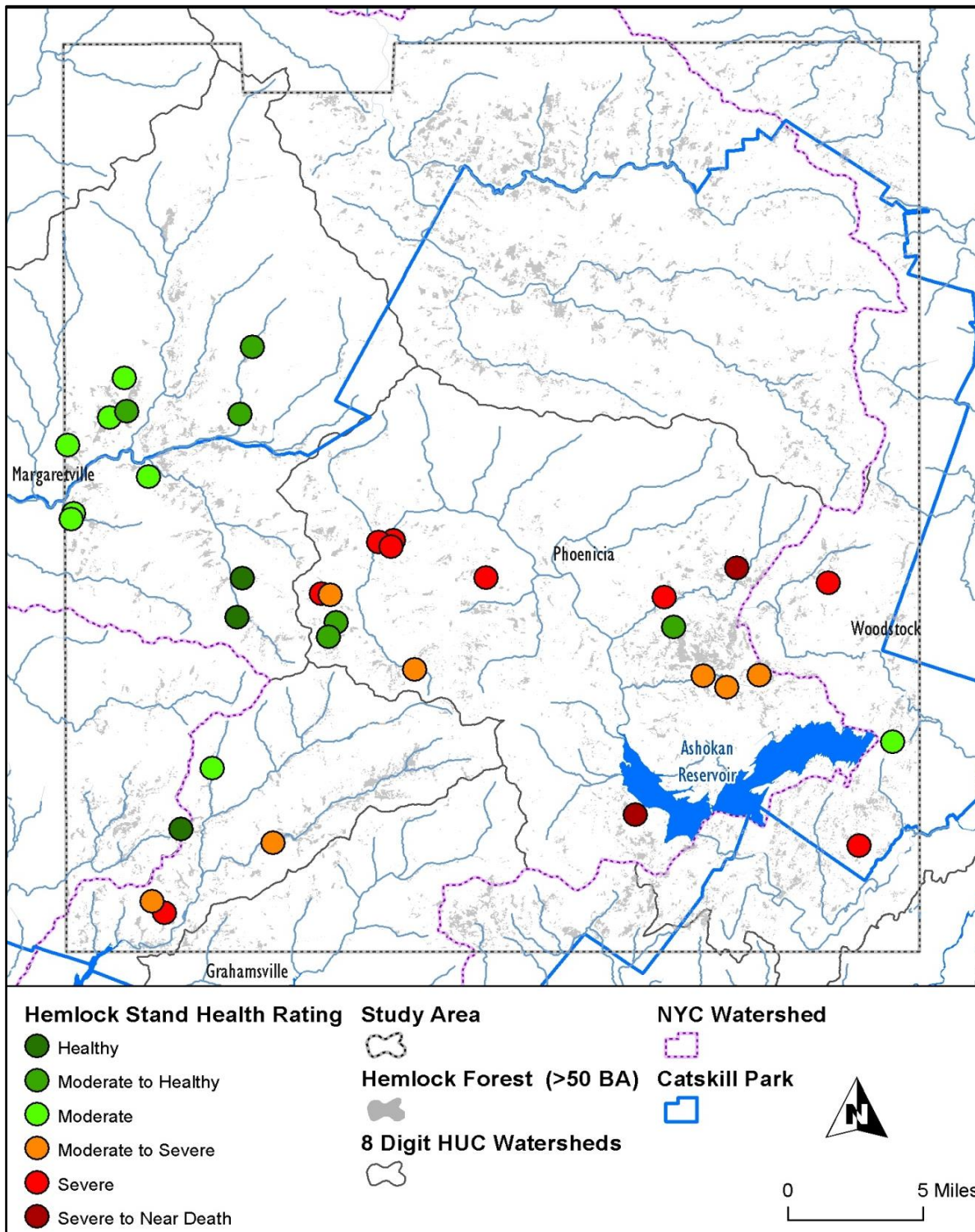


Figure 17. Hemlock sample stands by health class rating.

### 3.0 Hemlock Woolly Adelgid Biocontrol Release Criteria

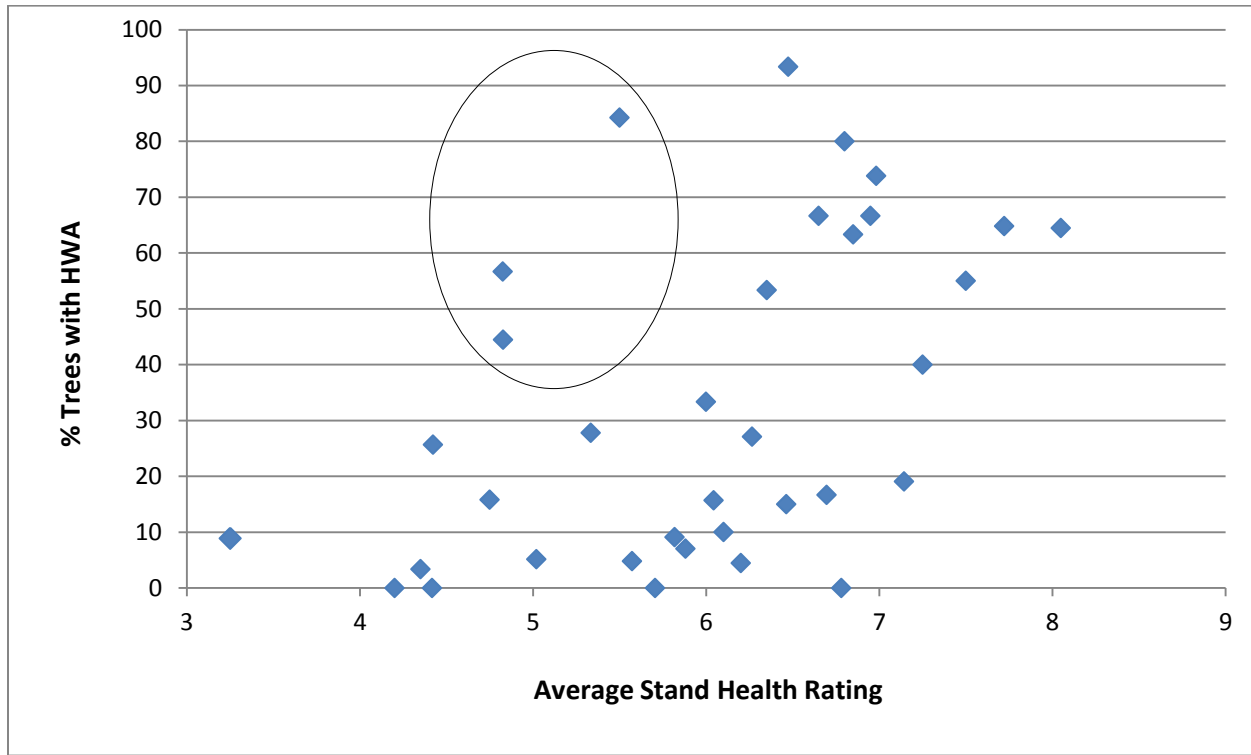
The most promising long-term management solution to HWA is biological control. Currently, the preferred biological control agent in the state of New York is *Laricobius nigrinus*, because of its high survival rate in harsh winters and life-cycle matching with HWA. *L. nigrinus* has been successfully released and recovered in the Smoky Mountain National Park, but its use is not widespread yet in New York or the Northeast. There have been difficulties with mass-production of the insect, mostly due to its complex life cycle. The low manufacturing rate of these beetles combined with a high need over most of the east coast, means that most regions receive lower than ideal numbers of *L. nigrinus*. Therefore, release locations should be as ideal as possible to encourage population establishment of *L. nigrinus* and spread.

We have drafted bio-control (*Laricobius nigrinus*) release criteria to identify hemlock stand that maybe good sites for release (Table 9). The criteria should be used as an initial screening tool, with the recognition that follow-up surveys will be required. For a hemlock stand to be a good candidate site for biological control release, it should be healthy or just in the early stages of decline. *L. nigrinus* is estimated to take ~ 5 – 10 years to get established, therefore the health of the stand needs to be moderately healthy or better to ensure the trees do not die before *L. nigrinus* is established. Additionally, hemlocks do not re-leaf once HWA causes needle loss. They will put out new foliage, but their old needles do not grow back. This makes it even more important to focus on stands of healthy trees. Secondly, suitable food sources for the bio-control agent are necessary. We estimate that at least five lower hemlock branches need to be infested with a high density of HWA egg sacks for establishment. Spread of *L. nigrinus* is more likely in stands with a higher percentage of hemlock and in areas with a high hemlock forest cover. We use a threshold of >50% hemlock basal area in the stand and >100 acres of hemlock per one mile squared. Also, we recognize that minimum winter temperatures have been correlated with recovery of *L. nigrinus* beetle larvae, and successful establishment of a population was positively correlated with both minimum winter temperature and beetle release size (Masuel et al. 2010). Therefore we recommend further investigation of minimum temperatures in multiple locations across the Catskills to evaluate release sites. The elevation of hemlock stands might be an indicator of minimum temperature. If a hemlock stand meets the criteria for release, a more detailed assessment is needed.

**Table 9.** Hemlock woolly adelgid bio-control release site criteria.

Attribute	Criteria
Stand Health Rating	Moderate to Healthy
% Lower Hemlock Branches Infested	> 25%
HWA Egg Sack Density	>5 High Density Lower Branches
% Stand Basal Area Hemlock	>50%
Hemlock Forest Cover	>100 Acres/1 Mile <sup>2</sup> (~15%)

Three hemlock sample stands partially meet the bio-control release criteria and they are all located in the Esopus Creek watershed (Figure 18, Table 10). All three stands were “Moderate to Moderately Healthy”, however the remaining sample stands in the watershed were found to be in “Severe Decline”, which might be an indication of hemlock forest health in the greater landscape. They had a high frequency of HWA on lower branches (>40%), but a high density of egg sacks were only found on one branch, which most likely is not sufficient for *L. nigrinus* establishment. Only stand #164 met the hemlock stand basal area and hemlock forest cover criteria. We recommend yearly monitoring to detect an increase in the density of HWA egg sacks of moderate to healthy stands in areas with a high percent cover of hemlock to identify suitable release sites near future.



**Figure 18.** Average tree health rating and % of sample hemlock branches with hemlock woolly adelgid present.

**Table 10.** Hemlock stands that partially meet the bio-control release criteria.

Stand Name	Stand Health	Elevation	% BA Hemlock	Woolly Adelgid			% Scale	
				% Absent	%Low	%Mod.		
164 - Beaver Kill - Esopus Creek	Moderate to Healthy	1677	71	43	53	2	2	100
173 - Birch Creek - Esopus Creek	Moderate to Healthy	2201	46	56	42	0	3	0
7 - Stony Creek - Esopus Creek	Moderate	486	68	16	53	32	0	72

## 4.0 Conservation and Management Implications

### Hemlock Forest Health and Conservation

The success of hemlock conservation in the Catskill Region is dependent on numerous factors, which likely include, but are not limited to the current health of hemlock forest and the rate of decline, feasibility and effectiveness of treatment methods.

Approximately, half of the hemlock sample stands were in “moderately severe to severe decline”. This is in contrast to a study in 2001, when Pontius et al. (2001) found a majority of the hemlock stands in the Catskills in an early stage of decline. However, they did note more severe decline in the southeastern portion of the study area, which is believed to coincide with the area first infested by HWA. We found a similar pattern, with decline and mortality greatest in the eastern portion of the Catskills. Over the last 13 years, these hemlock forests generally appear to have gone from moderate decline to severe decline with high mortality in some stands.

Hemlock forests in the East Branch of the Delaware River Watershed (EBDRW) (western portion of the study area) appear to be healthier and will likely persist longer than the stands to the east, therefore this area may be considered a higher priority for hemlock conservation over the long-term. All of the sample stands in the EBDRW were rated “moderate to healthy”. The rate of decline of hemlock stands is difficult to predict, but mortality is likely 10 to 20 years after the initial infestation with multiple factors such as winter temperatures and site conditions affecting the rate of decline. Ridgetops and dry sites have been reported to be most susceptible to rapid adelgid-induced decline due to stressful growing conditions (Orwig et al. 2002). Currently, HWA populations are low in hemlock stands in the EBDRW, making bio-control release not feasible at this time. These hemlock forest stands most likely have ~ 10 years before showing signs of significant decline. Populations of the bio-control agent *Laricobius nigrinus* are likely to take ten years to become established and spread. Therefore, hemlock forest stands in the EBDRW should continue to be monitored for increases in HWA populations that would support bio-control release.

Integrated pest management (IPM) has been effective in controlling HWA in small hemlock groves or on individual trees (Ward et al. 2004). IPM may be considered as a potential management strategy in the Catskills to maintain hemlock genetics. This strategy would be most effective in currently moderate to healthy stands, such as in the EBDRW, before HWA has reached detrimental levels. A pesticide application to healthy, high diameter hemlocks can prevent the initial HWA damage, while allowing time for biological controls to establish in surrounding trees. It is particularly important to prevent defoliation to large hemlocks, which represent the best genetics of the species, because the defoliation caused by HWA is not repairable; trees can put out new needles, but not regrow. This report is not intended to provide a comprehensive discussion of HWA control options or establish hemlock conservation goals. For more information on HWA management see:

[http://na.fs.fed.us/pubs/tps/eastern\\_hemlock/eastern\\_hemlock.pdf](http://na.fs.fed.us/pubs/tps/eastern_hemlock/eastern_hemlock.pdf)

<http://ccesuffolk.org/assets/Horticulture-Leaflets/Hemlock-Woolly-Adelgid.pdf>.

### Expand Survey Efforts

Survey efforts should be expanded in the Neversink and to the Schoharie Watersheds. The hemlock stand health ratings were mixed in the Neversink Watershed, with two “moderate to healthy” stands and three declining. The number of sample stands surveyed was fairly limited given the high concentration of hemlock-dominated forest

in the stream buffer in this area. Additional survey stands should be added to determine if the health of hemlock forest in the Neversink Watershed is sufficient to warrant investment of conservation resources. Hemlock forest stands in the Schoharie Watershed were not included in the stand survey for logistical reasons. Survey efforts should be expanded to the high concentrations of hemlock forest that are located in the Lewis-Batvia Kill and Little West Kill in the Schoharie Watershed. While most of the hemlock forest in this area is located on private land, ~ 18% is on NYC DEP owned lands.

### **Declining Hemlock Forest**

The majority of declining hemlock sample stands are located in the Esopus Watershed, with ~80% stands sampled in the watershed in a declining state (15 of 19). There is ~ 15,000 acres of hemlock dominated forest in the watershed and ~ 2,700 acres in stream riparian buffers. A majority of the hemlock dominated forest in the Esopus Watershed is on private land (~64%), while 10% is on NYC DEP and 26% on NYS DEC lands. The sample size of hemlock forest in the Esopus Watershed is low and we recognized that extrapolating this sample to the large landscape may not accurately depict the current condition. However these sample stands do provide some indication of hemlock forest health in this watershed. It is likely that severely declining stands will experience substantial hemlock mortality within five to ten years, which may have impacts to ecosystem functions, aesthetic values and recreation. Developing a plan to address this issue would establish priorities, standards, and practices that would facilitate objective decisions and allocation of limited resources to avoid crisis management (Ward et al. 2004).

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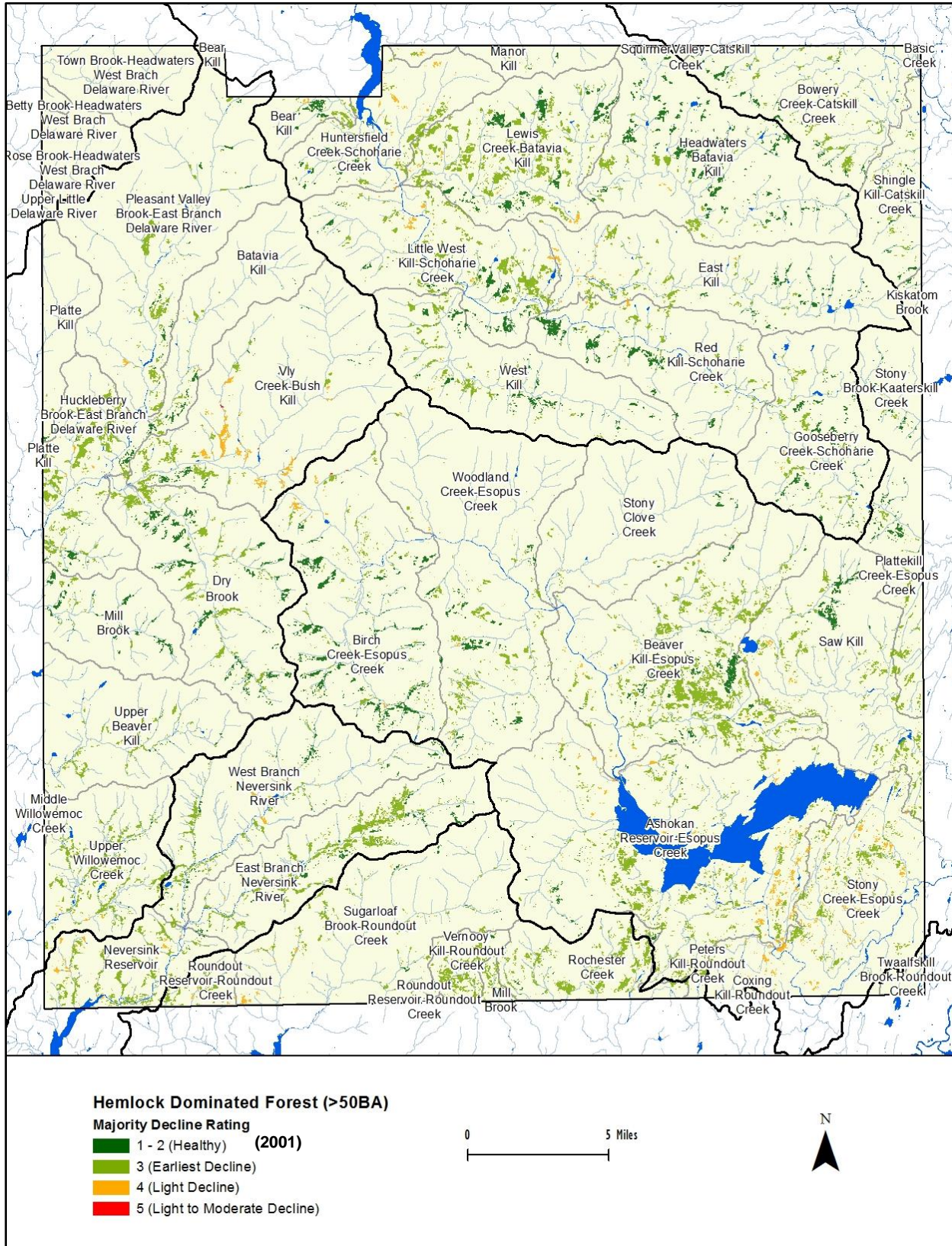
## Appendix I. Summary of Hemlock-Dominated Forest.

Includes hemlock-dominated forest (TSCA) by 12 digit watersheds, ownership and 300 ft. riparian stream buffer. Watersheds are ordered by 8 Digit HUC Watersheds. EBDR- East Branch Delaware River, MDR- Mid -Delaware River, MHR- Mid-Hudson River, RWR - Rondout - Wallkill Rivers, SC - Schoharie Creek and WBDR - West Branch Delaware River

HU 12 Watershed Name	HUC 8	% HU 12 TSCA	TSCA (ac)	% TSCA on DEC	% TSCA on DEP	TSCA Str. Buf. (ac)	% Str. Buf. TSCA
Huckleberry Brook	EBDR	12.6	1,653.1	7.7	19.0	389.4	11.2
Upper Willowemoc Creek	EBDR	8.4	1,173.1	72.3	0.0	0.0	Na
Dry Brook	EBDR	7.7	1,737.4	17.7	0.0	792.0	13.5
Mill Brook	EBDR	6.1	620.4	64.5	0.0	185.1	7.1
Vly Creek-Bush Kill	EBDR	4.0	1,201.6	0.6	10.6	410.1	5.4
Pleasant Valley Brook	EBDR	2.9	905.4	0.1	3.7	239.6	3.3
Batavia Kill	EBDR	2.4	294.9	0.5	7.8	62.2	1.8
Upper Beaver Kill	EBDR	2.3	397.8	78.7	0.0	0.0	Na
Platte Kill	EBDR	1.2	68.1	0.0	6.0	0.0	Na
Middle Willowemoc Creek	EBDR	0.1	0.2	100.0	0.0	0.0	Na
Neversink Reservoir	MDR	11.3	1,058.9	10.0	17.7	640.5	20.0
East Branch Neversink River	MDR	9.4	1,664.4	37.0	5.1	935.0	19.2
West Branch Neversink River	MDR	4.3	946.8	44.0	0.0	523.0	7.8
Beaver Kill-Esopus Creek	MHR	11.5	3,973.5	12.3	22.1	1,329.1	12.7
Stony Creek-Esopus Creek	MHR	8.2	1,836.8	10.4	0.7	0.0	Na
Saw Kill	MHR	7.9	1,784.2	20.3	5.5	0.0	Na
Plattekill Creek-Esopus Creek	MHR	7.0	573.5	34.0	0.0	0.0	Na
Ashokan Reservoir-Esopus Creek	MHR	5.8	2,953.5	8.5	14.8	516.4	5.7
Birch Creek-Esopus Creek	MHR	5.3	1,599.5	71.6	4.5	642.1	8.6
Shingle Kill-Catskill Creek	MHR	4.8	343.0	29.0	0.0	0.0	Na
Bowery Creek-Catskill Creek	MHR	4.7	794.6	9.7	0.0		Na
Woodland Creek-Esopus Creek	MHR	2.9	1,072.4	89.2	1.5	270.9	3.0
Kiskatom Brook	MHR	2.4	21.3	79.6	0.0	0.0	Na
Stony Brook-Kaaterskill Creek	MHR	1.9	116.4	66.1	0.0	0.0	Na
Stony Clove Creek	MHR	0.9	192.7	65.9	4.7	30.3	0.6

HU 12 Watershed Name	HUC 8	% HU 12 TSCA	TSCA (ac)	% TSCA on DEC	% TSCA on DEP	TSCA Str. Buf. (ac)	% Str. Buf. TSCA
Peters Kill-Roundout Creek	RWR	36.1	170.6	0.0	0.0	0.0	Na
Vernooy Kill-Roundout Creek	RWR	21.3	663.1	95.1	0.0	0.0	Na
Rochester Creek	RWR	12.5	1,217.5	15.1	0.0	0.0	Na
Roundout Reservoir-Roundout Creek	RWR	12.2	315.2	23.2	1.1	0.0	Na
Coxing Kill-Roundout Creek	RWR	6.0	7.0	0.0	0.0	0.0	Na
Sugarloaf Brook-Roundout Creek	RWR	2.5	658.2	71.3	3.2	264.3	4.0
Twaalfskill Brook-Roundout Creek	RWR	0.0	0.1	0.0	0.0	0.0	Na
Lewis Creek-Batavia Kill	SC	14.1	2,763.0	0.9	18.4	475.1	10.3
Little West Kill-Schoharie Creek	SC	9.2	1,838.6	2.1	5.0	500.2	10.0
Bear Kill	SC	8.6	315.5	0.0	29.8	0.0	Na
Huntersfield Creek-Schoharie Creek	SC	5.8	738.2	0.0	37.4	123.8	4.0
Red Kill-Schoharie Creek	SC	5.6	1,000.3	8.8	1.0	408.0	7.7
Headwaters Batavia Kill	SC	5.5	1,469.2	2.7	13.6	451.4	5.6
Gooseberry Creek-Schoharie Creek	SC	4.8	838.0	24.5	10.0	358.7	6.6
West Kill	SC	4.5	897.5	28.8	15.8	296.3	6.1
East Kill	SC	4.0	924.0	9.3	4.5	367.0	5.4
Manor Kill	SC	2.4	91.5	4.0	11.6	0.0	Na
Town Brook-Headwaters	WBDR	0.1	8.4	0.0	0.0	0.0	Na
Rose Brook-Headwaters	WBDR	0.0	0.3	0.0	0.0	0.0	Na

## Appendix II. Decline rating of hemlock dominated forest stands in 2001.



### Appendix III. Attributes of 35 sample stands in 2014.

Includes: % Live and dead hemlock (TSCA) basal area (BA), mean diameter at breast height (DBH), % of hemlocks sampled by health rating, stand health rating, % of sampled hemlock branches by HWA egg sack density class and % of branches with hemlock elongated scale.

ID #	Stand Name	Plots	% BA TSCA	% BA Dead TSCA	Mean DBH	% Healthy	% Mod.	% Severe Decline	% Near Death	Mean Health Rating	Stand Health Status	% HWA Present	HWA Low	HWA Mod.	HWA High	% Scale
9574	100 - Dry Brook	15	73.5	3	19	90	7	3	0	3.3	Healthy	9	9	0	0	0
17105	88 - Upper Willowemoc Creek	10	55.5	0	20	70	30	0	0	4.4	Healthy	3	3	0	0	0
10611	121 - Dry Brook	15	76.6	4	19	67	20	13	0	4.2	Healthy	0	0	0	0	0
6374	44 - Vly Creek-Bush Kill	12	52.7	0	18	58	38	4	0	4.4	Moderately Healthy	0	0	0	0	0
10690	162 - Birch Creek - Esopus Creek	14	46.3	0	16	54	38	8	0	4.4	Moderately Healthy	26	26	0	0	0
6233	32 - Huckleberry Brook-EBDR	19	82.2	1	17	50	32	18	0	4.8	Moderately Healthy	16	16	0	0	0
10980	164 - Beaver Kill - Esopus Creek	20	71.1	1	13	45	38	15	3	4.8	Moderately Healthy	57	53	2	2	100
11169	173 - Birch Creek - Esopus Creek	14	45.6	0	19	38	46	15	0	4.8	Moderately Healthy	44	42	0	3	0
5109	11 - Vly Creek-Bush Kill	13	54.7	1	16	38	54	8	0	5.0	Moderately Healthy	5	5	0	0	0
5678	6 - Huckleberry Brook - EBDR	11	50.0	2	18	32	32	36	0	5.7	Moderate	0	0	0	0	0
14167	7 - Stony Creek - Esopus Creek	19	67.6	0	NA	32	29	39	0	5.5	Moderate	84	53	32	0	72
14813	76 - West Branch Neversink River	18	75.2	0	26	28	61	11	0	5.3	Moderate	28	28	0	0	0

ID #	Stand Name	Plots	% BA TSCA	% BA Dead TSCA	Mean DBH	% Healthy	% Mod.	% Severe Decline	% Near Death	Mean Health Rating	Stand Health Status	% HWA Present	HWA Low	HWA Mod.	HWA High	% Scale
7827	91 - Huckleberry Brook - EBDR	7	42.2	2	20	21	57	14	7	5.6	Moderate	5	5	0	0	5
7151	14 - Dry Brook	19	74.8	2	13	21	37	42	0	5.9	Moderate	7	5	0	2	0
6521	54 - Huckleberry Brook-EBDR	11	46.2	1	17	14	64	23	0	5.8	Moderate	9	9	0	0	0
7934	96 - Huckleberry Brook - EBDR	13	51.6	1	16	12	54	35	0	6.0	Moderate	33	21	8	5	0
6590	60 - Huckleberry Brook - EBDR	10	50.2	1	18	10	50	40	0	6.1	Moderate	10	10	0	0	0
12407	278 - Beaver Kill - Esopus Creek	17	51.3	0	14	26	21	50	3	6.0	Severe to Moderate	16	16	0	0	100
17333	128 - East Branch Neversink River	15	72.0	1	17	17	27	53	3	6.2	Severe to Moderate	4	4	0	0	0
12988	343 - Beaver Kill - Esopus Creek	20	59.8	4	15	5	38	58	0	6.5	Severe to Moderate	15	10	5	0	100
12375	274 - Beaver Kill - Esopus Creek	15	77.4	2	16	3	40	53	3	6.4	Severe to Moderate	53	51	2	0	100
9948	124 - Birch Creek - Esopus Creek	10	47.5	1	20	0	55	35	10	6.5	Severe to Moderate	93	77	13	3	0
12241	233 - Birch Creek - Esopus Creek	16	63.8	2	23	0	53	47	0	6.3	Severe to Moderate	27	23	4	0	6
9688	49 - Woodland Creek - Esopus Creek	14	67.0	5	18	0	36	61	4	6.7	Severe to Moderate	17	17	0	0	0
9519	39 - Woodland Creek - Esopus Creek	14	74.9	4	17	11	11	68	11	7.0	Severe	74	48	14	12	19
8452	82 - Birch Creek - Esopus Creek	5	19.5	0	17	10	20	60	10	6.8	Severe	80	80	0	0	13

ID #	Stand Name	Plots	% BA TSCA	% BA Dead TSCA	Mean DBH	% Healthy	% Mod.	% Severe Decline	% Near Death	Mean Health Rating	Stand Health Status	% HWA Present	HWA Low	HWA Mod.	HWA High	% Scale
8599	89 - Birch Creek - Esopus Creek	10	40.9	1	20	5	20	70	5	6.7	Severe	67	63	3	0	0
9966	111 - Beaver Kill - Esopus Creek	14	55.2	2	15	4	18	61	18	7.1	Severe	19	19	0	0	100
8497	86 - Birch Creek - Esopus Creek	5	19.7	0	19	0	30	70	0	7.0	Severe	67	67	0	0	0
19749	68 - Neversink Reservoir	8	33.3	3	19	0	25	69	6	6.8	Severe	0	0	0	0	0
9929	123 - Birch Creek - Esopus Creek	10	35.3	1	16	0	15	80	5	6.9	Severe	63	57	7	0	0
9865	48 - Saw Kill	20	97.1	1	16	0	8	78	15	7.3	Severe	40	38	2	0	100
17432	140 - Stony Creek - Esopus Creek	20	92.5	2	15	0	5	80	15	7.5	Severe	55	45	7	3	95
9253	70 - Beaver Kill - Esopus Creek	15	49.1	42	16	0	3	50	47	8.1	High Mortality to Severe	64	58	7	0	98
16533	204 - Ashokan Reservoir	18	80.7	10	15	0	3	67	31	7.7	High Mortality to Severe	65	65	0	0	61