# The Effect of the Hemlock Woolly Adelgid, *Adelges tsugae* (Homoptera: Adelgidae) in New Jersey Hemlock Stands

## Annual Report 2008

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**Hemlock Woolly Adelgid**
photo: S. Geloski-Kimmel, Philadelphia Inquirer

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## Abstract

The hemlock woolly adelgid (HWA) continues to negatively impact hemlock stands in New Jersey as indicated by the decreases of new growth in 2008 in the 10 monitored permanent study plots. Past experience has shown that periods of decreased new growth are usually the direct result of an increase in HWA populations. Other environmental factors are involved such as water supply, elongate hemlock scale (EHS) *Fiorinia externa* (Homoptera: Diaspididae) and drought. However, the one factor that was consistent across the stands, where the trees are highly stressed or dying was a heavy population of HWA. The increase in HWA population resulted in a decline in new growth in 2008 and may cause increased stress in 2009, insuring a further decline in the health of hemlock forests in New Jersey.


## INTRODUCTION

This report is the result of the Permanent Hemlock Study Plot monitoring program partially funded by the United States Department of Agriculture-Forest Service. The objective of this work is to show the impact of the HWA and associated factors in natural hemlock stands over an extended period. Data collected include stand mortality, HWA population level, crown ratings and percent new growth. The overall goal was to get a relative assessment of the health of New Jersey hemlock stands.

## MATERIALS AND METHODS

### Study Plots

Eleven study plots were set up in 1988. These plots were chosen as representative of natural hemlock stands and adelgid populations. Of the 11 plots selected, nine were infested with adelgid and two were uninfested. The same 11 plots were monitored in 1989. Two of the plots were abandoned in 1990 because they were continually being treated with chemicals and/or fertilized and field personnel were unable to get an accurate record of the treatments. Subsequently, in 1990 two new plots were added to replace the plots that were dropped. These 11 plots have been continuously monitored since 1990. Data are occasionally not available from certain plots because permission to enter the property could not be obtained from the new property owners**.** In 2003, the last remaining trees in the Shades of Death study plot died, leaving only ten plots now being monitored. During 2008, the plot at Schooley's Mountain was dropped from the study as access to the plot became questionable and dangerous.

After a plot was chosen as representative of a noninfested, lightly infested, or heavily infested hemlock stand, three subplots were established within each plot to ensure that an undisturbed group of trees could be observed from year to year. Subplots were set up using the following criteria: 1) location in the densest parts of the hemlock stands; 2) good accessibility to branches; 3) open areas were avoided because they were not representative of a plot as a whole.

A #10 prism was used to delineate the sample hemlock trees within the subplot. One tree was designated as the center tree and any tree that was observed within the $360^{o}$ radius of the prism was included in the subplot. The tree lying closest to magnetic North with respect to the center

tree was designated tree number 1. All hemlock trees within the prism, moving in a clockwise direction, were numbered sequentially.

**New Growth - Foliage**

New growth counts were recorded annually using the trees in the three subplots to determine the quality and health of the trees at each site. New growth sprouts from the ends of the branches, with the new growth readily distinguishable from the previous year's growth by the light green color of the new needles and lighter colored stem. These counts were completed from June to August. The procedure was as follows: a branch on a tree was chosen skewed toward the branches showing the most potential for new growth. A twelve-inch (30 cm.) ruler was used to measure one foot of branch starting from the tip and proceeding toward the trunk. All the terminal ends of the shoots, both living and dead, were counted. The number of terminals with new growth was determined and the percent of new growth was calculated by dividing the total number of terminals into the total number with new growth. Ten samples were taken from each subplot, a total of 30 samples per plot. As many different trees were used as possible but if the branches could not be reached or if there were less than 10 trees in the subplot, more than one count was made per tree. If the branches on the subplot trees were inaccessible, counts were made from samples on trees as close as possible to the subplot.

**HWA Population Levels**

Previous work (Ward 1991) indicated that the percent new growth in hemlocks declines precipitously when a population of 25-30 HWA per 100 needles is reached. There was no appreciable effect on the percentage of new growth when populations of HWA were less than 25-30 HWA per 100 needles. The HWA population categories were then assigned as follows with H = heavy, > 30 adelgids per 100 needles; L = light, < 30 adelgids per 100 needles; N = none, no adelgids per 100 needles.

Population levels were determined by sampling HWA infested trees outside of the subplots. Cuttings were made from six different trees within the plot (2 cuttings each within the proximity of each subplot. These cuttings were brought back to the laboratory and ten -100-needle sections were randomly selected from each of the six cuttings; 6,000 needles were examined for each plot. All adelgids present in the sections were counted and then an average was obtained for each of the plots. No population data was collected in 1991 and in some plots in 1992 due to insufficient personnel to carry out the work.

**Crown Rating**

The crown ratings of ratio and transparency for all the plots were implemented as in Millers *et. al*. 1992. Dieback was not included in the crown ratings because the project has been ongoing for some time and there was no way to evaluate that measurement. Crown diameter was felt to be highly variable and thus was not included in the data. Crown density is the amount of foliage, branches *etc.* that blocks light visibility through the crown and is expressed as a percentage. Since this measurement did not appear to be important it was not included beginning with the 2007 survey. Crown ratio is the percentage of total tree height that supports living foliage. Crown transparency is the amount of visible light going through the live portion of the crown and is also

expressed as a percentage. A high percentage means that more light is visible through the crown, which indicates a distressed crown/tree. Crown transparency is akin to percent defoliation. Figure 1 shows a hemlock with a thin crown, which would have a high transparency percentage rating. Figure 2. shows a healthier crown, which would have a much lower transparency rating than the one in Figure 1.

**Figure 1. Hemlock with a thin crown**

**Figure 2. Hemlock with a healthy crown**

### Mortality

Mortality was defined as no cambial activity and no needles on the tree. Trees with any needles at all were considered to be living. Site mortality was calculated by counting the number of dead trees observed during the crown rating survey and dividing that number by the total number of trees in the plot to determine the percentage.

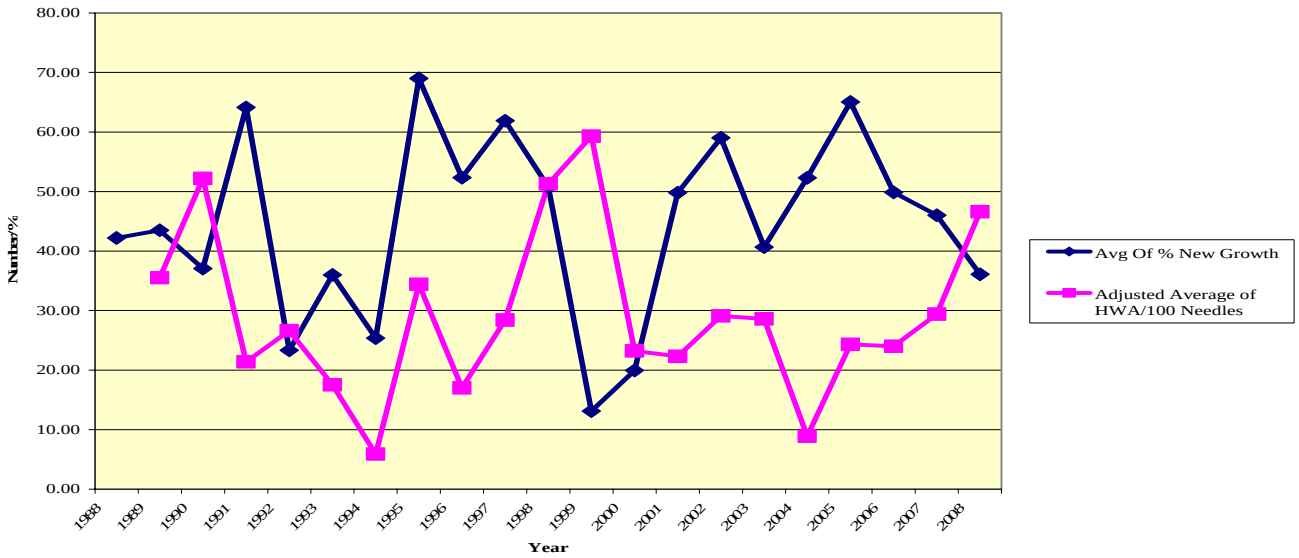
## RESULTS AND DISCUSSION

### New Growth and HWA Population

Figure 3. shows the average percent new growth and HWA population levels for the permanent study plots from 1988-2007. The pattern is a series of years when the trees put out more new growth as long as the HWA population is light (< 30 HWA/100 needles), but as soon as the population is > 30 HWA/100 needles, the amount of new growth declines. The trees become stressed and as the health of the tree declines less new growth is available, which results in a corresponding decline in the HWA population.

The sites all show the same pattern where the trees are able to recover slightly and produce more new growth due to the lower HWA populations, but after a year or two of recovery there is sufficient new growth again for the HWA to come back at high population levels, stress the trees

**Figure 3. % New Growth and HWA Populations 1988-2008**




and reduce the amount of new growth once again. This cycle is expected since the HWA prefers current year's growth and is rarely found on older material. After several years of heavy infestation the amount of new growth declines substantially (McClure *et. al.* 1996). There are exceptions to this depending on the environmental conditions at the site. Ward (1991) did find that when HWA populations at a site increased to 30 HWA/100 needles, the amount of new growth declined in the plots that he monitored for three seasons thereby giving us an accurate method for predicting the effects of the HWA population on new growth in a stand.

## Crown Ratings

The plots that have a series of years where the HWA population was heavy are the plots that have the lowest crown ratios, lowest crown densities and the highest transparencies. Taken all together, the relative health of the hemlock in those plots is poor when compared to stands where the trees have not been infested as long. In NJ, all of the Permanent Study Plots have unhealthy trees. The lower the transparency value, the healthier the stand or tree. The stands that have been attacked earliest by the HWA are the stands that are in the poorest health in New Jersey. Table 1 shows the crown transparency ratings for the plots.

**Table 1. Crown Transparency Ratings for All Plots**

| Plot Name | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clinton | 37.68 | 10.86 | 10.86 | 25.34 | 16.25 | 36.61 | 43.96 | 50.26 | 61.84 | 56.94 | 55.53 | 53.42 | 52.50 | 53.00 | 53.6 |
| Millbrook | 56.94 | 24.47 | 24.74 | 16.84 | 33.95 | 31.84 | 48.16 | 52.63 | 60.79 | 63.33 | 55.56 | 55.44 | 55.56 | 62.78 | 69.4 |
| High Point | 27.07 | 15.17 | 13.83 | 18.17 | 27.41 | 48.28 | 38.10 | 49.69 | 55.88 | 64.00 | 60.00 | 51.89 | 49.71 | 53.75 | 58.1 |
| Schooley's Mt | 79.41 | 30.74 | 33.21 | 66.00 | 0.00 | 47.27 | 67.50 | 72.86 | 68.33 | 64.00 | 66.00 | 66.00 | 58.33 | 63.33 | - |
| Lake Valhalla | 75.25 | 42.50 | 46.50 | 88.50 | 64.47 | 66.05 | 76.18 | 66.15 | 69.00 | 80.00 | 92.50 | 75.00 | 81.25 | 57.50 | 80.0 |
| Johnson Lake | 83.91 | 57.31 | 50.91 | 40.00 | 35.63 | 79.17 | 80.00 | 72.50 | 75.00 | 72.50 | 77.50 | 70.00 | 40.00 | 75.00 | 80.0 |
| Tillman's Ravine | 48.42 | 13.42 | 13.16 | 20.00 | 24.72 | 38.89 | 45.26 | 65.00 | 66.94 | 60.59 | 64.41 | 61.06 | 67.06 | 68.53 | 73.5 |
| Worthington | 20.48 | 36.67 | 31.47 | 15.00 | 39.00 | 33.33 | 62.69 | 62.27 | 65.91 | 69.00 | 61.67 | 59.78 | 61.44 | 72.22 | 72.8 |
| Hewitt | 81.16 | 33.42 | 33.16 | 68.89 | 54.12 | 63.13 | 76.56 | 69.67 | 77.31 | 74.62 | 69.17 | 65.92 | 70.42 | 70.00 | 77.0 |
| Shades of Death | 79.25 | 11.11 | 18.33 | 41.88 | 48.57 | 60.00 | 63.33 | 45.00 | 60.00 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Walnridge | 83.04 | 43.41 | 39.71 | 65.67 | 40.00 | 69.62 | 60.00 | 60.00 | 0.00 | 59.50 | 56.67 | 53.11 | 51.36 | 61.00 | 61.0 |

Overall, the plots with the most stress have high crown ratings for transparency. However, some of those ratings are due to heavy EHS infestations rather than to the HWA as in Clinton Reservoir and High Point. NJ had experienced a drought in 2001-2002 and again in 2005 and that also may have affected the tree health at those sites. Even so, Clinton and High Point, with histories of light HWA infestations have the lowest crown ratings and are the healthiest sites. The crown ratings in a hemlock stand deteriorate after the HWA population in that stand has reached high levels numerous times. The more often a stand is heavily infested, the higher transparency in the stand and the poorer tree health. This effect is not seen for a few years after the initial infestation, but when the earliest data from each stand is compared to the data from some years later, the effect is readily apparent.

Table 2. shows the average crown ratios for all plots since 1994. The upper part of the table shows the values for living trees in the plots, and the ratios have declined in the plots that have had the heaviest adelgid infestations since 1994 (Johnson Lake, Lake Valhalla, Schooley's Mt., Walnridge, Worthington and Shades of Death). This makes it difficult to sample for the hemlock woolly adelgid predators. The other stands that have not had numerous heavy infestations of hemlock woolly adelgid have much better crown ratios (data from the Clinton Reservoir is somewhat skewed because of mortality caused by drought and the EHS).

**Table 2. Crown Ratios for All Plots**

**Ratio for living trees**

| Plot Name | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clinton | 62.32 | 59.83 | 58.62 | 63.45 | 55.18 | 55.71 | 56.46 | 63.95 | 54.74 | 56.67 | 53.16 | 50.84 | 52.50 | 49.67 | 57.90 |
| Hewitt | 55.26 | 80.53 | 76.32 | 75.83 | 74.71 | 73.13 | 69.69 | 71.00 | 66.54 | 67.31 | 75.00 | 66.67 | 64.00 | 69.09 | 71.78 |
| High Point | 88.28 | 72.76 | 70.50 | 75.17 | 67.93 | 72.41 | 74.52 | 79.38 | 70.88 | 62.50 | 72.22 | 65.72 | 63.82 | 69.06 | 75.50 |
| Johnson Lake | 36.30 | 53.92 | 42.27 | 50.00 | 44.38 | 45.83 | 50.00 | 50.00 | 35.00 | 35.00 | 32.50 | 40.00 | 20.00 | 35.00 | 45.00 |
| Lake Valhalla | 75.71 | 72.75 | 68.00 | 72.00 | 64.47 | 63.95 | 57.06 | 52.69 | 51.00 | 40.00 | 30.00 | 53.75 | 35.00 | 37.50 | 26.70 |
| Millbrook | 60.83 | 70.32 | 67.11 | 70.53 | 68.16 | 65.79 | 68.95 | 65.53 | 60.79 | 68.61 | 60.28 | 68.39 | 62.94 | 61.39 | 65.33 |
| Schooley's Mt | 54.71 | 64.41 | 48.57 | 39.93 |  | 48.18 | 61.25 | 67.86 | 48.33 | 44.00 | 43.00 | 54.00 | 38.33 | 40.00 |  |
| Shades of Death | 28.50 | 35.56 | 27.78 | 26.25 | 24.29 | 23.57 | 21.67 | 30.00 | 25.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tillman's Ravine | 65.00 | 77.37 | 74.47 | 77.50 | 75.28 | 80.28 | 77.37 | 83.61 | 77.78 | 78.24 | 73.24 | 64.12 | 64.12 | 66.76 | 66.35 |
| Walnridge | 36.74 | 38.18 | 33.82 | 40.67 | 47.50 | 18.85 | 36.67 | 40.42 | 0.00 | 42.00 | 34.44 | 44.44 | 43.18 | 46.50 | 46.00 |
| Worthington | 7.86 | 50.71 | 43.53 | 50.33 | 45.33 | 47.33 | 48.46 | 60.91 | 38.18 | 56.00 | 44.44 | 42.78 | 45.56 | 48.33 | 49.44 |

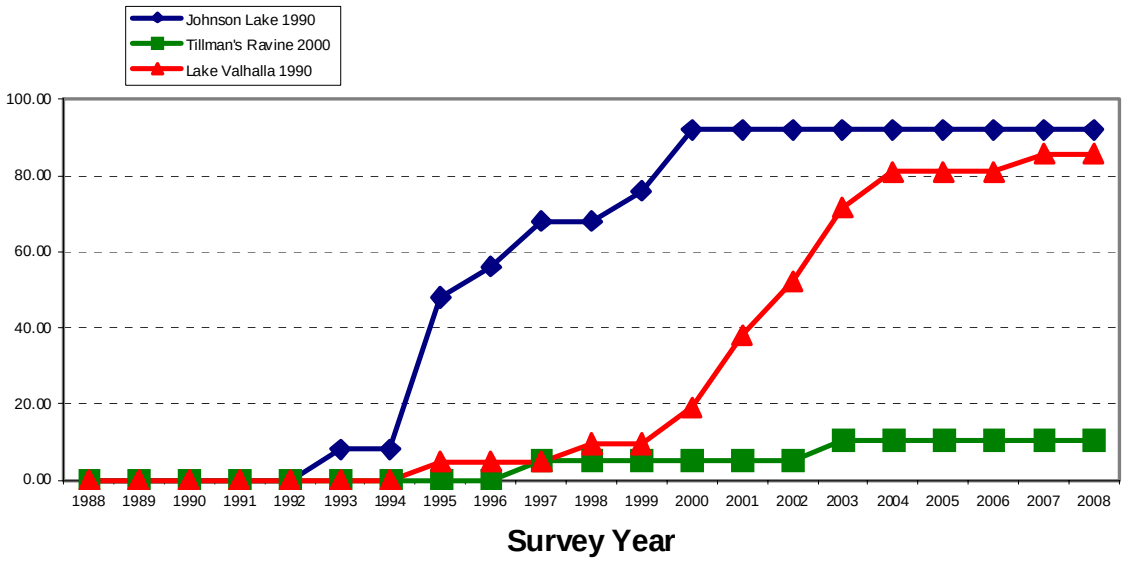
**Ratio including dead trees**

| Plot Name | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clinton | 62.32 | 59.83 | 58.62 | 63.45 | 53.28 | 53.79 | 46.72 | 41.90 | 35.86 | 35.17 | 34.83 | 32.20 | 28.97 | 25.69 | 28.93 |
| Hewitt | 55.26 | 80.53 | 76.32 | 71.84 | 66.84 | 61.58 | 58.68 | 56.05 | 45.53 | 46.05 | 47.37 | 42.11 | 40.42 | 40.00 | 47.05 |
| High Point | 77.58 | 63.94 | 62.21 | 66.32 | 57.94 | 61.76 | 46.03 | 38.82 | 35.44 | 36.76 | 38.24 | 34.79 | 31.91 | 32.50 | 36.60 |
| Johnson Lake | 33.40 | 28.04 | 20.20 | 16.00 | 14.20 | 11.00 | 4.00 | 4.00 | 2.80 | 2.80 | 2.60 | 3.20 | 2.80 | 2.80 | 3.60 |
| Lake Valhalla | 75.71 | 69.29 | 64.76 | 68.57 | 58.33 | 57.86 | 46.19 | 32.62 | 24.29 | 11.43 | 11.43 | 10.24 | 6.67 | 7.14 | 3.81 |
| Millbrook | 57.63 | 66.80 | 63.75 | 67.00 | 64.75 | 62.50 | 65.50 | 62.25 | 57.75 | 61.75 | 54.25 | 61.55 | 56.65 | 55.25 | 58.80 |
| Schooley's Mt | 46.50 | 54.75 | 34.00 | 29.95 | 0.00 | 26.50 | 24.50 | 23.75 | 14.50 | 11.00 | 10.75 | 13.50 | 5.75 | 6.00 |  |
| Shades of Death | 21.92 | 12.31 | 8.93 | 7.50 | 6.07 | 6.11 | 2.50 | 1.15 | 0.96 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tillman's Ravine | 65.00 | 77.37 | 74.47 | 76.84 | 71.32 | 76.05 | 77.37 | 79.21 | 73.68 | 70.00 | 65.53 | 57.37 | 57.37 | 59.74 | 59.37 |
| Walnridge | 32.50 | 32.31 | 22.12 | 23.46 | 25.58 | 18.85 | 16.92 | 18.65 | 0.00 | 16.15 | 11.92 | 15.38 | 18.27 | 17.88 | 18.40 |
| Worthington | 7.00 | 40.96 | 29.60 | 30.20 | 27.20 | 28.40 | 25.20 | 26.80 | 16.80 | 22.40 | 16.00 | 15.40 | 16.40 | 17.40 | 17.80 |

## Tree Mortality Considerations

Obviously the HWA is putting stress on the trees in the forest. Figure 5 shows the stand mortality in three permanent study plot stands, with the greatest mortality occurring in those that were heavily infested with the HWA for the longest period of time. The year of the first known heavy HWA infestation is in the legend. The stands that have the weakest overall crown ratings are the stands that have had the longest HWA infestations. The trend is disturbing but expected, in that where the HWA populations have been the heaviest in past years; the tree mortality is the highest. There was an increase in mortality at three of the ten monitored plots in 2007. This trend could continue in 2008, since increased HWA populations could have a further impact on hemlock mortality next year.

**Figure 5. % Mortality due to HWA in 3 Plots 1988-2008**




There are probably other factors that contribute to the death of the trees but the one factor that stands out consistently is the presence of a heavy HWA population. EHS is present in many of the stands and is also a stressor, but its effect on the stands is not altogether clear. Hemlock mortality does seem to be affected by the amount of water available to the trees and the amount of water available is related to the percent new growth. From observation in the heavily infested stands monitored in NJ., the closer a tree is to a water source, the healthier it appears. At Walnridge, Lake Valhalla and Johnson Lake, the trees that are still alive and the healthiest are either at the bottom of a slope, near a stream, or by a roadside, which is at the bottom of a slope. Shades of Death, Schooley's Mountain, Lake Valhalla and Johnson Lake are the plots with the highest mortality and they are all plots where the majority of the hemlocks are on a ridge or a site that is somewhat xeric. They were also the plots that have had numerous high HWA populations in the past. It seems that if a site has been heavily infested, the surviving trees are the ones that have the best access to a water supply. The presence of a water source or perhaps high soil moisture then, may affect the ability of a hemlock tree to survive stressors like the HWA. It must be emphasized that even the trees close to water in heavily infested stands are still stressed by the HWA. The water may be just giving them a little extra time but eventually those trees also succumb. Abundant water negatively affects sucking insect populations and it seems reasonable to infer that it negatively impacts the HWA as well. Figure 6 shows a healthy hemlock stand with no adelgid. This stand is well shaded, with an understory of young hemlock.

**Figure 6. Typical dark hemlock stand**

Figure 7 shows mortality as it first appears in a stand attacked by the HWA. Figure 8 illustrates the hemlock stand after mortality has been present for a few years. There is little understory and many branches have fallen onto the ground increasing the slash. The increase in slash also increases the fuel inventory making the stands more susceptible to forest fire. Widowmakers (trees leaning on other trees) are a common sight and many of the trees have split and fallen.

**Figure 7. Initial mortality at Newark Watershed**

**Figure 8 Stand mortality at High Point SP**

On windy days, it is hazardous to go into some of the stands due to the number of dead trees and falling branches. There was no concurrent mortality of other tree species in any of the stands. Mortality can show up about 3-4 years after the first heavy HWA infestation and does increase in succeeding years, but there is no gradual increase in mortality from year to year. The HWA population declines as the trees become a poor food source; followed by more new growth as the HWA population declines and the trees recover, but as the amount of new growth increases, the HWA population increases once again and the trees decline further.

## CONCLUSION

From the 2008 survey results presented here, it appears that the HWA continues to be negatively impacting hemlock stands in New Jersey and the percentage of highly stressed trees and mortality in the most heavily infested stands is increasing. The longer and more times that a stand has been heavily infested, the greater the stress and mortality. There was an increase in mortality at one of the ten monitored permanent study plots in 2008 as well as an overall increase in crown transparency ratings due most likely to the increased HWA population. Other factors such as water supply, elongate hemlock scale populations, and drought, are also probably contributing to the decline in hemlock health. However, the one factor that is consistent, where the mortality and transparency ratings are the greatest, is a heavy population of HWA.

## Photo credits:

Figures 7 – Jason Zhang and James Lashomb, Department of Entomology, Rutgers University, Cook College

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