Thirteen Years of Monitoring the Hemlock Woolly Adelgid In New Jersey Forests

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Abstract

The hemlock woolly adelgid (HWA) is negatively impacting hemlock stands in New Jersey. Mortality in the most heavily infested stands is increasing and is above 90% in some plots. There are 15 to 20 remaining moderately impacted hemlock stands in New Jersey, primarily in the northwestern corner of the State. The greatest mortality occurred in stands that were heavily infested during multiple periods. Tree mortality occurred within 5 to 6 years after a stand became heavily infested, followed by a crash in HWA populations. During periods of low adelgid densities, the remaining trees begin to recover until adelgid populations rebound, resulting in an increase in the rate of tree mortality. It has taken about 10 to 12 years from the initial heavy infestation to see mortality level of more than 90% in some stands. Other factors such as site conditions and water supply are likely a factor, but consistent across the stands where the mortality is the greatest is a heavy population of HWA. Foliage transparency typically increased in stands as the HWA populations increased, and significant tree mortality was observed when foliage transparency approached 60 percent. Foliage transparency would be a useful tool for forest managers interested in assessing tree health.

Keywords:

Hemlock woolly adelgid, crown ratings, foliage transparency, tree mortality.

Introduction

This report is the result of the Study Plot Monitoring Program partially funded by the United States Department of Agriculture, Forest Service and by the New Jersey Department of Environmental Protection, Division of Parks and Forestry. The objective of this work is to evaluate the impact of the hemlock woolly adelgid (HWA) and associated factors in natural hemlock stands over an extended period. Data collected include stand mortality, HWA population densities, crown ratings, and percent new growth.

Materials And Methods

Study Plots. Thirteen study plots were set up during the years 1988 to 1990, eleven of which were established in 1988. These plots were chosen as representative of natural hemlock stands and adelgid population densities. Of the eleven plots, nine were infested with varying levels of hemlock woolly adelgid and two were uninfested. The same eleven plots were monitored in 1989. In 1990, two of the plots were replaced, because they were continually being treated with chemicals, and field personnel were unable to get an accurate record of the treatments.

Plots were chosen to represent a noninfested, lightly infested, and 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 selected in the interior of the hemlock stands that had good accessibility to branches but avoiding the open areas.

A 10 factor prism was used to identify the hemlock trees within the subplot. One tree was designated as the center tree and any tree that was observed within the prism was included in the subplot. The tree lying closest to magnetic North with respect to the center tree was designated tree number one. 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. Branch tips were inspected for new growth with the new growth readily distinguishable from the previous year's growth by the light green color of the needles and lighter-colored stem. These counts were completed from June to August.

Selected branches were skewed towards branches showing the most potential for new growth. Measured from the tip and proceeding toward the trunk, a 12-inch branch sample was used and all 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, for a total of thirty 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 to 30 HWA per 100 needles is reached. There was no appreciable effect on the abundance of new growth when populations of HWA were less than this. The HWA population categories were then assigned as follows: H = heavy, greater than 30 adelgids per 100 needles; L = light, less than 30 adelgids per 100 needles; and N = none, no adelgids per 100 needles.

Population levels were determined by sampling HWA infested trees just outside of the subplots. Cuttings were made from six different trees within the plot, but outside the boundaries of the subplots. These cuttings were brought back to the laboratory, and ten 100-needle sections were randomly selected from each of the six cuttings. All adelgids present in the sections were counted and then averaged for each of the plots.

Crown Rating. The USDA Forest Service visual crown rating methodology of crown ratio, foliage transparency, and crown density (Millers et al. 1992) for all the plots were implemented in 1994. Crown ratio is the percent of total tree height that supports living foliage. Crown density is the amount of foliage; branches etc. that block light visibility through the crown. Foliage transparency is the amount of visible light going through the live portion of the crown. All estimates were made in 5% increments.

Mortality. Mortality was defined as no needles on the tree. The number of dead and live trees were tallied for each plot to determine the percent of tree mortality.

Statewide Hemlock Stand Survey. There are approximately 26,000 acres of eastern hemlock, *Tsuga canadensis,* in New Jersey. All natural stands are in the northern part of the State. Figure 1 shows the location and the extent of the HWA population in New Jersey by year. The New Jersey

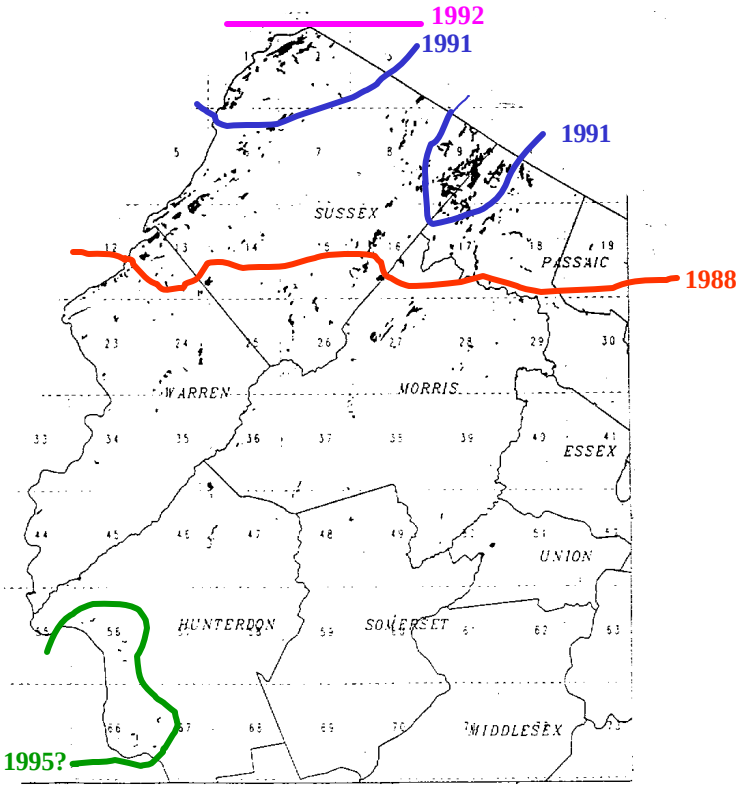

Figure 1. History of HWA infestation in New Jersey hemlock stands >10 acres in size.

Department of Agriculture did a survey of hemlock stands greater than 10 acres in size in the years 1988, 1992, 1997, and 2001. A total of 101 stands were surveyed in 1988, 111 in 1992, 159 in 1997, and 157 in 2001. The purpose of the survey was to delineate the hemlock woolly adelgid population in New Jersey and to assess tree health. In 2001, 20 trees were randomly sampled in each stand and data was collected on foliage transparency, crown ratio, adelgid population levels, slope, aspect, and the presence of *Fiorinia* scale.

Results And Discussion

New Growth and HWA Population. Generally, trees put out more new growth when the HWA population is light. As adelgid densities become heavy, the abundance of new growth begins to decline. As trees become stressed and new growth becomes less abundant, the HWA population declines. Trees appear to recover a bit and produce more new growth during the period of lower HWA densities but after a year or two, adelgid populations rebound and stress the trees once again. The HWA prefers new foliage and is rarely found on older material. After several years of heavy infestation the amount of new growth declines substantially (McClure 1996).

Figure 2 shows the percent new growth and population level for two plots representing a heavy and light infestation. The Shades of Death (SOD) plot was heavily infested in 1988. The Clinton Reservoir (CRS) has had a light population of adelgid since 1991, but heavy populations have never developed. The amount of new growth in the CRS plot was typically higher than in the SOD plot, especially in the early nineties. In 1993 to 1997, the SOD plot SOD shows that HWA populations declined and the new growth became more abundant but as HWA densities became heavier, new growth once again declined. Temperature is an important factor in the survival of the HWA.

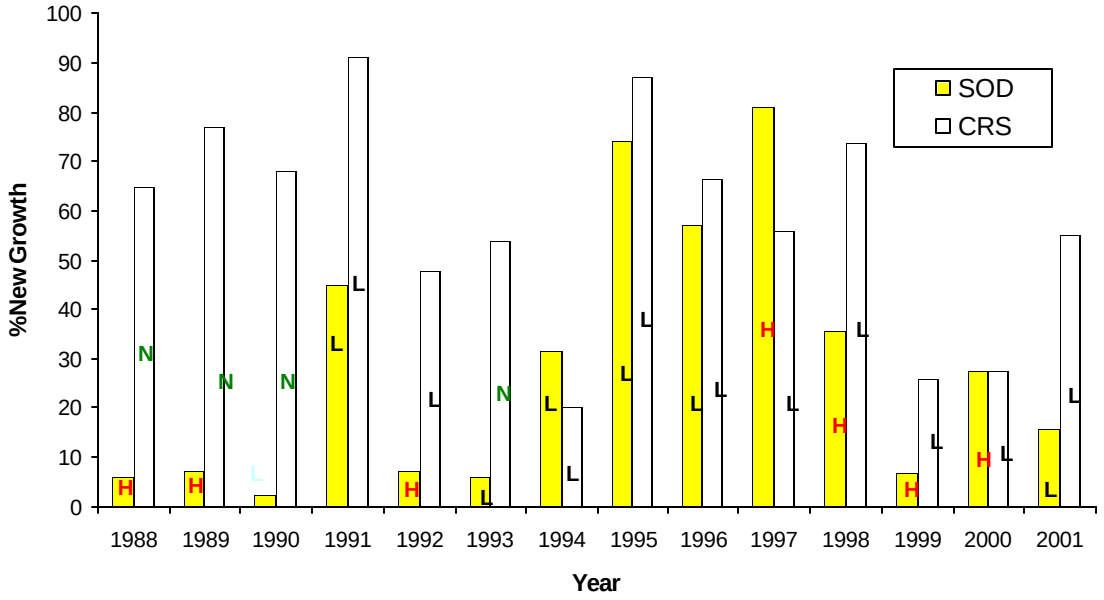

Figure 2. Percent new growth at Shades of Death and Clinton Reservoir plots 1988 to 2001 (N = No hemlock woolly adelgid infestation; H = Heavy hemlock woolly adelgid infestation; L = Light hemlock woolly adelgid infestation)

January of 1994 was the coldest of the decade, and HWA populations were reduced by more than 90% in the SOD plot. Adelgid populations did not recover until 1997 and remained heavy until 2000, which coincided with a decrease in the relative abunance of new growth. There was no such decline in the CRS plot.

The relative abundance of new growth is also affected by droughty conditions. In years following below normal precipitation, plot trees typically produced less new growth than in years following normal or above normal precipitation (Onken unpublished report, 1994).

Slope position and proximity to surface water also seem to play a major role in the amount of new growth and the survivability of the trees. In the plots with high tree mortality, it was observed that trees located at the bottom of a hill or near water have substantially more new growth and less mortality than treees gowing on upper slopes and dryer sites. Surviving trees with access to water in dry years generally appear healthier, although the amount of foliage left on these trees is still substantially less than they had been prior to becoming infested. Although it appears trees will eventually succomb even under optimum growing conditions.

Crown Ratings. Table 1 shows the population level of the HWA and cumulative tree mortality in plots over the course of the project. Figure 3 shows the foliage transparency ratings for four of the plots from 1994 to 2001. 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 foliage transparencies. These indicators reflect the relative health of the hemlock in Shades of Death, Schooley's Mountain, Johnson Lake, Lake Valhalla, Worthington State Forest, and Walnridge is poor when compared to lightly infested stands at High Point, Tillman's Ravine, and Clinton Reservoir. Stands that have been heavily infested for the longest period by the HWA are the stands that are in the poorest health.

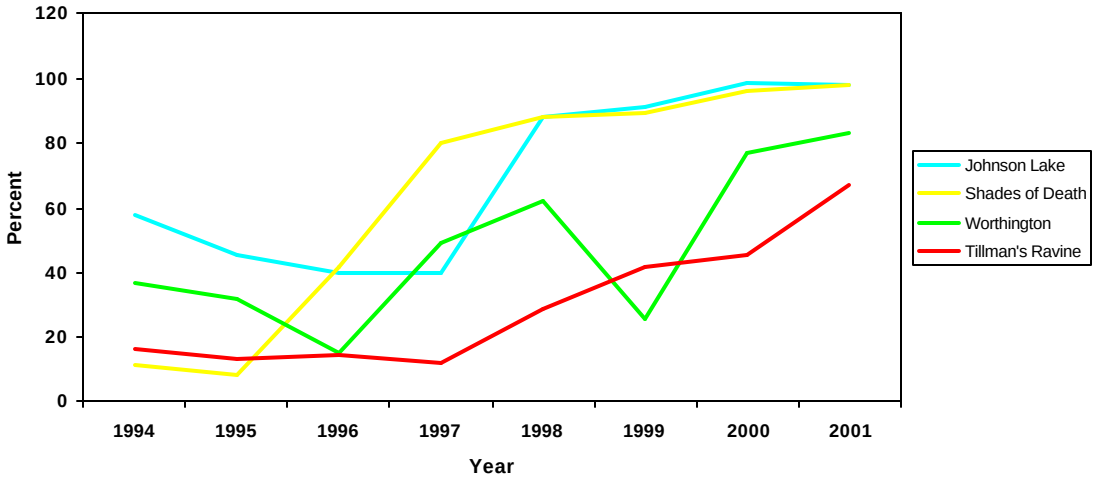

Figure 3. Average Crown Transparency for 4 Plots

Figure 3 shows that the trees do refoliate if given a respite from the HWA. The line for Worthington State Forest shows a decline in transparency from 1994 to 1996 and in 1999, which means that the

Table 1. Percent New Growth, HWA Population Levels and Mortality in the New Jersey Permanent Plots 1988 - 2001.

Plot, % NG/Year	88	89	90	91	92	93	94	95	96	97	98	99	00	01
Hewitt SF	-	-	72	87	14	23	27	80	50	64	18	2	34	60
HWA Pop'n	L	L	L	L	L	L	L	L	L	H	H	H	H	L
% Mortality	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clinton Res.	65	77	68	91	48	54	20	87	66	56	74	26	27	55
HWA Pop'n	N	N	N	L	L	N	L	L	L	L	L	L	L	L
% Mortality	0	0	0	0	0	0	0	0	0	3	3	3	14	35[1]
High Pt. SP	53	72	75	89	47	58	8	59	66	57	65	38	10	47
HWA Pop'n	N	N	N	L	L	L	N	L	L	L	L	H	H	L
% Mortality	0	0	0	0	3	9	9	12	12	12	15	15	23[2]	29[2]
Johnson Lake	58	42	7	9	1	12	8	69	59	58	34	4	22	63
HWA Pop'n	L	L	H	H	H	L	H	H	H	H	H	H	H	H
% Mortality	0	0	0	0	0	8	8	48	56	68	68	76	92	92
Lake Valhalla	65	74	51	47	0	28	30	78	35	41	40	7	17	50
HWA Pop'n	L	L	H	H	H	H	L	H	L	H	H	H	L	H
% Mortality	0	0	0	0	0	0	0	5	5	5	10	10	21	38
Millbrook	55	54	58	73	26	11	37	67	63	66	32	2	6	33
HWA Pop'n	L	L	L	H	H	H	N	L	L	L	H	H	L	L
% Mortality	0	0	0	0	5	5	5	5	5	5	5	5	5	5
Schooley's Mt.	6	4	6	59	25	44	24	80	55	50	-	14	25	55
HWA Pop'n	H	H	H	L	L	L	L	H	L	H	-	H	L	H
% Mortality	0	0	0	0	0	15	15	25	35	40	-	50	60	65
Shades of Death	6	7	2	45	7	6	32	74	57	81	35	7	28	48
HWA Pop'n	H	H	L	L	H	L	L	L	L	H	H	H	H	L
% Mortality	0	0	0	4	15	19	23	65	69	73	73	73	88	96
Tillman's Ravine	-	-	-	89	57	77	13	63	44	63	65	32	5	35
HWA Pop'n	-	-	-	N	L	N	N	N	N	L	L	L	H	L
% Mortality	-	-	-	0	0	0	0	0	0	5	5	5	5	5
Walnridge	75	51	20	-	21	46	60	40	31	82	72	6	33	75
HWA Pop'n	L	H	H	-	H	L	H	H	L	L	H	H	L	H
% Mortality	0	0	0	4	15	19	23	65	69	73	73	73	88	96
Worthington	7	12	13	3	0	25	21	64	58	80	72	6	13	28
HWA Pop'n	H	H	H	L	L	H	L	H	L	H	H	H	L	H
% Mortality	0	0	0	0	8	12	12	16	32	40	40	40	48	56

[1]Tree mortality is due to drought conditions and *Fiorinia externa* populations.

[2]Tree mortality is due to beaver damage and flooding in the plot rather than to the hemlock woolly adelgid.

tree refoliated. These were years in which the HWA population had declined and/or site conditions improved and the trees refoliated, only to be defoliated again when the trees became heavily re-infested. Tillman's Ravine became heavily infested in 2000 and its transparency had already begun to increase (probably due to the drought of 1999), but the transparency had substantially increased by 2001.

The most stressed trees have high crown ratings for transparency (the lower the number, the more dense the foliage). As the HWA population in that stand increases, the crown ratings deteriorate. The effect is not seen for a few years but when the initial data from each stand is compared to the data from some years later, the effect is readily apparent.

Tree Mortality Considerations. Obviously, the HWA is putting stress on the trees in the forest. Figure 4 shows the stand mortality from 1988 to 2001 in four of the monitored stands. The years listed after the text in the legend indicate the first year of heavy HWA infestation in a particular plot. The greatest mortality occurred in the stands that were heavily infested with the HWA for the longest period of time. These also are the stands that have the poorest crown ratings.

There is no hard and fast rule as to when substantial hemlock mortality may occur in an affected stand. In New Jersey, some tree mortality was observed 5 to 6 years after a heavy HWA infestation, but it increased substantially 7 to 8 years after the initial heavy HWA infestation. Twelve years after the initial infestations, tree mortality has reached more than 90% in some hemlock stands and is increasing. Probably there are other factors that contribute to the death of the trees, but heavy populations of HWA prior to significant tree mortality has been a constant association. *Fiorinia externa* (Homoptera: Diaspididae) is present in many of the stands and also is a stressor, but its overall effect on the stands is not clear. It appears to be a secondary pest. Populations of the hemlock borer, *Melanophila fulvoguttata* (Harris) (Coleoptera: Buprestidae), have also been building. 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. At Shades of Death, Walnridge, Schooley's Mountain, Lake Valhalla, and Johnson Lake, the least mortality has occurred among trees at the bottom of a slope or near a stream.

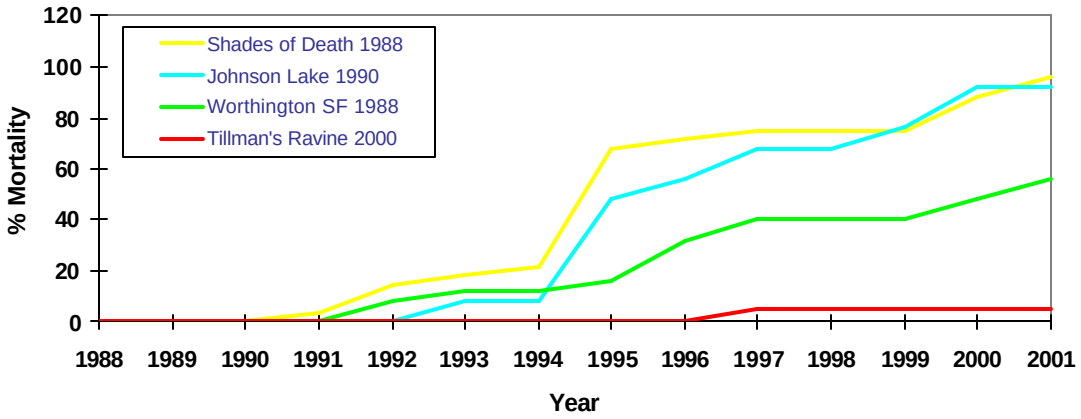

Figure 4. Cumulative tree mortality 1988 to 2001.

There is no concurrent mortality of other tree species in any of the stands. The HWA population declines as the trees become a poor food source. Initially, as the HWA population declines the trees recover, but as the amount of new growth increases, the HWA population increases once again, causing the trees decline further.

Hemlock is a shallow-rooted tree and are often blown over as the root system dies. Widowmakers are a common sight and many of the trees have split and fallen. A municipal park with an extensive hemlock forest in Sparta, New Jersey has been closed because of the hazard that the dead hemlock trees represent. High-use public recreation areas with high hemlock mortality will be a threat to public safety, especially on windy days, and will likely be closed, or the dead trees removed.

Statewide Stand Survey. The statewide stand survey was originally done in 1988 to get an idea of where the HWA was in New Jersey and to evaluate stand health. This was continued in 1992, 1997, and 2001. Table 2 shows the relationship between mortality and HWA population levels in 2001.

Table 2. Average Mortality in 2001 for Hemlock Stands in the New Jersey Statewide Survey in 1988, 1992, 1997, and 2001

Infestation Level	Number Times Infested	Average Mortality
Heavy	3X	42.5%
Heavy	2X	32.4%
Heavy	1X	19.6%
Light only	1-3X	10.1%
None	0	4.1%

Only stands that were surveyed in at least 3 of the 4 years are included. Not all stands were surveyed in all 4 years, especially in 1988 and 1992. Some stands were inaccessible due to topography, weather, or their location on military reservations. The relationship between mortality and the number of times that a stand has been heavily infested is quite evident. The stands that were heavily infested in three out of the four surveys had an average mortality of 42.5%; those that were heavily infested 2 out of the 4 years had an average mortality of 32.4%; those that were heavily infested 1 out of 4 years had an average mortality of 19.6%; and stands that have only ever been lightly infested had an average mortality of 10.1%. If the stand was never infested, the average mortality was 4.1 percent. In short, the more times that a stand was heavily infested, the greater the tree mortality.

Figure 5 shows the relationship between average percent mortality and foliage transparency by stand. The data show that as transparency increases, the mortality increases, and there is a

threshold of about 60% where the mortality increases substantially. Rhea (personal communication), found that if hemlocks were defoliated more than 50%, the trees would not recover. The transparency data shows something analogous in that stands with foliage transparencies more than 60%, have substantially increasing mortality. Currently, in New Jersey, only 22.9% of the stands have an average foliage transparencies of less than 50%; and only 8.2% of the stands have average transparencies of less than 40 percent. If condition of the stands with transparencies between 40 to 50% represent a borderline tree health, then out of the 157 stands surveyed, about 15 to 20 hemlock stands in New Jersey remain healthy.

Figure 6 shows the relationship between crown ratio and mortality. Again, there is a linear relationship. As the crown ratio decreases, mortality increases.

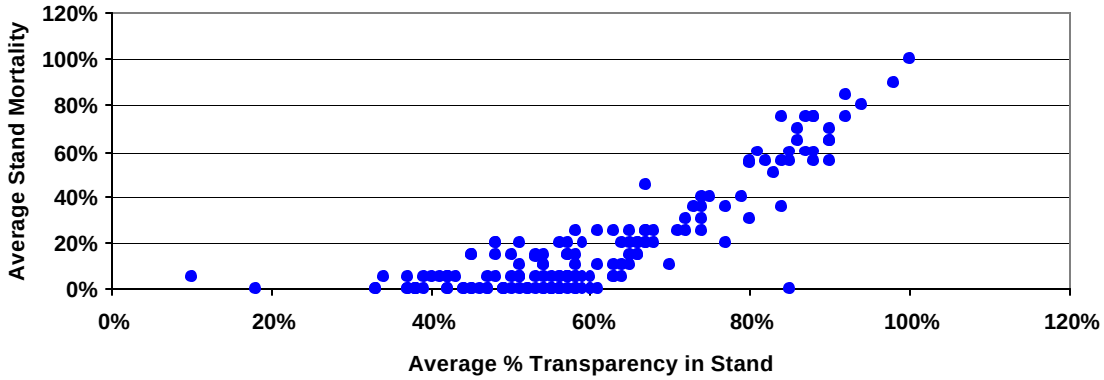

Figure 5. New Jersey 2001 Statewide Survey & Mortality and Foliage Transparency by Stand

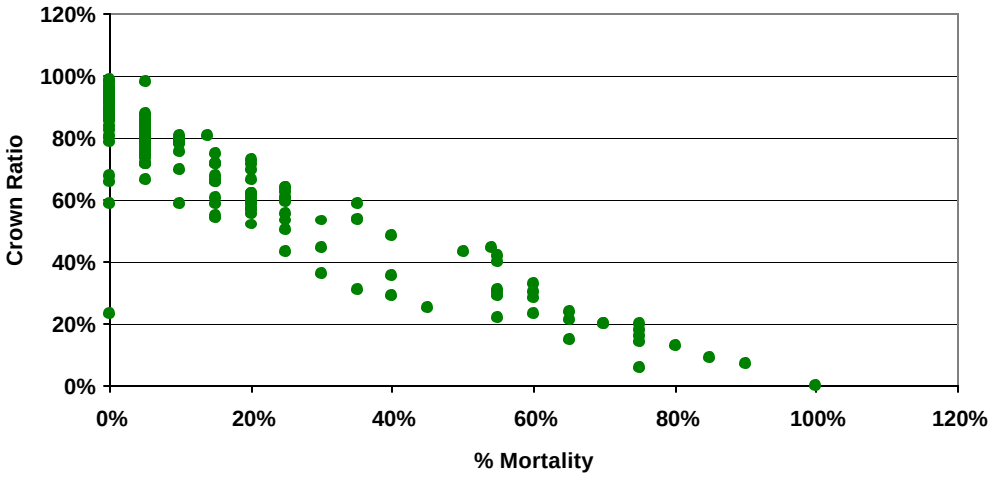

Figure 6. Average crown ratio and mortality in 2001 New Jersey statewide survey.

Conclusion

Survey results indicate that the HWA is negatively impacting hemlock stands in New Jersey and mortality in the most heavily infested stands is increasing. The longer that a stand has been heavily infested or the more times that a stand has been heavily infested, the greater the tree mortality. Tree mortality occurs 5 to 6 years after a stand has been heavily infested. Surviving trees may begin to recover if HWA populations decline but are not likely to survive a second heavy infestation. It has taken about 10 to 12 years from the initial heavy infestations to see mortality of more than 90% in some of the hemlock stands in New Jersey. Other environmental factors appear to be involved, but the one factor that is consistent where the mortality is the greatest is a heavy population of HWA.

In affected stands, foliage transparency increases and the crown ratio decreases. At a threshold of 60% foliage transparency, tree mortality increases significantly.

Only 15 to 20 hemlock stands out of the 157 surveyed in New Jersey are yet to be seriously impacted by the hemlock woolly adelgid.

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