

HEMLOCK ECOSYSTEMS and HEMLOCK WOOLLY ADELGID at DELAWARE WATER GAP NATIONAL RECREATION AREA

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INTRODUCTION

Hemlock forests continue to decline at Delaware Water Gap National Recreation Area (DEWA), and hemlock woolly adelgid (*Adelges tsugae*, “HWA”) is the main cause of this decline. However, other stressors – such as the droughts of recent years, and infestations of elongate hemlock scale (another insect pest of hemlock) – accelerate this decline and complicate management efforts. The best available information indicates that about 20% of hemlocks in DEWA are dead, 60% are at various stages of decline, and only about 20% are healthy. Continued decline of hemlock forests in DEWA will bring about major ecosystem transformations and loss of much valued biodiversity, as well as loss of recreational and esthetic resources (Evans 2002). Dead and dying hemlock trees add to the challenges of managing hazard trees in DEWA.

During the past eleven years, DEWA has conducted a program to address the threats that HWA poses to valued park resources. The efforts and support of many different agencies and cooperators have contributed greatly to this HWA-Hemlock Program over the years. The support of the USDA Forest Service in particular, in the form of funding, labor, and technical assistance, has been critical to the success of this program.

Since 1993, the **Hemlock Program Goals** have been to:

1. Generate information about HWA and hemlock tree health in the park.
2. Identify and document the distinctive characteristics of park hemlock ecosystems.
3. Manage HWA and maintain park hemlock ecosystems, to the extent possible.
4. Provide public information and technical assistance.

The year 2000 annual report (Evans 2001) provided a review of hemlock woolly adelgid related issues in DEWA, and our research, monitoring, and management efforts to address those issues. Accomplishments of the hemlock program (and contributors) during 2003 include the following (organized by program goals):

1. HWA and Hemlock Tree Health Monitoring
 - Obtained USDA Forest Service funding to support two seasonal biological technicians.
 - Completed annual assessments of HWA infestation levels and hemlock branch new growth.
 - Completed all permanent hemlock plot measurements at all plots in DEWA.
 - Received and evaluated park “crown health” data sets from the USDA Forest Service, covering the period from 1993 to 2002 (see results below).
 - Began to use GIS layers of hemlock forest conditions in the park, produced by satellite image analysis (provided by Dr. Royle, Rutgers University and USDA Forest Service), for DEWA hemlock forest management and research efforts (credit DEWA GIS staff and J. Shreiner).

- Completed training and received USDA Forest Service “tree climber” certification (made possible by the Massachusetts Dept. of Forestry). Obtained needed tree climbing equipment. Collected and analyzed samples from 60 feet high in tree crowns at Childs Park.
- 2. Hemlock Ecosystems
 - Assisted researchers from the University of California – Berkeley and Cornell University to repeat and expand upon the 1994-1995 understory vegetation studies at Adams Creek and VanCampens Brook.
 - Continued research into the vegetation, soils, and waters of hemlock and hardwood forests in the park (conducted mainly by the USDA Forest Service and US Geological Service through the Collaborative Environmental Monitoring and Research Initiative, or “CEMRI”).
- 3. Management of HWA and Hemlock Ecosystems
 - Released 15,000 HWA biocontrol beetles (*Pseudoscymnus tsugae*) within DEWA (beetles contributed by the NJ Dept. of Agriculture, Beneficial Insect Laboratory).
 - Organized a three-day, multi-agency and interdisciplinary workshop on strategies and techniques for management of declining hemlock forests (credit J. Shreiner).
 - Refined plans for chemical treatment of HWA infested trees (USDA Forest Service assistance).
- 4. Public Information and Technical Assistance
 - Completed a feature article for Park Science about HWA and hemlock forests (in press).
 - Presentation at the NE Forest Pest Council Conference (March).
 - Produced informational posters about HWA and hemlock management (with assistance from Visitor Services staff).
 - Provided information about HWA, hemlock decline, chemical treatments and biological controls to numerous private landowners and local communities.

More detailed descriptions of the methods, results, and activities of the DEWA HWA-Hemlock Program during 2003 are presented below.

1. HWA and HEMLOCK TREE HEALTH

1.1 Monitoring HWA Infestation Levels and Hemlock Branch New Growth

In 2003, as in previous years, DEWA staff collected data on HWA infestation levels and amount of new twig growth on hemlock tree branches (see Evans 1996 for methods) associated with 81 permanent plots distributed among seven sites around the recreation area. Funding provided by the USDA Forest Service was used to support two biological technicians to complete this and other hemlock program work.

Results of this monitoring from 1995 through 2003 at five of the sites are summarized in Figure 1. HWA infestation levels at the five sites during 2003 ranged from about 20% to 50%. The 2003 HWA infestation levels were moderate in comparison to those of previous years, which ranged from near zero to near 100%. HWA samples collected in

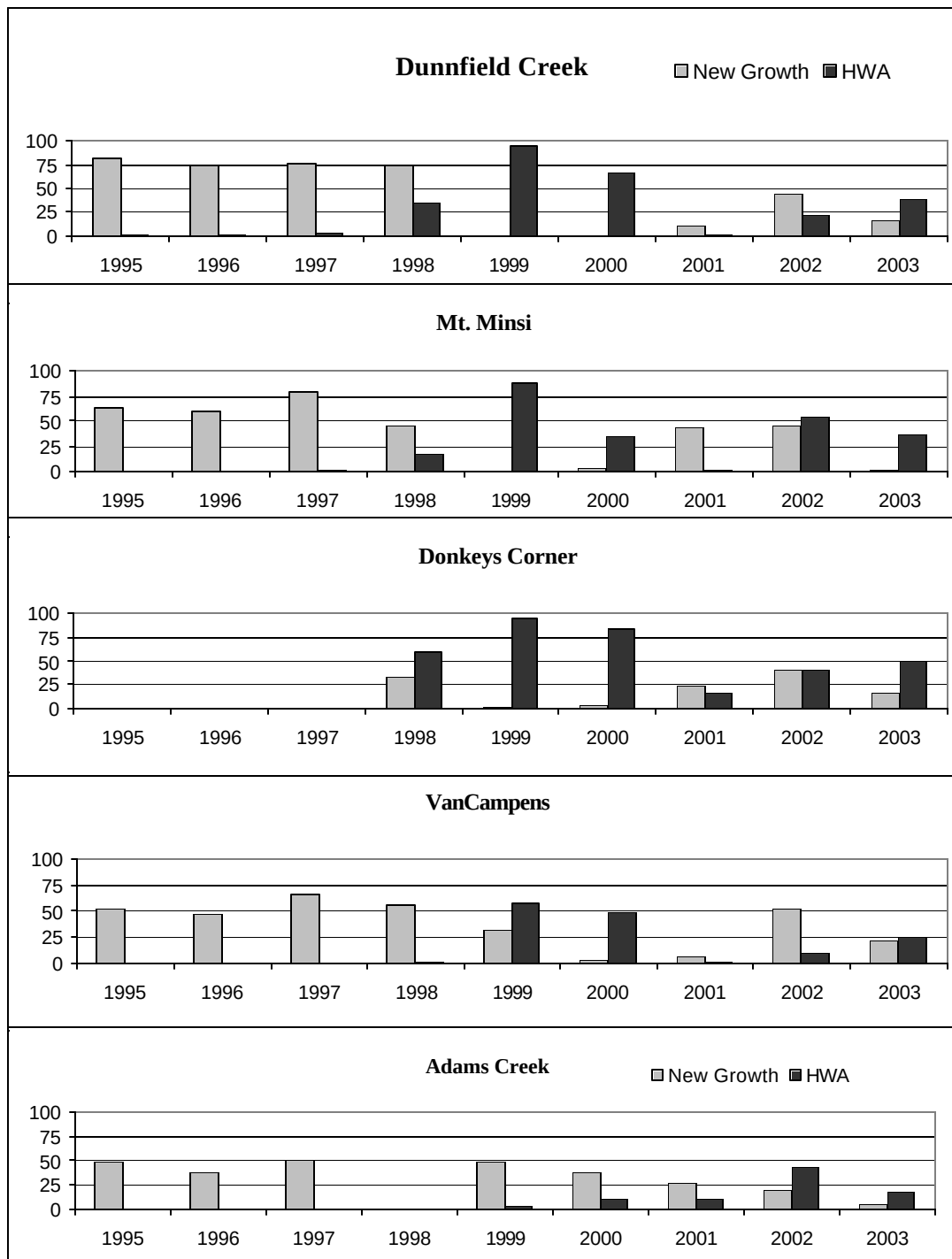


Figure 1. Average annual amounts of new growth (percent of twigs producing new growth) and HWA infestation levels (percent of twigs infested with HWA) at each of five monitoring sites, from 1995 through 2003. Prior to 1998, no data were collected at Donkeys Corner. HWA infestation levels were moderate during 2003, relative to infestation levels in the previous years.

March, 2003 indicated substantial mortality (over 50%) of over-wintering HWA. Undoubtedly, the relatively severe temperatures during the winter of 2002-2003 caused much HWA mortality. However, it's also likely that poor tree health resulting from HWA infestations and droughts over the past several years contributed to HWA mortality, and limited the HWA infestations of summer 2003.

The relationship between the level of HWA infestation and the amount of new growth on hemlock tree branches in the recreation area has changed over recent years (Figure 2). In 1999, branches with light HWA infestations (<40% of twigs infested) produced lots of new growth (>60%), and branches with relatively heavy HWA infestations (50% to 80% of twigs infested) managed to produce moderate amounts of new growth (about 40%). In 2000, lightly infested branches only produced moderate amounts of new growth, and heavily infested branches produced virtually no new growth. In 2003, even lightly infested branches produced very little new growth, and moderately to heavily infested branches produced virtually no new growth.

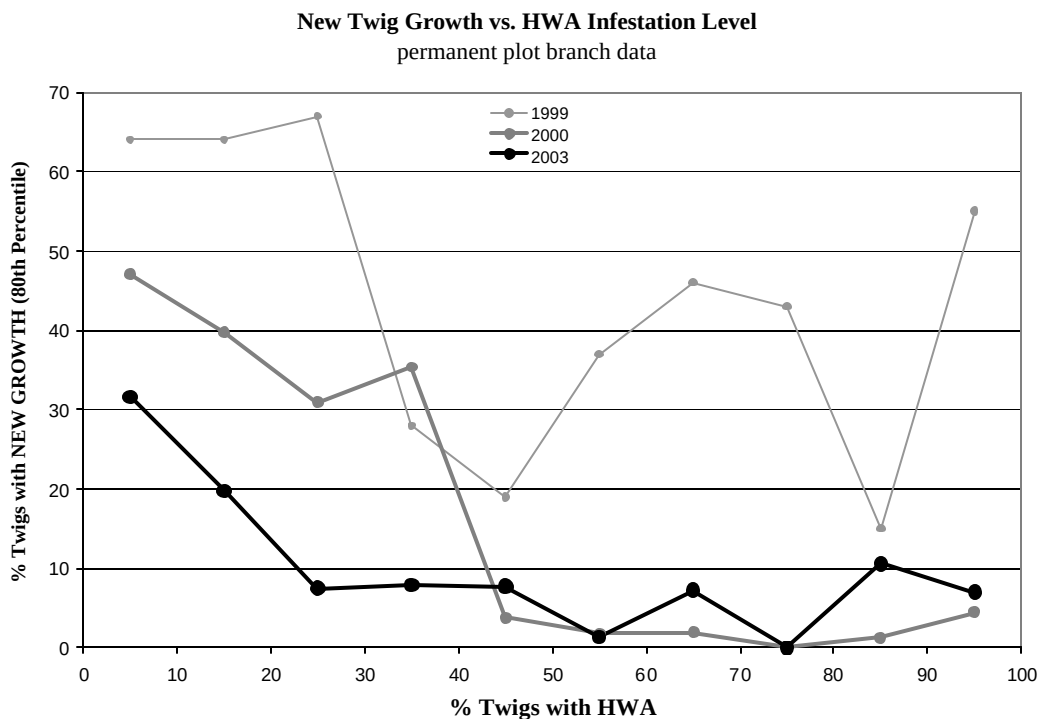


Figure 2. Decline in the amount of new twig growth on hemlock branches with increasing HWA infestation levels and cumulative “dose” of HWA over time.

The decline in hemlock new growth over this period is very likely the result of at least two factors: (1) the cumulative “dose” of HWA over time, and (2) the cumulative effects of drought stress over this period. Because there seems to be a one-year delay in response of hemlock trees to drought (Onken 1994), the droughts of recent years, through 2002, most certainly contributed to reduced hemlock tree new growth through the 2003

growing season. The unusually high precipitation of 2003 should alleviate stress on hemlock trees, and potentially allow for more new growth during the 2004 season.

The general pattern of decline in the potential for new growth on individual hemlock branches with increasing HWA infestation levels also appears at the forest stand level. Increasing HWA infestation levels in hemlock forest stands decreased the potential for new growth in those forest stands (Figure 3).

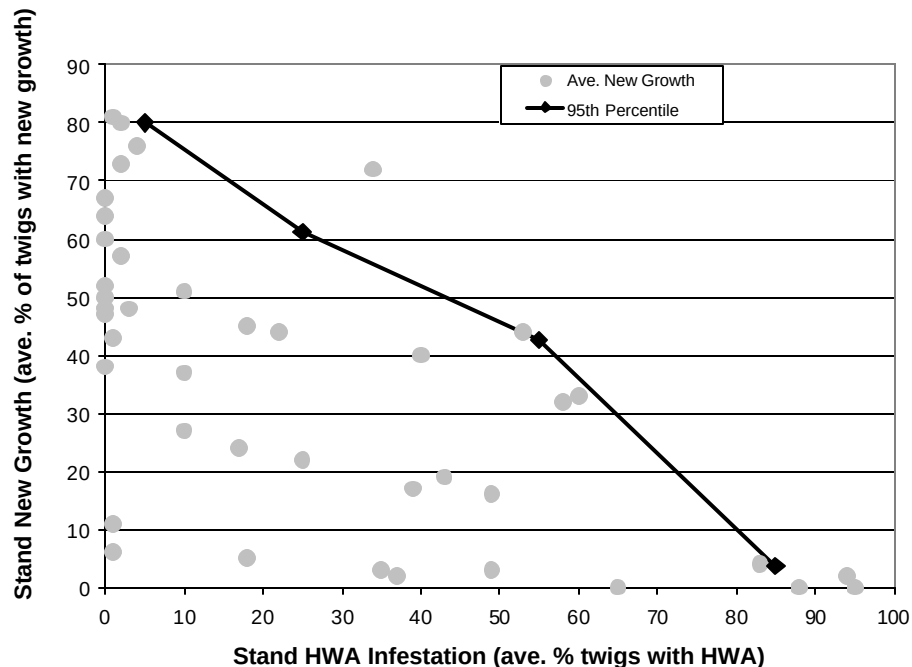


Figure 3. Decline in new growth potential in hemlock forest stands with increasing levels of HWA infestation. Each data point represents an average HWA infestation level and amount of new growth for a hemlock stand for each year over the period 1995 to 2003 (note: these are the same data as in Figure 1, presented differently). The black line shows the new growth potential (95th percentile) at a given HWA infestation level.

1.2 Hemlock Tree Crown Health and Mortality

1.2.1 Permanent Plot Monitoring

Every year since 1993, park and USDA Forest Service staff have evaluated individually marked hemlock trees in our permanent plots to assess hemlock tree health and mortality in DEWA (for methods, see USDA Forest Service 1998). To assess tree health, we use the “Visual Crown Rating Methods” (VCR) developed and widely used by the US Forest Service (USDA Forest Service 1998). We use four primary measures of tree crown health:

- crown ratio: ratio of the length of the live tree crown to the total height of the tree.
- crown density: “fullness” and density of branches and foliage.
- crown die-back: loss of needles at tips of branches.
- crown transparency: relative amount of light that can pass through the tree crown.

All these measures are recorded as a percentage compared to an ideal, healthy tree.

In addition, each hemlock tree was assigned to one of the following five “vigor” categories: healthy, slight decline, moderate decline, severe decline, or dead. The Forest Service assigned numeric values to each of the five tree vigor ratings as follows: healthy = 4, slight decline = 3, moderate decline = 2, severe decline = 1, or dead = 0.

In many years, only a fraction (a sub-sample) of the plot trees were evaluated because of staff and time limitations. In 2003, VCR data were collected from every plot tree possible (approximately 750 trees). Also, the diameter at breast height (DBH) of every live plot tree was measured; this was the first DBH re-measurement since the plots were established.

In 2003 the USDA Forest Service provided the park with Excel files containing our past hemlock plot VCR data from 1993 through 2002. Relatively simple summaries of these data are presented below. Analysis and interpretation of these data are complicated by the fact that different plots and trees have been sampled in different years. Much more sophisticated and powerful analyses of these data are possible, and would be very useful, but are beyond the scope of this report.

Figure 4 summarizes data on the percent of crown transparency, dieback, and mortality for DEWA hemlock plot trees from 1993 through 2002. Crown transparency (the relative amount of light that can pass through the tree crown) increased more-or-less gradually from about 15% in 1993 to 35% in 2002. Crown dieback remained at about 5% from 1993 to 2000, but then increased dramatically to over 20% in 2002. The proportion of dead hemlock trees in the plots increased from zero percent in 1993 to over 15% in 2002.

Average hemlock crown vigor has changed over time in different ways at different sites in DEWA (Figure 5) in relation to the history of HWA infestations at each site (shown in Figure 1). At VanCampens, hemlock vigor declined in 1999, 2000, and 2001 – apparently in response to high HWA infestations of 1999 and 2000 – but remains relatively high compared to other sites. At Adams Creek, vigor has declined substantially since 1998, while HWA infestations increased. At Mt. Minsi, vigor has declined slowly and unevenly over the years, despite many years of high HWA infestations. At Donkeys Corner, hemlock vigor declined to extremely low levels in recent years, as might be expected from the cumulative effects of many years of high HWA infestations.

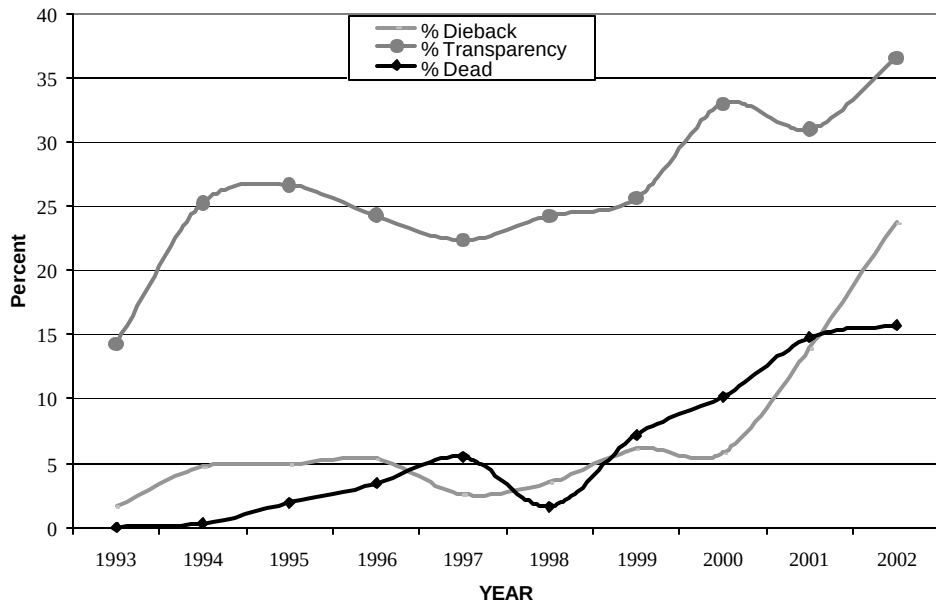


Figure 4. Increased hemlock crown transparency, dieback, and mortality of plot trees from 1993 to 2002.

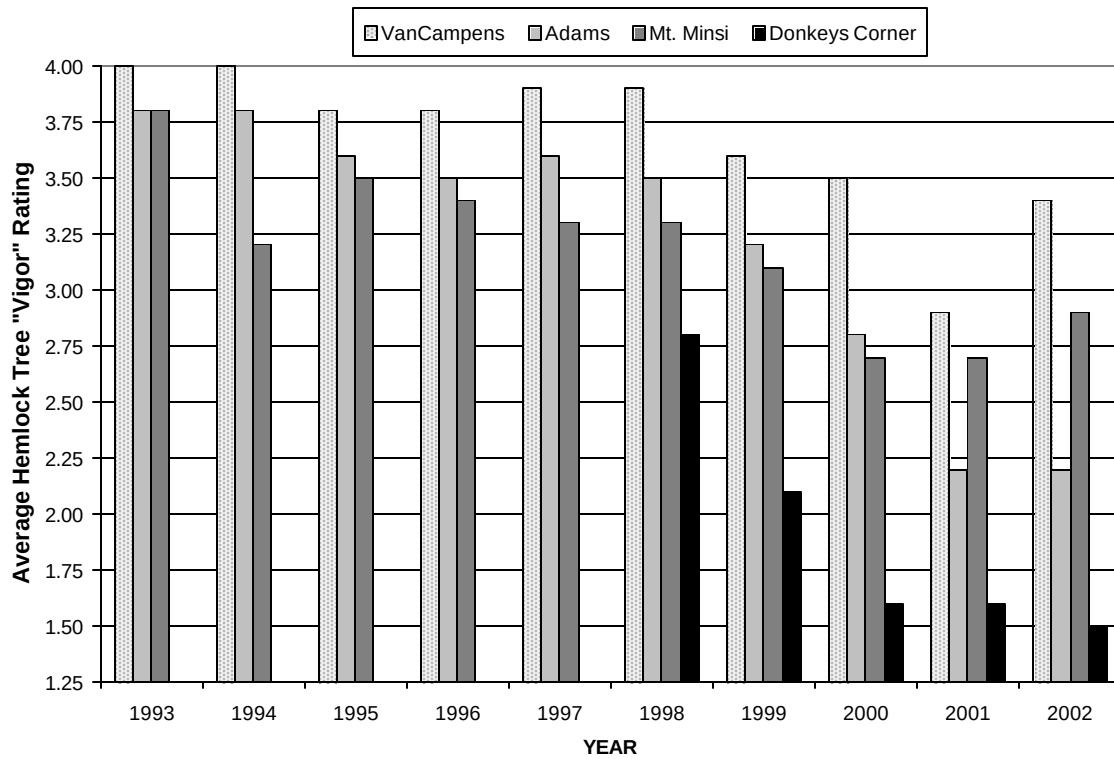


Figure 5. Declines in average hemlock tree vigor at four different sites in DEWA from 1993 to 2002.

Figures 6, 7, 8, and 9 illustrate in more detail the differences in hemlock “vigor” conditions at these four sites from 1993 to 2002. At VanCampens (Figure 6), about 90% of the hemlock trees remained either “healthy” or in “slight decline” in 2002, and only 6% of the hemlock plot trees had died. At Adams Creek (Figure 7), less than 50% of the hemlock trees remained either “healthy” or in “slight decline” in 2002, and about 20% of hemlock plot trees had died. At Mt. Minsi (Figure 8), about 75% of the hemlock trees remained either “healthy” or in “slight decline” in 2002, and about 10% of hemlock plot trees had died. At Donkeys Corner (Figure 9), no more “healthy” hemlock trees remained by 2002, and 50% were either dead (27%) or in “severe decline” (23%).

Figure 10 illustrates hemlock vigor ratings for all the plot trees sampled in 2002. These data indicate that 25% of the hemlock trees in our monitoring plots were either dead or in severe decline, 48% were in light to moderate decline, and 27% were healthy in 2002. However, these data may or may not accurately represent conditions throughout DEWA; the plots were originally distributed in such a way as to be representative of each hemlock stand they were located in, but not necessarily of the entire recreation area.

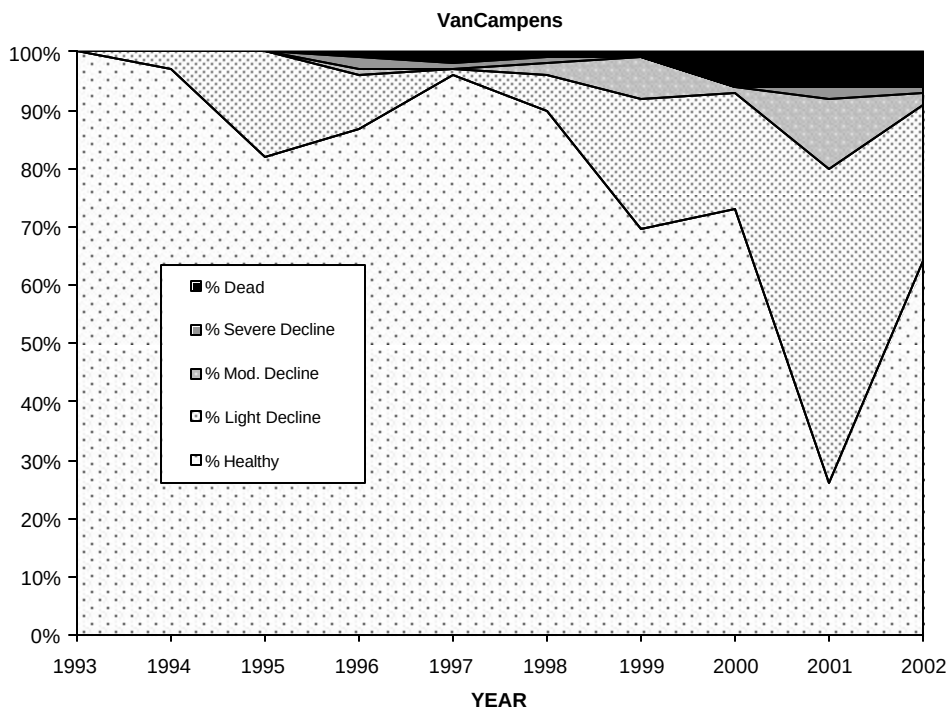


Figure 6. Changes in hemlock vigor at VanCampens from 1993 through 2002.

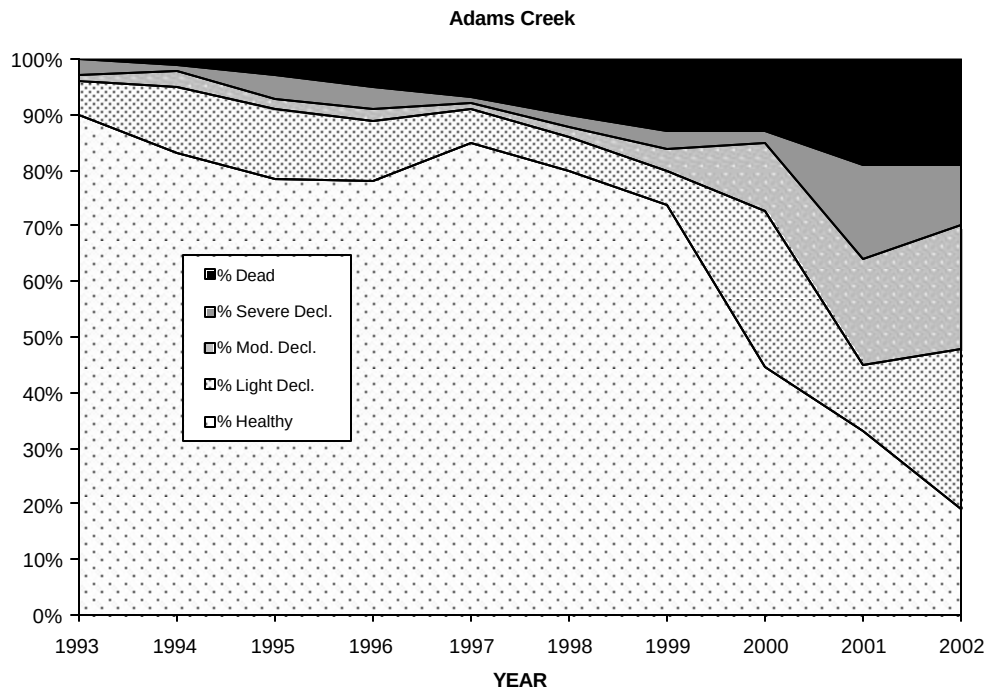


Figure 7. Changes in hemlock vigor at Adams Creek from 1993 through 2002.

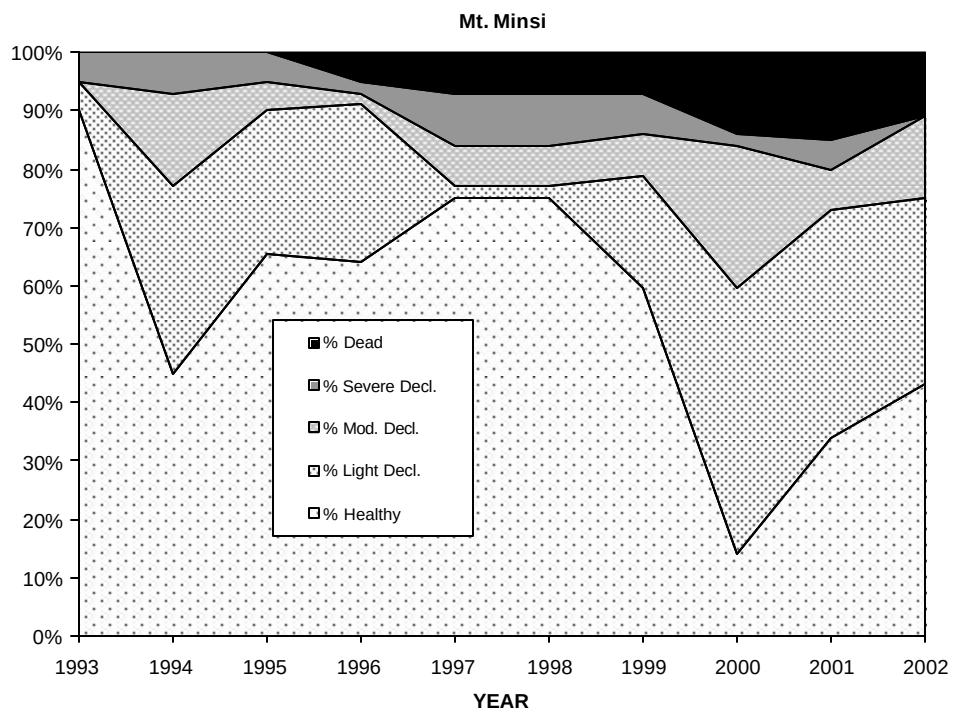


Figure 8. Changes in hemlock vigor at Mount Minsi from 1993 through 2002.

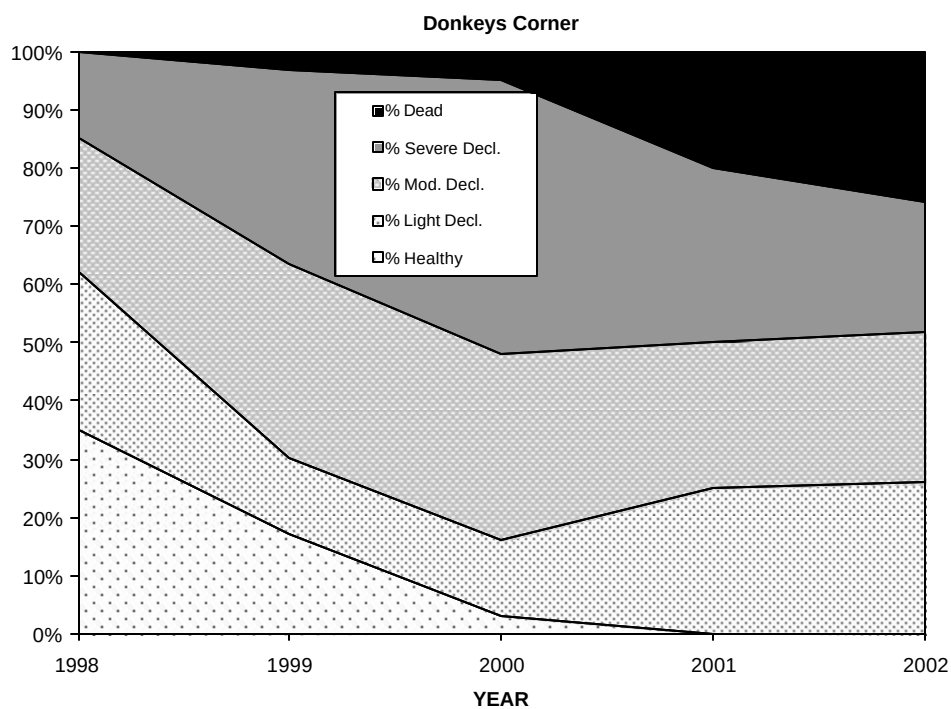


Figure 9. Changes in hemlock vigor at Donkeys Corner from 1998 through 2002; “healthy” hemlock trees no longer exist at this site.

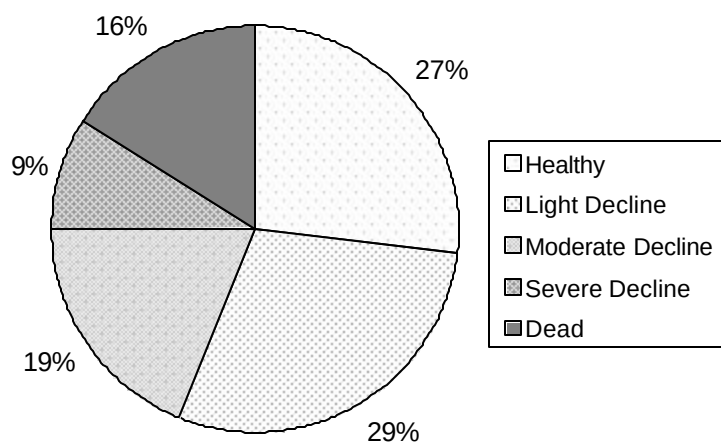


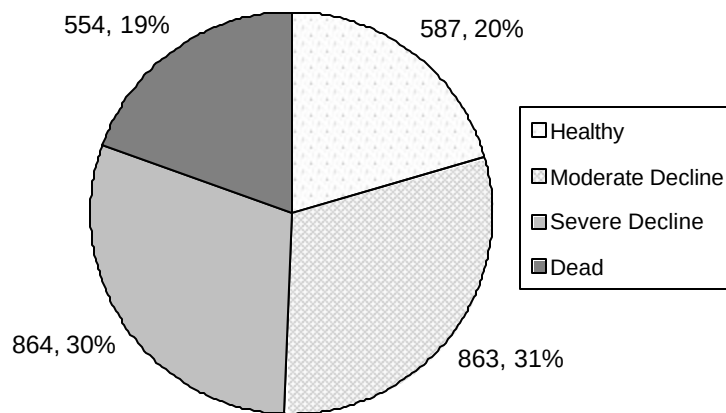
Figure 10. Hemlock “vigor” ratings for all plot trees sampled in 2002. These data may not accurately represent conditions throughout DEWA, because the plots were established to be representative of each local stand, not of the entire recreation area.

1.2.2 Satellite Data Analysis

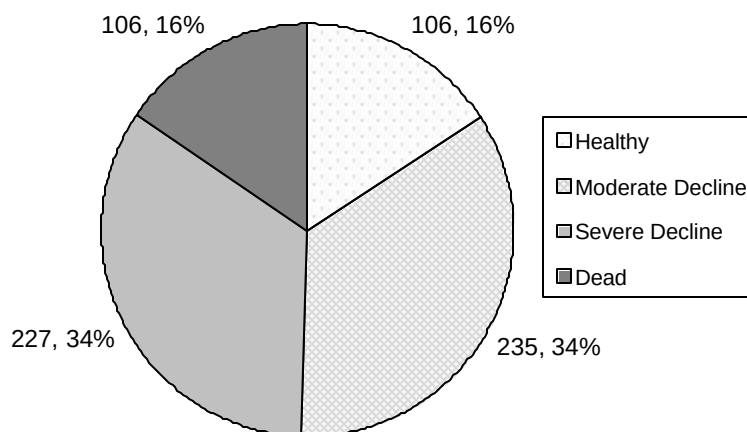
Royle and Lathrop (2002) recently used landsat Thematic Mapper satellite imagery to quantify and analyze hemlock forest decline over the entire landscape of northern New Jersey. As part of the Collaborative Environmental Monitoring and Research Initiative (CEMRI), Dr. Royle provided DEWA with GIS data files of the condition of hemlock forests throughout DEWA on a pixel by pixel (30m X 30m) basis, for a number of past years, based on satellite image analysis. These satellite based assessments are not completely accurate, but efforts continue to improve their accuracy. In the meantime, the assessments provide useful information about the spatial distribution, rate, and extent of hemlock decline in the recreation area that would not otherwise be available.

Figure 11 shows hemlock forest conditions in 2002, estimated from the satellite data analysis provided by Dr. Royle, for (A) the entire Delaware Water Gap National Recreation Area, and (B) the 14 hemlock forests selected as research sites by the USGS-BRD (Young et al. 2002). The satellite analysis indicated that in 2002 about 20% of the hemlock forest in the recreation area was healthy, 19% was dead, 31% was in moderate decline, and 30% in severe decline.

The fact that hemlock conditions in the 14 research sites are the same (no statistical difference) as those throughout the recreation area is further evidence that these 14 sites represent DEWA hemlock forests very well (Young et al. 2002). It may also be interpreted as evidence that hemlock decline is either random over the landscape, or else is correlated strongly with the terrain characteristics used to select the 14 research sites (elevation, slope, aspect, terrain shape, and solar illumination). Studies by Royle and Lathrop (2002) and Young and Morton (2002) have shown hemlock decline does in fact correlate with landscape terrain, and is not random over the landscape. Average hemlock conditions within each of the 14 research sites ranged from very healthy to severe decline (Figure 12).



A.



B.

Figure 11 (A & B). Charts of hemlock forest conditions in 2002, estimated from satellite data analysis provided by Dr. Denise Royle, for (A) the entire Delaware Water Gap National Recreation Area, and (B) the 14 hemlock forests selected for research by the USGS-BRD (Young et al. 2002). The first of each pair of numbers is the acres of hemlock forest within a given condition class (e.g. “moderate decline”); the second is the percentage of hemlock forest assigned to that condition class. The fact that hemlock conditions in the 14 research sites are the same (no statistical difference) as those throughout the recreation area is further evidence that these 14 sites are very representative of all DEWA hemlock forests.

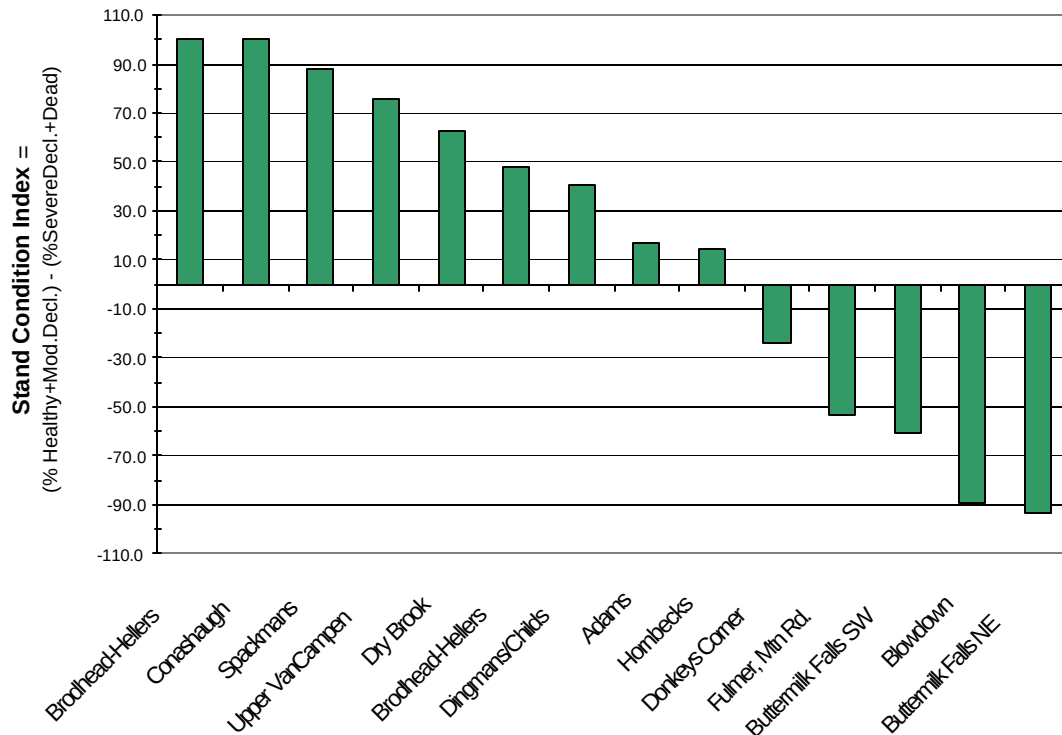


Figure 12. Range of conditions of the 14 hemlock forests selected as research sites by the USGS-BRD (Young et al. 2002), as estimated from analysis of 2002 satellite data provided by Dr. Royle.

2. HEMLOCK ECOSYSTEM & BIODIVERSITY STUDIES

A number of research projects in the park continue to focus on aspects of HWA and hemlock forest ecology and biodiversity. Topics studied include the effects of HWA and hemlock decline on understory vegetation, birds, hemlock tree growth and foliage chemistry, and nutrient (especially carbon and nitrogen) dynamics in forest vegetation, soils, and streams.

The Collaborative Environmental Monitoring and Research Initiative (CEMRI) has sponsored several of these studies during the past three years. The CEMRI is an effort to demonstrate how the effectiveness of different environmental research and monitoring programs conducted by different agencies can be improved through interagency collaboration (see www.fs.fed.us/ne/global/research/drb/). The Delaware River Basin was selected as a “pilot test” location of this concept, and DEWA is one of three “intensive research sites” included as part of it. Agencies participating include the USDA Forest Service (Forest Health Monitoring, Forest Inventory and Analysis, and Northern Global Change programs), US Geological Survey, National Park Service, and National Space and Aeronautics Administration.

CEMRI researchers established plots in ten of the hemlock and hardwood study sites (five hemlock, five hardwood) selected and used previously by Young et al. (2002), Snyder et al. (2002), and Ross et al. (2003). Over the past three years, Jenkins et al. (study # DEWA-00037 and DEWA-00056) have collected data regarding plant and lichen species, soil characteristics, foliage chemistry, and carbon stocks and fluxes (relating to atmospheric CO₂ and climate change) at these sites. In addition, similar data have been collected from three “HWA damage gradient plots,” one at Donkeys Corner, and two at VanCampens.

In an effort to determine whether or not hemlock forest decline increases the amount of nitrogen and calcium lost from the soil and released into streams, Murdoch (study number DEWA-00064) has continued and expanded studies initiated by T. Yorks and R. Evans to compare the chemistry of first order streams draining hemlock versus hardwood forests. In 2003, as part of the CEMRI, Murdoch increased sampling of these streams over a range of flows, especially during late winter and early spring snow melt.

Pontius et al. (study # DEWA-00047) collected live hemlock foliage in DEWA in an effort to relate the amounts of certain chemicals (nitrogen, calcium, magnesium, and lignin) in the foliage with HWA infestations and hemlock tree health (Pontius et al. 2002), and improve the ability to evaluate hemlock tree conditions using remote sensing (hyperspectral near infra-red) techniques. To date, Pontius et al. have been able to use “HWA relationships with foliar chemistry to predict HWA infestation with 89% accuracy,” and hemlock health with 89% accuracy.

In an effort to reconstruct the growth histories of hemlock trees in DEWA, and relate them to HWA infestations and droughts, etc., Gottschalk et al. (study # DEWA-00086) collected several hundred hemlock “tree ring” cores in November, 2003. They also obtained several cross-sections from dead hemlock trees, which will be prepared and returned to DEWA for possible display in visitor centers, etc.

Dr. Terry Master and students from East Stroudsburg University continued studies of two species of birds associated with hemlock forests in the park. One study measured the productivity and survivorship of Acadian flycatchers in relation to HWA infestations and hemlock condition at several locations in the park (study # DEWA- 00023). This study monitored one hundred Acadian flycatcher nests over a two year period, and found that (1) nesting success was relatively high (for an open cup nester), and (2) Acadian flycatcher density and productivity declined with a decline in hemlock health conditions. The other study focused on Louisiana water thrush (at Hornbecks Creek and Toms Creek) as an indicator of headwater stream and riparian area health (study # DEWA-00018). Results indicate that the productivity and survivorship of Louisiana water thrush are affected by land use and forest conditions from the local to landscape scales.

During the past two years, Hubner and Block (study # DEWA-00053) have worked to compare the extent of spread of invasive alien plants into eastern hemlock versus red oak dominated forests. These researchers have collected vegetation and soil data from eight

hemlock forests in DEWA, and found Japanese barberry, Japanese stiltgrass, tree-of-heaven, garlic mustard, and multiflora rose.

In 2003, Battles et al. (along with A. Eschtruth; study # DEWA-00077) repeated a study of vegetation and light availability in hemlock stands at Adams Creek and VanCampens Brook that they had originally conducted in 1993-1994 (Battles et al. 1997). In addition, they expanded the study to include ten pairs of the hemlock and hardwood stands of Young et al. (2002). These studies will provide a detailed comparison of understory vegetation and light availability in two “healthy” hemlock stands (1993-1994) with those stands ten years later, after hemlock decline has occurred. Figure 13 shows that understory light availability was higher in 2003 than in 1994, especially in Adams Creek, where there has been more hemlock defoliation and decline.

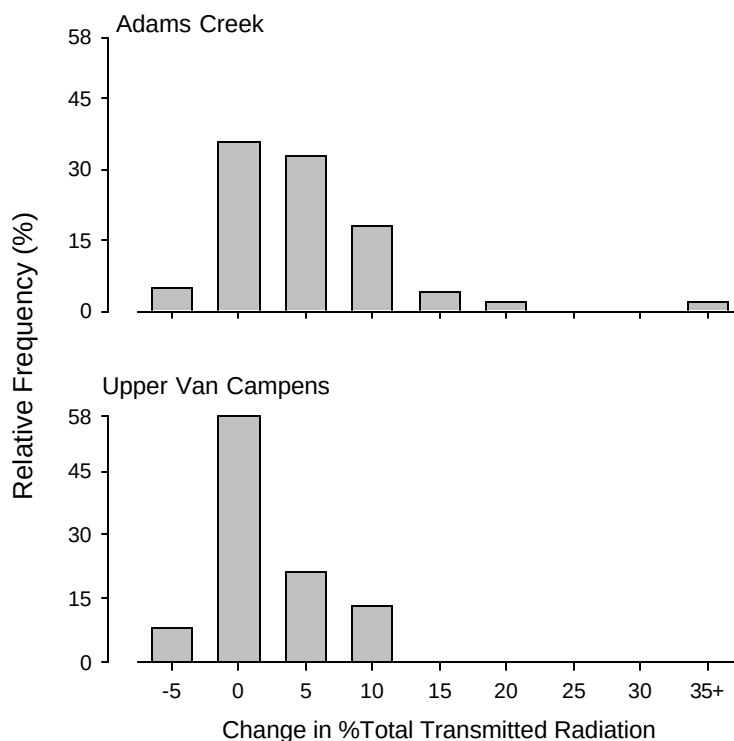


Figure 13 (provided by Battles and Eschtruth). Distribution of changes in percent total transmitted (%TT) radiation in the understory. Results based on comparisons of measurements taken at 79 points (n = 55 Adams; n= 24 VanCampens) in 1994 and again in 2003. Change calculated as differences in %TT with positive values indicating increased light availability in 2003.

The studies started in 2003 by Battles et al. focus on the importance of forest type (hemlock versus hardwood) and hemlock forest “health” to invasions of alien plants (tree-of-heaven, Japanese barberry, Japanese stiltgrass, and garlic mustard). These studies seek to determine how alien plant invasions are facilitated by hemlock decline, and how they are related the surrounding sources of invasive alien plant populations and

intense deer browsing. Preliminary data from 2003 indicate that healthy hemlock forests may be more resistant to invasion by alien plants than hardwood forests (Figure 14). However, declining hemlock stands are expected to become increasingly vulnerable to invasion by alien plants.

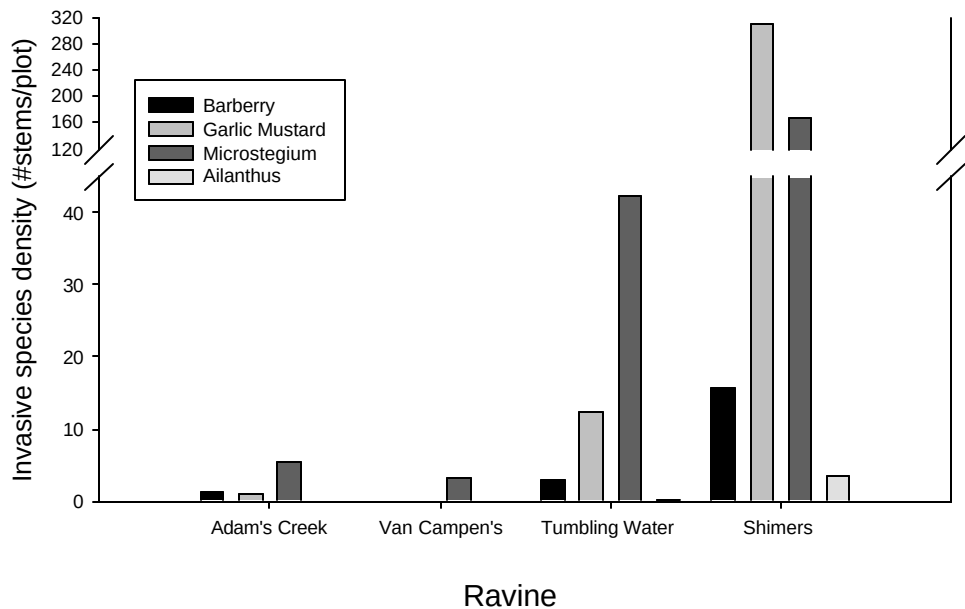


Figure 14 (provided by Battles and Eschtruth). Average density of four invasive alien plant species in two hemlock and two hardwood ravines. The sites with higher invasive plant populations (Tumbling Waters and Shimers) are hardwood forests, while the sites with much lower invasive plant populations (Adams Creek and VanCampens) are hemlock forests.

3. MANAGEMENT of HWA and HEMLOCK ECOSYSTEMS

3.1 HWA Biocontrol Beetle Releases

Biological control agents provide the only hope of substantially limiting the damaging effects of HWA in large or remote hemlock forests. Several biocontrol agents for HWA are in the research and development phase (see papers in Onken et al. 2002). However, only one, the predatory “Pt” beetle (*Pseudoscymnus tsugae*) has been available for use.

For the past four years Pt beetles for release in the park have been provided by the New Jersey Department of Agriculture (Philip Alampi Beneficial Insect Laboratory) and the USDA Forest Service. Since then, we have released a total of 65,700 Pt beetles in the park. In 2000 and 2001, Pt beetle releases were limited to two sites in the park: lower Adams Creek, and upper VanCampens Brook.

Because of the increasing prevalence of HWA and accelerating decline of hemlock trees in DEWA, Pt beetles were released at six new sites in 2002 and four new sites in 2003, for a total of 12 sites within DEWA over the past four years (Figure 15). All Pt beetle



Figure 15. HWA biocontrol beetle (Pt beetle) release sites within DEWA through 2003.

releases in DEWA have occurred during May or June. In 2003, 15,000 Pt beetles were released at four sites on 1 May. Table 1 summarizes the numbers of Pt beetles released at each site in the recreation area.

Monitoring for Pt beetles at release sites was inhibited during the summer of 2003 by the prevalence of rainy and windy weather. However, Pt beetles were recovered from 2003 release sites throughout the summer, into September. In mid-July as many as 80 Pt beetles per hour of searching were recovered from 2003 release sites (Hemlock Pond). In mid-September fewer than four Pt beetles per hour were recovered from these sites. Pt beetles were not recovered from any sites where beetles were not released in 2003.

Table 1. Number of <i>P. tsugae</i> beetles released each year at sites in the park.						
Release Site	State	2000	2001	2002	2003	Site Totals
Lower Adams	PA	7,500	5,000	0	0	12,500
UpperVanCampens	NJ	7,500	5,000	0	0	12,500
Lower Dingmans	PA	0	0	3,200	0	3,200
Upper Hornbecks	PA	0	0	5,000	0	5,000
Upper Buttermilk Falls	NJ	0	0	5,000	0	5,000
Lower Donkeys Corner	NJ	0	0	2,500	0	2,500
Old Mine Rd.	NJ	0	0	5,000	0	5,000
Upper Glen (VanCampens)	NJ	0	0	5,000	0	5,000
Hemlock Pond	NJ	0	0	0	5,000	5,000
Entrance road to Camp Ken-Etiwa-Pec	NJ	0	0	0	2,500	2,500
Old Mine Road, across from Youth Hostel	NJ	0	0	0	5,000	5,000
Lower White Brook	NJ	0	0	0	2,500	2,500
Annual Totals :		15,000	10,000	25,700	15,000	65,700

3.2 Management of HWA and Hemlock Stands

As noted in the 2003 annual report, funding for chemical treatments of HWA infestations at DEWA is being provided by the USDA Forest Service Forest Health Protection Program. Unfortunately, the funding for this project was not actually received until June, 2003, after the planned April-May treatment time. Therefore, a decision was made to postpone chemical treatments until 2004. Further research into the advantages, disadvantages, and risks of a variety of insecticides and application methods was conducted during 2003. A portion of the funds received in 2003 were used to purchase equipment, supplies, and training for pre-treatment evaluations, pesticide applications, and subsequent monitoring, so chemical treatments can be applied in 2004.

From November 4-6, 2003, DEWA hosted an interdisciplinary workshop on strategies and techniques for management of declining hemlock forests (thanks largely to the efforts of J. Shreiner). The purpose of the workshop was to gain expert input for (a) managing Childs Recreation Site, Dingman's Falls, and Raymondskill Falls, and (b) a methodology for assessing management needs and actions for all other hemlock stands within DEWA. Experts in silviculture, plant ecology, landscape management, forest pest management, and GIS and remote sensing participated. Representatives from the USDA Forest Service, Pennsylvania Dept. of Conservation and Natural Resource – Bureau of Forestry,

Connecticut Agricultural Experiment Station, Rutgers University, and The Nature Conservancy participated. A seven page summary of results and recommendations from the meeting was prepared. More detailed recommendations for management of declining/dying hemlock stands at DEWA should be completed in 2004.

4. PUBLIC INFORMATION & TECHNICAL ASSISTANCE

Information about HWA and treatment options was provided informally to numerous individuals and several local communities during 2003, as in other recent years. Many local private landowners and communities are now actively trying to suppress HWA infestations and maintain hemlock tree health on their properties by using insecticides, biocontrols, and good landscape management practices.

The following oral presentations were given, and written articles completed, about HWA and hemlock decline during 2003:

- Presentation at NE Forest Pest Council Conference, March 2003.
- Article submitted (in April, 2003) for publication in Park Science (in press).
- Posters created and produced (with assistance of VS&CR staff) about HWA and hemlock forest management.
- Summary analysis of DEWA crown rating data in the USDA Forest Service HWA Newsletter (submitted by M. Montgomery).
- Presentations at the Hemlock Forest Management Workshop November, 2003 (J. Shreiner, C. Thompson et al., P. Lynch, & R. Evans).

REFERENCES

- Battles, J.J., N. Cleavitt, T.J. Fahey. 1997. Quantitative inventory of understory vegetation of two eastern hemlock (*Tsuga canadensis*) stands in the Delaware Water Gap National Recreation Area. Final Report to the National Park Service.
- Evans, R. 2004 Hemlock woolly adelgid and the disintegration of eastern hemlock ecosystems. Park Science: *in press*.
- Evans, R. 2002. An ecosystem unraveling? Pages 23-33 in "Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium," edited by Onken et al. (see below).
- Evans, R. 2001. Hemlock ecosystems and hemlock woolly adelgid at Delaware Water Gap National Recreation Area. Year 2000 annual report of the Division of Research and Resource Planning.
- Evans, R. 1996. Revised protocols for new growth and HWA data. Unpublished. 3 pp.

- Onken, B.R. 1994. A summary of impacts from HWA and drought on eastern hemlocks in New Jersey. Unpublished, 2 pp.
- Onken, B., R. Reardon, and J. Lashomb, editors. 2002. "Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium," February 5-7, 2002, New Brunswick, New Jersey. Published and distributed by the USDA Forest Service, Rutgers University, and the New Jersey Agricultural Experiment Station.
- Pontius, J., R. Hallett, and M. Martin. 2002. Examining the role of foliar chemistry in hemlock woolly adelgid infestation and hemlock decline. Pages 86-99 in "Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium," edited by Onken et al. (see above).
- Ross, R. M., R. M. Bennett, C. D. Snyder, J. A. Young, D. R. Smith, and D. P. Lemarie. 2003. Influence of eastern hemlock (*Tsuga canadensis* L.) on fish community structure and function in headwater streams of the Delaware River basin. *Ecology of Freshwater Fish* 12(1): 60-65.
- Royle, D. and R. Lathrop. 2002. Using landsat imagery to quantify temporal and spatial patterns in hemlock decline. Pages 67-72 in "Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium," edited by Onken et al. (see above).
- Snyder, C.D., J.A. Young, D.P. Lemarie, and D.R. Smith. 2002. Influence of eastern hemlock (*Tsuga canadensis*) forests on aquatic invertebrate assemblages in headwater streams. *Canadian Journal of Fisheries and Aquatic Sciences* 59(2): 262-275.
- United States Department of Agriculture, Forest Service. 1998. Crown Condition Classification Methods.
- Young, J.A., and D.D. Morton. 2002. Modeling landscape-level impacts of HWA in Shenandoah National Park. Pages 73-85 in "Proceedings: Hemlock Woolly Adelgid in the Eastern United States Symposium," edited by Onken et al. (see above).
- Young, J., C. Snyder, D. Smith, and D. Lemarie. 2002. A terrain-based, paired-site sampling design to assess biodiversity losses from eastern hemlock decline. *Environmental Monitoring and Assessment* 76: 167-183.