5.0 MONITORING METHODS FOR FORESTS VULNERABLE TO NON-NATIVE INVASIVE PEST SPECIES

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Non-native invasive species pose a serious threat to forest resources, requiring programs to monitor their spatial spread and the damage they inflict on forest ecosystems. Invasive species research in the Delaware River Basin (DRB) had three primary objectives:

- To develop and evaluate monitoring protocols for selected pests and resulting ecosystem damage at the IMRAs that can be cost-effectively implemented as part of extensive monitoring programs
- To test a collaborative monitoring strategy for assembling pertinent information to track pest movement and mitigate the effects of pest infestation in the DRB
- To develop maps of forest condition in the DRB that depict areas most vulnerable to specific pests

5.1 Background

Invasion of the United States by non-native species of arthropods, plant and animal pathogens, and plants is a seemingly inevitable consequence of increasing international trade. Although invasions by non-native invasive species started with the European colonization of North America, they have increased at a high, linear rate since 1900 in concert with the boom of immigration and the burgeoning of international trade over the past century (Liebhold et al. 1995, Office of Technology Assessment 1993, Sailer 1983).

The risk of introduction of forest insects and pathogens has been exacerbated in recent years by the increasing intercontinental movement of wood in various forms. An obvious source of risk is the movement of forest products, major components of international trade that typically move from less developed to more developed nations. Less obvious is the extensive movement of shipping crates fabricated from raw wood. Such crates are a ready pathway for the introduction of wood-boring insects. Examples are the recent introductions of the pine shoot beetle and the Asian longhorned beetle, which arrived into the United States through shipping (Haack et al. 1997, Liebhold et al. 1995). Recent introductions of the Asian gypsy moth on both coasts of North America have been attributed to the insects hitchhiking on cargo (Liebhold et al. 1995).

Non-native tree-feeding insects are of great concern for forest ecosystems in the DRB. Many of the most destructive forest pests introduced into North America inhabit the region. Examples include Dutch elm disease, chestnut blight, gypsy moth, and most recently, hemlock woolly adelgid. Two major shipping ports, New York City and Philadelphia, near the DRB are a continuous source of potential new introductions.

Although most introduced insects and diseases do not become pests, the many foreign species that have become serious pests of forests in the Eastern United States show evidence that these forests are vulnerable to insects and pathogens from other continents. Their vulnerability may be high because native tree species have not evolved physiological resistance to exotic invaders and because forest habitats often do not harbor effective natural enemies of those invaders (DeBach 1974, Liebhold et al. 1995). In addition, ongoing global climate change may contribute to the ability of non-native species to establish, spread, and harm host trees (Williams et al. 2000). The most extreme effect of non-native invasive species on forests is catastrophic tree death. Fortunately, such a dramatic effect is caused by only a few invaders, most notably pathogens such as chestnut blight and Dutch elm disease. However, invasive pests have profoundly affected forest ecosystems in the DRB and elsewhere on the east coast of the United States as they virtually exterminated populations of dominant tree species over wide areas.

A common form of damage inflicted by invasive insects, defoliation, does not usually result in the immediate death of a tree. However, repeated defoliation can kill a tree as its effects accumulate over several seasons. Defoliation exerts both direct and indirect effects on tree physiology that may alter forest ecosystem processes. Direct effects of heavy defoliation include drastically reduced photosynthesis and transpiration, which may limit tree growth, nutrient flow, and accumulation of reserves. Indirect effects result from the presence of the defoliating insects and can include the buildup of frass and dead insects, which may alter streamwater quality and the quality and availability of nutrients for tree growth and other ecosystem processes.

Over the long term, non-native invasive species that kill trees will change the species composition of forests and in doing so may alter other aspects of forest habitats. For example, exchanging overstory species in a riparian habitat through selective mortality induced by a non-native invasive species can alter water quality in the stream below. In the DRB, hemlock stands are known to help sustain cool stream temperatures, and this cooling determines the composition of stream communities of macroinvertebrates and fish (Evans et al. 1996). As these stands are killed by the hemlock woolly adelgid and replaced by stands of deciduous hardwoods, stream communities in the DRB are altered (Evans et al. 1996).

5.2 Non-native Pests of Current Concern

Three insect species are of special concern in the DRB because they are currently or potentially very damaging to forests in the watershed. The gypsy moth was introduced into the United States well over 100 years ago and first appeared in the DRB around 1940, and the hemlock woolly adelgid was first noticed in the DRB in the 1970s. The Asian longhorned beetle is not known to be established in the basin, but it does attack forest types prevalent there and has entered North America through the port of New York City. These species are in widely different taxonomic groups, have diverse modes of feeding, do not overlap in the tree species they attack, and differ in the information available about their biology and ecology. Hence, they provide a case study of how forests vulnerable to historical, recent, and potential non-native pests can be identified and monitored.

5.2.1 Gypsy Moth

The gypsy moth was accidentally introduced into North America near Boston in the late 1860s. Although it is not highly mobile and has only one generation per year, the gypsy moth spread steadily south and west in the United States and advanced through the DRB region in the 1950s and 1960s. The forests in the region are the types very susceptible to the gypsy moth (Fig. 5.1A), and it continues to threaten to forests in the region. The gypsy moth is an outbreak species and, once established in an area, it exhibits dramatic regionwide population explosions about every 10 years. Destructive outbreaks occurred in the early 1970s and early 1980s, and some areas have been defoliated five to nine times in the last

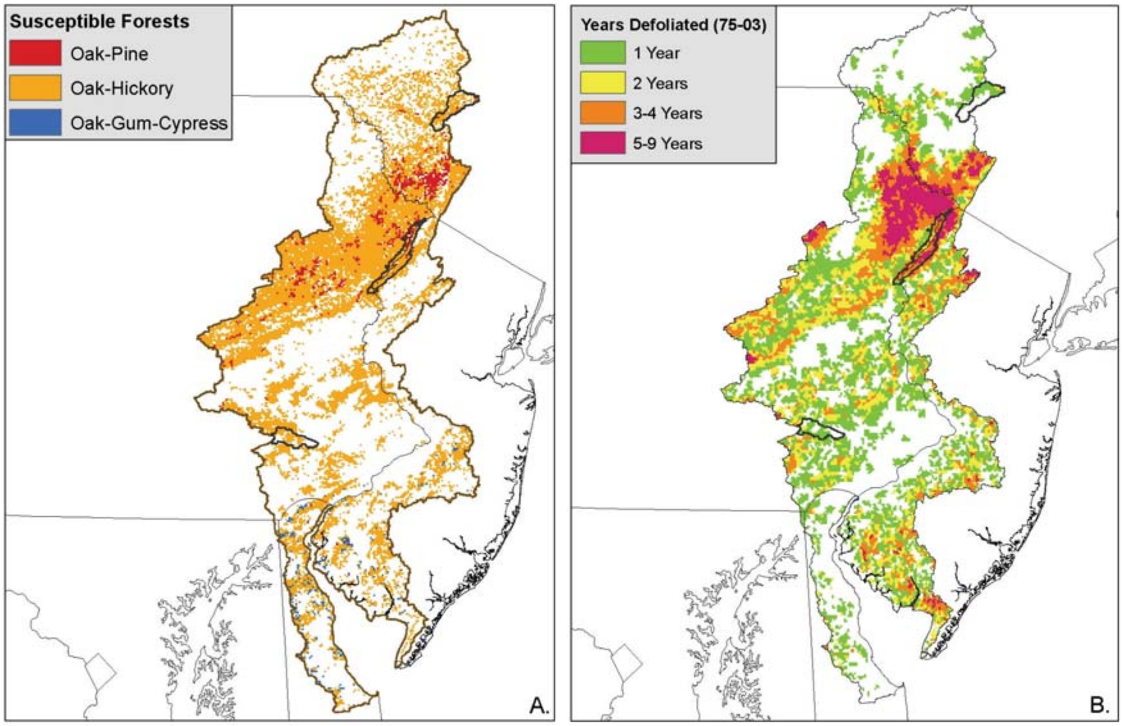

Figure 5.1. The gypsy moth and its host forests in the Delaware River Basin. A) Distribution of susceptible forest-type groups (Zhu and Evans 1994). B) Historical frequency of defoliation by gypsy moth over the years 1975 to 2003 (http://www.fs.fed.us/ne/morgantown/4557/gmoth/atlas/#defoliation).

28 years (Fig. 5.1 B). After 10 to 20 years of light and localized defoliation, populations are currently on the upswing in the DRB. During outbreaks, gypsy moth caterpillars defoliate trees extensively during their growth period from April through June (Leonard 1981). With repeated defoliation over the typical 3- to 4-year duration of an outbreak, many trees may be weakened and die (Davidson et al. 1999). The gypsy moth prefers to feed on oak species, but outbreak populations feed on many diverse species, including conifers (Houston 1974). Forests in the oak-hickory and oak-pine forest type groups are most vulnerable to gypsy moth, and they are prevalent throughout the Delaware River Watershed (Fig. 5.1A). Computer simulation studies have suggested that continued gypsy moth outbreaks will reduce the proportions of oak species significantly in eastern forests in the coming centuries (Byrne et al. 1987).

5.2.2 Hemlock Woolly Adelgid

The hemlock woolly adelgid was first found in the Eastern States, in Virginia, in 1951 (specimen record in Smithsonian Institution's National Collection) and likely came from Japan (McClure 1996). Like the gypsy moth, the hemlock woolly adelgid is not very mobile. However, because it has two generations per year and few natural enemies, it has spread rapidly and now occurs from North Carolina to Massachusetts (Souto and Shields 2000). It was found in the lower DRB in the 1970s and likely moved north, up the watershed, entering the Delaware Water Gap IMRA in the early 1990s; the adelgid was first found in the Neversink River Watershed in 2003 and may have moved westward to there from the Hudson River Valley (Fig. 5.2).

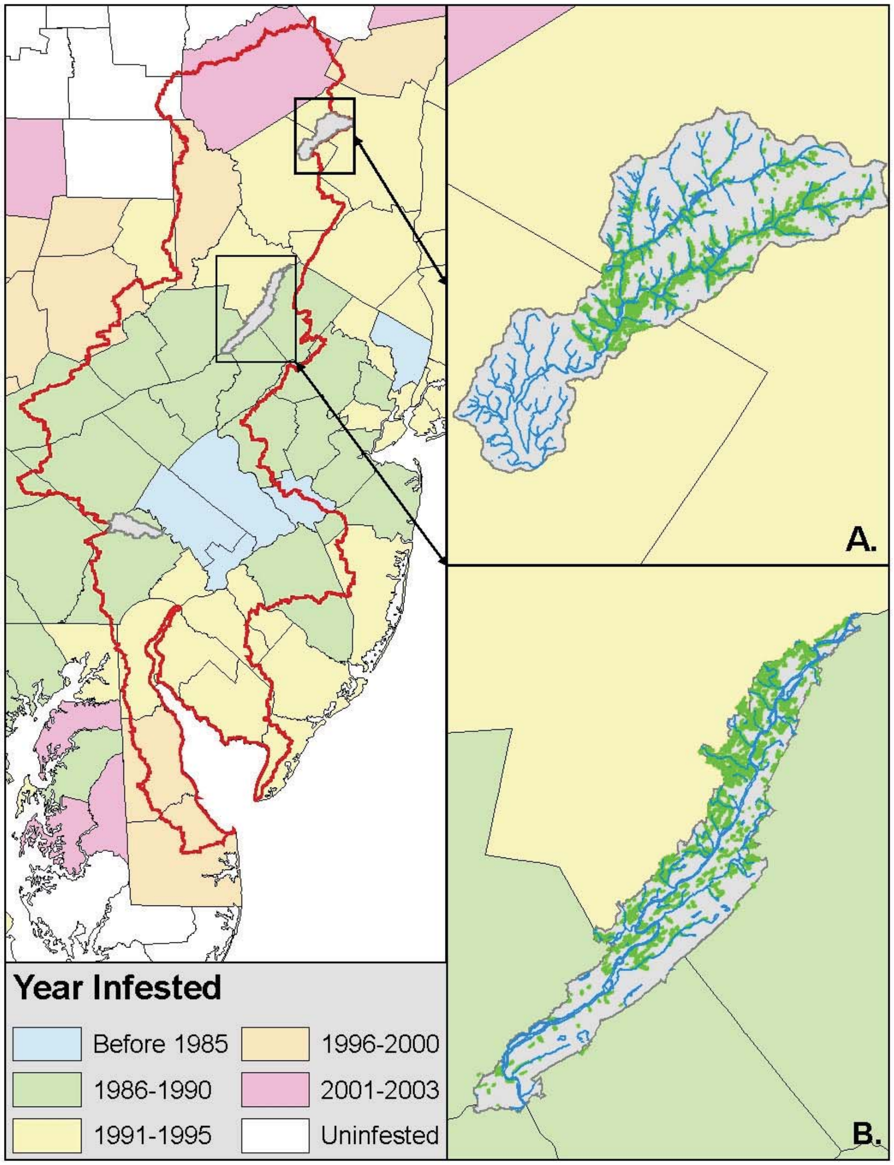

Figure 5.2.—History of hemlock woolly adelgid invasion of the Delaware River Basin (http://www.na.fs.fed.us/fhp/hwa/distribution_maps.shtm). A) Hemlock stands in the Neversink IMRA. B) Hemlock stands in the Delaware Water Gap IMRA.

Because of the adelgid's small size and generally sessile nature, its infestation is much less obvious than the ravages of an outbreak defoliator. It is a piercing and sucking insect that feeds on storage cells within the needle tissue. Feeding presumably weakens a tree, and the outward sign of this stress is needle drop. As populations build, extensive needle loss can overcome an individual tree and kill it in as few as 4 years (McClure 1991). Noticeable tree damage resulting from hemlock woolly adelgid infestation takes several years, but once apparent, damage to trees is visible throughout the year.

The insect has the potential to dramatically reduce the prevalence of hemlock forests in the Eastern United States. The loss of hemlock cover in riparian areas will have serious consequences for wildlife habitats, stream communities, and recreational values in the region.

5.2.3 Asian Longhorned Beetle

The Asian longhorned beetle was introduced from China into the New York and Chicago metropolitan areas about 1990. Infested street trees were first discovered in 1996 and 1998 in the respective urban areas. Since the discovery, a program of rapid removal of infested trees, intensive monitoring, and rigorous quarantine has been imposed that appears to have contained known populations of the Asian longhorned beetle. The beetle could become a serious pest in the DRB should it be discovered in a new location or escape the quarantine around New York City. The Asian longhorned beetle has only one generation per year, but successive generations continue to reproduce on individual trees. Damage is caused by the feeding of larvae, which first bore tunnels under the bark and then deep into the tree heartwood. When fully developed, the adults emerge from the tree by boring 1-cm-diameter holes in branches, trunk, and exposed roots. After several successive generations of the beetle, trees are weakened and may die. The Asian longhorned beetle has a wide host range that includes maple, poplar, willow, birch, elm, ash, horse chestnut, and locust. The maple-beech-birch forest type is likely to contain the most preferred hosts of the Asian longhorned beetle (Fig. 5.3). Maple-beech-birch forests are prevalent throughout the DRB, particularly in the

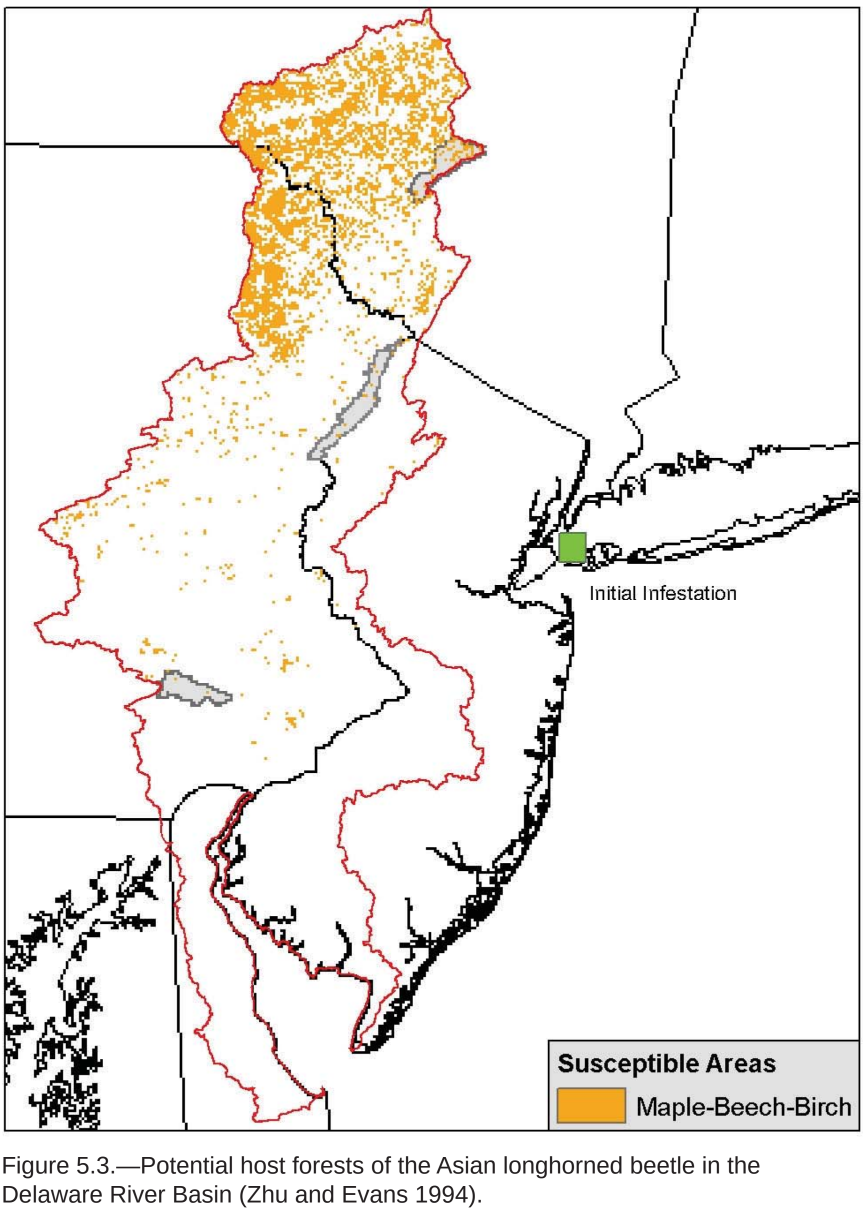

Figure 5.3.—Potential host forests of the Asian longhorned beetle in the Delaware River Basin (Zhu and Evans 1994).

Catskill Mountains that contain the northern basin boundary. Because sugar maple, with its colorful fall foliage and its sap production, is an important component of these forests both ecologically and economically, escape of the beetle from quarantine and associated sugar maple mortality could seriously jeopardize the maple syrup and tourist industries in local rural economies. The nearest quarantined area, in Brooklyn, is only 60 km from maple-beech-birch forests in the central DRB.

5.3 Existing Monitoring Programs and Regional Assessment Capability

Existing gypsy moth programs are an example of current large-scale monitoring of the status and effects of non-native invasive species. These programs are usually conducted by State agencies on State and privately owned land. The U.S. Forest Service (USFS) conducts parallel programs for federally owned lands and provides advice and support to the States. Gypsy moth monitoring programs typically consist of defoliation monitoring using aerial sketch mapping of areas with visible defoliation (usually >30 percent canopy defoliation) in June and July. In the fall, ground surveys count egg masses to assess where populations of gypsy moth may be sufficiently high to cause defoliation the next year. The objective of such monitoring programs is to determine where to apply pesticides to prevent further defoliation during an outbreak. The relationship between defoliation and population size is often not verified for specific forest types or regions. Other aspects of pest damage or environmental impact are not usually monitored, and physiographic, chemical, or climatic conditions that might influence defoliation intensity are not documented.

Like the gypsy moth monitoring program, the program for the hemlock woolly adelgid is currently a cooperative one among State agencies and the USFS; however, it also includes the National Park Service (NPS) at the Delaware Water Gap NRA (DEWA). Several types of remotely sensed information have been investigated for developing tools to assess the degree of adelgid infestation and hemlock decline (Pontius 2004, Royle and Lathrop 2002). The State of Pennsylvania, the USFS, and the NPS monitor permanent plots to help document tree health decline in the host trees over time. Sampling at these permanent plots occurs in stages. First, the overall health of an infested tree is evaluated using the Forest Inventory and Analysis (FIA) crown rating system. Second, counts are made on marked branches to estimate numbers of terminals that are infested by the adelgid and those that produce new growth. Over time this monitoring program gives a quantitative estimate of the effects of the hemlock woolly adelgid on its host. As with gypsy moth monitoring programs, however, other aspects of pest damage and environmental impact are usually not monitored, and physiographical, chemical, or climatic conditions that might influence damage intensity are not documented.

Because the Asian longhorned beetle was not known to be established in the DRB during CEMRI, all monitoring for this pest is carried out in the context of a quarantine program conducted by the USDA Animal and Plant Health Inspection Service. Monitoring involves visual searches of individual trees for adult beetles and evidence of oviposition sites and adult exit holes at ground level (using binoculars) and in the tree canopy (using bucket trucks).

In addition to these pest-specific studies, tree damage is recorded at FIA plots for all trees larger than 5 inches diameter at breast height (d.b.h.). These damage assessments, however, are typically limited to visual examination of bole defects, crown density, and foliar discoloration; they are not linked to pest population densities or even to pest presence-absence surveys. As a result, existing forest monitoring programs can provide a snapshot of pest impact when the plot is sampled, but only if the crews can be certain about the source of the damage and only if damage to trees is visible.

Existing monitoring programs have several inadequacies. Aerial surveys for defoliators like the gypsy moth record only the presence or absence of damage and provide no estimates of the sizes of populations causing the defoliation. Also, monitoring may be inconsistent from year to year because the focus is on outbreak periods, and monitoring is often discontinued to save money between outbreaks. However, when accumulated and plotted over space and time, aerial surveys can provide a picture of the historical trend of an outbreak.

At the opposite extreme, the current monitoring program for the hemlock woolly adelgid provides information on the interaction of the pest and its host at the tree and small plot levels, but not on the spatial distribution of the pest on a large scale. Anecdotal information on presence or absence of the adelgid at the county level is the only spatial monitoring currently done by State and Federal agencies. Ironically, some of the most detailed spatial information about non-native invasive species may exist for quarantine pests such as the Asian longhorned beetle, which are intensively monitored over small areas in conjunction with eradication efforts.

Due in large part to the weak links between spatially extensive pest monitoring and plot-level studies of pest effects for most invasive pest species, our ability to analyze linkages between environmental conditions and pest outbreaks is limited.

5.4 Information Available in the Delaware River Basin

For the CEMRI, we developed tighter links between large-scale spatial information and plot-level process studies. Rather than acquire new data by establishing a complex set of plots that would be expensive to maintain, we used information from existing sources for the analysis. Digitized spatial information (GIS layers) on forest composition and physiographic features (including soil, climate, slope, elevation, streams, roads, etc.) was available for both the DRB and the surrounding region. Existing spatial information providing an initial estimate of the regional extent of the three non-native forest pests had been assembled into a uniform database.

The Pennsylvania Department of Conservation and Natural Resources has digitized sketch maps of gypsy moth defoliation that date back more than 30 years. New Jersey also has sketch maps for a similar time period, but most have not been digitized. For this study, we digitized more than 500 defoliation maps to obtain a history of New Jersey gypsy moth defoliation. Spatial records of gypsy moth defoliation in New York are not available.

A history of damage resulting from hemlock woolly adelgid infestation before the CEMRI was developed for the DRB using Landsat Thematic Mapper images (Bonneau et al. 1999, Royle and Lathrop 1997). Leaf-off, cloud-free, and snow-free images from 1984 (before adelgid infestation), 1998, and 2001 were used for this purpose. By comparing the later images with the 1984 image, we identified changes in hemlock foliage in 30-m pixels over the entire region. We verified these remotely sensed images with tree health data acquired

Table 5.1.—Key variables and analyses for assessing invasive pest status, trends, and impacts in the Delaware River Basin, by monitoring tier

Tier 1: Intensive sites
Relationship between pest distribution and pre-infestation forest condition (hemlock wooly adelgid- only)
Relationship between pest distribution and soil condition (HWA only)
Effect of pest infestation on soil water and surface water quality/ quantity (HWA only at Delaware Water Gap IMRA)
Relationship between pest distribution and climate measures (HWA only)
Tier 3: Regional surveys
Pest population extent and degree of infestation (HWA only)
Forest health assessment- pre and post infestation
Geography of infestation: rate of spread (HWA only)
Tier 4: Remote sensing and mapping
Forest type (from Landsat Thematic Mapper)
Air photo assessment of forest health parameters such as defoliation (from color infrared aerial photographs)
Deposition from generated maps
Climate measures from generated maps

at FIA phase 3 plots on the ground. Before this study, ground monitoring of the adelgid in the DRB was limited to 14 pairs of plots within the DEWA. Each of the plots consists of 10 hemlock trees whose health was evaluated annually by using the FIA crown rating guide and by determining the percentage of terminals that were infested with the adelgid and that were producing new growth. This method was also used in other areas of Pennsylvania and in West Virginia. Examination of these data, and the investigator's experience in establishing similar monitoring plots in the DRB, indicated this type of plot-level monitoring was extremely expensive relative to the usefulness of the data obtained.

For the Asian longhorned beetle, investigators identified those areas in the DRB that would most likely incur damage should this insect disperse to the region and become established. Existing spatial data on the distribution of forest types were used for this purpose.

5.5 The CEMRI Monitoring Program for Non-Native Invasive Species

Consistent and extensive monitoring of regional pest populations, extent, and damage over time, combined with indepth process-level research at intensive study sites, was needed to begin to address ecosystem effects of invasive pests at large scales. The CEMRI study attempted to accomplish this by enhancing data collection within the hemlock intensive monitoring sites at DEWA, simplifying regional sampling methods, developing forest vulnerability maps, and linking physical and chemical environmental data with data on pest infestation. Table 5.1 presents an idealized summary of the key research and monitoring components needed for a regional and interdisciplinary assessment of the extent and impacts of invasive forest pests, as well as the CEMRI strategy for addressing these research and monitoring components.

5.5.1 Intensive Site Research and Monitoring (Tier 1)

The process-level information collected at the field plots was primarily derived from intensive studies of areas currently being affected by the hemlock woolly adelgid. Available funding limited intensive site analysis for the Asian longhorned beetle, which has not invaded the DRB to date, and the gypsy moth, for which several intensive-site studies have been completed (Townsend et al. 2004).

Paired hemlock and hardwood research stands had already been established in the DEWA by the NPS, and represented a gradient of exposure from heavy adelgid infestation in the southern portions of the park to lighter infestation in the north. Research teams from the NPS and the USFS collaborated on monitoring forest and soil conditions and adelgid status in these research stands, and the USGS and the State University of New York College of Environmental Sciences and Forestry (SUNY-ESF) collected water samples monthly from April to October from streams draining watersheds that contain the paired plots. Soil solution chemistry data below uninfested hemlock stands (USGS) and hemlock stands girdled to simulate adelgid effects (SUNY-ESF) were collected in the USGS research watersheds within the Neversink River Basin. Forest and soil measurements were consistent with FIA protocols, and stream samples were analyzed for several constituents including base cations, nutrients, pH, acid neutralizing capacity, and dissolved organic carbon (DOC).

5.5.2 Regional Survey Monitoring (Tier 3)

Simple methods developed at the IMRAs for monitoring adelgid distribution and abundance were integrated into the FIA sampling protocols as part of the CEMRI project. These protocols fill a gap in existing monitoring programs by making it possible to survey a spatially extensive set of plots for non-native invasive species and thereby facilitating continuous sampling in the DRB between and during outbreaks. The data collected provided continuous information on adelgid occurrence, as well as hemlock health and related damage in the upper DRB.

Because the hemlock wooly adelgid is not visible from the air until defoliation is well underway, a truly detailed assessment of the regional extent of its infestations required a separate ground survey focused on the small areas where the host tree species are present. The USFS's Forest Health Protection (FHP) network uses such a targeted survey approach to track the effects of invasive species on specific forest types. Collaborating with the State programs that carry out the FHP monitoring plan and enhancing that survey where gaps in data collection were observed were critical components of Tier 3 monitoring for this issue-based assessment.

Links between water quality and pest infestation at a larger scale were initially explored through an infestation-gradient study spanning the region between the Neversink in the Catskills and the DEWA in the Pocono Mountains, but the patchiness of hemlock stands rendered regional surface water effects undetectable through simple streamwater sampling techniques. The highest rates of infestation were observed in the southern part of the gradient, whereas the adelgid had been detected on only one tree in the Neversink IMRA. Methods of soil solution monitoring that could be used on a regional gradient were therefore tested in the later part of the CEMRI monitoring period, so detection of potential chemical effects on surface waters could be assessed on a hemlock stand scale, and could be used to draw maps of potential effects.

5.5.3 Remote Sensing and Inventory Monitoring (Tier 4)

The hemlock woolly adelgid and its effects are not visible from aerial photography until damage is so severe that many trees have already died. Techniques based on changes in spectral characteristics therefore needed to be developed to use remote sensing for detecting adelgid infestation. During the CEMRI, the USFS used separate funding to investigate the use of hyperspectral imagery for detecting hemlock mortality and decline (Pontius 2004; Pontius et al. 2005a,b; Pontius et al., in press). The resulting methodology was applied to the Catskill Mountain region; it is now being correlated with soil, soil solution, and stream chemistry collected by the USGS to draw regional maps of adelgid infestation and determine the factors controlling rates of hemlock decline and the biogeochemical responses in the ecosystem. This collaborative field program extended beyond the period of the original CEMRI, but it will contribute significantly to the CEMRI objectives.

5.5.4 Modeling of Pest Infestation and Damage to Ecosystems

The goal of the CEMRI pest assessment was to develop maps of current infestation and forest vulnerability to the respective pests and to develop methods for assessing water quality responses to current pest conditions. The CEMRI tested methods that rely on a combination of remotely sensed imagery, field data, and historical datasets of pest damage. Based on regional maps of vulnerability to the hemlock woolly adelgid and gypsy moth, forest stands across the DRB could be selected for future study and assigned to discrete health classes. Maps of damage could then be analyzed along with maps of other environmental factors (climate variability, soil fertility, and forest sensitivity to pests, etc.) in the study region. These maps could then be used in models that, when fully developed, could predict the rate and vectors of pest infestation based on specific climate scenarios. Funding and the current state-of-the-science were limited at the initiation of the CEMRI on linkages between pest infestation and environmental parameters and on the effect of pest damage and forest change on long-term water quality. Development of models for tracking pest infestation and damage was therefore not completed during this study.

5.5.5 Interpretation of the Integrated Dataset for Resource Managers

Forest vulnerability maps will be available for planning the mitigation of pest impacts as well as for assessing potential effects on surface water quality. For example, the map of hemlock health may be used to develop a map of expected water quality changes resulting from adelgid activity. Using information from the surveys and IMRAs on the relationship between hemlock health and soil solution or streamwater quality, a map of streams in the DRB that are vulnerable to water quality changes resulting from adelgid outbreaks could be developed. Such a product would help meet one of the overall goals of the CEMRI project—to bridge the gap in monitoring efforts among Federal agencies responsible for environmental monitoring.

In summary, soil chemistry and water quality studies conducted by the USGS, assessment of pest infestation at FIA monitoring points, and ancillary data from National Oceanic and Atmospheric Administration (NOAA) weather stations, as well as data from other ancillary monitoring networks within the region, were used to develop strategies for collaborative monitoring of the causes, extent, and consequences of forest pest infestation and to form an initial regional assessment of the environmental parameters associated with pest outbreaks and the resulting effects of those outbreaks on environmental quality. This work provided the first truly integrated effort to monitor the distribution and abundance of pest populations, as well as their effects on surface-water quality.

5.6 Preliminary Results

The USFS expanded the extent and intensity of its surveys of the hemlock wooly adelgid and integrated that survey data with aerial photo mapping of adelgid infestation by Rutgers University (Fig. 5.4). Intensive integrated monitoring of forest conditions, adelgid infestation, and soil and stream chemistry was established through collaboration among the NPS, USFS, USGS, and SUNY-ESF. Correlations between pest infestation and changes in stream chemistry were indicated during the short period of the CEMRI assessment (Fig. 5.5), and methods for integrated tracking of the effects of pest outbreaks on forest soil and stream biogeochemistry were developed and tested. Continued research in the Catskill Mountains involves testing the accuracy of remote sensing imagery for detecting adelgid outbreaks and biogeochemical responses.

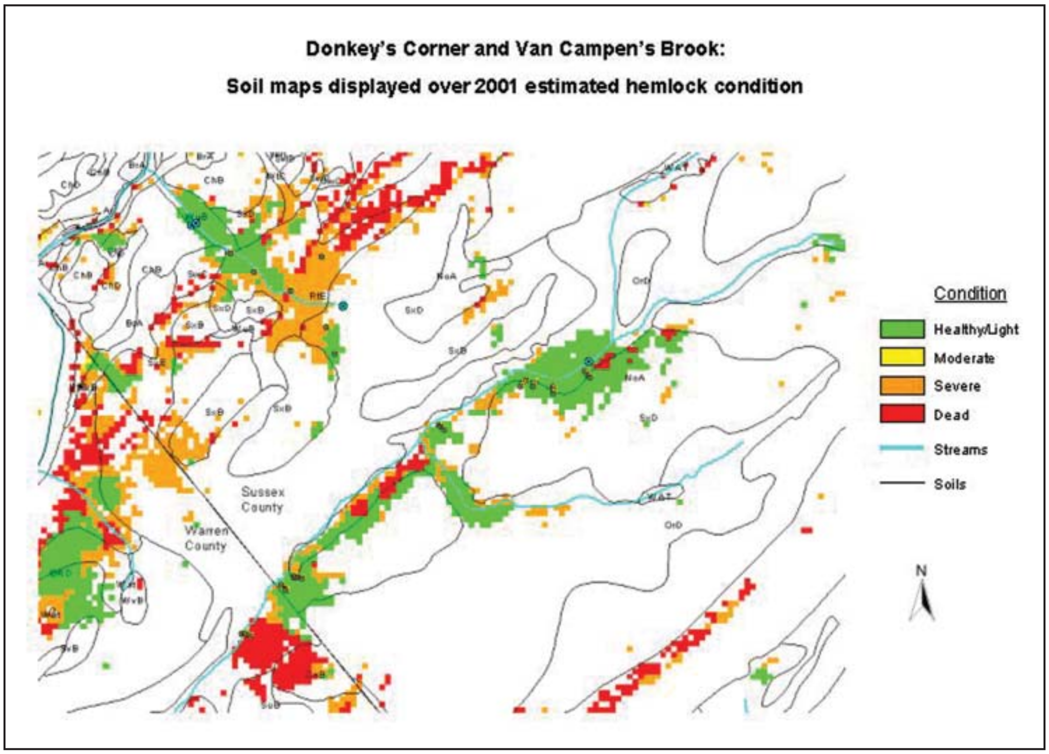

Figure 5.4.—Map of the intensity of damage from the hemlock wooly adelgid in the Delaware Water Gap area, derived from remote sensing data (Pontius et al. 2005).

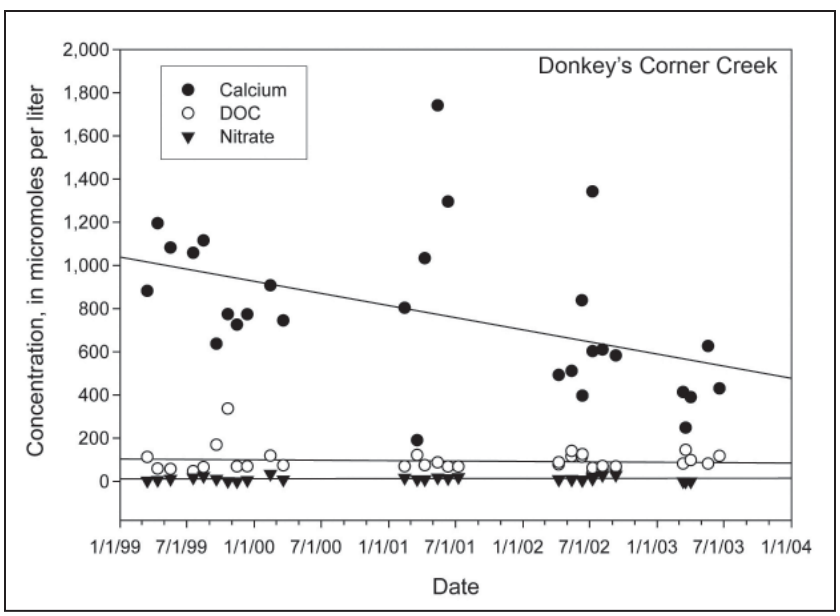

Figure 5.5.—Decrease in stream calcium concentration in a stream draining a forest stand with 80 percent hemlock wooly adelgid infestation, Delaware Water Gap National Recreation Area.