Ecosystems in Flux: The Lessons of Hemlock Hill

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Ten years after the first detection of hemlock woolly adelgid *(Adelges tsugae)* at the Arnold Arboretum, the hard lessons of biological invasion are written across the face of Hemlock Hill. Large gaps mark the loss of hemlocks, while many survivors, diminished by infestation, stand as relics in growing swaths of successional vegetation.

Introduced invasive organisms pose an increasing threat to native biodiversity. As is conspicuously evident on Hemlock Hill, newly arrived pests and pathogens can quickly decimate susceptible native species, creating issues that range from concerns for public access and safety to the long-term management of ecological disturbance. Invasive plant species often follow in the wake of such outbreaks, further disrupting native ecosystems.

Responding to invasive species in ways that safeguard people, plants, and the larger environment demands that we more wisely manage the uncertainties of a rapidly changing world. The story of hemlock woolly adelgid (HWA) at the Arnold Arboretum recounts the lessons learned in addressing the rarely predictable, often irreversible consequences of biological invasion.

New Invasives: A Steady Parade

The scope of the problem is substantial. A 2002 National Academy of Sciences study determined that the USDA inspects roughly 2% of cargo shipments yet intercepts over 53,000 arthropods, pathogens, and plants annually. Although few introduced organisms successfully establish, it is conservatively predicted that 115 non-native insect species and 5 plant pathogens will become naturalized in the United States between 2000 and 2020. Continuing loss of native biodiversity is recognized as perhaps the greatest long-term consequence of invasive species, which are second only to habitat loss as a primary cause of native species decline in the U.S. Of species on the threatened or endangered list, roughly 50% are at increased risk due to competition or predation from non-native organisms. Some unlisted species, such as the eastern hemlock *(Tsuga canadensis),* face extirpation or severe reduction over large parts of their range. Each region of the country has its own list of problematic introduced insects and pathogens, with growing public awareness that emerald ash borer *(Agrilus planipennis)* and Asian longhorned beetle *(Anoplophora glabripennis),* among others, are dire threats to both cultivated landscapes and native ecosystems.

The Home Front

It is with some irony that I survey the introduced invasive organisms that today inhabit the Arnold Arboretum. A leader in scientific collecting and importation of plants from east

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Egg masses in dense, cottony clusters provide a highly visible indication of the progress and intensity of hemlock woolly adelgid infestation.

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Sweet birch *(Betula lenta),* shown here in golden fall color, is now growing across large areas of Hemlock Hill. As is typical across southern New England, this birch species is a dominant colonizer of the post-hemlock landscape.

Asia in the decades before and after 1900, the Arboretum is one of a great many agents that unwittingly introduced species to the North American landscape that later naturalized and wrought destructive impacts. Regardless of our respective "rap sheets", the Arboretum and other public gardens now work diligently toward devising management strategies to deal with problematic introduced species.

At the Arboretum, developing appropriate responses to invasive species is an ongoing responsibility shared by horticulturists, managers, and administrators. Aggressive incursions of winter moth *(Operophtera brumata),* garlic mustard *(Alliaria petiolata),* Japanese knotweed *(Polygonum cuspidatum),* and other invasives require that we stay abreast of new methods and information, not only to improve the efficacy of our management measures but to do so with ever diminishing environmental impacts. This past fall, the position of Manager of Plant Health was created to coordinate integrated pest management and associated environmental monitoring.

Cautionary Tales

As we have learned over the years, "best" practices are moving targets that shift with increasing knowledge and a changing environment. This can be particularly true in managing recently introduced insects and pathogens whose life cycles, host impacts, modes of spread, and other critical traits may still be relatively unknown. The long-term consequences of various management options are often equally unknown. How we make decisions in the face of uncertainty is of great importance. Confronted with approaching waves of introduced species, what can we learn from previous efforts to manage new invaders?

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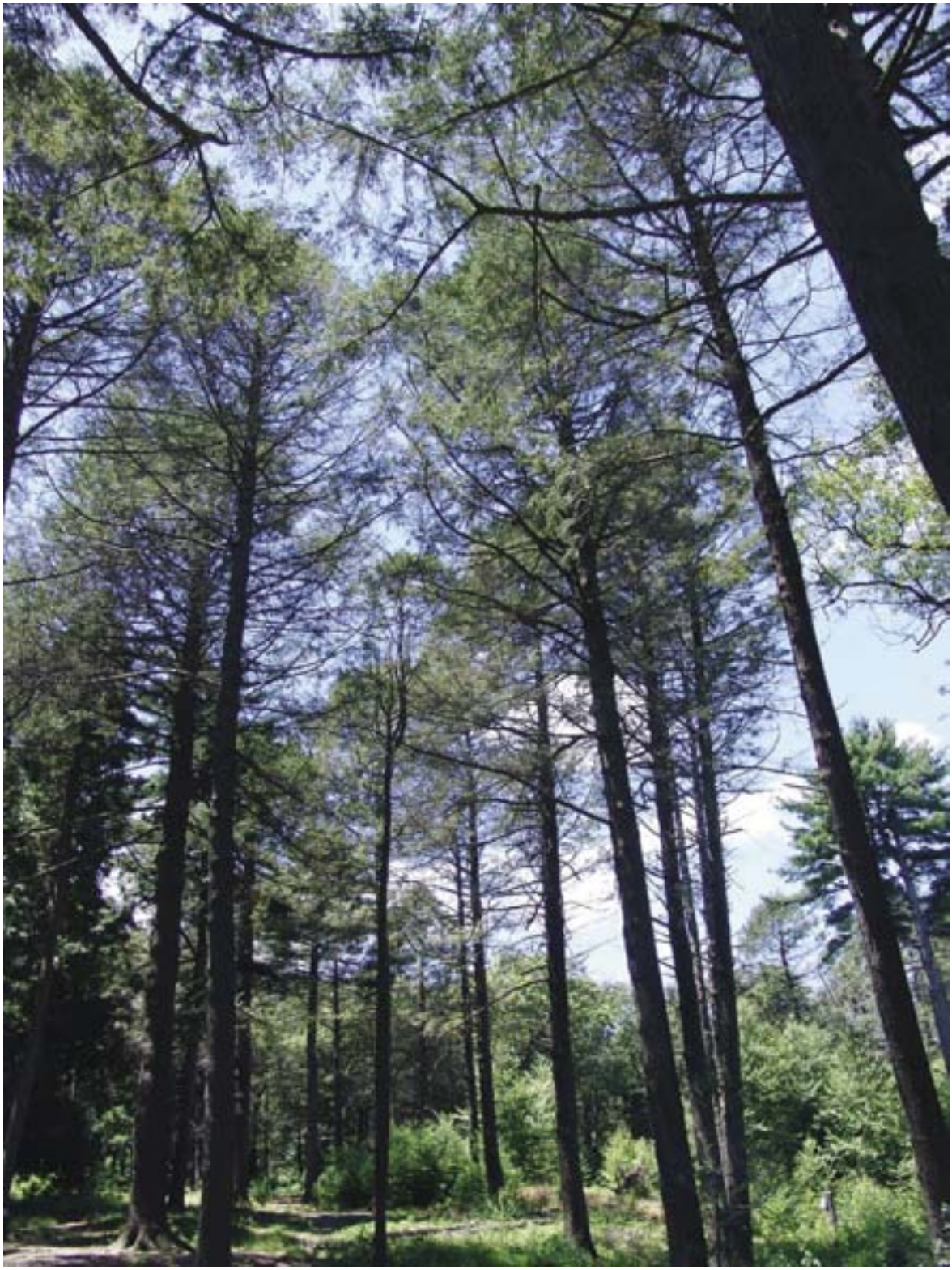

Infested trees on Hemlock Hill in 2003 showing the defoliation and reduction of new growth typical of hemlock woolly adelgid infestation.

Most recently, the potentially harmful effects of biocontrols—non-indigenous species released to control invasive pests—have received considerable attention. The multicolored Asian lady beetle *(Harmonia axyridis),* intended to control a range of insect pests, now appears to outcompete and replace some native lady beetle species, while becoming a nuisance in its winter aggregations in homes and buildings. In southern Florida, native *Opuntia* species are threatened by a South American moth *(Cactoblastis cactorum)* that had been introduced to control *Opuntia* naturalizing in the Caribbean. Cases of unforeseen consequence, the non-target effects of some biocontrols may be remembered as cures worse than the disease.

From an earlier period, management response to Dutch elm disease *(Ophiostoma ulmi),* a public and politically charged effort, targeted its primary vector, the elm bark beetle *(Scolytus multistriatus).* The American elm's *(Ulmus americana)* importance as an icon in the cultural landscapes of the Northeast made saving the species a priority for state and municipal agencies, and the resulting massive applications of toxic pesticides contributed to an environmental disaster all too well known today. Past actors on a period stage, decision-makers were undoubtedly influenced by historical biases and limited by critical gaps in knowledge, yet their legacies suggest that response to uncertainty—particularly the consequences of our own actions—merits particular focus today.

Managing Hemlock Woolly Adelgid

Our ten years of managing hemlock woolly adelgid is a story of decision-making in a rapidly changing informational environment. We began with many uncertainties and traveled a path of pivots and about-faces led by growing knowledge of our own site, analysis of outcomes elsewhere, and key findings from the research community.

In 1997 HWA was first detected on the Arboretum's Hemlock Hill, a 22-acre historic natural site whose early public use included frequent visits in the 1840s from Margaret Fuller and other members of the Transcendentalist circle. Prior to infestation, Hemlock Hill was home to over 1,900 eastern hemlocks, some dating to the early 1800s. With its several stands of fully mature hemlock-dominated forest, the Hill had long been appreciated as a place of seemingly wild nature in the midst of the city.

The Arboretum was hardly among the first sites to deal with HWA. First detected in Richmond, Virginia in the early 1950s, HWA spread rapidly, decimating hemlock populations in the Mid-Atlantic and coastal Connecticut before reaching Boston. Across much of the range of infestation, the ultimate consequence of HWA was near to complete hemlock mortality within four to twelve years. There were few exceptions. With the prospect of losing one of Boston's most significant natural sites and an integral part of our own history, Arboretum managers addressed challenges of a scope not seen since the 1938 hurricane.

The process began with questions. What would be the rate of decline for our hemlocks? How many trees could we protect and at what costs to the larger ecosystem? Could a biocontrol under development save our trees? Although these and other questions would remain unanswered for years, management goals drawn from our organizational mission provided a strong compass for initial decision-making. Protecting visitor and staff safety, protecting the larger environment, and preserving a still undetermined number of hemlocks were our key priorities. But where to start?

Through the Learning Curve

We determined that obtaining reliable, site-specific information about the spread of the infestation and rates of hemlock decline would be essential to planning an effective management response. Monitoring the health of our hemlocks required mapping the locations and assigning an accession number for each tree. This significant investment was abundantly repaid in data that detailed the progression and severity of the infestation as well as the efficacy of our control efforts; information that continues to inform our decisions. Using assessments of crown health, we evaluated all hemlocks, finding that from 1998 to 2002, the number of trees in poor health increased from 30% to 70%. By 2003, Hemlock Hill was a sickly gray-green color. Data from other sites indicated that we could expect large numbers of hazardous and dead trees within two to three years.

That winter we visited forests in Connecticut that had been closed to the public because of the danger presented by hundreds of disintegrating dead hemlocks. Further, we learned that the highly hazardous brittle snags had precluded both salvage operations and efforts to contain rapidly growing populations of invasive plants. Foreseeing similarly grim prospects for Hemlock Hill, we anticipated removing over 1,000 rapidly declining trees within the next two years.

Fortunately, that large-scale removal never occurred. The winter of 2004, the coldest in many years, brought several nights with temperatures of -5°F or colder, delivering an unexpected reprieve. Although not well documented at the time, HWA is highly vulnerable to extreme cold. Based on surveys at other sites, we estimate that well over 90% of the existing HWA population perished that winter. The following summer, which also brought much needed rain, saw a revitalization of our hemlocks that was a wonder to behold. For once, extreme cold had been a gift, resetting the clock of infestation and allowing more time to find new strategies.

Additional changes in approach came with new information from the research community. Publications that elucidated site factors affecting rates of hemlock decline, the relative efficacy of different HWA control methods, and the field performance of highly anticipated biocontrols were part of a burgeoning informational environment that enabled knowledge-based decisions. The Arnold Arboretum was fortunate in that HWA arrived in our vicinity just as many research efforts came to fruition, providing us with essential information that was unavailable to managers of previous infestations.

Perhaps our hardest decision thus far concerns the number of hemlocks we attempt to save. The absence of host resistance and limited cultural controls leave us with few management options. Clearly any chemical treatment, even relatively benign horticultural oil, brings concern for the larger environment. At the same time, we are an essential resource for a large urban population that for over 150 years has enjoyed the singular educational and aesthetic experiences of a majestic hemlock-dominated forest.

Finding balance among stewardship, education, and public service goals, we protect hemlocks that are of sufficient vigor to recover and that grow in conditions that are favorable for treatment and do not present risk of water contamination. HWA is controlled with applications of horticultural oil and, more recently, soil injections of imidacloprid , a treatment now provided to over 40,000 trees at Great Smoky Mountains National Park. We now use this method and pay close attention to ongoing research that monitors for non-target effects and persistence in the environment. Ultimately, it is hoped that these treatments will buy time for the Arboretum's hemlocks until biocontrols or other non-chemical options can offer reliable protection.

An ongoing challenge, symptomatic of ecosystem disturbances on a global scale, is the control of non-indigenous plants that often invade when native habitats are affected by introduced organisms. As hemlock mortality continues, canopy gaps become points of colonization for glossy buckthorn *(Frangula alnus),* Japanese knotweed, and other invasives. Our long-term goal is to promote native hardwood forest where hemlock once grew, and while we actively eliminate invasive vegetation, robust native species, particularly sweet birch *(Betula lenta),* are rapidly dominating large areas.

Adaptive Management

Our HWA management strategy continues to evolve, reflecting the iterative learning process needed to develop effective site-specific responses to invasive species. Gathering data that monitor changing conditions as well as the effectiveness of management actions is essential, as is a willingness to completely revise strategies based on new results.

Our experience speaks to the value of Adaptive Management, a process developed for the management of complex natural systems characterized by uncertainty. Borrowing from scientific method, it relies on carefully assembled hypotheses, field testing of proposed practices,

RESEARCH OPPORTUNITIES

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Chinese hemlock *(Tsuga chinensis),* planted in openings on Hemlock Hill, proved highly resistant to hemlock wooly adelgid.

An unanticipated silver lining was found in emerging research opportunities on Hemlock Hill. The severe consequences of HWA infestation pose compelling questions about the ecological changes associated with decimation of a foundation native species. Beginning a four-year investigation in 2004, the Arboretum collaborated with the Harvard Forest to establish six 15-meter by 15-meter research plots in order to measure the changes occurring when hemlock is abruptly removed from the forest system. We removed hemlocks from four of the plots, with the remaining two left unlogged for use as controls. Measurements established baseline data for soil temperature, available nitrogen, organic soil mass, and understory vegetation. Analysis compared nitrogen cycling, decomposition rates, and regeneration across the six plots. Scheduled to conclude in summer 2008, the study is part of a longer-term Harvard Forest effort to assess ecosystem impacts of HWA in southern New England.

A second project examined Chinese hemlock *(Tsuga chinensis),* a species first grown in North America at the Arnold Arboretum. The research established that Chinese hemlock is cold hardy through at least Zone 6 and is fully resistant to HWA, confirming its suitability as a promising landscape replacement for *Tsuga canadensis*.

and the monitoring of results to inform next steps and ongoing improvement. It is a model for managing disturbed natural systems that lack both predictability and stability, and for which management outcomes may be determined by variables that are unrecognized or unknowable at the outset—in short, much of the world as we now know it. At the Arboretum, we did not set out to adaptively manage; the approach was born of necessity. But with the appointment of a manager of plant health, we now seek to more fully implement its tenets.

Public Awareness

The dramatic losses on Hemlock Hill, roughly 30% of the original hemlock population, offer an important local example of a global phenomenon. To build public awareness, the Arboretum now offers school field studies and special tours that explore the fragility of native ecosystems, disturbance caused by invasives, and the complex challenges that result for environmental stewards. As former evergreen forest converts to deciduous woodland, programs will interpret changes in nutrient cycling and species inter-

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School children examine sweet birch seedlings as part of a new Arnold Arboretum field study investigating the ecological impacts of hemlock woolly adelgid.

actions. Presentations to the community and feature stories appearing in newspapers and on radio and the web have further disseminated the Hemlock Hill story in Boston and southern New England.

Introduced insects and pathogens are here to stay. Looking to the future, warming temperatures will likely enable HWA and other temperature-limited invasives to expand ranges of infestation and more quickly reach lethal densities on host species. The USDA, among other domestic and international agencies, must strengthen efforts to prevent unintended introductions as well as accelerate research programs to better inform management efforts. Institutions such as the Arnold Arboretum, committed to environmental stewardship and with unique expertise, will increasingly contribute to invasive species management. Perhaps more importantly, we can foster awareness, offering our public landscapes as places of witness and learning during a time of remarkable environmental change.

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