# CHAPTER 5

## Carolina Hemlock Distribution and Health in the Southern Appalachian Mountains

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### INTRODUCTION

Carolina hemlock (*Tsuga caroliniana* Engelm.) is a rare conifer species endemic to the Southern Appalachian Mountain regions of North Carolina, South Carolina, Tennessee, Virginia, and Georgia (Jetton and others 2008). The known distribution covers an area of approximately 465 x 165 km with a latitudinal range from 37°40' N in Rockbridge County, VA, south to 34°73' N in Rabun County, GA (fig. 5.1). Carolina hemlock stands typically grow along the margins of mixed hardwood-conifer forests on exposed rocky outcroppings at elevations between 600 and 1500 m. Individual populations tend to be small (in terms of both area and number of trees) and isolated, with high levels of genetic differentiation from one stand to the next (Potter and others 2017). Because of its narrow geographic distribution and these population characteristics, Carolina hemlock is highly susceptible to extirpation caused by large-scale forest disturbances.

The hemlock woolly adelgid (HWA; *Adelges tsugae* Annand) is an invasive piercing-sucking insect that has caused widespread decline and mortality of Carolina hemlock across its Southern Appalachian distribution. The insect is native to Asia and western North America and was introduced to eastern North America from Japan prior to 1951 when it was first detected in Virginia (Havill and others 2006). Since that time, HWA has spread throughout the hemlock forests of the Eastern United States and Canada where it also impacts the more widely distributed eastern hemlock (*T. canadensis* (L.) Carr.). HWA feeds on xylem ray parenchyma, depleting stored nutrients leading to premature needle loss, branch and crown dieback, and eventually death of the tree (Havill and others 2014). Hemlocks experiencing predisposing stress can be killed in as little as 4 years, though many trees persist for 10 or more years before succumbing. HWA now infests the entire range of Carolina hemlock and poses a significant threat to the long-term health and sustainability of this already rare conifer species.

The Camcore program at North Carolina State University (NCSU/Camcore) and the U.S. Department of Agriculture, Forest Service have been conducting HWA monitoring and genetic resource conservation efforts in Carolina hemlock stands since 2003. Initially, this work focused on nine well-known occurrences of the species in North Carolina (Tighe and others 2005). Over the next 10 years, the list of sites with active HWA monitoring grew to 15 (Jetton and others 2008) and then 32 (Potter and others 2017) as additional occurrences were reported. National interest in the conservation of Carolina hemlock led to the need to document additional occurrences of the species and to assess tree health, HWA infestation, and treatment status. To accomplish this goal, an Evaluation Monitoring project (EM-SO-15-01) funded by the Forest Service's Forest Health Monitoring Program was initiated in 2015 to delineate and map known and reported Carolina hemlock populations across the species range and assess their general health status. This article presents a project summary on the expanded map of species occurrences, stand characteristics, and overall health.

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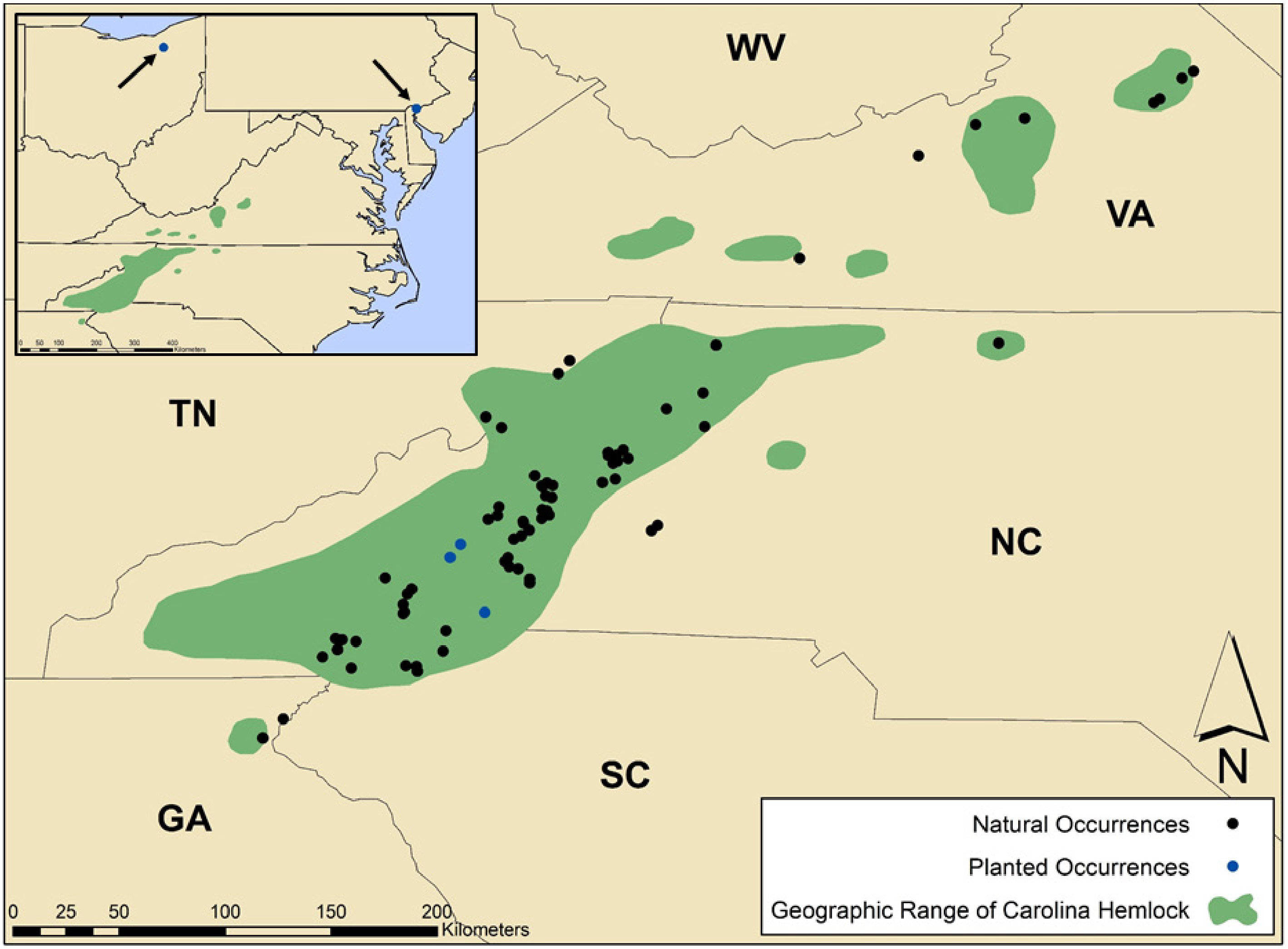


*Figure 5.1—Geographic range of Carolina hemlock with locations of the 79 natural and planted occurrences assessed during the project. Inset shows the locations of planted occurrences outside the natural range of the species in Delaware and Ohio.*

## METHODS

A list of 109 candidate Carolina hemlock occurrences was developed through reviews of the scientific literature and outreach to Federal and State resource managers, natural heritage programs, and private landowners across the natural distribution of the species. Between 2016 and 2020, field visits were made to each of the candidate occurrences to verify the presence of Carolina hemlock, map the trees, and assess health status. At sites where the species was confirmed, a custom form for the ArcGIS Collector smartphone app was used to gather stand- and tree-level attribute data as follows. Stand-level data included a total tally of Carolina hemlock trees, the presence/absence of Carolina hemlock seedling/sapling regeneration, and a list of dominant co-occurring species. Tree-level data included latitude (D.d), longitude (D.d), elevation (m), height (m), diameter at breast height (d.b.h.; cm), aspect, tree health rating, presence/absence of active HWA infestation, and presence/absence of previous HWA treatments. Tree health ratings were based on a 0–5 scale as follows: 0 = dead, 1 = 1–25 percent live crown remaining, 2 = 26–50 percent live crown remaining, 3 = 51–75 percent live crown remaining, 4 = 76–99 percent live crown remaining, and 5 = full, healthy crown with no signs of crown dieback. HWA infestation status was determined by examining the underside of four lower crown branches for presence of adelgid ovisacs. Presence of HWA treatments was based on treatment records provided by site managers and/or the presence of tree tags, tree paint, or other markers commonly used for indicating adelgid treatments. Tree-level data were collected for 14 percent of all trees tallied during the project. Analysis of variance was used to determine the effect of HWA infestation status, HWA treatment status, and their interaction on Carolina hemlock crown health ratings. Where significant differences were found, mean separation analysis was performed using Tukey-Kramer honestly significant difference (HSD).

## RESULTS AND DISCUSSION

Of the 109 sites visited during this project, 79 were confirmed to support living Carolina hemlock trees (fig. 5.1). The remaining 30 sites had no Carolina hemlock and consisted mostly of misidentified occurrences of eastern hemlock or red spruce (*Picea rubens* Sarg.). Others were likely occurrence reports for which inaccurate coordinate information was obtained, or possibly areas where HWA had already eliminated Carolina hemlock, though standing dead stems were not observed at these locations.

Among the 79 sites where Carolina hemlock was confirmed, 74 were identified as being of natural origin, while five were determined to have been planted (table 5.1, fig. 5.1). Two of these sites, Rockwood Park in Delaware and Cuyahoga Valley National Park in Ohio, are far outside the natural distribution of the species, and available records confirm the planted status of the trees at these locations (e.g., MacKay and Trimbath 2022). The three remaining planted sites are all found within the natural range of Carolina hemlock in North Carolina and include Bent Creek Experimental Forest, Biltmore Estate, and the Carl Sandburg Home National Historic Site.

Table 5.1—Stand- and tree-level data for Carolina hemlock occurrences assessed during the project

| Variable | Mean | SE | Range | Total |
|---|---|---|---|---|
| **Stand-level attributes** | | | | |
| Total occurrences | — | — | — | 79 |
| Natural | — | — | — | 74 |
| Planted | — | — | — | 5 |
| Regeneration present | — | — | — | 27 |
| HWA infestation present | — | — | — | 62 |
| HWA treatments present | — | — | — | 27 |
| **Tree-level attributes** | | | | |
| Total trees | — | — | — | 13,766 |
| Elevation (m) | 980.43 | 26.61 | 330–1580 | — |
| Height (m) | 12.32 | 0.50 | 3.70–22.38 | — |
| d.b.h. (cm) | 22.94 | 0.95 | 6.44–44.11 | — |
| Health (0–5)[a] | 2.70 | 0.07 | 0.80–4.00 | — |

d.b.h. = diameter at breast height; HWA = hemlock woolly adelgid; SE = standard error.

[a] Tree health ratings were based on a 0–5 scale as follows: 0 = dead, 1 = 1–25 percent live crown remaining, 2 = 26–50 percent live crown remaining, 3 = 51–75 percent live crown remaining, 4 = 76–99 percent live crown remaining, and 5 = full, healthy crown with no signs of crown dieback.

The planted nature of trees at these locations was confirmed by onsite resource managers. Among the 74 populations of natural origin, 48 were new to the NCSU/Camcore-Forest Service monitoring and conservation program for Carolina hemlock and 26 had been included in previous efforts (Potter and others 2017).

A total of 13,766 Carolina hemlocks were tallied across the 74 natural occurrences, ranging in elevation from 330 to 1580 m (table 5.1). Trees in five locations occurred below the lower elevation limit of 600 m previously reported for the species (Jetton and others 2008, Rentch and others 2000). Individual Carolina hemlocks were found growing on all aspects, but most (65 percent) occurred on northerly and westerly exposures (table 5.2). This is consistent with species descriptions indicating that Carolina hemlock typically grows on less productive, dry, exposed, nutrient-poor sites where its stress-tolerant life history strategy (drought and shade tolerance, slow growth, evergreen needles, long lifespan) allows the species to be successful (Humphrey 1989). Similar to other studies of Carolina hemlock communities (Keyser and others 2023, Rentch and others 2000), common associates included shade-tolerant blackgum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), and sourwood (*Oxydendrum arboreum* L.); mid-tolerant chestnut oak (*Quercus montana* Willd.) and northern red oak (*Q. rubra* L.); and understory ericaceous shrubs such as Catawba rosebay (*Rhododendron catawbiense* Michx.), mountain laurel (*Kalmia latifolia* L.), and a variety of *Vaccinium* spp.

The number of trees per occurrence varied greatly across the 74 natural Carolina hemlock sites, ranging from a single tree along the east bank of the Chattooga River on the South Carolina-Georgia border to more than 1,700 trees along the Appalachian Trail on Sinking Creek Mountain near Blacksburg, VA. The majority of occurrences (47) consisted of fewer than 100 scattered trees making up a minor component of the overall forest canopy (table 5.2). The remaining 27 were larger with 100 or more trees,

**Table 5.2—Percentage of trees per aspect and number of occurrences per occurrence size for Carolina hemlock occurrences assessed during the project**

| Variable | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Aspect** | **North** | **Northeast** | **East** | **Southeast** | **South** | **Southwest** | **West** | **Northwest** |
| Trees (percent) | 20 | 9 | 7 | 6 | 7 | 6 | 19 | 26 |
| **Occurrence size (trees per occurrence)** | **1–25** | **26–50** | **51–99** | **100–499** | **500–999** | **1,000+** | | |
| Number of occurrences | 24 | 13 | 10 | 20 | 4 | 3 | | |

but only 7 of these were pure stands with 500 or more trees dominating the canopy. The relative scarcity of mature Carolina hemlock in the forest canopy across sites was reflected in its lack of representation in the understory, with seedling/sapling regeneration present at only 27 of the sites. Keyser and others (2023) found similar trends for the species, with Carolina hemlock being of relatively low importance value in the overstory layer and representing a very small component (~3 percent) of the regeneration layer. Because Carolina hemlock requires the presence of mature trees in the canopy to maintain itself on site (Humphrey 1989) and due to the absence of significant advanced regeneration across most occurrences and likely loss of mature trees from the overstory due to HWA infestation, persistence of the species in these ecosystems without management intervention seems unlikely.

HWA infestations were present in 62 of the 74 natural occurrences and evidence of previous adelgid treatments was noted in 27 (table 5.1). Based on the tree-level assessments, the number of individual Carolina hemlocks with active HWA infestations was nearly double that of uninfested trees across occurrences, and nearly half had received previous adelgid management treatments (fig. 5.2A). Fifty-two percent of trees were confirmed to be untreated or were of unknown treatment status. Treatments consisted primarily of applications of the systemic neonicotinoid insecticide imidacloprid, while one site was reported to have been treated with dinotefuran and three had documented releases of HWA biological control agents in addition to insecticide applications. The average crown health rating across all trees assessed was moderate at 2.70 (table 5.1), ranging from 0.80 (near total crown mortality) to 4.00 (>75 percent live crown remaining). Tree health ratings were significantly affected by both HWA infestation status ($df = 1$, $F = 186.81$, $p < 0.0001$) and treatment status ($df = 2$, $F = 9.23$, $p < 0.0001$) but not their interaction (fig. 5.2B).

Although significant, the differences in Carolina hemlock health ratings based on treatment status were quite small, and trees across all three treatment types were of relatively poor crown health. Most trees had received treatment 5 years or more prior to assessment, and because imidacloprid effectiveness begins to wane 4 to 6 years following application (Benton and others 2016), most trees were likely no longer fully protected from HWA infestation. Similarly and encouragingly, uninfested Carolina hemlocks were identified and had significantly better crown health than infested trees. However, the 3.1 average health rating among uninfested trees indicates that this cohort had experienced an average of 51–75 percent crown decline and dieback, meaning these trees had likely been impacted by HWA in the past. This trend can be explained by expected variations in adelgid population density over time (Havill and others 2014) as populations can cycle from very high to very low or undetectable levels in response to variations in hemlock health or extreme winter and summer temperatures. In response, hemlocks decline gradually, cycling between periods of improved and reduced health, lingering in the forest for 10 or more years before finally succumbing to the infestation. This points to the

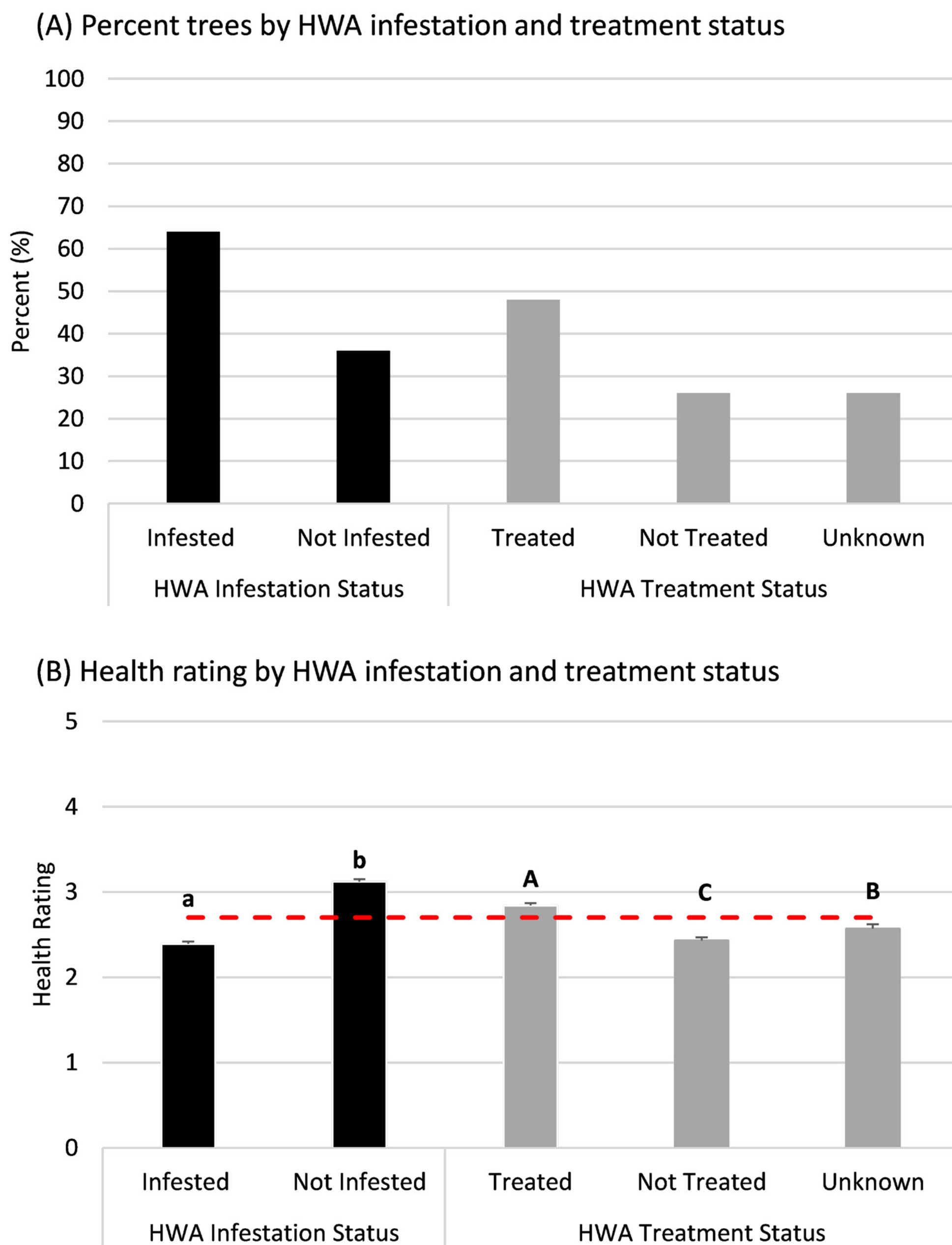


*Figure 5.2—Percentage of trees by hemlock woolly adelgid (HWA) infestation and treatment status (A) and response of crown health rating to HWA infestation and treatment status (B) across Carolina hemlock occurrences assessed during the project. Red dashed line represents the average health rating of all trees in the assessment (2.70). Bars with different lowercase or uppercase letters are significantly different α = 0.05.*

limitations of single "snapshot in time" monitoring efforts like the one reported here and the need for the establishment of long-term monitoring plots to better track Carolina hemlock health and identify areas most in need of management intervention.

## CONCLUSIONS

HWA has been established across the range of Carolina hemlock for approximately two decades. During this time, HWA monitoring and management efforts have focused on a small number of well-known occurrences of the tree species. This project added 48 occurrences to the list for which monitoring data were gathered to provide a better picture of Carolina hemlock health and HWA infestation and treatment status across the species range. While Carolina hemlock persists at all sites, the health of most trees assessed is poor to moderate, indicating that additional management intervention is needed to maintain the species as part of the Southern Appalachian ecosystem. Continued use of systemic insecticides integrated with expanded releases of HWA biological control agents will benefit the health of the trees (Mayfield and others 2020). However, opportunities also exist to explore the use of silvicultural tools that will promote seed production and germination, increase seedling/sapling recruitment into older age classes, and improve Carolina hemlock health and resilience to HWA infestation as has been documented for eastern hemlock (Mayfield and others 2023). Management success will depend on continued monitoring in stands where treatments are applied. The development of monitoring tools designed for Carolina hemlock ecosystems and the establishment of a plot network across the species range are the subject of a currently ongoing Evaluation Monitoring project (EM-SO-21-02).

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