Identifying sites to use for hemlock health monitoring or lingering tree searches

Dr. Radka Wildova and Jonathan Rosenthal, Ecological Research institute

Benefits/purposes of lingering hemlock searches

1) Obtain material to test for heritable resistance/tolerance to HWA and EHS.
2) If heritable resistance/tolerance found, use for breeding.

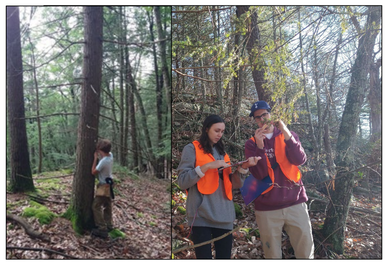
Criteria:
Lingering hemlock searches: sites where dead/dying trees ≥ 80%.

Lingering hemlock (left) at site in Mohonk Preserve (right) where 90% of hemlock trees are dead or dying. Both EHS and HWA are at the site and on the lingering tree; photos by R. Wildova.

Benefits/purposes of monitoring plots

1) Enable detection of when decline/mortality threshold reached.
2) Can assess factors influencing decline/mortality rates, thus better identification of where/when to search; also help fine-tune management responses.

Criteria:
Monitoring plots: sites where dead/dying trees < 80%.



Monitoring hemlock health at sites in Mohonk Preserve; photos by R. Wildova.

Factors related to hemlock mortality in stands infested by HWA/EHS*

Hemlock stress factors

Related to hemlock water budget, risk of drying:

- High summer temperatures, high winter temperatures
- Latitude and altitude (lower latitudes stressful due to temperature)
- Steepness of slope (steeper more stressful)
- Aspect (highest mortality on W, S – facing slopes; lowest mortality on N-facing slopes)
- Substrate's water availability (based on soil type, etc.)
- Summer drought (higher mortality with less precipitation)
- Ridgetops particularly stressful

Other stressors:

- Impacts of other pests (e.g., spongy moth)
- Light availability (higher mortality with lower light availability)

HWA favorability

- Warmer summer: positive effect on HWA
- Warmer winter: positive effect on HWA
- Cold due to altitude, latitude can have some negative effect on HWA

Tree characteristics

- Tree DBH (some studies have found higher mortality in larger trees)
- Total hemlock basal area (higher mortality in denser hemlock stands)
- Nitrogen content of foliage (higher mortality in stands with higher N in leaves)

Case study of site-to-site variation in hemlock mortality: Mohonk Preserve, NY

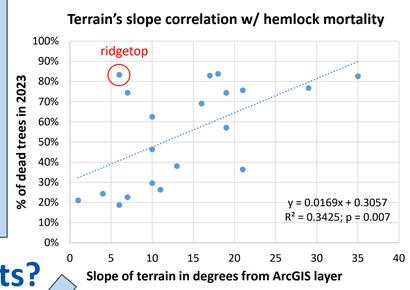
ERI established 20 monitoring plots in 2015. Previous researchers had recorded arrival of HWA and EHS at these sites, ranging from 20 to 30 years ago.

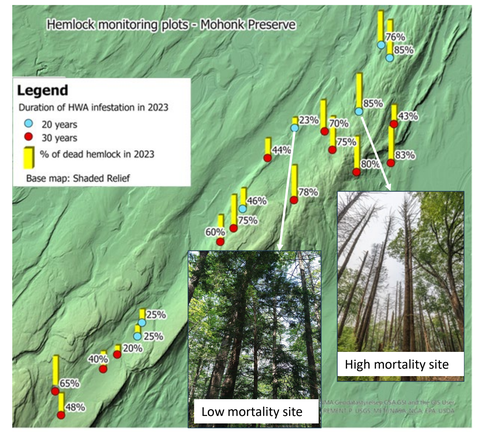
Great variation in decline and mortality rates even among nearby sites due to:

- invasion duration and
- environmental variables

Mortality ranges from 20% to 85% in stands with same infestation histories.

We analyzed multiple possible factors to find which one(s) contributed most to hemlock mortality at the preserve.



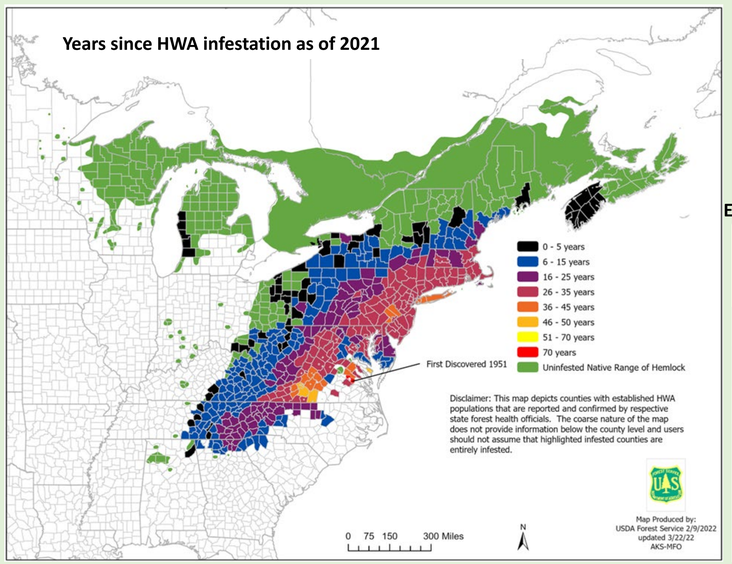


The main factor contributing to differences in hemlock mortality at the Mohonk Preserve is the **terrain's slope.**

Site with 20-degree slope; mortality in 2023 was 83% (92% dead + dying trees). HWA was first recorded in 2002 at this site.

Where to search for lingering hemlock vs. do monitoring plots?

HWA distribution and regional hemlock mortality patterns



This county-level map shows similar HWA infestation durations across broad areas. However, uniform mortalities across them cannot be assumed, as studies, such as those in table below, have shown great variation in mortality time courses. (*Note*: Hemlock mortality in absence of HWA and EHS is close to 0%.**)

Examples of hemlock mortality at sites in different regions:

Study site(s)	Time since infestation onset	Average mortality across sites included in each study	Resource
NC	8 yrs	84%	*Ford et al. 2012*
NJ	8 yrs	10%	*Eschtruth et al. 2006*
PA	8 yrs	20%	*Eschtruth et al. 2006*
CT	6 yrs	59% **range 14-97%**	Orwig & Foster 1998
NY	20 yrs	50% **range 23-85%**	*Wildova & Rosenthal unpubl. data*
VA	20 yrs	46% **range 0-100%#**	*McAvoy et al. 2025*

Site-to-Site mortality variation

Considerable mortality variation has been found even among nearby sites with the same infestation histories. This is likely largely due to environmental stressors, but might also reflect population-level genetic differences.

Type of sites where hemlock dies fastest after HWA or HWA/EHS arrival

- ❖ Steep slopes, especially facing S or W
- ❖ Ridgetops
- ❖ Limited soil water access (e.g. rocky field)
- ❖ Warmer sites
- ❖ Stands with large hemlocks and high hemlock density
- ❖ Accelerated decline where combination of stressors and/or unfavorable weather events and/or other forest pests occur

Guidance for where to search for lingering hemlock vs. do monitoring plots

- Even at a local scale (e.g., within a large preserve or state park), some sites can be ready for lingering tree searches while others are suitable for monitoring
- For long-invaded areas, probably best to start by doing lingering tree searches in the most stressful locations (and vulnerable trees, i.e., large, high-density) to not miss out on any lingering trees before they succumb; can then move on to progressively less stressful sites if no lingering trees found. Also, some long-invaded sites might have low enough mortality to be suitable for monitoring plots. Note: If you find a stand of relatively healthy hemlock in a long-invaded site with stressful conditions, this might comprise closely related trees all having heritable resistance/tolerance, so make sure to report them (as a lingering tree cluster).
- For shorter-invaded areas, some sites might be so stressful as to already have sufficient mortality/decline to reveal lingering trees, if they haven't yet reached it, such sites should be prioritized for monitoring, as mortality/decline rates likely to be most rapid there (and can overtake the rates at longer invaded but less stressful sites).
- Try to get a good sense of site's dead and dying percentage before further data collection for either protocol for greatest efficiency. Use the Rapid Hemlock Mortality Assessment tool on the **TreeSnap** app.
- If initial plot set-up reveals ≥ 80% dead/dying trees, you can then repurpose the data to immediately report lingering trees. Similarly, if a lingering tree search shows <80% dead/dying trees, you can then repurpose the data for initial plot set-up.

TreeSnap

*Studies that showed effect of environmental factors or tree characteristics: Orwig & Foster 1998, Trotter and Shields, 2009, Orwig et al. 2002, Rentch et al. 2008, Evans et al. 2011, Brantley et al. 2017, Lany et al. 2018, McAvoy et al. 2025, Wildova & Rosenthal unpubl. data.; **Studies that documented hemlock mortality in the absence of HWA and EHS: McAvoy et al. 2025 in Southwest VA; NE region - Orwig pers. com.; Southeastern states – Rose 2006, USFS study. # this range and average reflect mortality levels only in the study's plots that were infested for 20yrs.

Acknowledgements

Funding provided by the Tree Species in Peril collaborative initiative led by The Nature Conservancy in collaboration with the US Forest Service. Many thanks to the Mohonk Preserve and our field assistants Elon Rosenthal, Anna Taylor, Jack Navin and Sean Doran.