Management Guide for Eastern Hemlock Conservation in Vermont

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Jamaica State Park. Photo credit: Lauren Pellegrino, State of Vermont Department of Forest, Parks & Recreation.

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Executive Summary

From deer yards to log yards and from trout streams to beautiful recreation areas, eastern hemlock (*Tsuga canadensis*) carry value for all who call Vermont home. This foundational species holds ecological, economic, and cultural significance, and considering the threats to its survival (forest health, climate change, invasive species), deserves a thoughtful approach to conservation. This management guide offers comprehensive and sustainable strategies for maintaining hemlock as a component of Vermont's forests despite these abiotic and biotic stressors.

The guide:

- Establishes the significance of hemlock in Vermont;
- Provides information for the two significant forces currently threatening hemlock trees;
- Identifies management strategies.

An Integrated Pest Management (IPM) approach is taken, combining short-term methods like chemical controls and long-term ones such as biological controls, cultural methods, and active and passive silvicultural techniques. A prioritization tool is made available to guide land managers in selecting sites that will give the best long-term results for hemlock conservation.

In practice, managers of private and public lands may find variable objectives and reasons for management, therefore this guide takes a broad, landscape-wide approach. The spectrum of management techniques offered here will cover most situations, account for most biotic and abiotic stressors, and should be used in tandem with the basic steps of assessment and prioritization.

This document, however, is just a guide, and the use of mentioned control methods should be informed case by case through monitoring, prioritizing, and evaluating any methods employed. Additionally, this guide is intended to be a living document that will be evaluated and updated as new information is available. Should future threats emerge, this guide can be a model for response.

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Eastern Hemlock

Hemlock Biology/ Life History

Hemlock, the genus, *Tsuga,* has 11 species, four of which are native to North America. Eastern hemlock (*Tsuga canadensis)* and Carolina hemlock (*Tsuga caroliniana*) occur in the east, and mountain hemlock (*Tsuga martensiana*) and western hemlock (*Tsuga heterophyll*a) are native to the west. In the United States, eastern hemlock occurs in 29 continental states, including Vermont, with its northern limit running along the southern border of Canada from southern Ontario to Cape Breton Island, Nova Scotia; its southern limit extending south in the Appalachian Mountains to northern Georgia and Alabama; and its western limit extending to Indiana, western Ohio, and western Kentucky[1] (Figure 1). The range of eastern hemlock overlaps that of Carolina hemlock*,* which is naturally limited to the slopes of the Appalachians from Virginia and West Virginia into Georgia but occurs in ornamental plantings outside of this range[2].

Figure 1: Distribution map of eastern hemlock. Photo credit: Elbert L. Little, USGS Geosciences and Environmental Change Science Center.

[1] Carey, Jennifer H. 1993. Tsuga canadensis. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/tsucan/all.html [2022, September 26].
[2] Godman, R. M. and K. Lancaster. 1990. Hemlock. In: Volume I: Conifers. Silvics of North America. USDA Forest Service Agriculture Handbook 654. R. M. Burns and B. H. Honkala, Technical Coordinators. 877 p. https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_1/tsuga/canadensis.htm#:~:text=Seedling%20Development%2D%20Despite%20the%20high,than%2025%20percent%20(36).

Eastern hemlock is monoecious and has male and female flowers in separate clusters on the same branch. Depending on locality and season, the flowering period ranges from late April to early June. Pollen is wind-dispersed starting about two weeks after leaf buds burst, with fertilization taking six weeks to complete. Pollen is susceptible to drying, which can lead to seed failure. Cones reach maturity in late August to mid-October, with seed dispersal by wind extending into the winter[2]. Seeds are partially dormant at maturity and need approximately 10 weeks of cold stratification of near freezing temperatures and a constant temperature of 59° F (15° C) for optimum germination. Seed viability for this species is low, with a germination capacity of less than 25%[2,3].

With ideal growing conditions, eastern hemlock seedlings develop slowly. During this time, seedlings are sensitive to high temperatures and dry soils. After the second year, eastern hemlocks have established a deeper root system, allowing them to grow more rapidly without drying out. Due to its high shade tolerance, eastern hemlock is slow growing, with trees that are 2-3 inches (5-8 cm) in diameter at breast height (DBH) being recorded at 200 years old. Eastern hemlock can take 250-300 years to reach maturity and can live over 800 years. On average, eastern hemlock's ages have been reported to be 200-400 years, with diameters ranging from 35-40 inches (89 -102 cm) with heights over 100 feet[2].

Eastern hemlock prefers moist, well-drained soil and is highly susceptible to drought conditions. In the northeast eastern hemlock grows at elevations ranging from sea level to 2,400 feet (730 m), allowing them to be found in stream valleys, swamps, and on northern and eastern mountain slopes[2,3]. Although a shade-tolerant species, national Forest Inventory and Analysis (FIA) data indicates that eastern hemlock is not regenerating as well as expected in maturing forests and is often out-competed by hardwood species[2,1].

In Vermont, the highest proportion of eastern hemlock volume occurs in southeastern portions of the state, with smaller pockets distributed across the landscape (Figure 2). Logging, bark harvesting for the tanning industry, and land conversion following Euro-American colonization have strongly influenced and restricted the current distribution of eastern hemlock[4].

[3] Burns, Russell M., and Barbara H. Honkala, tech. coords. 1990. Silvics of North America: 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

[4] Thompson JR, Carpenter DN, Cogbill CV, Foster DR (2013) Four Centuries of Change in Northeastern United States Forests. PLOS ONE 8(9): e72540. https://doi.org/10.1371/journal.pone.0072540

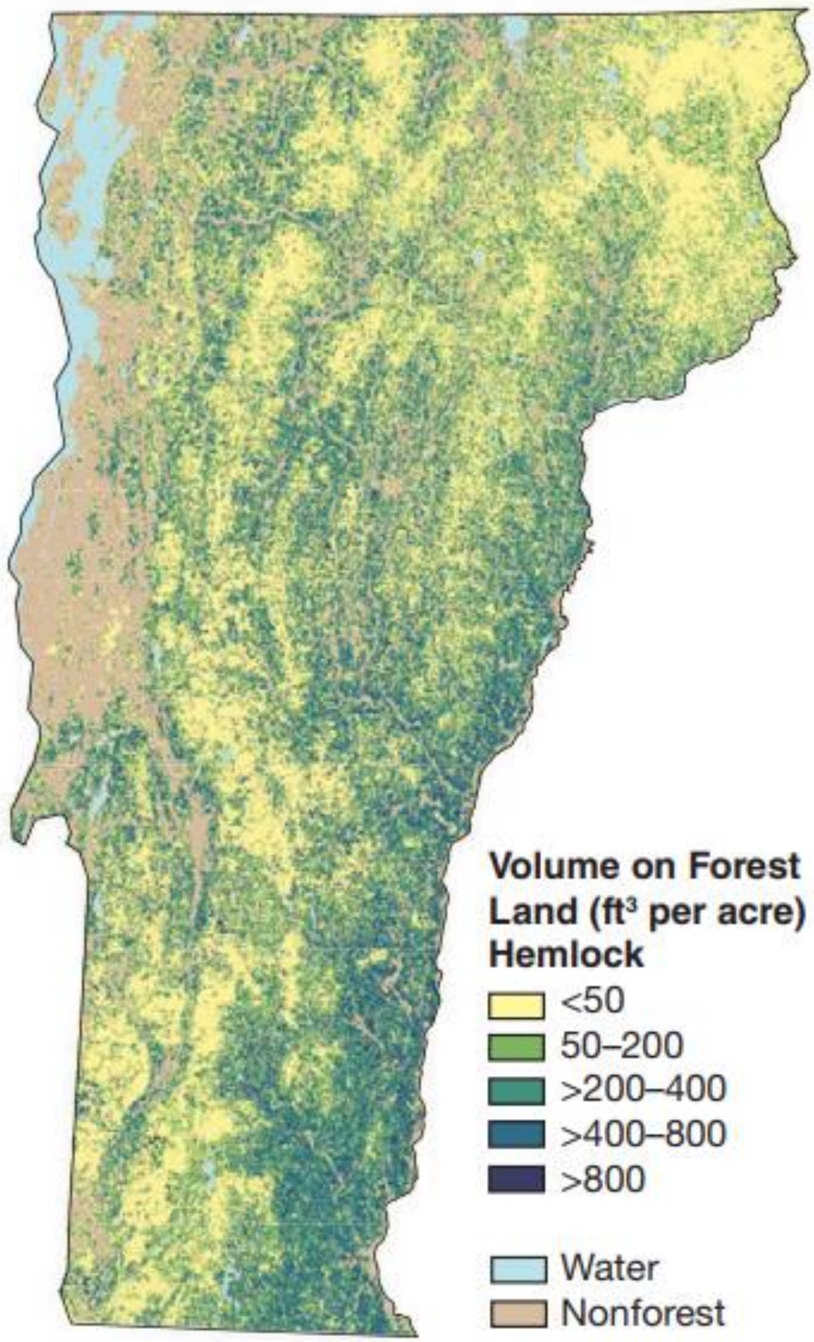

Figure 2. Volume per acre on forest land of Eastern hemlock in Vermont (from Morin et al. 2017). Although present throughout much of the state, eastern hemlock is most concentrated in southern Vermont. Data are from statewide FIA plots, measured by USDA Forest Service staff.

In the Northern Forest Region, eastern hemlock is a major component of three forest cover types, White Pine-Hemlock (Society of American Foresters Type 22), Eastern Hemlock (Type 23), and Hemlock-Yellow Birch (Type 24)[2]. To facilitate management, State of Vermont lands were classified by dominant vegetation type occurring in each area (referred to as natural community types), and four contained a significant hemlock component[5]. Table 1 presents the natural community types where eastern hemlock plays a significant role.

[5] **Synonymy of Vermont Natural Community Types with National Vegetation Classification Associations**; Eric Sorenson and Bob Zaino; Natural Heritage Inventory; Vermont Fish and Wildlife Department, October 17, 2019

Table 1: **Synonymy of Vermont Natural Community Types with National Vegetation Classification Associations**; Eric Sorenson and Bob Zaino; Natural Heritage Inventory; Vermont Fish and Wildlife Department, October 17, 2019. Vermont state ranks: S1: Very Rare, S2: Rare, S3 Uncommon, S4: Common, S5: Very Common. Patch sizes: M – Matrix (dominant, can occupy 1,000 to 100,000 contiguous acres), L – Large Patch (typically occurs in the landscape on a scale of 50 to 1,000 acres), S – Small Patch (occurs in the landscape as small, discrete areas typically less than 50 acres).

VT Natural Community Type	Patch Size	State Rank	National and International Vegetation Classification. NatureServe. 2019. NatureServe Explorer: An online encyclopedia of life. NatureServe, Arlington, Virginia.
Northern Hardwood Forest Formation			
Variant: Beech-Red Maple-Hemlock Hardwood Forest	L	S5	
Hemlock Forest	S	S4	*Tsuga canadensis* - (*Betula alleghaniensis*) - *Picea rubens* / *Cornus canadensis* Forest (CEGL006129)
Variant: Hemlock-Red Spruce Forest	S	S4	*Pinus strobus* - *Tsuga canadensis* - *Picea rubens* Forest (CEGL006324)
Hemlock-Northern Hardwood Forest	L-M	S5	*Tsuga canadensis* - (*Betula alleghaniensis*) - *Picea rubens* / *Cornus canadensis* Forest (CEGL006129); *Tsuga canadensis* - *Betula alleghaniensis- Acer saccharum* / *Dryopteris intermedia* Forest (CEGL006638)
Variant: Hemlock-White Pine-Northern Hardwood Forest	L	S5	
Variant: Hemlock-Yellow Birch Forest	L	S5	
Oak-Pine-Northern Hardwood Forest Formation			
Dry Transition Hemlock Forest	S-L	S4	*Pinus strobus* - *Tsuga canadensis* Lower New England-Northern Piedmont Forest (CEGL006328)
Dry Hemlock-Oak Forest	L	S3	*Tsuga canadensis* - *Fagus grandifolia* - *Quercus rubra* Forest (CEGL006088)
Hardwood Swamp			
Variant: Hemlock Seepage Forest	S	S3	
Softwood Swamp			
Hemlock-Balsam Fir-Black Ash Seepage Swamp	S	S3	*Acer rubrum* - *Fraxinus nigra* - (*Tsuga canadensis*) / *Tiarella cordifolia* Swamp Forest (CEGL006502)
Hemlock-Sphagnum Basin Swamp	S	S2	*Tsuga canadensis* - *Betula alleghaniensis* / *Ilex verticillata* / *Sphagnum* spp. Swamp Forest (CEGL006226)

In Vermont, hemlock is mostly found as a component of the Northern Hardwood Forest formation, a group of natural community types common at elevations below 1,800 feet in all regions excluding the Champlain Valley biophysical region. Dry Transition Hemlock Forests and Dry Hemlock-Oak Forests are both found in warm and dry regions along Vermont's western and southeastern borders, although the Hemlock-Oak Forest is uncommon. Hardwood swamps including the Hemlock Seepage Forest variant of Northern Hardwood Seepage Forest are documented in the northern parts of the state, and likely occur in the southern regions, although this is poorly documented. Softwood swamps are common and widely distributed across the state with Hemlock-Balsam Fir-Black Ash Seepage Swamps being distributed at low elevations[6].

Significance of Eastern Hemlock in Vermont's Forests

A. Ecological Significance

Eastern hemlock is considered a foundational species in the eastern forests because it is locally abundant and regionally common, and its structure and functional characteristics create microclimates and habitats for a range of other species[7,8]. Stands of eastern hemlock are often found on steep banks adjacent to streams such that their roots prevent soil erosion and dense canopy reduces water temperature fluctuations, both critically important for cold tolerant freshwater fish populations, such as brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*). Many species utilize eastern hemlock for both their food and habitat, including 96 bird species, 47 mammal species, and over 100 aquatic species[9]. These ecosystem services are threatened by the decline of hemlock due to invasive insects, climate change, and other stressors. Often when hemlock perishes, it is replaced by deciduous hardwood species, which cannot create the same microclimate and habitat that hemlock provides.

B. Wildlife Habitat

a. Cover

Hemlock-Northern Hardwood Forests occur as large patches and matrix forests and provide some of the most widespread mixed forest habitats in Vermont[6].

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[6] Thompson, Elizabeth H., et al. Wetland, Woodland, Wildland: A Guide to the Natural Communities of Vermont. Published by Vermont Fish and Wildlife Department, The Nature Conservancy, and Vermont Land Trust, 2019.

[7] Foster, DR et al. 2014. Hemlock: A Forest Giant on the Edge. Yale University Press.

[8] Ellison, A.M., Barker-Plotkin, A.A., Foster, D.R. and Orwig, D.A., 2010. Experimentally testing the role of foundation species in forests: the Harvard Forest Hemlock Removal Experiment. Methods in Ecology and Evolution, 1(2), pp.168-179.

[9] Thompson JR, Carpenter DN, Cogbill CV, Foster DR (2013) Four Centuries of Change in Northeastern United States Forests. PLOS ONE 8(9): e72540. https://doi.org/10.1371/journal.pone.0072540

Bird species like the black-throated green warbler (*Setophaga virens*), black-burnian warbler (*Setopaga fusca*), red-breasted nuthatch (*Sitta canadensis*), American goldfinch (*Spinus tristis*), American robin (*Turdus migratorus*), barred owl (*Strix varia*), black-capped chickadee (*Poecile atricapillus*), blue jay (*Cyanocitta cristata*), brown creeper (*Certhia americana*), Carolina wren (*Thryothorus ludovicianus*), red crossbill (*Loxia curvirostra*), dark-eyed junco (*Junco heymalis*), evening grosbeak (*Hesperiphona vespertin*), kinglets (Regulidae), pine siskin (*Spinus pinus*), purple finch (*Haemorhous purpureus*), rose-breasted grosbeak (*Pheucticus ludovicianus*), scarlet tanager (*Piranga olivacea*), warblers (Parulidae), wild turkey (*Meleagris gallopavo*), pileated woodpecker (*Dryocopus pileatus*), ruffed grouse (*Bonasa umbellus*) and wood thrush (*Hylocihla mustelina*) use hemlock as breeding habitat[10]. Northern saw-whet owl (*Aegolius acadicus*), an uncommon species in Vermont, is often associated with hemlock stands.

White-tailed deer (*Odocoileus virginianus*) utilize dense hemlock stands for winter cover when snow depths reach 20 inches or more. These dense stands provide thermal protection from cold winter nights and reduce the volume of snow that reaches the forest floor. Reduced snow loads allow for easier movement and lower energy consumption which is key for their winter survival. While in these stands, deer may consume foliage and twigs as high as they can reach (Figure 2) as hemlock is a "second choice" for preferred deer browse[11].

Figure 2: Deer browse on broken out hemlock top. Photo credit: Jim Esden, State of Vermont Department of Forest, Parks & Recreation.

[10] The National Wildlife Federation, *Eastern Hemlock Forests*, n.d., https://www.nwf.org/Educational-Resources/Wildlife-Guide/Threats-to-Wildlife/Climate-Change/Habitats/Eastern-Hemlock-Forests#section-2.

[11] Adams, David, et al. "Wildlife Habitat Management - a Landowner's Guide." Wildlife Habitat Management - A Landowner's Guide, Agency of Natural Resources Vermont Fish & Wildlife Department, 2014, https://vtfishandwildlife.com/learn-more/landowner-resources/wildlife-habitat-management-a-landowners-guide.

Snowshoe hare (*Lepus americanus*) depend on hemlock groves for nutritional value and thermal cover in the winter. Preferred hare habit requires two components: base cover which is the dense coniferous cover where the hare spends the day, and travel cover which is softwood corridors, or tracts, that allow the hare to move from base cover to a food source. The average tree height for adequate base cover is approximately 11 feet (range is 8 to 15 feet). High densities of softwoods that result in low visibility provide the best quality base cover, with hemlock being one of these preferred species.

Aquatic organisms benefit from eastern hemlock thermoregulating the stream system, stabilizing banks from erosion, and filtering water. Key aquatic species that live in these systems include native brook trout *(Salvelinus fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*). Other species such as the eastern red-backed salamander (*Plethodon cinereus*), spotted salamander (*Ambystoma maculatum*), blue-spotted salamander (*Ambystoma laterale*), eastern newt (*Notophthalmus viridescens*), and Jefferson salamander (*Ambystoma jeffersonianum*) have all been noted in the damp cool environments that dense hemlock overstories can provide[12].

b. Food

Eastern hemlock, as individual trees, inclusions, and stands, during the non-breeding season and throughout winter, provide an important food source for an assortment of birds. Goldfinch *(Spinus tristis*), red crossbill (*Loxia curvirostra*), white-winged crossbill (*Loxia leucoptera*), evening grosbeak (*Coccothraustes vespertinus)*, blacked capped chickadees (*Poecile atricapillus*), and dark-eyed juncos (*Junco hyemalis*) are known to feed on the seeds. This feeding can help with the dispersal of hemlock over the landscape. Yellow-bellied sapsuckers (*Sphyrapicus varius*) have been known to feed on eastern hemlock, which can lead to ring shake in highly damaged feeding sites and degrade the stem's overall health and vigor and contribute to mortality. Consumption of bark and twigs can cause decline and impact the survivability of young hemlock. Snowshoe hare (*Lepus americanus*) winter forage includes twigs, buds, and tender bark of young hemlocks.

Porcupines (Erethizontidae) will often seek out hemlocks and preferentially use them for feed and roost trees above what their abundance in an area would predict[13] (Figure 3). Porcupines are also known to feed on the same tree year after year, leading to a decline in the health and vigor of these stems. White-tailed deer and porcupines have a symbiotic relationship regarding winter forage. Porcupines chew branches from the tops of the trees and white-tailed deer consume them after they fall to the ground. One fur bearer species associated with hemlock forests in Vermont is the fisher (*Martes pennati*), which has a large home range (10 miles) and

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[12] Brooks, Mathewson. “The Relative Abundance of Eastern Red-Backed Salamanders in Eastern Hemlock-Dominated and Mixed Deciduous Forests at Harvard Forest.” Northeastern Naturalist, vol. 16, no. 1, 1 Mar. 2009, pp. 1–12., https://doi.org/10.1656/045.016.0101.

[13] Schmidt, K. N., and Christian, D. P. 1988 Porcupine-Eastern hemlock Interactions at Hemlock Ravine Scientific and Natural Area. Minnesota Department of Natural Resources

searches hemlock forests for prey including porcupines, red squirrels (*Sciurus vulgaris*), and northern flying squirrels (*Glaucomys sabrinus*)[5].

Figure 3: (Left) Porcupine in branch of eastern hemlock. Photo credit: Dave Bonta. (Right) Eastern hemlock twigs clipped from porcupine feeding. Photo credit: Seabrooke Leckie.

C. Cultural Significance

The northern extent of eastern hemlock's natural range coincides in great part with the homelands of the various Wabanaki peoples, from Lake Champlain along the St. Lawrence River to Cape Breton. Within these are the lands of the Western Abenaki, with their relatives the Mohican to the southwest. Given the slow growth habit and very long lifespan of hemlock, it is likely that there are individual multi-centenarians who have been present here since well before contact with Euro-American settlers. Following is a brief and partial compilation of Abenaki cultural relations with the eastern hemlock nation.

In the Western Abenaki language, this tree, in common with others, is encountered as an animate entity and addressed as "someone" rather than "something." The referent is alnisedi or alnizedi (pronounced ahl NEE seh DEE). This naming follows from being seen as the "vernacular conifer": the compound word used for hemlock combines alni- which means 'common or ordinary' with -sedi, denoting any 'evergreen bough'[14].

[14] Dann, Kevin. "Vermont's Original Forest Language." Winter 1994, Northern Woodlands, 2 Dec. 1994, https://northernwoodlands.org/articles/article/original-forest-language.

Several ethnobotanical uses are known. An infusion or decoction of the needles is used to treat rheumatism and itchiness[15]. This infusion is also prepared as a tea and used as a source of Vitamin C, especially as an anti-scorbutic. Some scholars believe that *Tsuga canadensis* (among others) may be the "tree of life" recorded by French explorer Jacques Cartier in 1535 when his crew – rapidly dying from scurvy – were gifted the branches of an evergreen and directed to drink the tea prepared from its needles. Within a few days, they were recovering[16].

Among the Abenaki, trees are seen as plant relatives and - more essentially - as an active and reciprocal participant in the intersectional communities (including human beings) of which they are a member. Even in the apparently limited understory of an eastern hemlock forest, other familiar entities can be expected and sought when searching for certain medicine plants. For example, partridge berry (*Mitchella repens*) and hemlock reishi (*Ganoderma tsugae*) have medicinal value and grow in the understory of eastern hemlock stands (Figure 4). Following those lines of perception, when the hemlock forest is healthy then their associated communities will also be thriving. The opposite also holds true, including the intersectional aspects of human participation in these vital exchanges.

Figure 4: Examples of medicinal plant associations. (Left) Partridge/twin berry, Western Abenaki - pabedgwibakazik ("little round leaf'). (Right) Hemlock reishi, Western Abenaki - alnisediagwôdawas ("hemlock bracket fungus"). Photo credits: Rich Holschuh, Atowi Project.

The bark of the tree is used as a tanning agent and dye material, due to the high tannin content. Hemlock boughs are often used in temporary brush shelters as a softening mattress

[15] Rousseau, Jacques, 1947, Ethnobotanique Abenakise, Archives de Folklore 11:145-182, http://naeb.brit.org/uses/search/?string=abenaki&page=3
[16] Durzan DJ. Arginine, scurvy and Cartier's "tree of life". J Ethnobiol Ethnomed. 2009 Feb 2; 5:5. doi: 10.1186/1746-4269-5-5. PMID: 19187550; PMCID: PMC2647905.

and ground-insulating bedding material and layered for protection overhead as a shelter roof. Although there are few companion medicine or food plant sources to be found in the densely shaded understory of hemlock forests, their open nature makes them good deer yards and an attractive roosting place for owls.

D. Economic Significance

a. Market Value

Eastern hemlock is one of the most abundant tree species in the state, comprising 34% of Vermont's softwood growing stock, with a total estimated stumpage value of $186,000,000 (stumpage based on current market prices and Vermont Forests 2017 stocking)[17]. Although it ranks third in species by sawtimber value and growing stock volume, hemlock products are in lower demand than other softwood species due to their uneven texture, ring shake, resistance to preservative treatment, lack of decay resistance, and moderate strength[1,2,17]. One of the earliest commercial uses for eastern hemlock in New England by Euro-Americans was for harvesting tannin compounds in the bark for use in the leather tanning industry[1,2]. As synthetic materials have now replaced leather in most products, hemlock is no longer exclusively harvested for tannins. Currently, hemlock markets include pulpwood, dimension lumber, boards, construction and landscape timbers, plywood core veneers, and bark for landscaping mulch[2] (Figure 5).

Figure 5. Hemlock logs harvested from Skitchewaug Wildlife Management Area. Photo credit: Brian Renfro, State of Vermont Department of Forest, Parks & Recreation.

b. Non-market Value

Hemlocks provide several non-market values, including wildlife habitat, ecosystem services, and recreation. These values indirectly contribute to economic value by representing the money

[17] Morin, Randall S., et al. "Vermont Forests 2017." Mar. 2020, https://doi.org/10.2737/nrs-rb-120

people pay to use the habitat, as well as the opportunity cost associated with losing non-market values. According to the Agency of Commerce and Community Development (ACCD), Vermont tourism is one of the largest industries in the state with over 13 million visitors each year[18]. With more than 850 recreation trails that comprise over eight thousand miles across the state, 139,588 fishing licenses, and 82,377 hunting and trapping licenses sold in 2022, people travel from all over the U.S. to spend time enjoying Vermont's outdoors[19,20]. ACCD reports that these visitors account for approximately $3.0 billion in annual spending on lodging, food and drink, goods, and services[18].

Although not all the tourism in Vermont is centralized around hemlock stands, losing a keystone species could have a rippling effect on our local ecosystems. In forest types where eastern hemlock is the least prevalent tree species, the loss of the species may have a minimal overall impact on the economic significance and would likely be replaced with more locally prevalent tree species. In habitats where hemlock dominates and/or is a significant species in the forest type, the loss of the species could lead to a forest cover type shift and a reduction in both market and non-market values.

Threats to Eastern Hemlock

A. Biotic Stressors

Most native biotic threats are kept in check by existing counterbalances including native predators, environmental conditions, and genetic resistance, although populations of pests and diseases may reach periodic outbreak levels. Non-native biotic threats lack these existing counterbalances that would help keep populations in check, and therefore have the potential to cause the most significant damage to our local ecosystems.

a. Native Insect Stressors

Eastern spruce budworm (*Choristoneura fumiferana)* is a native softwood defoliator found in Vermont, that is primarily a pest of balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), and black spruce (*Picea mariana*) (Figure 6). During outbreaks, its larval stage can defoliate and kill hemlock after defoliating all the balsam fir in the stand[2].

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[18] "Economic Impact and Visitation Trends." Tourism Research, State of Vermont Agency of Commerce and Community Development, June 2022, https://accd.vermont.gov/tourism/research.

[19] "VT Data - E911 Landmarks." Open Geodata Portal, State of Vermont, 19 June 2000, https://geodata.vermont.gov/datasets/VCGI::vt-data-e911-landmarks-1/about.

[20] VT Fish and Wildlife, Unpublished data

Figure 6: Spruce budworm larva and damage. Photo credit: Neil Thompson, University of Maine at Fort Kent, Bugwood.org.

Hemlock borer (*Melanophila fulvoguttata)* is a native beetle that is a secondary pest of hemlock in Vermont, although eastern white pine (*Pinus strobus*), eastern larch (*Larix laricina*), fir (*Abies* spp.), and spruce (*Picea* spp.) can also be affected[21,22]. In its larval stage, this borer creates galleries under the bark, attracting woodpeckers (Figure 7). Woodpeckers slough off the bark in search of larvae, leaving piles of bark fragments at the base of the tree and exposing its red inner bark. With increased populations, galleries lead to girdling which reduces growth and leads to crown yellowing and dieback[22]. Since this is a secondary pest, decreasing stress and promoting overall tree health and vigor can help keep populations low[23].

[21] Faulkenberry, Mark, et al. "Eastern Hemlock Conservation Plan." Home Page - DCNR ELibrary 07, PA Department of Conservation and Natural Resources , 23 Apr. 2019, https://elibrary.dcnr.pa.gov/GetDocument?docId=1753173&DocName=dcnr_20030071.pdf.
[22] Hanson, T., and E. B. Walker. [2015.] Field guide to common insect pests of urban trees in the Northeast. Waterbury, VT: Department of Forests, Parks and Recreation. https://www.forestpests.org/vermont/hemlockborer.html
[23] USDA Forest Service, Northeastern Region "Hemlock Borer." Pest Alert: Hemlock Borer, NA-PR-03-00, Aug. 2000, http://hwa.ento.vt.edu/hwa/wp-content/uploads/2016/03/hborer.pdf. Accessed 30 Jan. 2023.

Figure 7: (Left) Hemlock borer larvae. (Right) Woodpecker damage associated with hemlock borer larvae. Photo credits: Steven Katovich, Bugwood.org.

Hemlock looper (*Lambina fiscellaria*) is a native softwood defoliator that can be a serious pest of eastern hemlock in its larval stage (Figure 8). Since it is a native pest in Vermont, hemlocks have coevolved with this stressor and developed chemical defenses that help them tolerate this stress[21,24]. In its larval stage, this moth can defoliate entire trees, leading to dieback and mortality in already stressed or damaged trees[21]. When no other abiotic or biotic stressors are present, research has shown hemlocks that are more than 70% defoliated experience dieback and mortality, with significant mortality when defoliation is over 90%. Mortality is more likely to occur with consecutive years of severe defoliation[25]. In Vermont, populations of spring and/or fall hemlock looper were monitored using pheromone traps between 1992 and 1996, however, population monitoring has been reduced to the observation of bycatch in other forest health trapping efforts.

[24] Lagalante, Anthony & Montgomery, Michael & Calvosa, Frank & Mirzabeigi, Michael. (2008). Characterization of Terpenoid Volatiles from Cultivars of Eastern Hemlock (Tsuga canadensis). Journal of agricultural and food chemistry. 55. 10850-6. 10.1021/jf071947o.

[25] "Hemlock Looper Lambdina Fiscellaria (Gn.)." Hemlock Looper: Insect & Disease Fact Sheets, Forest Health & Monitoring: Maine Forest Service: Maine DACF, Jan. 2001, https://www.maine.gov/dacf/mfs/forest_health/insects/hemlock_looper.htm.

Figure 8: Hemlock looper larva and damage. Photo credit: Pennsylvania Department of Conservation and Natural Resources - Forestry, Bugwood.org.

Hemlock scale (*Hemiberlesia ithacae*) is a scale insect often confused with short needle conifer scale since it also causes yellowing needles and premature needle drop in infested hosts (Figure 9). It can cause branch dieback and tree mortality when outbreaks are severe[26]. Although native to the U.S., hemlock scale has not been detected in Vermont, but is prevalent in several Mid-Atlantic states, with its northern documented range extending to New York and Connecticut[27].

Figure 9: Hemlock scale. Photo credit: Jim Stimmel, Pennsylvania Department of Agriculture, Bugwood.org.

[26] Cschelleng. “Hemiberlesia (Formerly Abgrallaspis) Ithacae.” Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, 18 Jan. 2023, https://ag.umass.edu/landscape/publications-resources/insect-mite-guide/hemiberlesia-formerly-abgrallaspis-ithacae.
[27] Leathers, Jason. “Hemiberlesia Ithacae (Ferris): Hemlock Scale – Synonym: Abgrallaspis Ithacae.” Pest Rating Proposals and Final Ratings, 16 May 2022, https://blogs.cdfa.ca.gov/Section3162/?p=1075.

Hemlock rust mite (*Nalepella tsugifoliae*) is a host-specific mite that feeds only on hemlock needles (Figure 10). When populations are high, feeding can cause infested hemlocks to turn yellowish to grayish before prematurely dropping needles. Since feeding starts in early spring, new growth can be unaffected[28]. Although native to North America and not a major pest of concern in Vermont, this mite has been documented to cause damage to nursery stock in southern New England[29].

Figure 10: (Left) Hemlock rust mite. Photo credit: Sandy Gardosik, Pennsylvania Department of Agriculture. (Right) Hemlock rust mite damage. Photo credit: Phil Nixon, the University of Illinois Extension.

Spruce spider mites (*Oligonychus ununguis)* are a native, cool season spider mite, that is one of the most destructive spider mites in North America (Figure 11). Although present in Vermont, this mite has been reported as causing minimal damage in forested settings. These mites feed on numerous conifers including hemlock, sucking up sap from older needles on the lower and inner portions of the tree canopy. This feeding causes infested needles to appear speckled and yellowish, and prolonged feeding can cause premature needle drop. In high populations, silken webbing from the mites surrounds infested needles[21,30].

[28] Baker, James. "Hemlock Rust Mite." Hemlock Rust Mite | NC State Extension Publications, NC State Extension, Sept. 2019, https://content.ces.ncsu.edu/hemlock-rust-mite.
[29] "Nalepella Tsugifoliae." Nalepella Tsugifoliae, UMass Extension Landscape, Nursery and Urban Forestry Program, 13 Sept. 2022, https://ag.umass.edu/landscape/publications-resources/insect-mite-guide/nalepella-tsugifoliae.
[30] Hoover, Greg. "Spruce Spider Mite." Penn State Extension, 23 Mar. 2017, https://extension.psu.edu/spruce-spider-mite#:~:text=Introduction,this%20pest's%20preferred%20host%20plants.

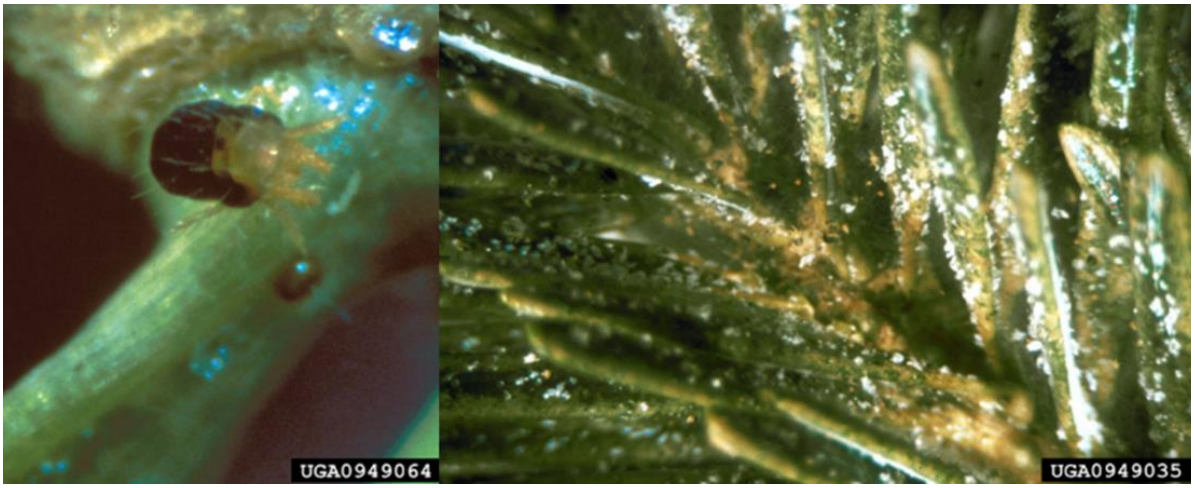

Figure 11: (Left) Spruce spider mite. Photo credit: USDA Forest Service, Bugwood.org. (Right) Spruce spider mite damage. Photo credit: USDA Forest Service - Region 4 - Intermountain USDA Forest Service, Bugwood.org.

b. Native Fungal Stressors

Armillaria root rot (*Armillaria* spp.) is a genus of several cosmopolitan fungi that are both saprotrophs and parasites[31,32] (Figure 12). The most common species of Armillaria to impact hemlock in Vermont include *Armillaria gallica* and *Armillaria solidipes,* although hemlock is generally more resistant to Armillaria than other species[21]. In its parasitic stage, this pathogen causes reduced growth, smaller needles, yellowing of needles, dieback, and mortality of infected hosts. In forested stands, symptomatic trees will appear in circular patterns as this pathogen spreads through the root systems of neighboring trees[21,31]. Although these fungi cannot be practically eradicated from a forested site and may have an increased presence in recently harvested stands, their presence can be reduced by removing infected trees and stumps, maintaining tree health and vigor, and selecting Armillaria-resistant varieties when planting.

[31] Agrios, George N. "Root Rots of Trees." *Plant Pathology*, Elsevier Academic, Amsterdam, 2004, pp. 602–605.

[32] Hagle, Susan K. "Management Guide for Armillaria Root Disease." Forest Health Protection and State Forestry Organizations, US Forest Service, July 2010, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5187208.pdf.

Figure 12: (Left) *Armillaria gallica* fruiting bodies. Photo credit: Michael Kuo, MushroomExpert.com. (Right) *Armillaria solidipes* fruiting bodies. Photo credit: Richard Nadon, MushroomExpert.com.

<u>Cytospora canker</u> (*Cytospora kunzei*) is a cosmopolitan fungal canker pathogen of many coniferous species including hemlock, that causes sunken cankers that girdle and kill branch tips[34] (Figure 13). This disease is more prevalent in urban landscapes and is rarely documented in a forested setting[33].

Figure 13: Cytospora canker damage. Photo credit: Joseph OBrien, USDA Forest Service, Bugwood.org.

[33] Brazee, Nicholas. "Cytospora Canker." Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, 20 Mar. 2018, https://ag.umass.edu/landscape/fact-sheets/cytospora-canker.

Fabrella needle blight (*Fabrella tsugae*) is a native foliar pathogen of hemlock that causes rapid needle necrosis and premature needle drop (Figure 14)[34]. Although no control has been developed, reducing tree stress, and increasing tree vigor may help reduce the severity of this pathogen[34]. Fabrella needle blight has not been detected in Vermont, but is prevalent in several Mid-Atlantic states, and its northern range extends to southern New York and southern Massachusetts[35].

Figure 14: Fabrella needle blight fruiting bodies and damage. Photo credit: Penn State Department of Plant Pathology & Environmental Microbiology Archives, Penn State University, Bugwood.org.

Hemlock reishi is a native fungus that is both a saprotroph and parasite of hemlock in Vermont (Figure 15). In its parasitic stage, this pathogen causes white rot in the heartwood of infected trees[36]. Although not typically the causal agent of mortality, decreased heartwood can decrease structural integrity and make infected trees more susceptible to windthrow and breakage.

[34] Moorman, Gary W. "Hemlock Diseases." Penn State Extension, 31 July 2016, https://extension.psu.edu/hemlock-diseases.
[35] Brazee, Nick. "Landscape Message: Oct 7, 2016 - Archives.lib.state.ma.us." Scouting Information by Region, UMass Extension Landscape, Nursery and Urban Forestry Program, 7 Oct. 2016, https://archives.lib.state.ma.us/bitstream/handle/2452/428737/ocn319079567-2016-10-07.pdf.
[36] Kuo, M. (2019, January). Ganoderma tsugae. Retrieved from the MushroomExpert.Com Web site: http://www.mushroomexpert.com/ganoderma_tsugae.html

Figure 15: Hemlock reishi fruiting body. Photo credit: Steven Katovich, Bugwood.org.

Hemlock Twig Rust (*Melampsora farlowii)* is a native rust pathogen that causes yellowing and necrosis of current-year needles, twig curling, and aborted cones (Figure 16)[37]. Unlike most rust fungi that have a taxonomically unrelated alternate host, hemlock twig rust only needs hemlock to complete its lifecycle, making it a considerable pest in nurseries. In forested settings, this pathogen has been documented throughout the eastern U.S., including Vermont, but is not generally a problem in forests[21,37].

Figure 16: (Left) Hemlock twig rust fruiting bodies and damage. (Right) Hemlock twig rust damage. Photo credits: Bruce Watt, University of Maine, Bugwood.org.

[37] Kenaley, S C, and George Hudler. "Hemlock Twig Rust Caused by Melampsora Farlowii (Arth.) Davis." Cornell University PDDC - Factsheets, Cornell University, Nov. 2010, http://plantclinic.cornell.edu/factsheets.html.

Needle rusts including *Melampsora abietiscanadensis* (native pathogen of hemlock and poplar (*Populus* spp.) in the U.S.), *Pucciniastrum* hydrangeae (native pathogen of hemlock and hydrangea (*Hydrangea* spp.) in the U.S.), *Pucciniastrum vaccinii* (cosmopolitan rust pathogen of hemlock and rhododendron (*Rhododendron* spp.) and others) are additional rust pathogens of hemlock that can be prevalent in urban landscapes[34,38].

c. Non-native Insect Stressors

Cryptomeria scale (*Aspidiotus cryptomeriae*) is a non-native scale insect from Japan, that can be a significant pest of firs and hemlocks, especially in Christmas tree plantations (Figure 17). Cryptomeria scale is prevalent in the Mid-Atlantic region, with its northern range extending to southeastern Massachusetts[21,40]. This pest causes yellowing needles on lower and inner branches and leads to premature needle drop in infested hosts[39].

Figure 17: (Left) Cryptomeria scale. Photo credit: John.A. Davidson, Univ. Md, College Pk, Bugwood.org. (Right) Cryptomeria scale damage. Photo credit: Rayanne Lehman, Pennsylvania Department of Agriculture, Bugwood.org.

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[38] Li, Yonghao, et al. "Diseases of Hydrangea." Handbook of Plant Disease Management, Jan. 2016, pp. 1–19., https://doi.org/10.1007/978-3-319-32374-9_36-1.

[39] Scheufele , Susan, and Nicholas Brazee. "Cryptomeria Scale." Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, Feb. 2014, https://ag.umass.edu/landscape/fact-sheets/cryptomeria-scale#:~:text=Cryptomeria%20scale%20can%20cause%20economic,growing%20degree%20days%20have%20accumulated).

Elongate hemlock scale (EHS, *Fiorinia externa*) is an invasive scale insect from Japan that was introduced to the U.S. in Long Island, New York in tandem with short needle conifer scale in 1908 (Figure 18)[21,40].

Figure 18: Elongate hemlock scale and damage. Photo credit: Barbra Schultz, State of Vermont Department of Forest, Parks & Recreation.

This insect is primarily a pest of hemlocks, firs and spruce trees but can infest other conifers[41]. It has since been established in 20 states and the District of Columbia, with infestations of forested areas in Vermont being reported in 1999, but not reported again until 2013[41]. As of 2023, EHS has been reported in forested settings in Windham and Winsor Counties, and in urban settings in Chittenden County. EHS and hemlock woolly adelgid (HWA, *Adelges tsugae*), often coexist on the same tree, sucking sap, and rapidly depleting resources. When feeding alone, EHS-infested needles are mottled yellow, starting at the interior of the lower canopy, and moving upwards through the tree[21,41]. In heavy infestations, prolonged feeding will cause premature needle drop, branch dieback, and mortality[41]. EHS is slower to build high population densities compared to HWA, so symptom progression is also slower[21]. For more information on EHS or to report a sighting, please visit https://vtinvasives.org/invasive/elongate-hemlock-scale. In Vermont, EHS has been increasing in severity and presence since 2014, where it can now be observed in nine towns and three counties (Figure 19).

[40] McClure, Mark S. 1991. Adelgid and scale insect guilds on hemlock and pine. In: Baranchikov, Yuri N.; Mattson, William J.; Hain, Fred P.; Payne, Thomas L., eds. Forest Insect Guilds: Patterns of Interaction with Host Trees; 1989 August 13-17; Abakan, Siberia, U.S.S.R. Gen. Tech. Rep. NE-153. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 256-270.

[41] Kanoti A, Lombard K, Weimer J, Schultz B, Esden J, Hanavan R, and Bohne M.. Managing Hemlock in Northern New England Forests Threatened by Hemlock Woolly Adelgid and Elongate Hemlock Scale. U.S. Forest Service, Sept. 2015, https://extension.unh.edu/sites/default/files/migrated_unmanaged_files/Resource005573_Rep7772.pdf.

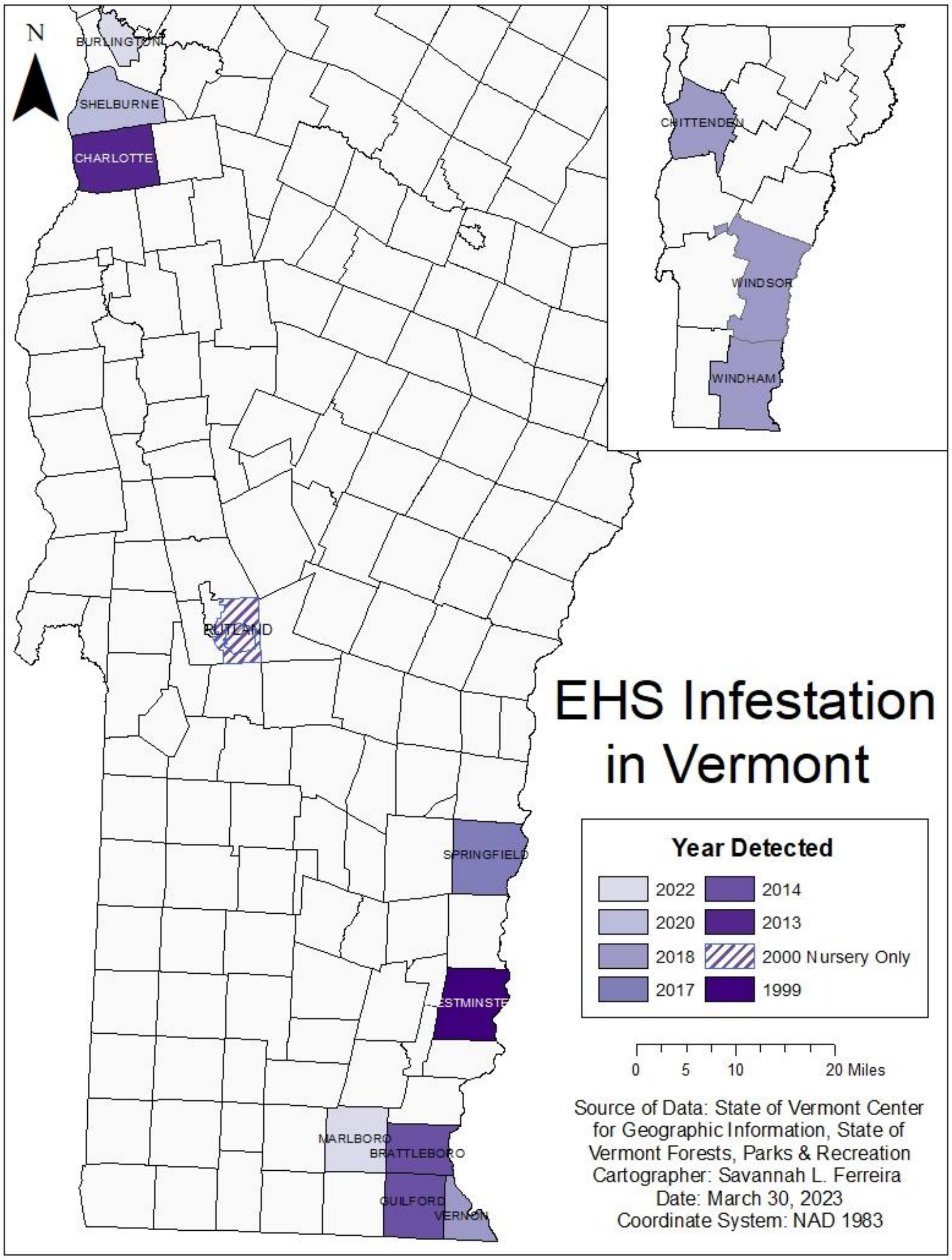

Figure 19: Map of elongate hemlock scale infestation by year in Vermont. 1999: EHS was detected in Westminster. 2000: EHS was detected in Rutland in nursery only. 2013: EHS was detected in Charlotte. 2014: EHS was detected in Brattleboro and Guilford. 2017: EHS was detected in Springfield. 2018: EHS was detected in Vernon. 2020 EHS was detected in Shelburne. 2022: EHS was detected in Burlington and Marlboro. EHS is present in Windham, Windsor, and Chittenden Counties. Source of data: State of Vermont Center for Geographic Information and Forests, Parks & Recreation. Cartographer: Savannah L. Ferreira. Date March 30, 2023. Coordinate System: NAD 1983.

Hemlock woolly adelgid is, an invasive sapsucking insect from Japan and was first reported in the eastern U.S. in Virginia in 1951[42,43] (Figure 20). Since this introduction, HWA has spread across 20 states, now occupying approximately half of hemlock's (*Tsuga* spp.) eastern native range and becoming the most serious threat to hemlocks on the east coast. HWA affects both eastern and Carolina hemlock, but western hemlock is tolerant to HWA due to an effective natural enemy community and therefor has sustained minimal damage[43,44]. HWA feeds on twigs of eastern and Carolina hemlock, causing needle yellowing, premature needle-drop, branch dieback, crown thinning, and eventual mortality of infested hosts.

Figure 20. (Left) Hemlock woolly adelgid eggs. Photo credit: Trish Hanson, State of Vermont Department of Forest, Parks & Recreation. (Right) Hemlock woolly adelgid infested branch. Photo credit: Ron Kelley, State of Vermont Department of Forest, Parks & Recreation.

HWA was first detected in natural woods in Vermont in 2007, and as of 2022, is present in 21 towns in three counties (Figure 21).

[42] Bureau of Invasive Species and Ecosystem Health. *Hemlock Woolly Adelgid?*. NYS Department of Environmental Conservation, 8 Jan. 2018, https://www.dec.ny.gov/docs/lands_forests_pdf/hwafactsheet.pdf.

[43] McCullough, Deborah G. "Hemlock Woolly Adelgid." Extension Bulletin, Michigan State University Extension, Dec. 2015, https://www.michigan.gov/-/media/Project/Websites/invasives/Documents/ID/Insects/HWA_Bulletin.pdf?rev=28531c1b676e407a94702f339a84410e.

[44] Crandall, Ryan, "Impact of Predators on Hemlock Woolly Adelgid (Hemiptera: Adelgidae) in the Eastern and Western United States" (2020). Master's Theses. 958. https://doi.org/10.7275/16540493 https://scholarworks.umass.edu/masters_theses_2/958

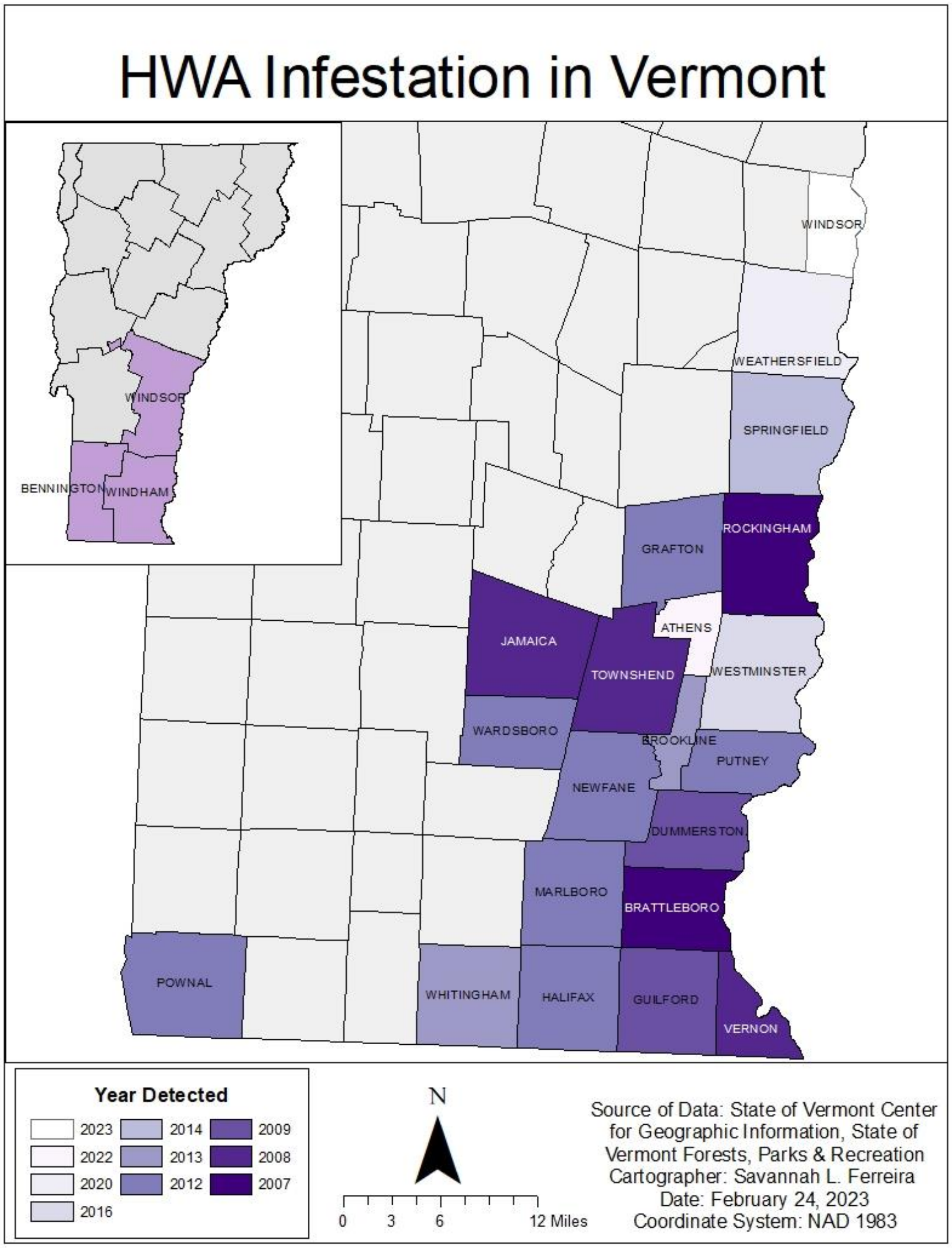

Figure 21: Map of hemlock woolly adelgid infestation by year in Vermont. 2007: HWA was detected in Brattleboro and Rockingham. 2008: HWA was detected in Jamaica, Townshend, and Vernon. 2009: HWA was detected in Dummerston and Guilford. 2012: HWA was detected in Grafton, Halifax, Marlboro, Newfane, Pownal, Putney, and Wardsboro. 2013: HWA was detected in Brookline and Whittingham. 2014: HWA was detected in Springfield. 2016: HWA was detected in Westminster. 2022: HWA was detected in Athens. 2023: HWA was detected in Windsor. HWA has been detected in Windham, Windsor and Bennington Counties. Source of data: State of Vermont Center for Geographic Information and Forests, Parks & Recreation. Cartographer: Savannah L. Ferreira. Date February 24, 2023. Coordinate System: NAD 1983.

Since 2007, annual surveys have been conducted in towns and counties without infestations as part of early detection efforts. Due to the possible long-range vectoring from birds and wind, selected towns are sometimes far from known infestations. In 2022, 27 surveys were conducted in Bennington, Charlotte, Duxbury, Fair Haven, Fairlee, Hartford, Hartland, Hubbardton, Jericho, Moretown, Poultney, Pownal, South Burlington, Springfield, Thetford, Wallingford, Weathersfield, and Windsor. These annual surveys provide presence or absence data for the selected stands.

Since 2012, long-term surveys have been conducted biannually at Atherton Meadows Wildlife Management Area, Roaring Brook Wildlife Management Area, Townshend State Park, Ft. Dummer State Park, and Black Mountain Natural Area. At each inspection, diameter, live crown ratio, crown density, crown transparency, and regeneration are observed and recorded to observe the impacts of an HWA infestation over time.

Winter mortality surveys have historically been conducted at four long-term monitoring sites in Jamacia, Townshend, Brattleboro, and Vernon. Research has shown that absolute minimum daily winter temperature, the number of subzero days, and negative degree days (sum of subzero days, multiplied by the respective minimum daily temperature) are all significant predictors of HWA winter mortality, with cold and long winters increasing winter mortality[45,46]. Due to warming climates, we are expected to observe a decrease in winter mortality, which may lead to an increase in new locations following years with mild winters. Newer research has reported that increasing temperatures, as well as dramatic fluctuations in temperatures, may cause increased summer mortality of the insect during the summer aestivation (dormancy) period[47]. In 2021, summer mortality surveys were conducted in the same aforementioned monitoring sites and will continue to be conducted annually. The combination of winter and summer mortality help kill HWA before they can reproduce and spread to new locations.

HWA is most efficiently spread by wind and birds, averaging an annual spread of 7.6-7.8 miles, but other insects and animals can serve as vectors including human-assisted transport[48,49]. Many states, including Vermont, have an HWA quarantine to slow the spread of HWA into new locations. State regulations place restrictions on hemlock nursery stock and seedlings. More

[45] Cheah, Carole A.S.-J. "Predicting Hemlock Woolly Adelgid Winter Mortality in Connecticut Forests by Climate Divisions." Northeastern Naturalist, vol. 24, no. sp7, 2017, pp. 90–118., https://doi.org/10.1656/045.024.s713.
[46] McAvoy, Thomas. J., et al. "Mortality and Recovery of Hemlock Woolly Adelgid (Adelges Tsugae) in Response to Winter Temperatures and Predictions for the Future." MDPI, Multidisciplinary Digital Publishing Institute, 12 Dec. 2017, https://www.mdpi.com/1999-4907/8/12/497.
[47] Elizabeth M. Sussky, Joseph S. Elkinton, Survival and Near Extinction of Hemlock Woolly Adelgid (Hemiptera: Adelgidae) During Summer Aestivation in a Hemlock Plantation, Environmental Entomology, Volume 44, Issue 1, February 2015, Pages 153–159, https://doi.org/10.1093/ee/nvu007
[48] Evans, Alexander M., and Timothy G. Gregoire. "A Geographically Variable Model of Hemlock Woolly Adelgid Spread." Biological Invasions, vol. 9, no. 4, 11 Nov. 2006, pp. 369–382., https://doi.org/10.1007/s10530-006-9039-z.
[49] Morin, Randall S.; Liebhold, Andrew M.; Gottschalk, Kurt W. 2009. Anisotropic spread of hemlock woolly adelgid in the eastern United States. Biological Invasions 11: 2341-2350.

information on this quarantine administered by the Vermont Agency of Agriculture, Food and Markets can be found online at: https://agriculture.vermont.gov/sites/agriculture/files/documents/PHARM/Plant_Pest/2021%20Revised%20Final%20Hemlock%20Woolly%20Adelgid%20Quarantine.pdf. For more information on HWA or to report a sighting, please visit https://vtinvasives.org/invasive/hemlock-woolly-adelgid.

Short needle conifer scale (*Dynaspidiotus (Nuculapis) tsugae*), a non-native scale insect from Japan, is an occasional, but serious pest of eastern hemlock in the eastern U.S.[21](Figure 22). This scale was introduced to the U.S. near New York state in the early 1900s where it causes yellowing needles and premature needle drop in infested hosts[40]. This pest has a sporadic and not well-documented presence in Vermont, being more commonly reported on spruce and fir.

Figure 22: (Left) Short needle conifer scale. (Right) Short needle conifer scale damage. Photo credits: John A. Davidson, Univ. Md, College Pk, Bugwood.org.

Spongy moth (*Lymantria dispar dispar*) is an invasive hardwood defoliator that was introduced from Europe and primarily feeds on deciduous trees in its larval stage, but during outbreaks, can defoliate hemlock (Figure 23). Spongy moth has been present in North America since 1869 and has spread across the eastern U.S. including Vermont[50]. Mortality is more likely to occur

[50] "Spongy Moth." Spongy Moth, USDA Animal and Plant Health Inspection Service, n.d., https://www.aphis.usda.gov/aphis/resources/pests-diseases/hungry-pests/the-threat/spongy-moth/hp-spongy-moth.

with consecutive years of severe defoliation and when other stressors such as HWA are present[51,52].

Figure 23: Spongy moth larvae and damage. Photo credit: Tim Tigner, Virginia Department of Forestry, Bugwood.org.

d. Non-native Fungal Stressors

Sirococcus tip blight (*Sirococcus tsugae*) is a canker pathogen that causes tip dieback in hemlock and true cedar (*Cedrus* spp.) trees (Figure 24). Infection occurs in young needles and shoots, causing cankers, distorted growth, shoot discoloration, and dieback[21,53,54]. Eastern strains of this pathogen have been shown to be less aggressive than western strains although symptoms and disease progression are similar. Sirococcus tip blight has not been detected on hemlocks in Vermont but was documented in Maine in 2006[55], although its origin and native host range is currently unknown. Similar to the previously mentioned forest pathogens, there are no

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[51]Lovett, G.M., Canham, C.D., Arthur, M.A., Weathers, K.C. and Fitzhugh, R.D., 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. *BioScience*, *56*(5), pp.395-405.

[52] Kinahan, I.G., Baranowski, A.K., Whitney, E.R., Savage, S.K., Rigsby, C.M., Shoemaker, E.E., Orians, C.M. and Preisser, E.L. (2020), Facilitation between invasive herbivores: hemlock woolly adelgid increases gypsy moth preference for and performance on eastern hemlock. Ecol Entomol, 45: 416-422. doi:10.1111/een.12829.

[53] Perez-Sierra, Ana, and Steve Hendry. “Sirococcus Blight (Sirococcus Tsugae).” Pest and Disease Resources, Forest Research, 14 Feb. 2022, https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/sirococcus/.

[54] Rossman, et al. Sirococcus Shoot Blight. Forest Health Protection, Forest Service, USDA, AK, 2021, https://www.fs.usda.gov/detailfull/r10/forest-grasslandhealth/?cid=FSEPRD535117&width=full.

[55] Ostrofsky, William. “New Tip Blight Recognized on Eastern Hemlocks.” Hemlock Tip Blight: Insect & Disease Fact Sheets: Maine Forest Service, 2021, https://www.maine.gov/dacf/mfs/forest_health/diseases/hemlock_tip_blight.htm.

effective control measures in forest stands, and this pathogen is not reported as causing high levels of stress or decline in infected stands[53,56].

Figure 24: Sirococcus tip blight fruiting bodies and damage. Photo credit: Bruce Watt, University of Maine, Bugwood.org.

B. Abiotic Stressors

Eastern hemlock has vulnerabilities to several natural disturbances and has only minimal biological capacity for adaptation (Figure 25)[57]. In addition to its vulnerability to insect pests, eastern hemlock is sensitive to drought, wind, and animal browsing. Eastern hemlocks are extremely susceptible to drought because of their shallow roots, especially in the seedling stage. During establishment, hemlock seedlings are very sensitive to soil drying caused by the combination of high temperature and low humidity conditions. First-year seedlings grow only about an inch in height and root depth, but by the second year, its root system usually reaches a soil depth less affected by soil surface drying[3]. Because hemlock has evergreen needles, it is susceptible to winter desiccation on warm, sunny, and windy days when frozen soils limit water uptake. Their shallow root system also makes them vulnerable to windthrow[3]. Abiotic stressors can interact with biotic stressors to elevate risk. For example, research has found that warmer mid-winter temperatures and steep slopes may increase the risk of decline from HWA for

[56] Munck, Isabel A., et al. "Impact of Sirococcus Shoot Blight (Sirococcus Tsugae) and Other Damaging Agents on Eastern Hemlock (Tsuga Canadensis) Regeneration in Northeastern USA." Forest Ecology and Management, vol. 429, Dec. 2018, pp. 449–456., https://doi.org/10.1016/j.foreco.2018.07.043.
[57] USDA Forest Service. Climate Change Tree Atlas: Eastern Hemlock. https://www.fs.fed.us/nrs/atlas/tree/261

hemlock trees[58]. Another example is that fungal pathogens, like armillaria, may be more likely to infest trees following root damage.

Eastern hemlock grows in moist environments and in association with hardwoods that rarely burn. Larger trees have some resistance to fire damage because of their thick bark; however, their shallow roots can be damaged. Because of their small size and thin bark, seedlings and saplings can be killed even by low-intensity fires. Although fires are usually damaging to hemlock, seed germination and subsequent seedling establishment may be promoted by low-intensity fires that expose partially decomposed litter but do not kill or top kill overstory trees that shade the forest floor and retain moisture[3].

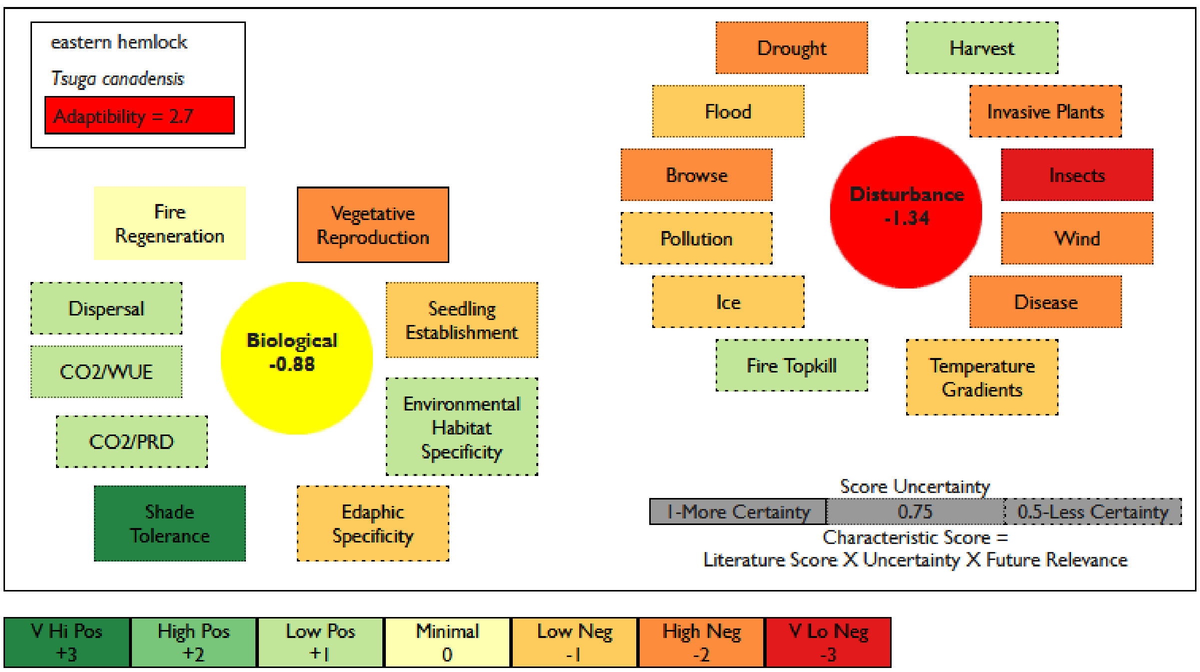

Figure 25: Adaptability rating for eastern hemlock based on vulnerability and response to disturbance and biological factors according to the Climate Change Tree Atlas. Eastern hemlock is rated low in adaptability to disturbances, mostly due to negative impacts by insects, animal browsing, drought, wind, disease, and competition from invasive plants. Eastern hemlock is also rated low in biological adaptability because of a lack of vegetative reproduction (i.e., stump or root sprouting). Among Vermont tree species, eastern hemlock is ranked the third lowest for adaptability.

[58] Livingston, W.H., Pontius, J., Costanza, K.K.L. et al. Using changes in basal area increments to map relative risk of HWA impacts on hemlock growth across the Northeastern U.S.A. Biol Invasions 19, 1577–1595 (2017). https://doi.org/10.1007/s10530-017-1380-x

a. Climate Change

Climate change is beginning to shift growing conditions for Vermont's trees, including eastern hemlock. Vermont has experienced nearly a 2°F increase in average annual mean temperature since 1900[59], and the freeze-free season (i.e., the functional growing season) has increased by over three weeks since 1960 (Table 2). The winter season has seen the most rapid change with winter temperatures increasing 2.5 times faster than annual temperatures over the last 60 years[59]. In addition to changes in temperature, Vermont has experienced a 21% increase in precipitation since 1990, with more heavy rainfall events. More winter precipitation is falling as rain rather than snow, and as a result, annual snowfall has declined in many parts of the state[59]. The combination of continued increases in summer temperature and decreases in winter snowpack may lead to a higher incidence of drought[60]. Climate change is also expected to result in more frequent and intense disturbance events, like wind and ice storms[60], although these events are difficult to project in the future. Vermont's climate is projected to warm faster than the global average, possibly rising another 5-9°F by 2100 depending on the emissions scenario[59] (Figure 26).

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[59] Clark, M., Crossett, C., 2021. Climate Change in Vermont. In Galford, G.L., Faulkner, J. et al. (Eds), The Vermont Climate Assessment 2021. Burlington, Vermont: Gund Institute for Environment at the University of Vermont.

[60] Dupigny-Giroux, L. (2001). Towards Characterizing and Planning for Drought in Vermont-Part I: A Climatological Perspective 1. JAWRA Journal of the American Water Resources Association, 37(3), 505–525. https://doi.org/10.1111/j.1752-1688.2001.tb05489.

Table 2. Observed temperature changes for Vermont from the 2021 Vermont Climate Assessment (Figure 1-2)[59] from Crossett and Clark 2021. Trend and total change in temperature variables are computed on annual averages using available data for each year for all stations.

	Trend (per decade)			**Total change**		
	1900–2020	**1960–2020**	**1991–2020**	**Since 1900**	**Since 1960**	**Since 1991**
Annual Avg. Temperature (°F)	+0.04	+0.26*	+0.52	+1.95	+1.47	+1.04
Winter (DJF)	+0.12	+0.66*	+0.54	+3.35	+3.08	+0.90
Spring (MAM)	−0.03	+0.10	+0.15	+0.15	+0.94	+0.31
Summer (JJA)	+0.03	+0.29*	+0.42	+1.45	+1.84	+0.92
Fall (SON)	−0.001	+0.23*	+0.75*	+1.59	+1.04	+1.80
Avg. Max. T. (°F)	−0.06	+0.18*	+0.51	+1.06	+1.04	+0.84
Avg. Min. T. (°F)	+0.15*	+0.47*	+0.70*	+2.79	+2.63	+1.33
Days with max. T. > 90°F	−0.01	+0.11	+0.48	+1.49	+1.19	+1.32
Days with min. T. > 70°F	+0.04*	+0.20*	+0.48*	+1.14	+1.51	+1.15
Days with max. T. < 0°F	−0.63*	−2.08*	−3.04	−10.81	−10.01	−3.97
Winter days w/ max. T. > 50°F	+0.12*	+0.31*	−0.04	+1.85	+1.82	−0.17

Key:

< -5	-5 – -2	-2 – -0.5	-0.5 – 0	0 – 0.5	0.5 – 2	2 – 5	> 5

Note: Trend values (°F/decade or days/decade) that are bolded and noted by an asterisk are statistically significant to 95% confidence. Total change since 1900 is the difference between the 1900–1909 and 2011–2020 averages, total change since 1960 is the difference between the 1960–1969 and 2011–2020 averages, and total change since 1991 is the difference between the 1991–2000 and 2011–2020 averages. There is no estimate of significance for the total change values. Cells in the table are color-coded based on their value using the key below.

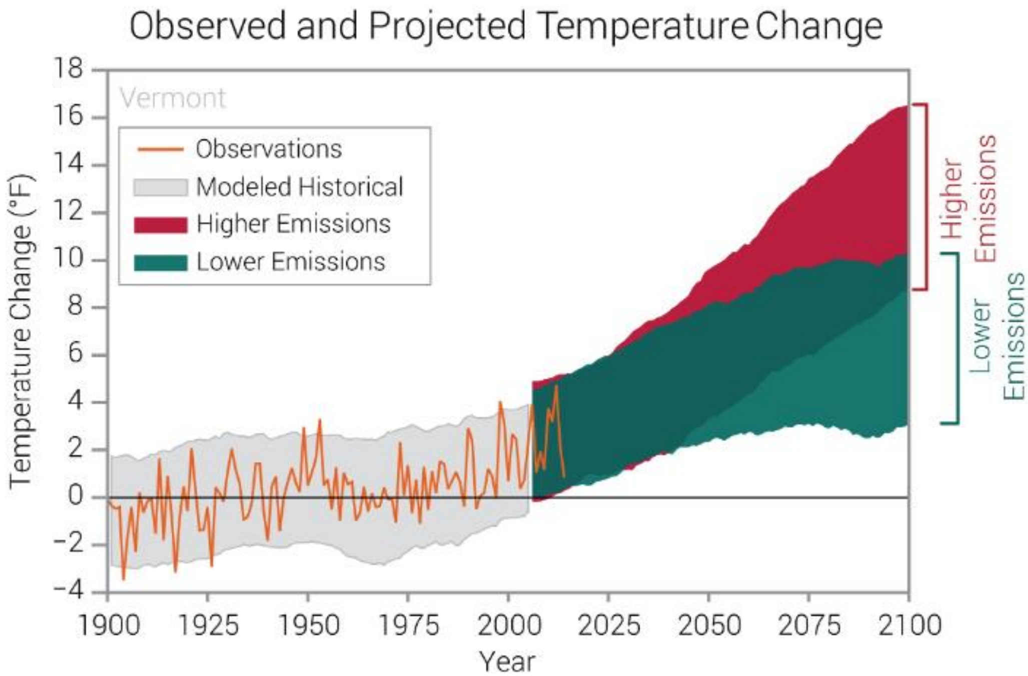

Figure 26. Observed and projected temperature increase for Vermont, 1900 to 2100[61] from Runkle et al., 2017, Fig. 1.

The cool microclimate created by the dense canopy and deep duff layer of hemlock forests may buffer mature stands from high temperature swings with continued climate change[3]. However, changing precipitation patterns may affect the health, productivity, and success of hemlock by creating novel conditions that result in stress to the species. Warmer air can hold more moisture, allowing higher summer temperatures to cause more evaporation from leaf and soil surfaces which could contribute to more frequent fires in the state. The Climate Change Tree Atlas projects only a small decrease in suitable habitat for eastern hemlock in Vermont under future warming scenarios[57]. However, the species has the third lowest adaptability rating among Vermont tree species and faces other stressors in addition to climate change. Climate change can act as a threat multiplier by creating more opportunities for insect and disease infestations or damaging natural disturbance events. One major concern is that warmer winters

[61] Runkle, J., Kunkel, K. E., Champion, S., & Dupigny-Giroux, L. (2017). Vermont State Climate Summary. NOAA Technical Report NESDIS 149-VT.
https://statesummaries.ncics.org/chapter/vt/#:~:text=Average%20annual%20precipitation%20has%20increased%20nearly%206%20inches%20since%20the%201960s.&text=Below%20average%20annual%20precipitation%20occurred,of%2042.4%20inches%20per%20yea

could lead to the range expansion of HWA, which historically has been limited by cold winter temperatures[45,46,62].

Implications of Hemlock Decline and Mortality

As hemlock trees gradually die from HWA the amount of light reaching the forest floor will increase[63, 64]. How many years a tree remains alive between infestation to death is not yet known for trees in Vermont. In southern New England, mortality typically occurs 4-12 years post infestation[63]. As mortality does occur, the loss of hemlock will result in changes to site characteristics and species composition that may have cascading effects to other ecosystem functions[65].

Canopy gaps created by hemlock mortality typically result in colonization by other species, many that vary ecologically from the hemlock they replace. For example, in southern New England where HWA has been confirmed since 1985, hemlock mortality has resulted in the establishment of fast-growing deciduous species like black birch (*Betula lenta*)[64]. Forest stands dominated by deciduous species do not provide the same dense, year-round shade and temperature moderating effects that hemlock stands do. In northern New England, hemlock is expected to be replaced by a mix of species, including eastern white pine (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), oak (*Quercus spp.*), and maple (*Acer spp.*)[65]. In addition, higher light availability on the forest floor may increase the abundance of herbaceous plants, like ferns and sedges, which can also change the characteristics of the site[66]. These conditions may promote the establishment and/or population expansion of invasive plants which can outcompete native plants, reduce biodiversity, and alter other ecosystem properties.

The transition of hemlock-dominated to hardwood-dominated stands is a concern, because of the changes to canopy conditions, leaf litter, and resulting soil properties. Due to the high concentration of acidic polyphenols in hemlock foliage, coupled with the microclimate created by the dense canopy, the litter layer covering the soil in a hemlock forest decomposes slower than in a forest dominated by northern hardwood species. This slow decomposition results in

[62] Dukes, J.S., Pontius, J., Orwig, D., Garnas, J.R., Rodgers, V.L., Brazee, N., Cooke, B., Theoharides, K.A., Stange, E.E., Harrington, R. and Ehrenfeld, J., 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict?. Canadian journal of forest research, 39(2), pp.231-248.
[63] Orwig, D.A. and D.B. Kittredge. 2005. Silviculture Options for Managing Hemlock Forests threatened by Hemlock Woolly Adelgid. pp. 7.
[64] Orwig, D.A. and Foster, D.R., 1998. Forest response to the introduced hemlock woolly adelgid in southern New England, USA. *Journal of the Torrey Botanical Society*, pp.60-73.
[65]Vose, J.M., Wear, D.N., Mayfield III, A.E. and Nelson, C.D., 2013. Hemlock woolly adelgid in the southern Appalachians: control strategies, ecological impacts, and potential management responses. *Forest Ecology and Management*, *291*, pp.209-219.
[66] Orwig, D.A., Foster, D.R. and Mausel, D.L., 2002. Landscape patterns of hemlock decline in New England due to the introduced hemlock woolly adelgid. Journal of Biogeography, 29(10-11), pp.1475-1487.

the characteristic deep soil organic layer found in hemlock stands, which retains nutrients and water, stores carbon, and resists erosion[67].

Hemlock morality will also result in high volumes of dead standing and downed wood. Deadwood provides multiple ecological functions, including soil protection and moisture retention, wildlife habitat, carbon storage, and nutrient cycling[68]. Although many Vermont forests lack sufficient deadwood due to past land use management, in some cases, high volumes of deadwood, especially when tree mortality occurs abruptly, could increase the risk of fire. Dead trees can also pose a hazard in recreational areas and to infrastructure.

A. Carbon

Hemlock forests are some of the most carbon-dense forests in Vermont. Compared to the forest-wide average of 82 metric tons (MT) of carbon per acre, hemlock forests store an average of 89 MT carbon per acre[69]. In particular, the soil in hemlock forests store more carbon than the average across all forest types (32 vs 30 MT carbon per acre)[69]. Continued threats to hemlock could pose a risk to the carbon that these forests have stored, and to their continued sequestration[70]. Studies have shown that when deciduous species replace hemlock stands, there can be a significant decrease in soil carbon[71]. Mortality of hemlock trees would result in a transfer of stored carbon from the live tree carbon pool to the deadwood pool. Because decomposition emits some of the stored carbon back to the atmosphere there will likely be a period of time between mortality of hemlock and regrowth of newly established trees when the stand is a net source of carbon (i.e., emitting more carbon that it sequesters); however, whether with hemlock or other species, the forest will sequester and store carbon, and in time return to being a carbon sink. The length of time between a forest stand being a net carbon source and a net carbon sink depends on the amount and speed of hemlock mortality, presence, age, vigor of other species on site, and post-mortality forest dynamics.

B. Wildlife Impacts

Hemlock decline will have a large and cascading effect on wildlife habitat and the landscape. Warming of streams due to the loss of thermal protection provided by the dense, evergreen

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[67] Finzi, A.C., Van Breemen, N. and Canham, C.D., 1998. Canopy tree–soil interactions within temperate forests: species effects on soil carbon and nitrogen. Ecological applications, 8(2), pp.440-446.

[68] Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R. and Lienkaemper, G.W., 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in ecological research, 15, pp.133-302.

[69] USFS Forest Inventory and Analysis EVALIDator. Version 2.0.3. [Accessed 11/18/2022].

[70] Albani, M., Moorcroft, P.R., Ellison, A.M., Orwig, D.A. and Foster, D.R., 2010. Predicting the impact of hemlock woolly adelgid on carbon dynamics of eastern United States forests. Canadian Journal of Forest Research, 40(1), pp.119-133.

[71] Daley, M.J., Phillips, N.G., Pettijohn, C. and Hadley, J.L., 2007. Water use by eastern hemlock (Tsuga canadensis) and black birch (Betula lenta): implications of effects of the hemlock woolly adelgid. Canadian Journal of Forest Research, 37(10), pp.2031-2040.

hemlock canopy, and the water/snow holding capacity will limit the critical habitat and refugia for cold-water species like native brook trout that rely on these headwater streams for survival. Warming of streams proximal to hemlock stands will result in further warming of streams down the watershed and into the lakes and ponds, potentially degrading the habitat and negatively impacting water quality.

Conversion of habitat types from a dense coniferous forest to deciduous hardwood forest has the potential to impact the species that rely on hemlock for one or more parts of their lifecycles. Bird species like the black-throated green warbler, and the blackburnian warbler are examples of species that would be directly impacted as these dense hemlock canopies are primarily used for breeding and nesting.

Along with this loss of habitat type, the threats of non-native invasive species altering the habitat where these hemlocks once were is of great concern. These non-native plants can outcompete the native species further impacting habitat degradation as these plants provide inferior habitat for the wildlife that use them for one or more parts of their lifecycle.

C. Water Impacts

Due to hemlock's affinity to grow near water, the deep shade its canopy provides, and the chemical properties of its foliage, hemlock decline and mortality has the potential to change stream microclimates and their associated living communities. A loss of hemlock can lead to a reduction in nutrient cycling, acidification of soil and stream water, and changes in stream hydrology[1,72,73].

New England-based research suggests that sites infested with HWA experienced greater stream flashiness, lower baseflow volumes and higher surface runoff during precipitation events compared to sites without HWA infestations[72]. These changes are likely due to a reduced canopy evapotranspiration from HWA needle drop and dieback and consequently a climbing water table[72,73]. In Massachusetts, evapotranspiration in HWA infested stands reduced evapotranspiration by 24-37% due to a 25-50% foliage loss, while increasing annual water yield of 15.6%[73]. Long-term effects on the hydrologic behavior of streams will be dependent on what species replace the dying hemlock.

Research from the southeastern U.S. suggests that if hemlock in riparian areas is replaced by hardwood species, it may have minimal impact on the long-term stream conditions and forest

[72] Singh, Kanishka, et al. "Simulation and Statistical Modelling Approaches to Investigate Hydrologic Regime Transformations Following Eastern Hemlock Decline." Hydrological Processes, vol. 34, no. 5, 22 Nov. 2019, pp. 1198–1212., https://doi.org/10.1002/hyp.13666.
[73]Kim, Jihyun, et al. "Increased Water Yield Due to the Hemlock Woolly Adelgid Infestation in New England." Geophysical Research Letters, vol. 44, no. 5, 15 Mar. 2017, pp. 2327–2335., https://doi.org/10.1002/2016gl072327.

hydrology, however the transition period between forest types may have larger impacts[74]. The transition period and associated impacts will vary based on the speed and extent of mortality, with larger impacts, like soil erosion observed with larger climatic events. The loss of overstory hemlock may increase sunlight reaching the stream and as a result, elevate water temperature during transition periods. The changes following the loss of hemlock may be minimized in sites with other evergreen plants because leaf litter chemistry and the provisioning of shade and temperature moderation mimic hemlock. This effect has been observed in locations where rhododendron (*Rhododendron* spp.) forms a dense understory. Although when looking at long-term data, changes in temperature and shade were not statistically significant in the southern U.S. study sites, changes to the macroinvertebrate population and distribution was[74,75]. These studies indicate that the loss of this keystone species can have a cascading effect on local water, with the greatest impacts being a change in short term stream hydrology and a shift in long term habitat and species populations alongside and within the water bodies.

Management Guidance and Current Efforts

Considering the threats that hemlock face from HWA, EHS and other pests, as well as the continued impacts from a changing climate, it is critical for landowners and managers to have a suite of strategies to conserve, protect, monitor, and manage hemlock into the future.

Several components of this effort are made possible through funding from the USDA Forest Service's HWA Initiative (e.g., suppression, training, and outreach, data reporting, technical support, surveying, biological control). This conservation guide was initiated in 2022 with guidance and framework from the Pennsylvania Department of Conservation and Natural Resources' Eastern Hemlock Conservation Plan. The focus of the guide is on providing information for rapidly developing and implementing management options to reduce the spread and impact of HWA and aid in hemlock conservation efforts.

The integration of pest management techniques is the most practical and sustainable method for conserving eastern hemlock in Vermont. HWA is currently the largest threat to eastern hemlock in North America. Although HWA is not present throughout hemlock's entire range in Vermont, infestations are expected to expand, particularly as the climate warms. Of the biotic stressors mentioned in this document, HWA and EHS should be managed in forested settings because both insects are non-native and invasive in Vermont. The other insects and pathogens

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[74] Roberts SW, Tankersley R Jr, Orvis KH. Assessing the potential impacts to riparian ecosystems resulting from hemlock mortality in Great Smoky Mountains National Park. Environ Manage. 2009 Aug;44(2):335-45. doi: 10.1007/s00267-009-9317-5. Epub 2009 Jun 4. PMID: 19495859; PMCID: PMC2717373.

[75] Che, Celestine, "ASSESSING THE INFLUENCE OF HEMLOCK MORTALITY ON STREAMS DUE TO HEMLOCK WOOLLY ADELGID INFESTATION" (2011). All Theses. 1215. https://tigerprints.clemson.edu/all_theses/1215

mentioned may be more of an issue in nursery settings compared to forests where natural predators, pathogens, and hemlock's own defenses can successfully keep populations and resulting damage low. In general, maintaining overall tree health and vigor can reduce impacts from opportunistic biotic stressors that attack weakened or stressed trees, as well as to provide stand resilience under a changing climate. Rarely do biotic stressors occur independently, and damage is often amplified by abiotic stressors.

A. Surveying and Monitoring of Hemlock Health and Decline

Continued surveying and monitoring of hemlock health and condition, as well as documentation of biotic and abiotic stressors, is critical since management efforts can become both more expensive and limited as the decline progresses. Similarly, reports from the public on possible occurrences of HWA, EHS or other decline symptoms are critical for statewide monitoring. Sightings can be submitted to Vermont Invasives Report It at https://vtinvasives.org/get-involved/report-it.

a. Vermont Department of Forests Parks and Recreation-Initiated Efforts

Select hemlock stands on State of Vermont public land continue to be monitored for HWA and EHS infestations. FPR is currently conducting four simultaneous programs for surveying, monitoring, and mapping hemlock and hemlock decline in Vermont.

I) Establishment and Monitoring of HWA Plots

In areas that have been historically infested with HWA, permanent plots are established and inspected annually. A map of all sites surveyed is presented in Figure 27. As of 2021, additional sites in non-infested sites including towns in Orange, Addison and Rutland counties were included and will also continue to be inspected annually. A list of counties and towns inspected by year can be found in FPR's Annual Forest Insect & Disease Conditions report that are archived at https://fpr.vermont.gov/forest/forest-health/current-forest-health-issues-and-updates.

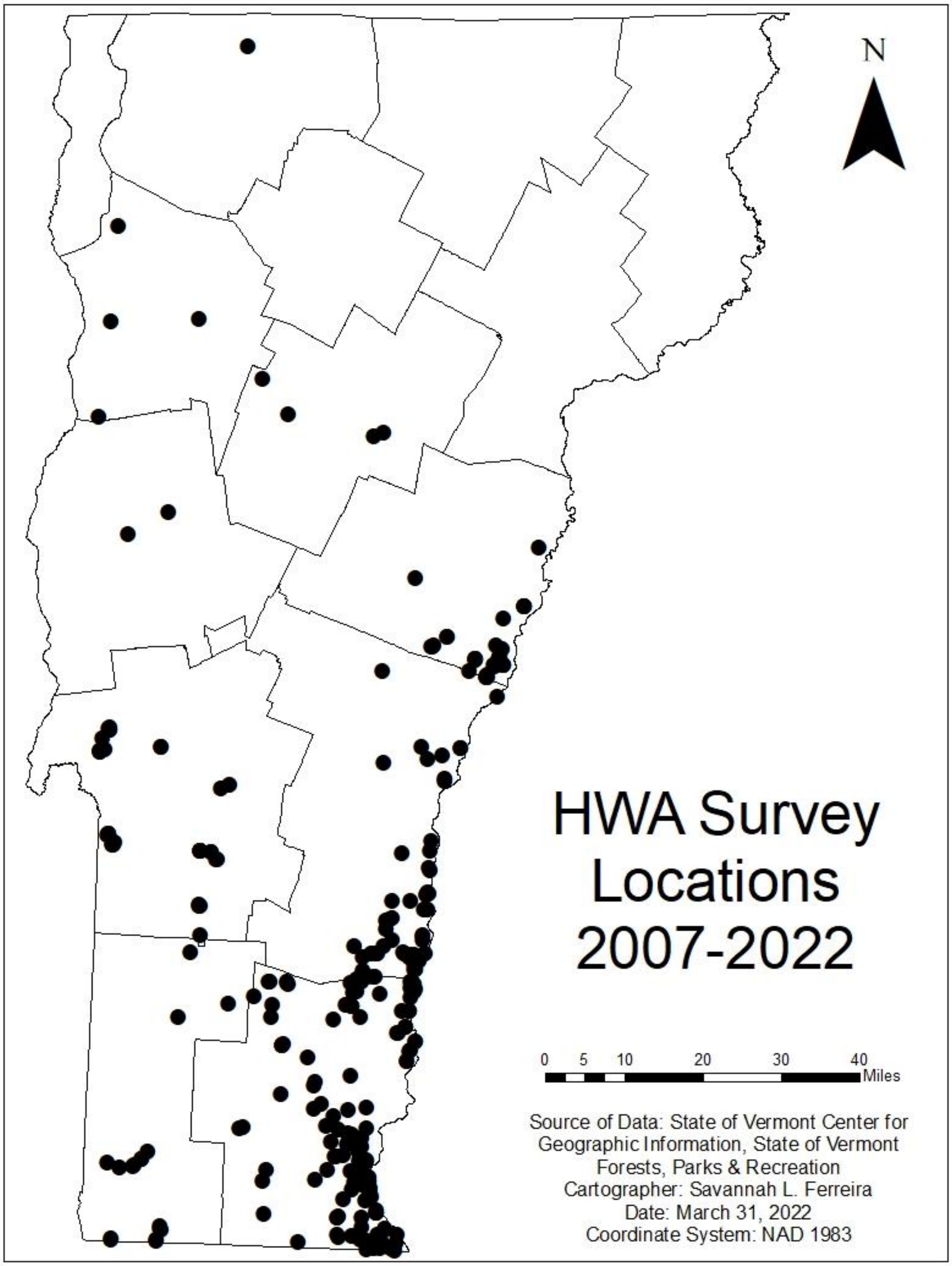

Figure 27. Map of hemlock woolly adelgid survey locations between 2007-2022. Source of data: State of Vermont Center for Geographic Information and Forests, Parks & Recreation. Cartographer: Savannah L Ferreira. Date: March 31, 2022. Coordinate System: NAD 1983.

II) Aerial Mapping of Hemlock Decline

Annually since 2019, hemlock decline related to HWA infestations have been mapped from the air through FPR's aerial detection surveys (ADS). Despite having been present in VT for over a decade, there has been minimal acreage of HWA-related decline observed in the state thus far (15 ac. in 2019, and 16 ac. in 2021; 0 ac. in 2022, and no ADS occurred in 2020 due to COVID-19 restrictions). Before 2022, drought was the most frequently observed decline symptom for hemlock.

III) HWA Mortality Assessment

Winter mortality studies are conducted annually to observe mortality of HWA sistens (first) generation during the winter and subsequent recovery of the progredien (second) generation. In the past, new infestations have been found in new locations following years with mild winters and HWA mortality less than 90%. Since 2010, mortality surveys have been conducted at infested sites in Vernon, Townshend, Jamaica, and Brattleboro. Results of these surveys are published in VT's annual Insect & Disease Conditions Report.

Summer mortality studies have recently been established to observe mortality of aestivating HWA sistens during the summer. Knowing sisten survival may help predict the density of HWA during the coming winter. In 2021, an initial summer mortality survey was conducted in Jamacia and in 2022, surveys were expanded to also include Vernon, Townshend, and Brattleboro. Summer mortality will also be observed annually, with results published in VT's annual Insect & Disease Conditions Report.

IV) Public-Initiated Surveys

FPR staff respond to reports submitted to VTInvasives.org as well as other public reports about declining hemlock in the state. Although less formal, causal agents of decline are catalogued and reported in VT's annual Insect & Disease Conditions Report.

b. Monitoring of Hemlock on Private Land

Landowners should assess the distribution, condition, and health of hemlock on their property, especially if the property resides within an infested county. These assessments should be conducted annually to monitor for change.

Live crown ratio, crown dieback, and foliar transparency assessments can be used as indicators of hemlock health using the United States Forest Service's publication, Crown-Condition Classification: A Guide to Data Collection and Analysis: https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs102.pdf (Figure 28). Although hemlock health and vigor does not predict susceptibility to HWA, trees with higher vigor may be able to survive longer once infested. Hemlocks with higher live crown ratios and those trees in the upper portion of the canopy (i.e., dominant and co-dominant crown positions) have been shown to better survive HWA infestation[64,76,77]. In general, there is a higher likelihood of hemlock dying within a year if crown dieback exceeds 30%, foliar transparency exceeds 35%, and/or live crown ratio is less than 30%[76,77].

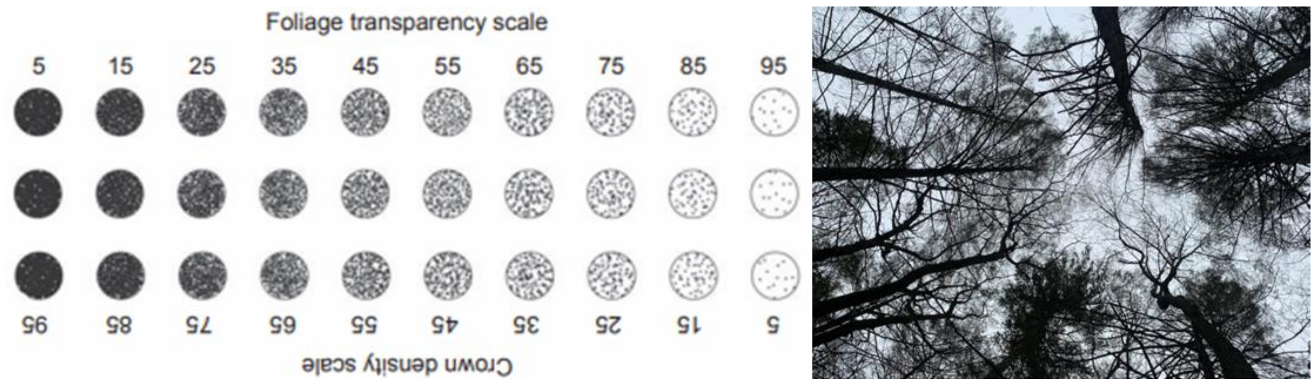

Figure 28: (Left) Foliage Transparency Card. Photo credit: USDA Crown-Condition Classification: A Guide to Data and Collection and Analysis. (Right) Thin canopy/high transparency hemlock stand. Photo credit: Jim Esden, State of Vermont Department of Forest, Parks & Recreation.

The causal agent of declining hemlock should be determined before any treatment or management occurs. If unknown, reach out to your county forester, consulting forester or FPR's forest protection team for a consultation. FPR Staff contact information can be found at: https://fpr.vermont.gov/forest/vermonts-forests/meet-team. For HWA and EHS, landowners should prioritize treatments if they have multiple stands/ properties, as wide-scale treatments are not usually economically feasible.

FPR and UVM Extension coordinate education and outreach regarding hemlock pests through presentations, Forest Pest First Detector trainings, and monthly and annual insect and disease reports. Due to the significant threat of HWA, surveys, and monitoring should be conducted in hemlock stands by landowners and land managers on an annual basis.

1. During the winter months (between November and May) survey for HWA. White woolly material produced by the adelgid is more apparent during this time, which makes it easier to detect low infestations.

[76] Fajvan, Mary Ann, and Petra Bohall Wood. "Maintenance of eastern hemlock forests: Factors associated with hemlock vulnerability to hemlock woolly adelgid." In In: Rentch, James S.; Schuler, Thomas M., eds. 2010. Proceedings from the conference on the ecology and management of high-elevation forests in the central and southern Appalachian Mountains; 2009 May 14-15; Slatyfork, WV. Gen. Tech. Rep. NRS-P-64. Newtown Square, PA: US Department of Agriculture, Forest Service, Northern Research Station: 31-38., pp. 31-38. 2010.
[77] Eschtruth, A.K., Evans, R.A. and Battles, J.J., 2013. Patterns and predictors of survival in Tsuga canadensis populations infested by the exotic pest Adelges tsugae: 20 years of monitoring. Forest Ecology and Management, 305, pp.195-203.

2. If surveying several acres of hemlock, make observations on 10-25 trees, with two to four branches per tree.
3. HWA suspects should be reported to VTInvasives.org with the following information included.
    a. Survey date
    b. Town and County
    c. Property Address
    d. GPS coordinates (latitude/longitude)
    e. Picture of infested branches
4. Once an HWA infestation has been confirmed by FPR, the proportion of infested branches of the tree needs to be visually estimated.
    a. Research reports that hemlock growth is hampered or halted when the proportion of infested branches reaches 45%[78].
    b. Start HWA control if the proportion of infested branches equals or exceeds 45%.

B. Prioritization of Hemlock Sites

Managers and landowners may want to identify those stands that should be prioritized for management and control efforts based on their condition, ecological and cultural importance, and other factors. It is also important to identify locations that may be refugia for hemlock in the future.

Table 3 was developed by Pennsylvania's Department of Conservation and Natural Resources to recommend treatment priority with a supplemental set of criteria to consider with recreational/aesthetic sites.

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[78] Ward, Jeffery S., et al. Eastern Hemlock Forests: Guidelines to Minimize the Impacts of Hemlock Woolly Adelgid. United States Department of Agriculture Forest Service, May 2004, https://portal.ct.gov/-/media/CAES/DOCUMENTS/Special_Features/MinimizingimpactsofHWApdf.pdf.

Table 3: Additional criteria to consider when identifying high priority sites[21].

Low Priority Sites	High Priority Sites	High Priority Sites (recreational/ aesthetic)
1. Areas that have already suffered heavy insect pest induced mortality or decline (~>70% defoliation)	1. Old growth present	2. Old growth present
2. Hemlock growing in shallow, excessively drained soils are highly susceptible to drought stress	2. Potential habitat of refuge for hemlock	2.Hemlock of historical or cultural significance
3. Hemlock growing on waterlogged soils	3. Hemlock providing habitat for species or resources of greatest conservation need	3. Areas known for or defined by their characteristic hemlocks
4. Sites not easily accessible for treatment	4.Hemlock shading exceptional value streams	4. Hemlock in high use areas such as hiking trails or campgrounds

a. Identify and Maintain Refugia

Refugia are areas that are buffered against dramatic environmental change because of landscape position, weather patterns, or site characteristics. Identifying and conserving these sites may allow for the continuation of small relict populations of hemlock. Landowners should identify likely areas of refuge for hemlock where they may be able to persist despite climate change. Refugia will be locations that are cooler and moister than other locations, like riparian areas, north facing slopes, seeps, lake edges, wetlands, and cold air drainages.

Certain hemlock natural communities that retain water year-round, such as Hemlock Seepage Forest, Hemlock-Balsam Fir-Black Ash Seepage Swamp, and Hemlock-Sphagnum Basin Swamp, may be locations of refugia. The Vermont Fish and Wildlife Department's Natural Heritage Inventory Program identifies and tracks state-significant examples of natural communities. Landowners who would like assistance with classification of hemlock natural communities, and landowners who may have rare hemlock stands should contact the Department of Fish and Wildlife or fill out and submit the Natural Community Survey Form (found in Appendix).

Landowners with old forests and/or state-significant natural communities that are enrolled in UVA may be eligible to have land enrolled as Ecologically Significant Treatment Areas (ESTAs).

For more information on natural communities in Vermont, visit:
https://vtfishandwildlife.com/conserve/conservation-planning/natural-community-inventory.

b. Focus Areas

Focus areas are hemlock stands that are closely monitored for HWA and prioritized for hemlock conservation based on site characteristics and land management goals. Managers and/or owners of multiple properties with hemlocks may want to prioritize some stands over others because of time and resource constraints. If so, use VT's Hemlock Prioritization Tool which can be found at: https://fpr.vermont.gov/document/vts-hemlock-prioritization-tool. This tool is an adaptation of New York State Hemlock Initiative's Regional Hemlock Prioritization Tool.

This tool helps managers rank multiple properties by using information on stand traits, aquatic ecosystem values, terrestrial ecosystem values, cultural values, and sustainability. To use, follow the directions included in the tool. First, assess each stand and provide details about their condition and characteristics in the table. The tool will help you rank and compare scores to aid in optimizing your management efforts.

I) Focus Areas on State Land

The State of Vermont is designating Jamacia State Park, Bomoseen State Park, and West Mountain Wildlife Management Area as Hemlock Conservation Focus Areas that will serve as a demonstration forests, applying various silviculture, chemical and biocontrol management techniques described in this guide. These state lands were chosen to be focus areas based on their score using the VT Hemlock Prioritization Tool and will be used to conduct field tours and to showcase different conservation strategies based on management goals for the public.

C. Control & Management Options

The primary tools used for controlling hemlock pests and pathogens include insecticides, biological control agents, and silvicultural practices. Each of these strategies may be better suited to different situations, for example management considerations for a few yard trees will differ from a forest stand. This document should only serve as a guide since appropriate integrated pest management (IPM) and best management practices (BMPs) are influenced by a wide spectrum of variables, including but not limited to, owner objectives, risk tolerance, resources available, and natural variation in the forest.

a. Chemical Tools

Chemical tools available to control insects and diseases that affect hemlock are divided into insecticides and fungicides. Always refer to the pesticide label for approved target pests, allowed sites, annual limits on material used, proper storage, application, and safety information. Pesticide users must follow all the instructions and directions for use as described in the products' pesticide labeling.

I) *Insecticides*

Insecticide treatments can maintain the health of infested high-value trees, but they do not provide long-term protection, and treatments will need to be repeated. In addition, the insecticides described below are not always applicable to every site and are not commonly used in a forested setting.

Horticultural oils and insecticidal soaps are topical contact pesticides that kill soft-bodied insects by suffocation. Although typically chosen as a non-toxic alternative to other pesticides, there is conflicting information in the scientific literature about the consistency of its control for numerous scale insects, including armored scales[21,79]. For EHS management, multiple foliar applications of horticultural oils can be applied between March and June, or between September and October[80]. These oils are only effective while the product is wet and once dry, provide no insecticidal action[81]. Since it dries quickly, it can be difficult to time applications accurately so that they will impact the vulnerable crawler stage[21]. To be effective, horticultural oils and insecticidal soaps need to cover the entire plant, making it an unsuitable control method in forested settings. To properly treat tall trees requires specialized, high-pressure equipment that is not as readily available to homeowners. Recommendations for landowner response for HWA in Vermont can be found at: https://fpr.vermont.gov/sites/fpr/files/Forest_and_Forestry/Forest_Health/Library/VTFPR_HWAinVT_RecommendationsforLandownerResponse.pdf.

Neonicotinoids are systemic insecticides used for both HWA and EHS infestations that include the active ingredients acetamiprid, clothianidin, dinotefuran, imidacloprid, and thiamethoxam. This class of insecticides is typically applied as foliage sprays, soil drenches, trunk injections, or basal trunk sprays and is transported through conducting vessels within the tree[21,82]. Systemic treatments are well suited for trees that are vigorous enough to have good water movement that will carry the insecticide throughout the tree. Systemic treatments have a time lag before control begins, but some may remain effective for several years. Neonicotinoids often have high persistence and high-water solubility, increasing the environmental risk, however, soil and

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79 Quesada, Carlos R., and Clifford S. Sadof. "Efficacy of Horticultural Oil and Insecticidal Soap against Selected Armored and Soft Scales." HortTechnology, vol. 27, no. 5, Oct. 2017, pp. 618–624., https://doi.org/10.21273/horttech03752-17.

80 Simisky, Tawny. "Elongate Hemlock Scale." Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, 26 Oct. 2016, https://ag.umass.edu/home-lawn-garden/fact-sheets/elongate-hemlock-scale#:~:text=Elongate%20hemlock%20scale%20is%20an,as%20well%20as%20forested%20areas.

81 Jackson, David R. "Integrated Approach to Hemlock Woolly Adelgid Mitigation." *Penn State Extension*, Pennsylvania State University, 24 Nov. 2021, https://extension.psu.edu/integrated-approach-to-hemlock-woolly-adelgid-mitigation.

82 Tsimisky. "Tree and Shrub Insecticide Active Ingredients: Alternatives to Neonicotinoids." Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, 19 Oct. 2018, https://ag.umass.edu/landscape/fact-sheets/tree-shrub-insecticide-active-ingredients-alternatives-to-neonicotinoids.

basal trunk treatments can reduce this risk in forested settings[21,83]. Neonicotinoid pesticides are very effective systemic insecticides but are restricted-use pesticides because special precautions must be taken to protect pollinators. Although hemlock pollen is not likely to be collected by these insects, if other flowering plants take up the pesticides, pollinators may be affected.

Imidacloprid is a commonly used neonicotinoid that is widely used for HWA control. Imidacloprid is highly toxic to insects and other invertebrates, and its residues can last for months to years in the soil. These insecticides are commonly applied as soil drenches, soil tablets, and stem injections. Soil applications can leach from the soil into groundwater and streams but will rapidly break down in water and sunlight[81,84]. Depending on the application method and product used, the label restrictions may include limiting the use of this active ingredient near water bodies and in rocky soils[81]. In known locations (outside of Vermont) where imidacloprid has been detected in streams near HWA treatment sites, concentrations were found to be below the benchmark chronic toxicity to aquatic invertebrates set by the U.S. Environmental Protection Agency[21,85]. Imidacloprid dosage should vary based on tree diameter, allowing for a more cost-effective and environmentally conscious treatment compared to broadband or uniform application[21].

This systemic insecticide is slow acting, often requiring three months to observe HWA mortality and at least two years following application to see the full treatment effects[86]. This insecticide can remain active within hemlocks for 4-6 years[81]. The slow movement within the plant makes this treatment ineffective for the treatment of scales, including EHS[21].

Optimized Insecticide Dosage: https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/7151/files/2016/10/Benton-Feb-2017-optimized-insecticide-doseage-1yncs02.pdf

Soil Drench Treatment Instructions for Imidacloprid: https://bpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/7151/files/2020/05/2020-HWA-Treatment-Instructions_drench.pdf

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[83] Simisky, Tawny. "Tree and Shrub Insecticide Active Ingredients: Alternatives to Neonicotinoids." Center for Agriculture, Food, and the Environment, UMass Extension Landscape, Nursery and Urban Forestry Program, 19 Oct. 2018, https://ag.umass.edu/landscape/fact-sheets/tree-shrub-insecticide-active-ingredients-alternatives-to-neonicotinoids.

[84] Gervais, J. A.; Luukinen, B.; Buhl, K.; Stone, D. 2010. Imidacloprid General Fact Sheet; National Pesticide Information Center, Oregon State University Extension Services. http://npic.orst.edu/factsheets/imidagen.html.

[85] Benton, E. P. and R. S. Cowles. 2016. Optimized Insecticide Dosage for Hemlock Woolly Adelgid Control in Hemlock Trees. The University of Georgia Warnell School of Forestry and Natural Resources, Tifton, GA, WSFNR-17-01.

[86] Cowles, R. S., M. E. Montgomery, and C. A. S. J. Cheah. 2006. Activity and residues of imidacloprid applied to soil and tree trunks to control hemlock woolly adelgid (Hemiptera: Adelgidae) in forests. Journal of Economic Entomology. 99: 1258.

Soil Injection Treatment Instructions for Imidacloprid: https://bpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/f/7151/files/2020/05/2020-HWA-Treatment-Instructions-2-Injection.pdf

Dinotefuran, another commonly used neonicotinoid, has been used for HWA and EHS control. This insecticide has higher water solubility, allowing for greater mobility and quicker action in trees than imidacloprid[21,81,87]. This insecticide is not as long-lasting as imidacloprid, only being effective one to two years after application but is quick to knock down HWA populations[21,81]. When used as a basal trunk spray for HWA control, this insecticide takes two to three weeks to transport throughout the tree and has an impact on HWA populations within four weeks. This insecticide has historically been used when trees present with thin crowns during an HWA infestation[21,81]. Dinotefuran is recommended for controlling EHS, however, applications alone do not provide long-lasting control in nursery settings[81,87]. This neonicotinoid should be first applied when EHS crawlers are active, usually between 360-700 growing degree days, then reapplied every three to four weeks in a twelve-week period if needed[87].

Some states allow and recommend tank-mixing of imidacloprid and dinotefuran for basal trunk applications to take advantage of the quick uptake of dinotefuran *and* the longer efficacy of imidacloprid. Dinotefuran rapidly reduces HWA populations on declining trees and may allow them to recover enough to take up the imidacloprid for long-term protection[81]. The Vermont Agency of Agriculture, Food and Markets allows both tank mixes and basal trunk spraying unless the label explicitly prohibits it. Pesticide users are strongly encouraged to check with the Vermont Agency of Agriculture, Food and Markets to ensure they are following the most up-to-date rules. Applicators must follow the pesticide label; ***the Label is the Law!***

Chemical treatments including either imidacloprid or dinotefuran in highly infested stands are recommended when being used for ecologically significant preservation efforts. The application method of these insecticides will vary based on site conditions, such as soil characteristics, accessibility, and proximity to sensitive resources.

II) Fungicides

Control of fungal pathogens is not often effective in forested settings due to the vector ability and often widespread inoculum presence within a stand. To reduce the damage caused by most fungal pathogens, managers should focus on increasing tree health and vigor while decreasing the favorable environment of the fungus. Managing un-even aged stands reduces canopy crowding, decreases moisture holding retention of the stand, increases sunlight infiltration, and reduces between-tree competition. This allows the stand to dry out, thus creating less favorable habitats for fungal growth and decreasing stress on trees. In non-forested stands, fungal foliar pathogens including rusts may be managed using fungicides[21,32,37].

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[87] Sidebottom, Jill. “Elongate Hemlock Scale: Christmas Tree Notes.” Elongate Hemlock Scale, NC State Extension, 9 Mar. 2019, https://content.ces.ncsu.edu/elongate-hemlock-scale.

Fungicides including triadimefon and manacozeb can be used to control hemlock twig rust in non-forested settings by being applied after bud break, then repeated twice at 7–14-day intervals [37.]

Triadimefon is an active ingredient of numerous systemic fungicides that are used to control powdery mildews, rusts, blights, and other fungal pests on a variety of agricultural crops and trees[88,89]. This active ingredient is slightly toxic to fish and has a low to moderate persistence in soils making it a moderately toxic compound. Its class, Triazoles, are typically applied as a wettable powder, emulsifiable concentrate, granular or paste forms. Systemic treatments are well suited for trees that are vigorous enough to have good water movement that will carry the fungicide throughout the tree[88].

Mancozeb is an active ingredient in several broad-spectrum, systemic fungicides that are used to control fungal diseases including blight, leaf spot, scab, needlecast, and rust[89,90].This active ingredient is water insoluble and binds tightly to soil, and can be highly toxic to freshwater fish[90].

b. Biological Control

Biological control (biocontrol) is the reduction of pest populations using natural enemies to suppress pest populations[91]. In forested settings, biological control agents are the most viable control method for HWA and EHS since they do not require additional treatments and may be more economically feasible. After the initial investment of releasing and getting a self-sustaining/reproducing population established, biocontrol agents will increase in population and reduce target pest populations. This can be a form of sustainable management because a perpetuating population will spread naturally and could serve as a field insectary, providing an ongoing supply of natural enemies that can be captured and redistributed to other areas of the state.

The goal of biological releases is not to eradicate HWA (which is considered impossible in the U.S. at this level of infestation) but to establish a self-sustaining population of biocontrol that will improve hemlock health and vigor by lessening the impact of HWA in infested areas in Vermont. Due to the lack of native predators of HWA in the eastern U.S., researchers had to search elsewhere for non-native predatory insects and parasitoids that could control HWA in

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[88] "Triadimefon." Pesticide Information Profiles, Extension Toxicology Network, 1996, http://extoxnet.orst.edu/pips/triadime.htm.
[89] https://extension.unh.edu/sites/default/files/migrated_unmanaged_files/Resource000986_Rep2330.pdf
[90]Mancozeb Fungicide. Minnesota Department of Agriculture, n.d., https://www.mda.state.mn.us/mancozeb-fungicide.
[91] "Biological Control Program." USDA APHIS | Biological Control Program, Animal and Plant Health Inspection Service U.S. DEPARTMENT OF AGRICULTURE, 2 June 2020, https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/biological-control-program

other parts of its range. The organisms described below are biocontrol agents recommended by the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) to combat HWA populations in North America. At the time of this guide's development, not all listed biocontrol agents have been included in the State of Vermont's biocontrol permit but are included to provide information if they are used in the future. At the time of this writing, *Laricobius nigrinus* is the only biocontrol agent for HWA being released in Vermont.

FPR will continue to release biocontrol agents on public land and maintain cooperative ties with government agencies and universities that are researching, collecting, and/or rearing them. Releases will continue until populations of a suitable biological control agent (or suite of agents) become self-sustaining and spread into new HWA-infested areas. There are biological control agents that are available to private landowners, but they are prohibitively expensive and have not been confirmed to control HWA in their new habitats.

Laricobius nigrinus is a predatory beetle that is native to the Pacific Northwest (PNW) region of the U.S. This beetle has a significant impact on the sisten (winter) generation of HWA, with its adults and larvae consuming HWA eggs, nymphs, and adults. It has a highly synchronized lifecycle with HWA, and in the PNW, has been reported as a significant enemy of HWA in both high and low densities[92,93]. *L. nigrinus* was approved for environmental release in the eastern U.S. in 2000 and was first released in Vermont in 2009 (Figure 29). Since then, it has been released at selected sites in Brattleboro, Vernon, Pownal, and Jamaica. Release sites are monitored annually with beat sheets for adults and cut foliage to monitor for larvae in the lab. Although a native insect with over 400,000 releases in the eastern U.S. it has a lower likelihood of establishment in areas that have a low minimum annual temperature[94,93]. FPR continues to release *L. nigrinus* annually, with 425 released in 2020 and 2,000 released in both 2021 and 2022. Recovery efforts are also conducted annually, although current methods have only recovered a single *L. nigrinus* from the Brattleboro biocontrol release site in 2010.

[92] Zilahi-Balogh, Gabriella, et al. "A Review of World-Wide Biological Control Efforts for the Family Adelgidae." Virginia Tech, Department of Entomology, 2002, https://www.academia.edu/72986154/A_Review_of_World_Wide_Biological_Control_Efforts_for_the_Family_Adelgidae. Accessed 18 Jan. 2023.

[93] Havill, Nathan P.; Salom, Scott; Davis, Gina; Fischer, Melissa; Mausel, David; Onken, Bradley. 2011. The introduction of Laricobius nigrinus as a biological control agent for the hemlock woolly adelgid: Is there a threat to the native congener, L rubidus. In: Onken, B.; Reardon, R. eds. Implementation and status of biological control of the hemlock woolly adelgid. FHTET-2011-04. Morgantown, WV: U.S. Department of Agriculture, Forest Service Forest Health Technology Enterprise Team: 212-221. Chapter 21.

[94] Farmer, Sarah. "Hemlock Woolly Adelgids & Their Predator Beetle, Laricobius Nigrinus." CompassLive, USDA Southern Research Station , 22 Sept. 2020, https://www.srs.fs.usda.gov/compass/2020/09/22/hemlock-woolly-adelgids-their-predator-beetle-laricobius-nigrinus/.

Figure 29. HWA biocontrol release in Jamaica State Park. (Left) Wood shavings containing *Laricobius nigrinus* adult beetles are clipped to hemlock twigs. (Right) Close-up of wood shavings containing adult beetles. Photo credits: Jim Esden, State of Vermont Department of Forests, Parks and Recreation.

Laricobius osakensis is a predatory beetle that is native to Japan and was approved for release in the U.S. in 2012. In its native range, this beetle is from the same region in Japan as the original HWA population that was introduced to the U.S.[95101]. This beetle has similar limitations with cold temperatures as *L. nigrinus* and has not yet been released in Vermont[96].

Laricobius rubidus is a predatory beetle that is native to eastern North America. Its primary host is pine bark adelgid (*Pineus strobi*) but also occasionally feeds on balsam woolly adelgid (*Adelges piceae)* and HWA. This beetle is not a significant control option for HWA but is mentioned in this document due to its documented presence in Vermont and its ability to interbreed with *L. nigrinus*[93]*.* In 2022, an *L. rubidus* was recovered from the Brattleboro *L. nigrinus* biocontrol release site. DNA analysis of the recovered *L. rubidus* indicated the presence of *L. nigrinus* DNA, indicating the released *L. nigrinus* survived long enough to mate.

Leucotaraxis is the genus of two fly species, *Leucotaraxis argenticollis,* and *Leucotaraxis piniperda* that are native to the Pacific Northwest (PNW) region of the U.S. and are currently being released for HWA biocontrol. Their family Chamemyiidae contains numerous predators of adelgids, aphids, coccids, and scales that are distributed across the globe. These two flies have a

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[95] Lamb, Ashley; Montgomery, Michael E.; Viera, Ligia Cota; Shiyake, Shigehiko; Salom, Scott. 2011. Laricobius osakensis, a hemlock wooly adelgid predator from Japan. In: Onken, B.; Reardon, R. eds. Implementation and status of biological control of the hemlock woolly adelgid. FHTET-2011-04. Morgantown, WV: U.S. Department of Agriculture, Forest Service Forest Health Technology Enterprise Team: 90-96. Chapter 7.

[96] Toland AA, Wantuch HA, Mullins DE, Kuhar TP, Salom SM. Seasonal Assessment of Supercooling Points for Two Introduced and One Native Laricobius spp. (Coleoptera: Derodontidae), Predators of Adelgidae. Insects. 2019 Nov 26;10(12):426. doi: 10.3390/insects10120426. PMID: 31779092; PMCID: PMC6955739.

highly synchronized life cycle to HWA and have two generations per year which overlap with the phenology of the HWA eggs stage[97]. In 2005, these files were observed and collected from HWA-infested branches in the PNW and underwent field and laboratory studies to determine their viability and safety as biological control agents for HWA in the eastern U.S.[98].

Sasajiscymnus tsugae is a predatory beetle native to Japan that was approved for release in the U.S. in 1995. Both the adult and larval stages of *S. tsugae* feed on all life stages of HWA. This beetle has a highly synchronized lifecycle with HWA, having two generations per year and the ability to feed on dormant HWA between generations[99,100]. Since the first field release in Connecticut in 1995, over one million *S. tsugae* have been released in the eastern U.S.[99]. Although this biological control agent was released broadly, there have been considerable discrepancies in field recovery success and HWA impact[101].

Unlike HWA predators, EHS has native and non-native biocontrol agents that help keep down populations. At the time of this guide's development, none of the following biocontrol agents have been included in the State of Vermont's biocontrol permit but are included to provide information if they are approved for future use.

Conoideocrella luteorostrata is an entomopathogenic fungus that infects armored scales and whiteflies has been reported to infect EHS in Asia and the U.S. Although not currently registered as a biocontrol agent, populations of this fungus have been reported in several eastern states. This fungus is currently being researched to fill in knowledge gaps regarding environmental limitations and host specificity but has proven pathogenicity to EHS[102].

Cybocephalus nipponicus is a predatory beetle that is native to Asia that has become established in the eastern U.S. This beetle was approved for release in 1998 to control cycad aulacaspis scale *(Aulacaspic yasumatsui*) in Florida, and euonymous scale (*Unaspis euonymi*) in

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[97] Ross, Darrell W., et al. "Chamaemyiid Predators of the Hemlock Woolly Adelgid from the Pacific Northwest." Implementation and Status of Biological Control of the Hemlock Woolly Adelgid, Jan. 2011, pp. 97–106.
[98] Dietschler, Nicholas J, et al. "Biological Control of Hemlock Woolly Adelgid: Implications of Adult Emergence Patterns of Two Leucopis Spp. (Diptera: Chamaemyiidae) and Laricobius Nigrinus (Coleoptera: Derodontidae) Larval Drop." Environmental Entomology, vol. 50, no. 4, 4 May 2021, pp. 803–813., https://doi.org/10.1093/ee/nvab037.
[99] Cheah, Carole. "Sasajiscymnus Tsugae." HWA/Sasajiscymnus Tsugae, Bugwoodwiki, Nov. 2010, https://wiki.bugwood.org/Archive:HWA/Sasajiscymnus_tsugae.
[100] Cheah, Carole, and Mark McClure. "Sasajiscymnus (Formerly Pseudoscymnus) Tsugae (Coleoptera: Coccinellidae)." Biological Control, Cornell University College of Agriculture and Life Sciences, n.d., https://biocontrol.entomology.cornell.edu/predators/sasajiscymnus.php.
[101] Lamb, Ashley; Montgomery, Michael E.; Viera, Ligia Cota; Shiyake, Shigehiko; Salom, Scott. 2011. Laricobius osakensis, a hemlock wooly adelgid predator from Japan. In: Onken, B.; Reardon, R. eds. Implementation and status of biological control of the hemlock woolly adelgid. FHTET-2011-04. Morgantown, WV: U.S. Department of Agriculture, Forest Service Forest Health Technology Enterprise Team: 90-96. Chapter 7.
[102] Barrett, Hana, et al. "Conoideocrella Luteorostrata(Hypocreales: Clavicipitaceae), a Potential Biocontrol Fungus for Elongate Hemlock Scale in United States Christmas Tree Production Areas." 18 Oct. 2022, https://doi.org/10.1101/2022.10.18.512709.

the northeast[103]. Although not originally released to be a predator of EHS, this beetle feeds on a variety of scale insects.

Encarsia citrina is a native predatory wasp that has a cosmopolitan distribution and a broad host range. Although this wasp will feed on EHS, it has poor host-parasitoid synchrony with it, which leads to the wasp seeking out other food options[104].

There are several native generalist predators including brown lacewings (Hemerobiidae), dusty wings (Coniopterygidae), and lady beetles (Coccinellidae) that are generalist predators that will consume EHS, but since they have a broad host range, do not significantly decrease EHS populations.

c. Silvicultural Tools

I) Street and Yard Trees

Several effective measures can be used to control HWA and EHS for ornamental yard trees. Some can be carried out by homeowners, and some must be applied by certified pesticide applicators. Reducing abiotic stresses on hemlock can increase overall tree health and vigor, reducing the likelihood of biotic infections and infestations from becoming established. This can include planting disease and insect-resistant hemlock varieties, removing disease inoculum when able, and working to slow the spread of insects and diseases into unaffected stands[37,34,87]. Hemlocks that are infested with HWA and/or EHS should not be fertilized with nitrogen, as this will also boost adelgid and scale health and populations.

Homeowners can reduce the number of adelgids and scale and, possibly the amount of damage in a tree, by pruning infested branches. Mechanical cutting should be done between August and February when adelgids are less likely to be spread. Wherever possible, leave debris from infested hemlocks onsite. Chipping does not eliminate HWA or EHS, but surviving insects do not live for a long time. Cut branches can be burned if safe to do so, but only with a burn permit from the Town Fire Warden. Infested hemlock debris can be safely moved after one of the treatments below.

- Debris may be disposed of in plastic bags at the local landfill. To comply with state law, do not move debris with live HWA.

[103] Cave, R. D., A. Moore, and M. Wright. 2022. Biological control of the cycad aulacaspis scale, Aulacaspis yasumatsui, pp. 189–203. In: Van Driesche, R. G., R. L. Winston, T. M. Perring, and V. M. Lopez (eds.). Contributions of Classical Biological Control to the U.S. Food Security, Forestry, and Biodiversity. FHAAST-2019-05. USDA Forest Service, Morgantown, West Virginia, USA. https://bugwoodcloud.org/resource/files/23194.pdf

[104] Abell, Kristopher, J., Van Driesche, Roy, G., "The use of Cohorts to Evaluate the Impact of Encarsia citrina (Hymenoptera: Aphelinidae) on Fiorinia externa (Hemiptera: Diaspididae) in the Eastern United States," Florida Entomologist, 94(4), 902-908, (1 December 2011)

- Drench cut stems and branches with soapy water (1/4 cup of liquid soap/1 gal water) to suffocate the insects.
- Cover debris for three weeks with a clear plastic tarp. This method is only effective if daytime temperatures are above 50°F.

Other best management practices include cleaning off vehicles, clothing, and other tools after visiting properties with infested hemlocks and removing residential birdfeeders between April and August to reduce bird vectors.

II) Forests

In the forested setting, there are a range of management options that depend on the status of the hemlock, the site conditions and sensitivities, and the landowner's objectives. First assess whether the stand is declining, and if so, what are the causal agents. Understanding the current condition and stressors of the stand will help guide selection of the management options described below. This guide briefly discusses both passive and active silvicultural techniques for hemlock stands, however more long-term monitoring of surviving hemlock stands is needed to refine management recommendations.

In considering forest management, anticipate that climate change will impact hemlock trees and many of the stressors they face. Certain weather events may make stressors more or less impactful. For example, anticipate increased hemlock mortality in HWA infested stands following a mild winter or a dry summer. Consider managing hemlock stands for increased resilience to climate change as well as identify stands that may be possible future climate refugia, such as hemlock natural communities with wet soils (hemlock swamps, north-facing slopes, stream sides and wetlands). To manage for increased resilience, assess hemlock health and potential vulnerabilities before making any management decisions. Vulnerabilities may include proximity to known infestations of HWA or EHS, likelihood of extreme weather events, extent and type of invasive plant infestations, severity of wildlife browse damage, sites with dry or thin soils, and degradation from past management[41,105]. For long-term success, make a plan to lessen the threat of these vulnerabilities. Consider diversifying the species composition by releasing or promoting other species already established on site[105], particularly other conifers that can maintain the softwood component of the stand if an infestation of HWA does occur[105]. Where this is not feasible, enrichment planting of other conifer species can be explored. For a list of possible replacement species and their characteristics refer to Table 1 in the Appendix.

a. Silvicultural Recommendations in Non-HWA-Infested Hemlock Stands

Where HWA does not yet occur, there is no need to alter current forest management in anticipation of the insect, however one should anticipate that HWA could affect the stand in

[105] Kosiba AM. 2022. 12 Steps for Climate Resilience: Managing your Forest with Climate Change in Mind. Available at https://www.vermontwoodlands.org/wp-content/uploads/2023/01/Climate_12Steps_Flyer_logos-1-1.pdf

the future. Healthy hemlocks, growing on deep soils with good water availability, are more likely to better withstand HWA and the stresses of a changing climate compared to low-vigor trees on moisture-limited sites[41]. In non-infested stands, strive to maintain the hemlock component, release young hemlock, and avoid significant disturbances that may stress trees[63]. Pre-emptive salvage logging in non-HWA infested stands is not recommended because cutting could remove HWA-tolerant genetics[41,63]. In general, hemlock is sensitive to soil drying, so care should be taken to not thin stands too heavily. As with any forest management activities, acceptable management practices (AMPs) should be followed to protect soil and water during harvest operations. Hemlock's affinity to grow close to water and importance on water quality warrants even more care to limit unintended impacts. State of Vermont AMPs and additional resources can be found at: https://fpr.vermont.gov/forest/managing-your-woodlands/acceptable-management-practices.

b. The Importance of Promoting Regeneration During Active Management

A significant bottleneck in the continuation of hemlock stands is the establishment of multiple cohorts of hemlock due in part to the silvics of the species, and significant reductions in regeneration success caused by heavy deer browse and competition from other plants (e.g., hay scented fern (*Dennstaedtia punctilobula*)). Regardless of HWA status, active forest management should aim to promote hemlock regeneration. The high shade tolerance of hemlock means that advance regeneration can be established and released under a high-density overstory (i.e., 70-80% crown cover) using single-tree or group selection or a shelterwood system (irregular or regular)[106]. A 2- or 3-cut shelterwood system works well because it does not increase moisture stress on germinating seeds and developing seedlings[3].

An essential component for natural regeneration is to retain large hemlock trees as a source of locally adapted pollen and seed. Hemlock will not reach reproductive maturity until at least 15 years old, but even trees over 400 years old can be excellent seed producers[3]. Although eastern hemlock is a frequent cone producer, with good cone crops occurring in more than 60% of the years, the viability of the seed is usually low (less than 25%) and cones may only contain a few viable seeds[3]. Management activities should consider these seed viability factors by timing activities with good cone years, particularly if advanced hemlock regeneration is not already present on-site.

Successful seed germination and seedling establishment often requires site preparation to create favorable soil conditions. These conditions can be achieved by scarification (i.e., mixing organic and mineral soil layers) or by prescribed fire that exposes partially decomposed organic

[106] Kenefic, Laura S., John M. Kabrick, Benjamin O. Knapp, Patricia Raymond, Kenneth L. Clark, Anthony W. D'Amato, Christel C. Kern, Lance A. Vickers, Daniel C. Dey, and Nicole S. Rogers. "Mixedwood silviculture in North America: the science and art of managing for complex, multi-species temperate forests." Canadian Journal of Forest Research 51, no. 7 (2021): 921-934.

soil layers[3]. Without these soil conditions present, hemlock regeneration may be restricted to rotten logs and stumps, which tend to be warmer and moister compared to forest floor.

Hemlock is considered fully established when they are three to five feet tall; at this time, they can be released from overhead competition with less risk of mortality[3]. During seedling establishment and recruitment, deer populations should be monitored because browsing can severely limit successful recruitment. In stands with high populations and dense hemlock, deer barriers may be needed to deter feeding[107].

Figure 30: Hemlock seedling growing out of a previously cut hemlock stump. Photo credit: Alexandra Kosiba, the University of Vermont Extension.

c. Silvicultural Recommendations in Declining Hemlock Stands

In HWA-infested stands there are multiple silvicultural options depending on landowner goals, severity of infestation, site characteristics, co-occurring species on site, and other vulnerabilities (i.e., disturbances, climate, invasive plants). Due to the rarity of hemlock wetlands and the sensitivity of their soils, passive management is a god fit for hemlock wetlands including Hemlock Seepage Forest, Hemlock-Balsam Fir-Black Ash Seepage Swamp, and Hemlock-Sphagnum Basin Swamp. A passive approach may also be suitable for sites that have sufficient natural regeneration to replace declining overstory trees. A passive approach should include frequent monitoring and evaluation of site conditions and impacts for hemlock decline and mortality.

[107] Long, Z.T., Carson, W.P. and Peterson, C.J., 1998. Can disturbance create refugia from herbivores: an example with hemlock regeneration on treefall mounds. Journal of the Torrey Botanical Society, pp.165-168.

Depending on the site and stand characteristics, an active approach may facilitate hemlock regeneration or accelerate the transitioning of the stand to a more diverse, non-hemlock composition. Due to the importance of species diversity and the risk of hemlock mortality in declining stands, the decision to remove species other than hemlock should be done only when necessary. When actively managing HWA-infested hemlock stands, harvests and removals should be planned between August and February, when HWA is the least mobile[108].

To identify target trees for removal, live crown ratio can be a useful metric because it is generally easier to visualize and estimate compared to the other crown health metrics (see United States Forest Service's publication, Crown-Condition Classification: A Guide to Data Collection and Analysis: https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs102.pdf). Trees with live crown ratios <30% could be targeted for removal because they will likely decline[76,77]. If the primary objective is to remove infested hazard trees cutting should occur when the trees have no less than 50% of their live crown ratio. As these trees decline, they will become more hazardous to remove[63,76,77]. Regardless of management approach, monitoring of outcomes is essential.

For hemlock stands in heavy decline from HWA, and where no chemical or biological controls are planned, it is important to initiate regeneration as quickly as possible to maintain the forest's ecosystem services, like erosion control, water cycling, and shading[76,77].For sites where hemlock regeneration is lacking, establishing another conifer species with similar functional niche may better mimic the microclimate effects of hemlock compared to a hardwood species; even so, a different conifer species will not replace all ecosystem functions that hemlock provides. It is more cost-effective to manage for species that are already present on-site, but when it is not feasible, landowners and managers may want to consider supplementing natural regeneration with underplanting. Attention should be made to promote conditions that favor the establishment of desired and appropriately adapted tree species.

If underplanting or promoting an alternative tree species to replace hemlock, choose tree species that will be more suitable for the site and anticipated climate conditions. The shade-tolerance of the selected underplanted species is important to consider depending on the level of decline in the overstory trees. For a list of possible replacement species and their characteristics, refer to Table 1 in the Appendix. Although the location information may not be available from tree nurseries that this time, it is advised to select planting stock that were grown from regionally local seed sources to reduce unintended genetic consequences. Considering the threat of climate change, selecting a seed source within the region that comes from a location slightly warmer (i.e., to the south) of the planting location may give better outcomes, but at this time, doing so is likely not feasible.

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[108] Hemlock Wolly Adelgid *Adelges tsugae*. Insect and Disease Laboratory: Maine Forest Service: Maine DACF, June 2010, https://www.maine.gov/dacf/mfs/forest_health/documents/hemlock_woolly_adelgid.pdf.

D. Restoration

a. Preservation of Hemlock Genetic Material

The Vermont Agency of Natural Resources Forests, Parks and Recreation has been preserving hemlock genetic material since 2009. This effort is in collaboration with Camcore, a non-profit organization specializing in tree improvement efforts including breeding and ex-situ (off-site: i.e., laboratory, collection, botanical garden) conservation plantings. The hemlock seeds collected from Vermont have been planted outside of known HWA infestations, and in the future, if HWA populations have been reasonably controlled, these genetics can be reintroduced to our state.

b. Funding for Management and Treatment of Hemlock on Private Lands

United States Department of Agriculture is one of the primary sources for conservation funding in Vermont. Through Farm Bill programs, forest landowners can take advantage of cost share funding to help address resource concerns on their property. Programs like Environmental Quality Incentive Program (https://www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives) and Conservation Stewardship Program (https://www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program), landowners can work to address issues on their individual properties ranging from water quality, invasive species, poor plant health/vigor, and low-quality wildlife habitat. Landowners interested in learning more about United States Department of Agriculture programs should contact the local service center in their county or their FPR County Forester. To find your county forester, visit: https://fpr.vermont.gov/forest/list-vermont-county-foresters.

Next Steps

This management guide offers comprehensive, sustainable, and strategic landscape-wide information to achieve the goal of maintaining hemlock as a component of Vermont's forests despite numerous abiotic and biotic stressors. The information is meant to be broad and applicable to both public and private lands of any size. Because hemlock is not bound by property boundaries and collaboration will be needed for successful conservation, this resource aims to bridge the knowledge gaps and encourage communication between non-state and state entities. This guide is intended to serve as a starting point to reassess current management operations, implement appropriate actions to conserve hemlock in Vermont, and set the foundation for the development of a strategic conservation plan for the species.

Appendix

NATURAL COMMUNITY SURVEY FORM

Vermont Natural Heritage Inventory (VNHI)

Vermont Fish & Wildlife Department

Revised: August 20, 2021

Contact Bob Zaino with questions about natural communities or this form: 802-279-5320 or robert.zaino@vermont.gov

Natural Community Type: Click here to enter text.
Natural Community Variant Name (if applicable): Click here to enter text.
Association Name (NHI office only): Click here to enter text.

Is this an update of an existing NHI record? (NHI office only) Yes ☐ No ☐
Site Name: Click here to enter text.

Site Location Road Address: Click here to enter text.
Town: Click here to enter text.

Surveyor(s): Click here to enter text.
Mailing Address: Click here to enter text.
Phone: Click here to enter text.
E-mail: Click here to enter text.

Survey Date(s): Click here to enter text.

Owner(s) of Natural Community: Name(s): Click here to enter text.
Address: Click here to enter text.
Phone: Click here to enter text.
E-mail: Click here to enter text.

GENERAL DESCRIPTION OF THE SITE

Briefly describe the natural and man-made features of the site and setting in which the natural community occurs, including topography, size of the contiguous forested area, other natural community types present, surface waters and drainage patterns, and land use history and land management.

Click here to enter text.

Natural Community Information

Concisely describe the natural community, including canopy cover, dominant species, the physical setting, evidence of human and natural disturbance, forest community age, woody debris abundance, and presence of invasive species.

Click here to enter text.

Elevation (feet): minimum: Click here to enter text. maximum: Click here to enter text.

Slope (degrees): Click here to enter text.

Aspect (degrees or cardinal direction): Click here to enter text.

Bedrock geologic type (2012 VT bedrock geology map): Click here to enter text.

Soil type (Natural Resources Conservation Service) or description: Click here to enter text.

Vegetation Description: To be applied to a representative area of the community large enough to capture most species.

Total Canopy Cover: Click here to enter text.% Total Shrub Cover: Click here to enter text.%

	Trees			Shrubs				
	T1Emergent	T2 Canopy	T3 Subcanopy	S1 Tall (> 4 ft.)	S2 Short (<4 ft.)	H Herbaceous	N Nonvascular	V Vine
Height (ft.)								
% Cover								

Dominant Species and their cover for each stratum (T1- emergent, T2-main canopy, T3-subcanopy, S1-tall shrub, S2-short shrub, H-herb, N-nonvascular, V-vine). Give average DBH (inches) for trees. For each species estimate actual percent cover or use one of the cover class categories below. Use the species list table below or attach a separate sheet.

Stratum	Species	DBH	Cover	Stratum	Species	Cover

Cover Classes	
r	< 1% rare
+	< 1% occs
1	1-5 %
2	6-25 %
3	26-50 %
4	51-75 %
5	76-100 %

OR

Cover Classes	
D	Dominant; cover > 50%
C	Common; 6 to 50 % or numerous individuals
O	Occasional; 1 to 5% or scattered individuals
R	Rare; < 1% or one to a few individuals

Provide ages for representative trees in the community (optional).

Tree Species	DBH	Age

Comments about the natural community that do not fit in another field:

Click here to enter text.

NATURAL COMMUNITY MAPPING

Attach GIS shapefiles (preferred) or digital or paper map of the natural community boundaries with labeled polygons

Estimate percent of mapped polygon occupied by the natural community: >95%☐; 80-95%☐; 20-80%☐; 0-20%☐

Explain if <95%, explain what other communities are present: Click here to enter text.

Indicate type and scale of Base Map used to map the natural community: Click here to enter text.

Confidence in the Extent of the Natural Community as Mapped (check one)

☐ Confident that the full extent is known and mapped:

☐ Full extent is not known:

☐ Uncertain if full extent is known:

Comments: (If the natural community extends off the subject property, explain, and estimate total area of community.)

Click here to enter text.

COMMUNITY OCCURRENCE RANKING: a range of ranks may be used (such as AB)

Using **VT NHI ranking specifications** (if available)*: OR Using **Generic ranking specifications** (provided below):

	Rank (A-D)	**Comments**
Current Condition		Click here to enter text.
Landscape Context		Click here to enter text.
Size (acres)		Community size and how determined: Click here to enter text.
Overall Rank		Click here to enter text.

* Available for some natural communities from Eric Sorenson (robert.zaino@vermont.gov) or 802-279-5320.

Generic ranking specifications

Use the following guidelines to fill in the grid above if VT NHI ranking specifications are not yet available for the community type.

Current Condition

A: mature example of the community type (forests with trees generally >150 years old); natural processes intact; no exotics
B: some minor alteration of vegetation structure and composition, such as by selective logging; minor alterations in ecological processes; exotics species present in low abundance
C: significant alteration of vegetation structure and composition, such as by heavy logging; alteration of ecological processes are significant, but community recovery/restoration is likely; exotic species are abundant and control will take significant effort

D: ecological processes significantly altered to the point where vegetation composition and structure are very different from A-ranked condition and restoration/recovery is unlikely; exotic species are abundant or control will be difficult

Landscape Context

A: highly connected; area around EO (>1,000acres) is largely intact natural vegetation, with species interactions and natural processes occurring across communities; surrounding matrix forest meets at least B specifications for Condition.
B: moderately connected; area around EO (>1,000acres) is moderately intact natural vegetation, with species interactions and some natural processes occurring across many communities, although temporary disturbances such as logging have reduced condition of the landscape; surrounding matrix forest meets at least C specifications for Condition

C: moderately fragmented; area around EO is largely a combination of cultural and natural vegetation with barriers to species interactions and natural processes across communities; surrounding land is a mix of fragmented forest, agriculture, and rural development

D: highly fragmented; area around EO is entirely, or almost entirely, surrounded by agriculture or urban development

Size

No Generic ranking applicable. Please provide size of community in grid above.

Overall Rank (based on best judgment)

A: excellent estimated viability

B: good estimated viability

C: fair estimated viability

D: poor estimated viability

NATURAL COMMUNITY MANAGEMENT

Discuss management needs and plans for this natural community, including need for invasive species monitoring and control. If the natural community requires a buffer with specific management, describe and map the buffer width and specifically explain the ecological need for the buffer:

Click here to enter text.

ADDITIONAL INFORMATION; (none required) (check those that are attached):

☐ Additional plant species list attached

☐ Plot form(s) attached

☐ Animal list attached

Please send completed form and GIS shapefiles to Bob Zaino:

robert.zaino@vermont.gov
or
Bob Zaino
Natural Heritage Inventory
Vermont Fish and Wildlife Department
5 Perry Street, Suite 40
Barre, Vermont 05641

Table 1: Replacement Table

Species	Habitat Preferences	Form	Shade Tolerance	Wildlife Use	Pests of concern	Considerations of replacement	References
Hemlock	Moist to very moist soil with good drainage; cool humid climates	Broadly pyramidal, pendulous branches that provide deep shade cover	High shade tolerance	Eastern hemlock is forage for deer, hare, porcupines, and yellow-bellied sapsuckers. It provides vital winter cover for white-tailed deer and unique thermoregulation of stream bed temperatures for aquatic species.	HWA, EHS	Hemlock grows in moist to very moist soil with good drainage in cool and humid climates. It is utilized by many species of wildlife including white-tailed deer, ruffed grouse, and turkey. When growing along streams, it is a vital streambed regulator for brook trout and salamanders. This tree is sensitive to pests including the invasive HWA and is drought intolerant.	
Balsam fir (*Abies balsamea*)	Acidic soils- any soil type	Dense, narrowly pyramidal crown; branches are present from ground to crown	Very tolerant	Balsam fir provides vital winter cover for white-tailed deer and moose. Dense thickets are used all season for small coverage by small mammals and birds. This tree is primarily winter forage for moose but is also occasional forage for spruce grouse, and red squirrels.	Balsam woolly adelgid, spruce budworm, red heart fungus, armillaria root rot, cubical and white rots	Balsam fir is a short-lived species that can grow in a wide range of soil textures and soil acidity. This tree is sensitive to insect pests including spruce budworm and balsam woolly adelgid, and climate conditions including drought and fire-all of which can cause mortality. Though it is shade tolerant, it can be readily outcompeted by hardwood species.	Uchytil, Ronald J. 1991. Abies balsamea. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/abibal/all.html [2022, October 5].
Black spruce (*Picea mariana*)	Requires abundant moisture and prefers slightly acidic sites; long cold winters with short warm summers	Branches are present from ground to the crown. Irregular shape	Tolerant	Black spruce provides a habitat for wildlife and is the second-best species on this list for the northern flying squirrel. However, most wildlife avoids browsing, and some will consume its seeds.	Balsam woolly adelgid	Black spruce can grow on a wide range of sites and in a variety of soils. It can tolerate nutrient-poor sites but prefers slightly acidic sites with abundant moisture. It has intermediate sensitivity to sulfur dioxide and is drought intolerant. Although fire aids in reproduction, trees are killed by any severity of fire.	Fryer, Janet L. 2014. Picea mariana. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov /database/feis/plants/tree/picmar/all.html [2022, October 4].

Eastern white pine (*Pinus strobus)*	Most competitive on well-drained, dry sites with coarse textured soils, but can tolerate almost all soil types; disturbed sites	Often has loss of lower branches in forested settings	Intermediate	Eastern white pine provides food and habitat for wildlife in all life stages. Songbirds and small mammals eat seeds, white-tailed deer and hares browse foliage, and bark is consumed by larger mammals. Eastern white pine is critical for black bear cubs to climb to avoid predation, crowns are used by birds for breeding and nesting and broken and damaged pines are used by cavity nesting-wildlife.	White pine weevil, sirex woodwasp, WPBR, WPND	Eastern white pine can grow in a variety of sites and soil types but is most competitive in disturbed, well-drained dry sites. This tree is fast-growing and long-lived, providing habitat and forage for animals in all life stages. It is sensitive to ozone and sulfur dioxide, insect pests and diseases and can be outcompeted by hardwood species in less-than-ideal sites. Young trees are easily killed by fire, but mature trees are tolerant due to their thick bark.	Carey, Jennifer H. 1993. Pinus strobus. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/pinstr/all.html [2022, October 13].
Eastern red cedar (*Juniperus virginiana*)	Can grow in a large range of climatic conditions-deep, moist, well-drained sites; alkaline or acidic soil; diverse soil types	Has two forms: narrowly conical with a compact crown and broadly conical with wide spreading branches	Intermediate to intolerant	Despite being low-quality forage, eastern redcedar's berry-like cones are consumed by birds, foxes, coyotes, and other small mammals, and its foliage is browsed by white-tailed deer when other forage is not available. It provides good nesting and roosting cover for birds.	Bagworms, spruce spider mites, root weevil, root rot fungi, cedar apple rust	Eastern redcedar can grow in a variety of sites and climatic conditions. It is both a pioneer and invader species, lowering species diversity where present. This tree is long-lived and drought and saline tolerant. This tree does not survive on sites that have frequent fires.	Anderson, Michelle D. 2003. Juniperus virginiana. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/junvir/all.html [2022, October 14].
Northern white cedar (*Thuja occidentalis*)	Moist, nutrient-rich sites, calcareous soil; low and upland sites	Narrow crown with branches present from the ground to the crown in open-grown trees; loss of lower branches in forested settings	Very tolerant	Northern white cedar provides an abundance of food and cover for wildlife. Its preferred browse for white-tailed deer, snowshoe hares, and porcupines, and occasional browse for moose. It provides winter cover for white-tailed deer, moose, and black bears.	Carpenter ants, arborvitae leafminers	Northern white cedar can grow in both upland and lowland sites provided there are moist, nutrient-rich sites. This tree is relatively pest and pathogen-free but can be over browsed by wildlife. It is tolerant of shade, sulfur, dioxide, and ozone. These trees are easily killed by fire and high water levels.	Carey, Jennifer H. 1993. Thuja occidentalis. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/thuocc/all.html [2022, October 5].

Pitch pine (*Pinus rigida*)	Dry, low-quality sites with poor sandy soils; mineral soil seedbed for regen; humid environment	highly variable growth forms; irregular branching; retains deadwood; twisted branches	Intolerant	Pitch pine provides food and habitat for wildlife including white-tailed deer, squirrels, and birds. White-tailed deer browse seedlings and sprout, and squirrels and birds consume seed. Birds use stand habitat for nesting and mating.	Sirex wood wasp and various wood boring bark beetles; potential for southern pine beetle	Pitch pine prefers to grow on dry, low-quality sites and in low-nutrient soils. It has a highly variable growth form depending on the site, ranging in dwarf to tall trees. This tree is susceptible to various insects including the southern pine beetle, and when stressed, can easily die from insect outbreaks. Pitch pine is tolerant of fires, cold, and drought however is sensitive to shade. Pitch pine requires fire for seedling establishment, which leads this species to be outcompeted by hardwoods in low-fire climates.	Gucker, Corey L. 2007. Pinus rigida. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/pinrig/all.html [2022, October 13].
Red pine (*Pinus resinosa*)	Dry sites; level sand plains or low ridges; adjacent to lakes and swamps; can tolerate poorly drained slopes; cool summers and cold winters with low to moderate precipitation	Dense and symmetrical, Ovid-shaped crown	Intolerant-very intolerant	Red pine is seldom used for habitat and food by wildlife. Snowshoe hares consume bark and needles in northern climates but remain a poor habitat for game birds and animals.	Sirex wood wasp and various wood boring bark beetles, red pine decline, red pine scale	Red pine prefers to grow on dry and level sites but can tolerate growing on poorly drained slopes. This tree is long-lived, and its thick bark aids in fire tolerance. Red pine is susceptible to various insects and pathogens including the invasive red pine scale. Although trees are ozone tolerant, it has intermediate sensitivity to sulfur dioxide. Red pine requires fire for seedling establishment, which leads this species to be outcompeted by hardwoods in low-fire climates.	Hauser, A. Scott. 2008. Pinus resinosa. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.usda.gov/database/feis/ [2022, October 13].
Red spruce (*Picea rubens*)	Acidic and shallow soils; cool moist summers and cold winters	Conical narrow shape, broader crown than other spruces	Tolerant	Red spruce is forage for grouse, mice, voles, birds, porcupines, bears, snowshoe hares, and red squirrels. It is unpalatable to white-tailed deer and provides habitat for grouse.	Spruce budworm eastern spruce beetle, European pine sawfly, yellowhead spruce sawfly, and eastern spruce gall adelgid	Red spruce grows in acidic and shallow soils that have parent materials of glacial drift. It prefers well-drained soils. This tree is sensitive to atmospheric pollution and climate stress including drought and is easily killed by fire.	Sullivan, Janet. 1993. Picea rubens. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/picrub/all.html [2022, October 4].

Tamarack (*Larix laricina*)	Cold, poorly drained sites- to dry upland ridges	Medium-sized tree with a narrow pyramidal crown; sheds lower branches	Intolerant	Tamarack is seldom used for habitat and food by wildlife. Snowshoe hares and porcupines may occasionally feed on twigs and bark but to a limited extent. Small rodents and birds will consume its seed.	Larch sawfly, larch casebearer	Tamarack is a deciduous conifer that can be found primarily growing in mineral soil in poorly drained sites and along streams, however, is also found in dry upland ridges in northern parts of its range. This tree is seldom used for food for wildlife and because it loses its foliage in the winter, is not used for cover. It is easily killed by fire.	Uchytil, Ronald J. 1991. Larix laricina. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov/database/feis/plants/tree/larlar/all.html [2022, November 9].
White spruce (*Picea glauca)*	Moderately to well-drained, upland or floodplain soils; floodplains, upland slopes and treeline sites	Densely foliated with high branch and needle retention on lower trunk	Intermediate	White spruce is habitat for deer, red squirrels, porcupines, grouse, and black bears. Although most wildlife avoids browsing it, some will consume its seeds.	Spruce budworm, European spruce needleminer, Tomentosus root disease, and various bark and wood boring beetles	White spruce is a long-lived species that can be found growing in floodplains, upland slopes and treeline sites. It can grow in both acidic and alkaline soils. This tree is sensitive to nutrient deficiencies and can tolerate large variations in temperature.	Abrahamson, Ilana. 2015. Picea glauca, white spruce. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: https://www.fs.usda.gov /database/feis/plants/tree/picgla/all.html [2022, October 4].