REGIONAL FOREST HEALTH MONITORING PROGRAM

2021 Report

Forest Ecosystem Monitoring Cooperative

Last updated: January 12, 2023

Regional Forest Health Monitoring Program: 2021 Report

Published 3/21/2023
Version 1.0

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DOI: https://doi.org/10.18125/4x75j6

Cover image: Gwyn, E. 2020.

Preferred Citation
Porter B, Sirch M, Cutler N, Schuett E, and Pontius J. 2022. Regional Forest Health Monitoring Program: 2021 Report. Forest Ecosystem Monitoring Cooperative. South Burlington, Vermont. https://doi.org/10.18125/4x75j6

Acknowledgements
The Forest Ecosystem Monitoring Cooperative (FEMC) is grateful for the guidance and support provided by the numerous partners that helped make the regional expansion possible as well as all the state employees that assisted FEMC FHM crews at campsites and with accessing gated roads. We would also like to thank the FEMC FHM student technicians for all their hard work collecting data during the summer.

We are appreciative of the long-term funding from the U.S. Department of Agriculture, Forest Service State & Private Forestry, Vermont Agency of Natural Resources, and the University of Vermont.

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Executive Summary

Annual forest health monitoring can help capture subtle changes and long-term trends in forest composition and condition. The health of mature, overstory trees in the forest can be tracked by measuring annual diameter and height, evaluating canopy condition, determining the overall vigor, and identifying specific damages. Changes in forest composition can be assessed by tracking regeneration, growth and mortality patterns. Monitoring the prevalence of invasive pests, pathogens, and animal browse provides further understanding of the impacts of common stressors on forest health and condition. Healthier forests have greater carbon sequestration, provide higher quality wildlife habitat, and are more resilient to ongoing stressors. An understanding of forest health and how our forests are changing provides critical information for mitigation and adaptation strategies. This information will also ensure the sustained provisioning of key ecosystem services in the face of a changing climate.

By the 2021 field season, the Forest Ecosystem Monitoring Cooperative (FEMC) worked with state partners in Connecticut, Maine, New Hampshire, Massachusetts, and Rhode Island to expand the Forest Health Monitoring (FHM) network outside of Vermont to include permanent plots in each of the 7 northeastern states (New York to be established in 2022). These FHM plots were co-located with each state's existing Continuous Forest Inventory (CFI) or Forest Inventory and Analysis (FIA) plot network, and were designed to complement the state's network with a higher temporal resolution (annual vs 5 to 10-year rotation for re-measurements) on a subset of FIA or CFI plots.

In 2021, FEMC visited 154 plots from CT (13), MA (25), ME (35), NH (25), RI (7), and VT (49). Results from the 2021 monitoring season indicate that red maple (*Acer rubrum*; 15%), balsam fir (*Abies balsamea*; 14%), and sugar maple (*Acer saccharum*; 10%) were the most abundant species across the 154-plot network. From the 6,594 trees (≥5 inch DBH) measured, average live overstory tree density in 2021 was 183 stems per acre (SPA) and 123 ft^2/ac basal area. Regeneration assessments show sapling densities of 493 live SPA with balsam fir and American beech (*Fagus grandifolia*) representing the most abundant species. Red maple was the most abundant seedling tallied in 2021 (24% composition, 5,709 SPA), followed by sugar maple (22%, 5,317 SPA), and balsam fir (12%, 2,794 SPA; Table 11).

While there are a wide range of stressors and vulnerabilities impacting northeastern forests, data from the 2021 season suggest that the region's forests are overall diverse, vigorous, and healthy. However, there are notable exceptions that we should continue to monitor. From the 2021 crown health assessments, we identified black cherry (*Prunus serotina*), gray birch (*Betula populifolia*), and paper birch (*Betula papyrifera*) as species of concern. Average vigor ratings for these species were 2, 1.5, and 1.4, respectively (where 1 is healthy and 4 is severe decline; Table 2) and defoliation ratings were 0.8, 1.2, and 0.8 (where 0 is no to trace defoliation, 1 is less than 30 percent crown defoliated, and 2 is 30-60% defoliation; Table 3). The percent of fine twig dieback for these species was 13, 11, and 10% of the tree crown. With the recent spongy moth outbreaks across the Northeast, we recorded 11% of oaks with >30% defoliation. Seedling regeneration was also sparse for pitch pine (*Pinus rigida*; 3 SPA), American elm (*Ulmus americana*; 3 SPA), and silver maple (*Acer *saccharinum*; 7 SPA; Table 11). This highlights the importance of continuing annual assessments to better understand trends, patterns, and drivers of change for the state's forested ecosystems.

Background

In 1990 a national Forest Health Monitoring program was established by the U.S Forest Service to monitor forest health and detect emerging threats (Bechtold et al., 2007). Plots consisting of four fixed area subplots, measuring 7.32 m (24 ft) in radius, were initially set up across six northeastern states. Eventually, the program was expanded to 45 states (Bechtold et al., 2007). Since 1999 Forest Health Monitoring (FHM) field plots have been integrated into the ground plot network which is maintained by the US Forest Service's Forest Inventory and Analysis (FIA) program. Continuous Forest Inventory (CFI) networks have also been established across the region by a variety of state and public agencies. The FIA program assesses demography and forest utilization trends (Gillespie, 2000). CFI programs record similar metrics to assess timber stocks and yields. For both FIA and CFI programs, periodic inventories are designed to assess a subset of plots each year to capture changes over time across a large network of plots (Gillespie, 1998). FIA programs run on 5-7 year re-measurement cycles (USFS 2013) while CFI rotations vary by agency but typically follow a 10 year return cycle (Nevins et al., 2019).

Annual plot assessments can better capture year-to-year changes that can fluctuate due to weather, disturbance, or pest and pathogen outbreaks. Examples of these changes include seedling abundance, sapling survivorship, ungulate browse, tree crown health, and damages. While periodic inventories allow for a larger number of total plots across the landscape, this is accomplished at the expense of the information revealed by annual inventories.

In response to this need for more detailed annual measurements to provide a more nuanced and informative understanding of forest health, the FEMC established 49 FHM plots in Vermont between 1991 and 2018 that span Vermont's forest types and biophysical regions. For each plot, FHM technicians annually assess tree demography, canopy condition, seedling abundance, sapling survivorship, invasive species, browse presence, and damage agents. These metrics were designed to provide information on early symptoms of tree stress and changes in forest structure and composition. The information obtained from the FHM program provides timely assessments of current forest conditions and emerging trends while complementing other forest assessment programs that have longer re-measurement cycles, such as the FIA and CFI programs.

After successfully establishing and conducting annual assessments on FHM plots in Vermont for almost three decades, the FEMC has been preparing for an expansion of its FHM program into surrounding states to yield a more complete picture of forest health across the New England and New York region. In 2019, the FEMC collaborated with MA DCR to establish 20 FHM plots on MA state lands to add to its annual FHM network. In 2020 the FEMC expanded to CT (15 plots), RI (7 plots), ME (35 plots), and NH (30 plots) to add permanent FHM plots in a similar manner. To improve comparability and utility of each program, the FHM plots were co-located at established, long-term plot locations, representing the major forest types and geographies on public lands in each state.

Co-locating FHM plots with the FIA and CFI networks provides the FEMC FHM program with access to historic long-term data that may give insight into previous land use, forest health, and large-scale changes that have occurred over time. The state and federal programs will have access to annual measurements on a subset of plots to better understand year-to-year changes and detect emerging forest health issues. This report provides details on the FEMC FHM program, plot selection, and highlights findings from the 2021 FEMC FHM field season.

Methodology

Plot selection

Plots in VT and MA were already in place prior to the 2021 season. Previous reports can be referenced for more detailed descriptions of how those plots were selected and established (Wilmot et al., 2019; Sirch et al. 2020).

In expanding the FHM Network, FEMC opted to create a sampling concentration akin to that of the plot network in Vermont. The amount of forestland in Vermont, as defined by FIA, was used to calculate the number of acres per plot in Vermont and was applied to the other states' forestland area to determine a similar density. The USFS FIA Forest Type (2008) spatial layer was used as a coarse filter to determine the species composition in certain areas. Ground truth assessments of the species composition were made in the field. Backup plots were also created to be used if a plot does not match forest type or if other factors inhibit data collection.

For each state, the overall percentage of each forest type was calculated and combined with the target plot density to identify a target plot number for each forest type within each state. We chose to remove any forest types with a total regional target plot number less than two (2), since these were generally rare forest types or subsets of major forest types.

FEMC partnered with various organizations and agencies within each of the seven states to gather existing long-term monitoring plot information. Nesting FHM plots on top of or adjacent to these existing networks, when possible, allows for longer temporal assessments of the metrics monitored at those sites.

Plots were established using these existing FIA and CFI plot networks when available. New plots were also established where current networks did not exist or where certain forest types were underrepresented by existing plot locations.

If a plot network was already in place, we prioritized plot locations based upon the following criteria:

1) The plot must be within a natural forest (plantations are not considered natural forests).
    a. We prioritized plots that landed on public lands over those on private lands; however, plots on private lands were not excluded.
    b. All plots located on non-forest land or non-natural forest land were removed.

2) Plots on conserved land or in reserve status were prioritized over lands designated for timber management.

3) Plots had to be more than 200 ft, but less than 10,000 ft, from roads. New plots also had to be no more than 2,000 ft from a trail.

    a. All plots outside of these parameters were removed.

4) Plots had to be on a slope less than 15%.

5) The plots had to be representative of the overall forest composition for the state and spatially balanced across the state's forestland.

When a state's historical monitoring plots were not available or were otherwise not suitable to be surveyed as FHM plots, new plots were established. The same criteria as above were used to select randomly generated plot locations for these states.

We buffered from roads to reduce the impact that roads and traffic may introduce to the forest ecosystem. The FHM program's main goal is to measure disturbance impacts driven by climate change and the disturbance from roads and trails can interfere with detection of these impacts.

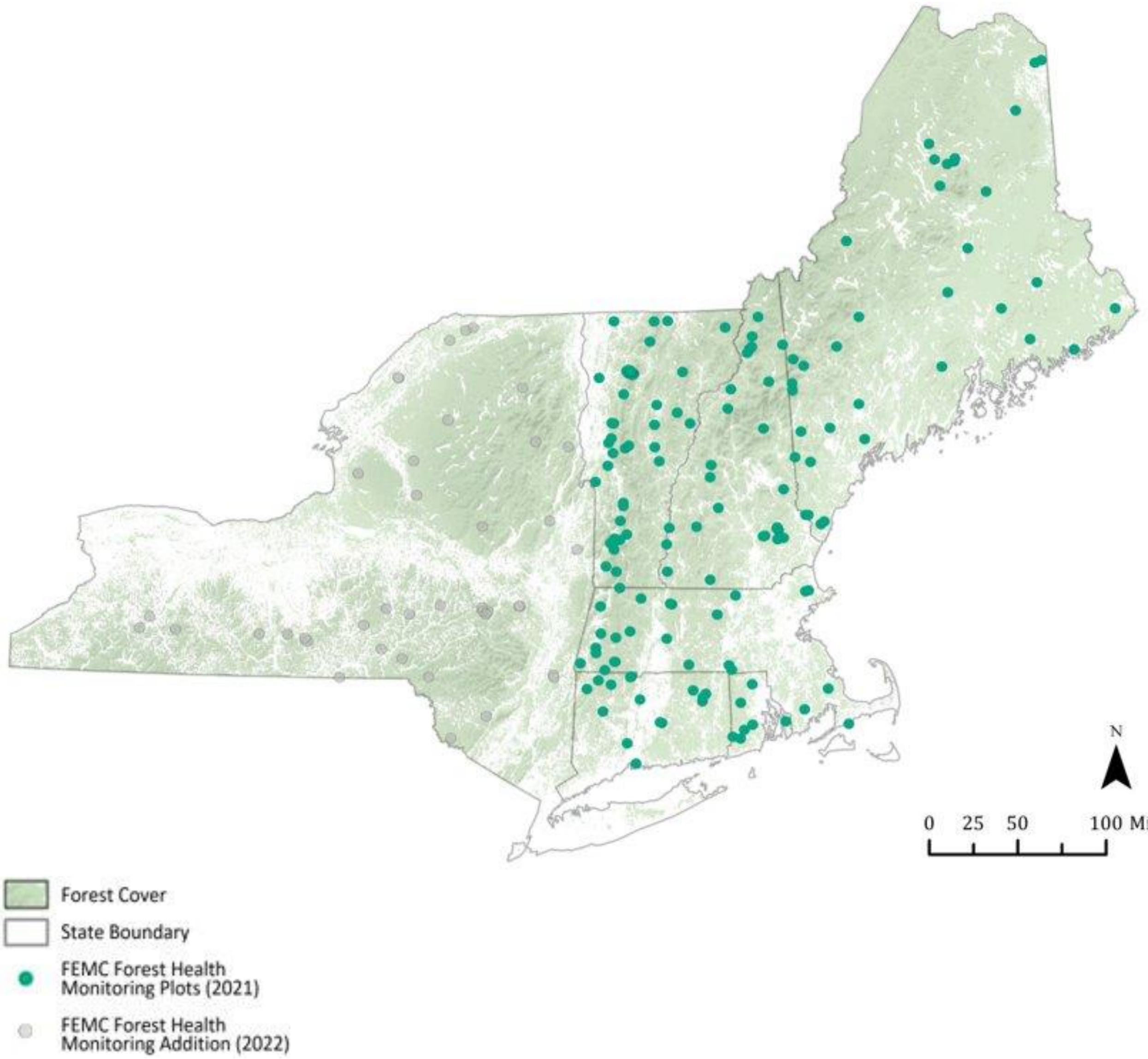
We also removed plots that were more than 2000 ft from a road or trail to allow crews ample time to hike to and sample the entire plot within a 10-hour field day. Without a maximum distance, the majority of our random points landed in remote areas that could take multiple days to survey. Priority was given to plots with reasonable access for sampling purposes.

If a plot network was already in place, we selected points representing each of the statewide forest types, and scaled the distribution down to represent the percent forest cover of each forest type in each state. In states without an existing plot network, randomly generated points based on the above criteria were generated to match the number of plots required to best represent the particular forest types required for the state. Final plot selections were then visually inspected in Google Earth to exclude plots that: were not within forest land, fell within wetland or other body of water, landed on an unmarked road or man-made feature, and/or were difficult or dangerous to navigate to (i.e., cliff, steep gradient).

Based on the proportion of forest composition by species (Figure 5), we selected a proportional number of plots per species from the resulting plot list generated with the aforementioned filtering steps. We also overlaid plots on Level IV ecoregions (EPA) to ensure that the plots represent all forested ecoregions across the state and implemented a 10 mile buffer between plots to ensure they were spatially distributed across the state. For example, for plots dominated by northern red oak (*Quercus rubra*), we attempted to ensure that selected locations were spatially distributed in northern red oak forests in different locations rather than clustered in a single region. The resulting plot network is show on the map in Figure 1.

The final plot selections were then sent to state partners for review. Some changes were made based on plot access, incorrect forest type designation, management considerations, and other factors. The final location review was confirmed or amended by the crew as they visited each plot for the first time during the field season. Individual plots may be moved in future years based upon feedback from the field crew and review of the data.

Figure 1. The one hundred and fifty-four (154) plot locations of the FEMC Forest Health Monitoring program in 2021. New York plots were established in 2022 and are not yet included in analyses.



Plot layout

FIA (Clustered) Style

To maintain continuity with historical inventories, the New Hampshire, Rhode Island, and Vermont FHM plots follow the layout shown in Figure 2, which mirrors the FIA plot layout. The FIA plot style consists of 4 subplots, each with a 24 ft radius and area of 1809.6 ft^2, and one nested regeneration microplot per subplot, each with a radius of 6.8 ft and an area of 145.3 ft^2 (Figure 2). The four regeneration microplots are 12 ft from the subplot center at 90° from true north. Three subplots radiate from a central subplot 120° apart, 120 ft from the center of the central subplot (subplot 1).

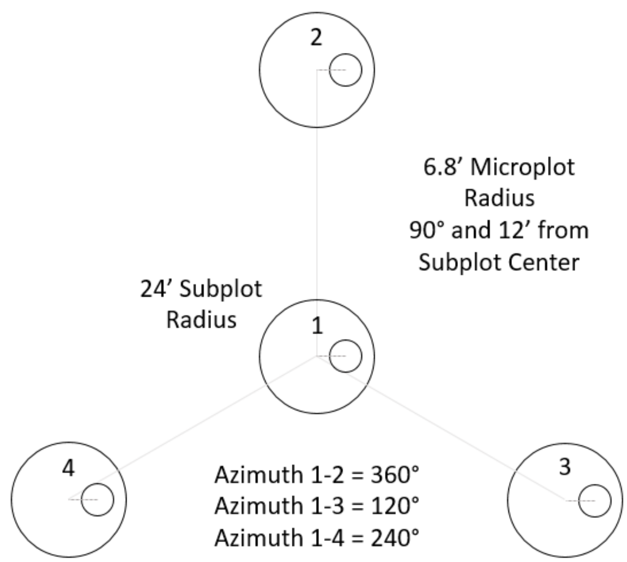


Figure 2. Layout of VT-Style FIA and FEMC FHM plots showing the 4 clustered subplots and four regeneration micro-plots within each.

Larger CFI (Nested) Plot Style

Connecticut, Massachusetts, Maine, and New York FHM plots are laid out in the nested CFI style. The CFI-style plot style consists of one large overstory plot, with a radius of 52.7 ft and area of 8,725.11 ft^2, and four nested regeneration microplots each with a radius of 6 ft and an area of 113.1 ft^2 (Figure 3). The four regeneration microplots are 26ft from the overstory plot center at the cardinal directions (referenced to true north). To maintain continuity with historical inventories on these plots, the FEMC utilized this same plot design for the plots in Connecticut, Massachusetts, Maine, and New York. State CFI plots typically have the overstory plot center permanently marked, but not the locations of the regeneration subplots. As it is critical that regeneration subplot locations remain consistent for annual assessments, the FEMC technicians marked the regeneration subplot centers of our plots with fiberglass or wooden dowel stakes.

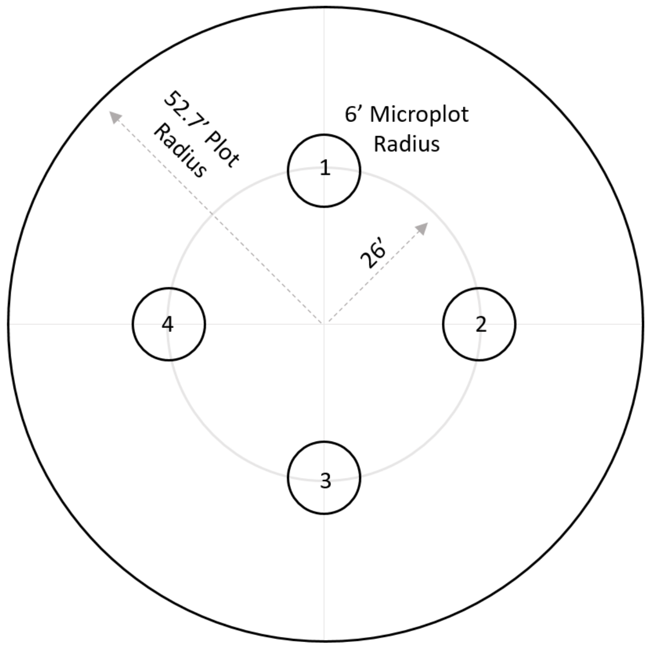


Figure 3. Layout of MA-Style CFI and FEMC FHM plots showing the overstory plot (large circle) and four nested regeneration micro-plots (small circles at cardinal directions; MA DCR 2014).

Field metrics

For the 2021 field season, FEMC inventoried the 154 plots across the six New England states for all metrics outlined in the Vermont FEMC FHM protocol (Wilmot et al., 2019). These metrics include assessments of tree biometry and health in the overstory plot, regeneration assessments that include seedling tallies by species and size class, and sapling biometry and health (species, diameter, status) assessments in the four sub-plots. Other metrics, like animal browse, invasive plants, and forest composition (prism plots) were collected at the overstory plot level. Details of each metric are provided below.

Tree biometry and health

Within the overstory subplots, FEMC FHM technicians assessed all trees ≥5 in. diameter at breast height (DBH, measured at 4.5 ft). Each sampled tree within the overstory subplots were either marked with paint or a bark scoring to signify the tree is within the subplot radius and should be sampled. Distance and azimuth from the plot center were recorded for each individual tree for future inventories. Any new trees (in-growth) were assessed, assigned a number, and mapped. Species, DBH, height, special damages, vigor, and crown health assessments were recorded for all trees.

Diameter and height

Diameters of all trees were measured at traditional breast height (4.5 ft from the ground) following the guidelines in the FEMC FHM protocol (Wilmot et al., 2019). Heights were assessed to the top of the tree, regardless of whether the tallest leader was alive or dead. If applicable, the amount of dead top was recorded. The length of the live crown was also measured. Trees marked with a paint line at DBH will be measured using a "modified" DBH approach in future years. Trees marked with this method were painted at DBH and will be measured along that line in future years to account for tree growth and to track changes over time. Trees without painted lines will be measured using the traditional DBH method, measuring 4.5ft up from the ground.

Special Damages

For each tree in the overstory plot, any recent bole or crown damages were recorded, if obvious. It should be noted that these damages are not comprehensive and some damages may not be recorded if they are not obvious to a technician from the ground. Damage categories include: animals, borers, insects, cankers, conks, diseases, human causes, and weather. Up to three damages for each tree may be recorded. For special damage codes and descriptions, see Table A2 in the Appendix.

Vigor

Tree vigor is a categorical assessment on a 1 to 8 scale that summarizes the overall health or status of the tree (Table 1) and comprises the total impact of a combination of stress-induced characteristics, including branch mortality, dieback, and missing crown area. Dead, cut and fallen trees are recorded as vigor 5, 6, and 8, respectively. Vigor was assessed on all trees in the overstory plot. Note that we also utilized a vigor code of 9 for all missing trees in the data that could not be identified as standing or dead and down.

Table 1. Tree vigor codes and definitions from the FEMC FHM protocol (Wilmot et al. 2019).

Code	Definition
1	Healthy; tree appears to be in reasonably good health; no major branch mortality; crown is reasonably normal; less than 10 percent branch mortality or twig dieback.
2	Light decline; branch mortality, twig dieback present in 10 to 25 percent of the crown; broken branches or crown area missing based on presence of old snags is less than 26 percent.
3	Moderate decline; branch mortality, twig dieback in 26 to 50 percent of the crown; broken branches, or crown area missing based on presence of old snags is 50 percent or less.
4	Severe decline; branch mortality, twig dieback present in more than 50 percent of the crown, but foliage is still present to indicate the tree is alive; broken branches, or crown area missing based on presence of old snags is more than 50 percent.
5	Dead, natural; tree is dead, either standing or down; phloem under bark has brown streaks; few epicormic shoots may be present on the bole; no further entries needed.
6	Dead, human caused; tree removed; tree has been sawed or girdled by humans.
8	Dead and down; If a tree is found to be dead and down two years in a row, it is removed from the tree list.

Crown health assessments

Ocular crown health assessments are conducted on all trees inventoried in the overstory plot. Prior to the field season, training and calibration of crew members conducting crown health assessments are led by Vermont Forest Parks and Recreation (FPR) forest health specialists to ensure standardization of ratings from year-to-year. Assessments are conducted by two trained technicians using binoculars to distinguish seeds from leaves and detect presence of insect defoliation. When the technicians conducting crown health assessments disagree on the rating, they discuss the estimates and move around the tree to view it from different angles until an agreement can be reached. Crown health metrics include dieback, foliar transparency, discoloration, and defoliation.

Percent fine twig dieback

The amount of fine twig dieback in a tree's crown reflects a response to recent stress events. Dieback is visually estimated as a percentage of the total live crown volume that is occupied by fine twig dieback in 5% classes, rounded up to the nearest 5% (Wilmot et al., 2019) (Table 3). For example, if a tree has 1-5% dieback it is assigned a rating of 5. As some species experience natural dieback of lower and interior limbs that is not stress related, the fine twig dieback assessment in the FEMC FHM protocol only considers dieback *of upper and o*uter branches where dieback is likely a result of stress and not due to self- pruning or shading (Figure 3).

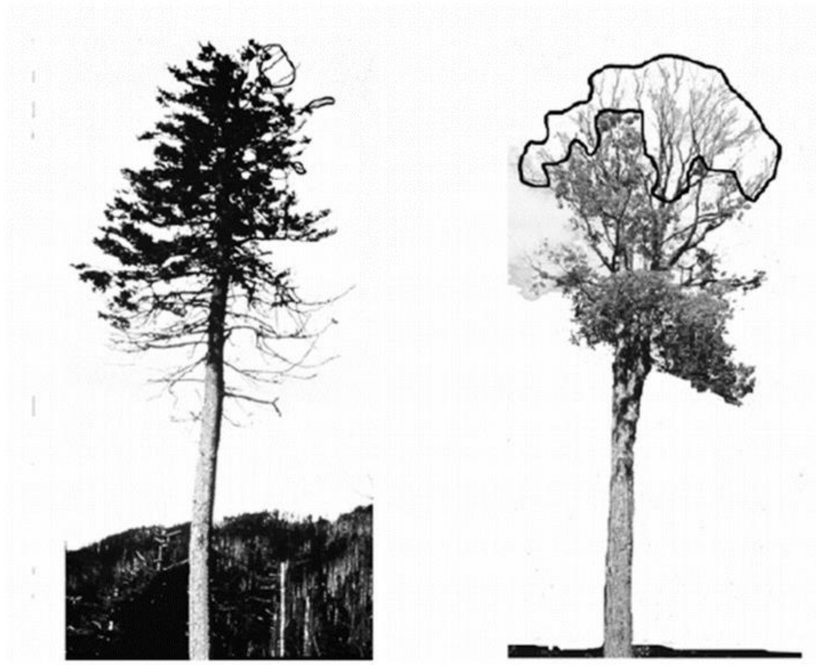


Figure 4. Crown dieback rating outline examples (Randolph, 2010). Dieback of left tree: 5%. Dieback of right tree: 30%. Note that self-pruning of lower branches is not included in the assessment.

Percent foliar transparency

Foliar transparency is the amount of light visible through the live, normally foliated portion of the crown, excluding areas that are occupied by branches. FEMC FHM technicians estimate each tree's crown transparency, rounding up to 5% intervals, such that a rating of 10% indicates that only 6-10% of the total possible skylight is visible through the foliage (Wilmot et al., 2019). Transparency considers live foliage only; branches and areas of dieback are not included, while areas exhibiting defoliation are.

Percent defoliation

Defoliation is an estimate of leaf area missing as a result of leaf-eating insects (such as spongy moth caterpillars or pear thrips) or due to weather related leaf damage (such as frost or hail). This metric includes leaves with missing sections or, in severe cases, leaves with only veins intact (Wilmot et al., 2019). Areas of the crown experiencing fine twig dieback where entire leaves are missing are not included. Defoliation is estimated in four broad categories based on the total live crown with reduced leaf area (Table 2).

Table 2. Foliar discoloration and defoliation classes and definitions from the FEMC FHM protocol (Wilmot et al., 2019).

Class	Definition
0	None to trace defoliation or discoloration
1	Less than 30 percent of crown defoliated or discolored.
2	31 to 60 percent defoliation or discoloration.
3	More than 60 percent defoliation or discoloration.

Percent foliar discoloration

Foliar discoloration is estimated in the same four percentage classes as for defoliation (Table 3). Only foliated portions of the crown are assessed. Foliage is considered discolored when the overall appearance of a leaf is more yellow, red, or brown than green (Wilmot et al., 2019). Binoculars are highly recommended during this assessment as masting can be mistaken for discoloration. It is important to note that normal discoloration will begin to occur as deciduous trees prepare for fall leaf senescence. This should be noted if monitoring is conducted during this time.

Regeneration assessments

Regeneration assessments were completed on all four microplots within each overstory plot or subplot. At each regeneration microplot, saplings (≥1” and <5” in DBH) were assessed for DBH, status (live or dead), and species. Each sapling was given a unique ID and the location (azimuth and distance from microplot center) was also recorded. Additionally, all live seedlings with at least one true leaf and < 1” DBH were tallied by species and height class based on the heights as shown in Table 3.

Table 3. Definitions of seedling classes used in regeneration assessment.

Seedling Type	Class 1	Class 2
Conifer	< 6 in (15 cm) tall	≥ 6 in (15 cm) tall
Hardwood	<12 in (30 cm) tall	≥ 12 in (30 cm) tall

Other assessments

Invasive plants

Non-native invasive plants were recorded on each overstory plot or subplot using a 5-class abundance system for each species on the invasive plant list (Table 4). For a list of invasive plant species that one would expect to find on these plots, see Table A3 in the Appendix.

Table 4. Invasive plant abundance codes and definitions from the FEMC FHM Program protocol (Wilmot et al. 2019). Invasive species abundance is determined by searching the entirety of the overstory plot for invasive species and estimating prevalence.

Code	Description	Density
1	Infrequent occurrence	1 to a few present
2	Sparsely throughout	1-2 plants together, in a few locations
3	Localized patches	Several plants together, occurring in a few locations
4	Frequent in stands	Dense areas of plants occurring in a few locations
5	Densely throughout	High populations making up understory and/or regeneration

Animal browse

Evidence of browse on the vegetation in the overstory plot was assessed as either: (1) Present or (0) Absent. A code designating the amount of animal browse pressure exerted on the regeneration of the accessible forest area within the overstory plot or subplot was recorded on a scale of 1-5 (Table 5).

Table 5. Browse codes and definitions from the FEMC FHM Program protocol (Wilmot et al. 2019).

Code	Definition
2	Low – no browse evidence observed, vigorous seedlings present
3	Medium – Evidence of browse observed but not common. Seedlings common
4	High – Browse evidence common. Seedling presence rare.
5	Very high – browse evidence omnipresent. Forest floor bare, or severe browse line present

** A browse code of 1 refers to a site that is within a well-maintained, deer-free exclosure. No plots are within such conditions, so our scale begins at 2**

Forest composition

A 10 basal area factor wedge prism was used to assess the forest composition of the larger forest stand. The prism was held over the overstory plot/subplot center, and the number of trees of each species within the prism's variable radius plot were tallied. Trees determined to be 'in' were tallied by species and status (live or dead); those that were 'borderline' were counted every other time.

Canopy cover

Hemispherical photos were taken at the overstory plot/subplot center and at each of the subplot centers, when possible. The presence of dense understory, or a tree close to the plot center, renders the photo unusable. Photos were not taken under these conditions. Hemispherical photos will be converted to a leaf area index and canopy gap fraction to quantify subtle changes in canopy cover over time.

Data entry, quality control, and analysis

Data were collected on paper field forms and entered into a custom Microsoft Access database following field collection. All paper field forms were scanned and digitally archived. Original physical copies were also retained.

Quality assurance

Standard field quality assurance (QA) was performed on field data collection for 10% of plots assigned to each field crew regionally. Therefore, QA was scaled proportionally to cover 10% of all FHM plots and each field crew was checked periodically for tool, technique, and human errors. Field QA procedure consists of physical visits from a supervisor to each selected plot within two weeks of when the original data collection occurred, in which data for all metrics was re-collected for a randomly selected subplot. A QA subplot is said to have failed the data-entry QA protocol if more than 10% of its metrics are outside of the specified tolerance and measurement quality objective (MQO) standards (available upon request). If a plot failed a QA visit, that plot was re-sampled and further QA checks were performed on the respective crew.

Quality control

Several protocols were followed to ensure accuracy of data entry. After each data section of a plot was entered (e.g., sapling data) it was compared to the field data sheet for any potential entry mistakes. Spot checks were conducted on random entries within each section. On average, one data entry point out of every five was compared during the spot check.

Following the manual quality checks, we identified any outlier data that needed to be reviewed. These outliers were identified by querying the data for any measurements outside of a typical range for that metric. These standards were based off of the database QA procedures from the VT FEMC FHM program.

The following queries were run on the data:

- Tree heights that exceeded 30.48 m in total.
- Dieback and transparency ratings that exceeded 55%.
- Live or standing dead trees (vigor <5) with missing height measurements.
- Tree diameters that were missing in cases where tree vigor was <5.
- Trees with missing vigor measurements.
- Trees and saplings where IDs were missing.
- Additional queries were run to check that spatial measurements were within the plot boundaries. These include tree and sapling distance from plot center and azimuths that exceeded the range of 0-360 degrees.

Where outliers or errors were found in the queries, appropriate correcting action was taken. Once outlier measurements were identified, technicians reviewed the corresponding raw digital data, compared to field sheet entries, to ensure that data entry errors did not occur.

Data analysis

Data from the 2021 field season were analyzed across all regional FEMC FHM plots. Overstory composition was computed in several different metrics for each species, including: total stems (*N*), average stems per acre (SPA), basal area (ft^2/acre; BA), percent composition, and importance value (IV). Total stems and average trees per acre provide raw metrics of the composition, while basal area and percent composition provide more information on the prevalence of each species relative to the total stocking. Only standing trees (vigor ratings 1-5) were included in most analyses for overstory trees. However, in some analyses, it was appropriate to include only live trees (vigor ratings 1-4). The importance value is a representation of how dominant a species is in a given forest, and is calculated as follows for given species:

$$\left(\left(\frac{SPAspecies1}{SPAallspecies}\right)+\left(\frac{TotalBAspecies1}{TotalBAallspecies}\right)\right)\div 2\times 100\%$$

*SPA = Stems Per Acre; BA = Basal Area

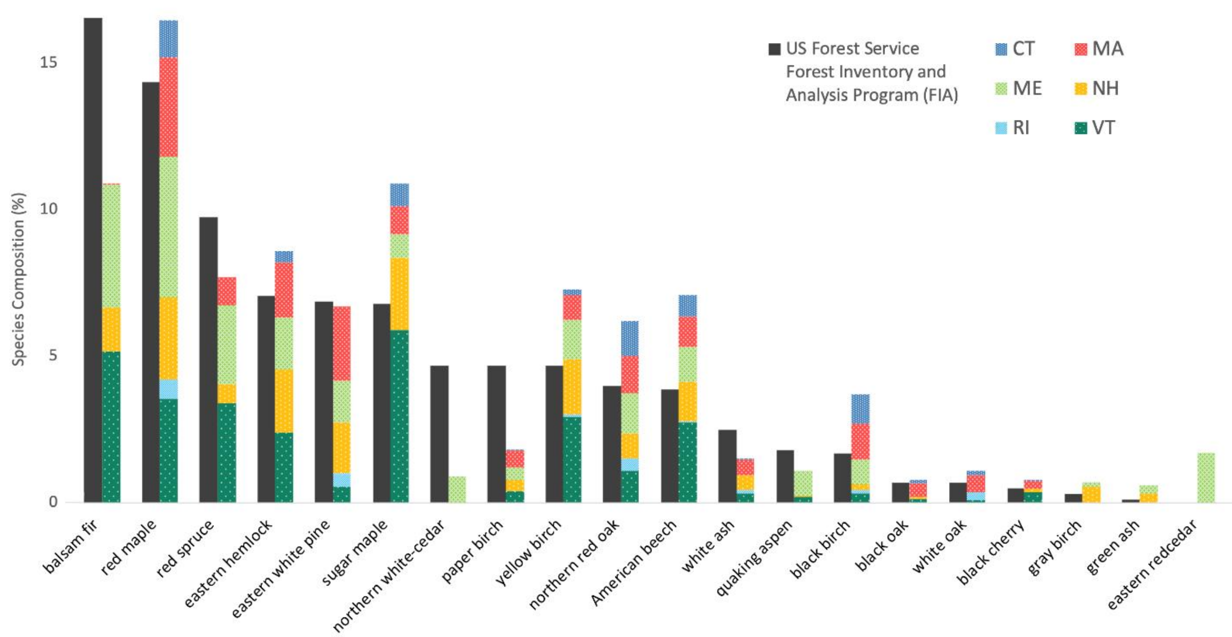
Results & Discussion

In 2021, FEMC FHM crews measured 5,149 live trees, 818 standing dead trees, 1,130 saplings, and tallied 43,950 seedlings across the 154 FEMC FHM plots. Below, we provide summaries of data collected from the 2021 field season.

Overstory composition

We found that species composition across the 154 plots was similar to the region-wide composition, according to FIA data (USFS 2019, Figure 5).

Figure 5. Percent live species composition for CT, MA, ME, NH, RI, and VT from the FEMC Forest Health Monitoring plots from the 2021 season alongside FIA estimates of live growing stock (≥5 inch DBH; USFS 2019).



Across the 154 FEMC FHM plots, there were a total of 5,149 live and 818 standing dead trees. For live trees, this equated to an average of 185 live stems per acre (SPA) and basal area (BA) of 124 ft^2/ac basal area. Standing dead trees averaged 52 SPA and a BA of 16 ft^2/ac. The total BA (live and standing dead) was 140 which may be too high to encourage regeneration, especially for shade-intolerant species. However, the high number of standing dead snags (14% of the standing trees sampled) suggests that these forests have opportunities for wildlife habitat.

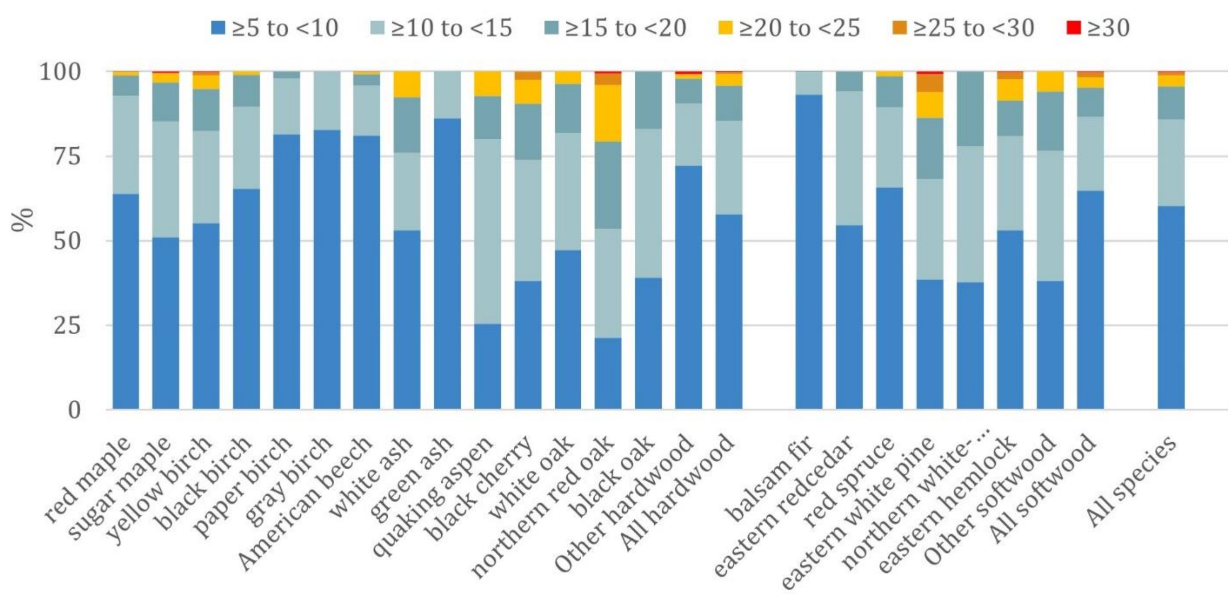
Across the survey area, hardwoods comprised 63% of the total overstory composition by live stem count. Red maple had the greatest live SPA (31 stems per acre), followed by sugar maple (20) and balsam fir (20; Table 6). Red maple also had the highest live Importance Value with an IV of 14.9% and BA of 17 ft^2/ac across all plots. Sugar maple had the second highest live IV (11.3%) with a BA of 15 ft^2/ac, followed by northern red oak (9.6%, BA 16 ft^2/ac) and eastern hemlock (*Tsuga canadensis*; 9.5%, BA 13 ft^2/ac).

Table 6. Overstory composition of trees from the FEMC FHM plot network in 2021 showing total live stems (*N* live), total standing dead trees (*N* snags), live tree stems per acre (SPA), live tree basal area per acre (BA, ft^2/ac), percent composition by live tree count (%), and live tree importance value (IV).

Species	N Live	N Snags	SPA	BA	%	IV
red maple	851	133	31	17	17	15
sugar maple	561	77	20	15	11	11
northern red oak	320	42	11	16	6	10
eastern hemlock	441	69	16	13	9	10
eastern white pine	347	142	12	14	7	9
balsam fir	559	351	20	6	11	8
yellow birch	375	75	13	10	7	8
red spruce	398	92	14	8	8	7
American beech	364	120	13	5	7	6
black birch	193	28	7	4	4	3
white ash	79	23	3	2	2	2
eastern redcedar	86	7	3	2	2	2
paper birch	92	56	3	1	2	1
quaking aspen	55	36	2	2	1	1
white oak	55	31	2	2	1	1
black cherry	42	19	2	1	<1	<1
northern white-cedar	45	8	2	1	<1	<1
black oak	41	25	1	1	<1	<1
pitch pine	29	8	1	<1	<1	<1
gray birch	35	11	1	<1	<1	<1
green ash	29	3	1	<1	<1	<1
shagbark hickory	17	0	<1	<1	<1	<1
eastern hophornbeam	21	2	<1	<1	<1	<1
chestnut oak	7	0	<1	<1	<1	<1
blackgum	17	0	<1	<1	<1	<1
Other hardwood	85	86	3	1	2	1
Other softwood	5	1	<1	<1	<1	<1
Total	5,149	1,445	185	124	100	100

The distribution of size classes across the FEMC FHM plot network in 2021 reflects the typical age of forests in the region, resulting from the widespread abandonment of agriculture in the mid-twentieth century (Hall et al. 2002). The majority of trees are in the 5-10 inch tree diameter size class, dominated by mid-successional species that would have become established around that time period. Some larger trees persist that measure greater than 30 inches DBH, particularly eastern white pine (*Pinus strobus*), northern red oak, and sugar maple specimens. As these stands continue to age, we can expect to see the numbers of large stems increase, particularly for late successional species such as eastern hemlock, American beech, and sugar maple (Figure 6).

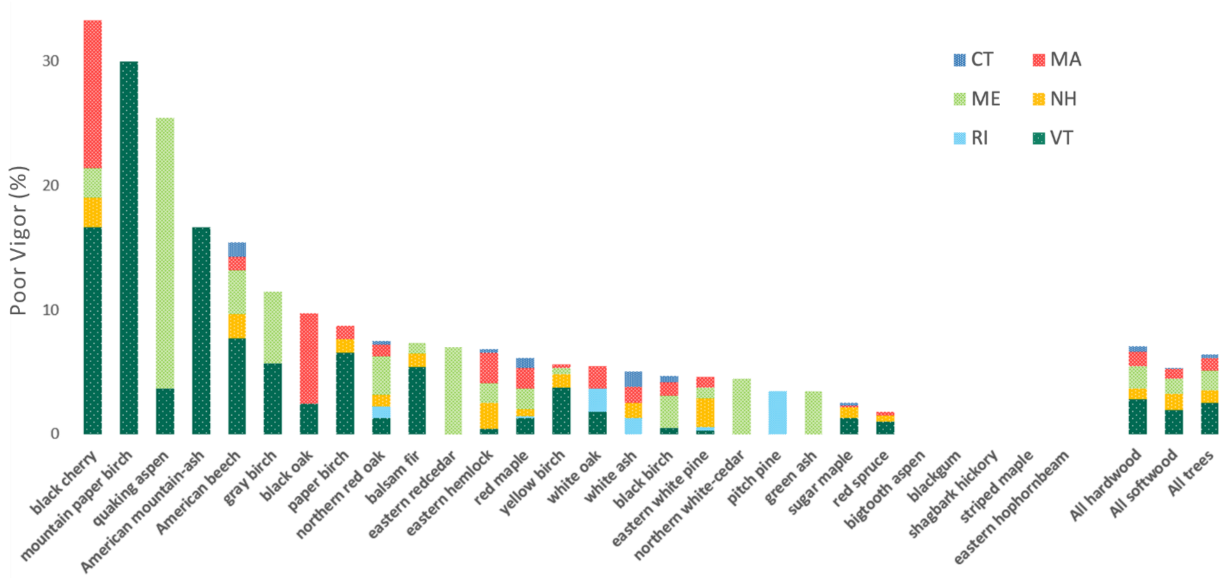
Figure 6. Size classes of live trees by diameter at breast height (DBH; inches) across the FEMC FHM plot network in 2021.



Tree health

Across the 154 FEMC FHM plots assessed in 2021, live tree vigor (mean ± SD) was 1.3 ± 0.6, or between 'healthy' and 'light decline.' Of live trees measured, we found that 4,811 trees (93.4%) had vigor ratings corresponding to 'healthy' and 'light decline' (vigor 1 and 2, respectively) and 338 trees (6.6%) were in 'moderate' to 'severe decline' (vigor 3 and 4, respectively).

Figure 7. Percentage of trees with a 'poor vigor rating' sampled in 2021 across the six states in the FEMC Forest Health Monitoring plot network where at least 10 individuals of each species were measured. Percent poor vigor is the proportion of trees per species that were classified to be 'in decline' (vigor ratings of 3 or 4).



For tree species with more than 10 individuals measured, crown health assessments show black cherry with lower vigor rating (average vigor of 2, where 1 is healthy and 4 is severe decline), and average crown dieback of 13%, and defoliation of 0.8 (where 0 is no defoliation to trace defoliation and 1 is <30% defoliation). Two other species of concern were gray birch with vigor 1.5, dieback 11%, and defoliation of 1.2, and paper birch with vigor 1.4, dieback 10%, and defoliation of 0.8.

The overstory trees with the highest average rates of moderate or severe decline were black cherry (7.1%), American beech (4.4%), balsam fir (2.9%), gray birch (2.9%), and eastern red cedar (*Juniperus virginiana*; 2.3%). Across all species, <2% of total live stems surveyed were determined to be in severe decline. Overall, this points to a healthy, vigorous population of trees in the sampled plots.

Across all live trees, the average fine twig dieback was 8.2%. Black cherry had the highest mean dieback at 13.3%, while black oak (*Quercus velutina*) and quaking aspen (*Populus tremuloides*) had 12.4% and 12.1% mean dieback, respectively (Table 7). These values do not suggest widespread crown health issues, but certain species or genera (e.g., oaks) should continue to be monitored for widespread changes in dieback over time.

Table 7. Crown health metrics from live trees in 2021 across the FEMC FHM plot network where at least 10 individuals of each species were measured. Percent poor vigor is the proportion of trees per species that were classified to be ‘in decline’ (vigor ratings of 3 or 4). Dieback and transparency recorded in bins of 5% intervals. Discoloration and defoliation are estimates associated with the class assignment (Table 3). For example, a species with a mean discoloration rating of 0.5 will be between class 0 (none to trace discoloration) and class 1 (<30% discoloration). Percent class is based on the mean discoloration and defoliation. Species are ranked by % poor vigor.

	Poor Vigor	**Dieback (%)**		**Transparency (%)**		**Discoloration** (0-3)			**Defoliation** (0-3)		
Species	%	*mean*	*median*	*mean*	*median*	*mean*	*median*	*% Class*	*mean*	*median*	*% Class*
black cherry	33	13	10	26	25	0.1	0	none to trace	0.8	1	none to trace
quaking aspen	25	12	10	24	25	0.2	0	none to trace	0.1	0	none to trace
American mountain-ash	17	8	5	21	20	0.2	0	none to trace	0.5	0.5	none to trace
American beech	15	11	8	22	20	0.2	0	none to trace	0.5	0	none to trace
gray birch	11	11	10	28	25	0.2	0	none to trace	1.2	1	<30%
black oak	10	12	10	21	20	0	0	none to trace	0.3	0	none to trace
paper birch	9	10	10	24	25	0.3	0	none to trace	0.8	1	none to trace
northern red oak	8	9	10	20	20	0.1	0	none to trace	0.7	0	none to trace
red maple	6	8	5	19	20	0.2	0	none to trace	0.6	1	none to trace
yellow birch	6	7	5	20	20	0.1	0	none to trace	0.7	1	none to trace
white oak	5	7	5	19	20	0.2	0	none to trace	0.7	1	none to trace
white ash	5	8	5	21	20	0	0	none to trace	0.3	0	none to trace
black birch	5	7	5	20	20	0.1	0	none to trace	0.5	0	none to trace
green ash	3	7	5	23	25	0	0	none to trace	0.3	0	none to trace
sugar maple	2	7	5	18	20	0.1	0	none to trace	0.5	0	none to trace
All hardwood	**7**	**8**	**5**	**20**	**20**	**0.1**	**0**	**none to trace**	**0.6**	**1**	**none to trace**
balsam fir	7	10	5	17	15	0.1	0	none to trace	0	0	none to trace
eastern redcedar	7	10	10	21	20	0.1	0	none to trace	0	0	none to trace
eastern hemlock	7	7	5	19	20	0.1	0	none to trace	0	0	none to trace
eastern white pine	5	8	5	20	20	0.1	0	none to trace	0	0	none to trace
northern white-cedar	4	8	5	18	15	0.2	0	none to trace	0	0	none to trace
pitch pine	3	7	5	19	20	0.3	0	none to trace	0	0	none to trace
red spruce	2	7	5	17	15	0	0	none to trace	0	0	none to trace
All softwood	**3**	**8**	**5**	**18**	**15**	**0.1**	**0**	**none to trace**	**0**	**0**	**none to trace**
All live trees	**7**	**8**	**5**	**19**	**20**	**0.1**	**0**	**none to trace**	**0.4**	**0**	**none to trace**

Across all live trees, average foliar transparency ranged from 17% to 28% (Table 7). Transparency is rated the same way across all species; however, each species has a different range of commonly observed transparency ratings due to the general structure of each species crown. Black cherry and gray birch had mean transparency >25%.

Foliar discoloration impacted pitch pine the most with a mean discoloration estimate of 0.3 (Table 7), which indicates pitch pine exhibited zero to trace discoloration on average. Only slightly higher than all other species measured, which averaged a discoloration score of 0.1 (zero to trace discoloration on average). Since some monitoring occurred in early September, it is possible that some of the deciduous species' leaves were beginning to change color, particularly for black gum (*Nyssa sylvatica*), which is known to begin the senescence process early. It is possible that the eastern hemlock discoloration noted was related to hemlock woolly adelgid infestations, but our data cannot confirm this.

Defoliation rates were highest among gray birch with mean defoliation rates above 1 (defoliation class <30%; Table 7). Nearly every species saw some level of defoliation, with minimal defoliation recorded on softwood species. In several plots, we observed spongy moth caterpillars and egg masses on the trunks of trees.

Agents of change: tree damage, browse, and invasive plants

In 2021, damage related to beech bark disease (BBD) was the most common damage agent recorded across plots. In total, 38% of the plots (58) were impacted by BBD and approximately 73% of live American beech trees showed symptoms of the disease (Table 8). Another prevalent damage was crack and seam, which occurs when a tree splits due to weather. This damage was present on 56% of plots (87) and impacted 4% of trees (Table 8). Asian long-horned beetle, emerald ash borer, hemlock woolly adelgid, and sapsucker damage was observed on <1% of trees. Of the other damages recorded, "other canker", was the most common damage category. Evidence of browse was recorded on 85% of plots (130), which may impact regeneration success. For invasive species, we found 4% of plots (6) with buckthorn (*Rhamnus cathartica* or *Frangula alnus*) present, 3% of plots (5) containing honeysuckle (*Lonicera spp.*), and 1% of plots (2) containing barberry (*Berberis spp.*).

Table 8. Special damages recorded on live trees across the 154 FEMC FHM plots in 2021. Damages are shown as the percent affected per species and damage type. Note that not all damages were recorded if damages were not obvious or visible from the ground. For example, many eastern hemlock trees that were surveyed appeared discolored and showed symptoms of hemlock woolly adelgid (HWA), but often we cannot confirm the presence of HWA.

Species	Live trees	Asian long-horned beetle (%)	Beech bark disease (%)	Crack and seam (%)	Emerald ash borer (%)	Hemlock woolly adelgid (%)	Sapsucker (%)	Other damages (%)	Damage recorded (%)
alders	1							100	100
pin cherry	1							100	100
American beech	364		73	<1				2	81
striped maple	18			38				22	55
green ash	29			6	24				27
quaking aspen	55			16				12	27
eastern redcedar	86			15				5	18
northern white-cedar	45			15				17	17
bigtooth aspen	13			7				7	15
paper birch	92			6				7	14
pitch pine	29						3	10	13
red maple	851			5				8	13
white ash	79			6	6			2	12
sugar maple	561			3			<1	7	12
American mountain-ash	18			5				5	11
yellow birch	375			4				5	10
black birch	193			4				5	10
mountain paper birch	10			10					10
balsam fir	559			3			<1	4	9
black cherry	42							7	7
eastern hemlock	441			1		1	2	1	6
red spruce	398			4			<1	2	6
blackgum	17							5	5
black oak	41							4	4
eastern hophornbeam	21						4		4
northern red oak	320			1			<1	<1	3
eastern white pine	347			<1				1	2
gray birch	35			2					2
white oak	55							1	1
All live trees	**5,149**	**0**	**5**	**4**	**<1**	**<1**	**<1**	**5**	**15**

Tree regeneration

Saplings

Thirteen (13) out of 154 plots did not contain any saplings within the plot's four microplots. There were 907 living saplings across the remaining 140 plots, with 496 stems per acre (SPA). The sapling layer displayed the lowest species diversity of the three strata (trees, saplings, seedlings). Across all plots, there were 33 different species recorded in the sapling plots, compared to 47 tree species and 43 seedling species. The number of sapling species recorded per plot ranged from 0 to 6. We found that balsam fir (28% of the total sapling composition, 124 SPA), American beech (19%, 19 SPA), and red spruce (15%, 15 SPA) where the most abundant species in the sapling layer (Table 9). American beech stems were likely suckers based on their small size (Figure 6) and due to the prevalence of BBD on mature trees (see Agents of Change section).

Table 9. Sapling composition from the FEMC FHM regeneration microplots in 2021 including total stems (N), saplings per acre (SPA), percent composition (%) of sapling layer, and basal area per acre (BA, ft^2/ac). Information for the aggregate for all species sapling data is shown in the last row.

Species	Live saplings	SPA	BA	%
balsam fir	227	124	3.4	28
American beech	155	85	1.9	19
red spruce	122	67	1.8	15
red maple	54	30	1	7
yellow birch	37	20	0.6	5
sugar maple	32	18	0.5	4
striped maple	29	16	0.5	4
eastern hemlock	26	14	0.4	3
white spruce	22	12	0.3	3
eastern hophornbeam	21	11	0.3	3
black birch	18	10	0.3	2
eastern white pine	17	9	0.3	2
white oak	6	3	0.1	0.8
northern red oak	5	3	0.1	0.6
black cherry	4	2	0.1	0.5
green ash	3	2	<0.1	0.4
mountain maple	3	2	<0.1	0.4
white ash	3	2	<0.1	0.4
American elm	2	1	<0.1	0.3
American mountain-ash	2	1	0.1	0.3
Other hardwood	8	4	0.1	1
Other softwood	3	2	0.1	0.4
All species	**799**	**437**	**11.8**	**100**

Seedlings

In total, 43,882 seedlings (<1-inch DBH) were tallied within the FEMC FHM regeneration microplots in 2021. Of all seedlings counted, 85% (37,295) were classified as class 1 (hardwood seedlings <12 inches tall and softwood seedlings <6 inches tall) while 15% (37,295) were classified as class 2 (more established with hardwood ≥12 and softwood ≥6 inches tall). Seedling counts per plot ranged from 6 seedlings to 2,553 seedlings per plot. There was an average density of 24,003 stems per acre (SPA) across the entire 154-plot network in 2021.

Seedling diversity was high within microplots with seedlings identified to a total of 34 species, and 9 genera where species identification was not clear. Species diversity per plot ranged from one to 12 unique species, and there did not appear to be a relationship between the number of species of overstory trees and the number of species in the understory (paired t-test using R; $t(153) = 0.66995$, $p = 0.5039$).

Red maple was the most abundant seedling tallied in 2021 (24%, 5,741 SPA), followed by sugar maple (22%, 5,347 SPA), and balsam fir (12%, 2,810 SPA; Table 10). Seedling densities are subject to yearly shifts due to changing weather conditions (e.g., available precipitation), herbivory, and seed availability (e.g., masting events). Therefore, it will become increasingly valuable to assess shifts in composition and density over multiple years while tracking regeneration success.

Table 10. Seedling composition across FEMC FHM plots in 2021 showing total seedling (<1 inch DBH) count as well as class 1 (hardwood <12 inches tall, softwood <6 inches tall) and the more established class 2 (hardwood ≥12 inches tall, softwood ≥6 inches tall). Average density of stems per acre (SPA) and percent composition (%) of the seedling layer is also included.

Species	Seedling count	Class 1	Class 2	SPA	%
red maple	10,496	9,956	540	5,741	24
sugar maple	9,776	9,473	303	5,347	22
balsam fir	5,138	3,526	1,612	2,810	12
striped maple	4,475	3,909	566	2,448	10
American mountain-ash	3,283	3,255	28	1,796	7
eastern white pine	2,263	1,857	406	1,238	5
American beech	1,641	773	868	898	4
red spruce	1,177	638	539	644	3
yellow birch	688	527	161	376	2
northern red oak	615	507	108	336	1
eastern hemlock	470	170	300	257	1
black birch	333	217	116	182	0.8
black cherry	290	211	79	159	0.7
eastern hophornbeam	283	178	105	155	0.6
mountain maple	271	189	82	148	0.6
white spruce	238	17	221	130	0.5
white oak	152	118	34	83	0.3
green ash	123	85	38	67	0.3
eastern redcedar	120	29	91	66	0.3
white ash	111	75	36	61	0.3
quaking aspen	82	46	36	45	0.2
northern white-cedar	76	8	68	42	0.2
black oak	31	26	5	17	0.1
bitternut hickory	30	10	20	16	0.1
gray birch	29	23	6	16	0.1
Other hardwood	1,683	1,466	217	920	1
Other softwood	8	6	2	5	<0.1
All species	**43,882**	**37,295**	**6,587**	**24,003**	**1**

Conclusions

Annual monitoring of forests can provide valuable insights into subtle changes in the forest condition due to protracted weather (e.g. drought), and stress conditions (e.g. low-level pests and pathogens), as well as subtle changes in composition and health due to longer-term changes in climate. Assessments of crown health can provide early warning signs of subtle or pervasive stressors, while the understory condition can indicate what the future forest may look like. As the FEMC FHM program continues, and more annual measurements are collected, we can begin to assess emerging trends in forest health, particularly changes in seedling and sapling survivorship from year-to-year and changes in crown health that may signal chronic decline issues. These insights may prove important as managers look to ensure that forests remain healthy, productive, and resilient in the future.

While there is a wide range of stressors affecting northeastern forests, and significant vulnerabilities do exist, early indicators suggest these forests are diverse, vigorous, and healthy. Species diversity was evident across all three strata (overstory trees, saplings, and seedlings), although it was lowest in the sapling layer. On average, the overstory trees were vigorous with healthy crowns. Despite widespread spongy moth outbreak in southern New England, defoliation of oaks was <30%. While regeneration was evident in all plots, twelve plots did not contain saplings, which warrants ongoing monitoring and investigation.

Data

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Appendix

Table A1: List of special damages to trees in the FEMC Forest Health Monitoring program (Wilmot et al. 2019).

Bole Damage Code	Bole Damage Agent
Animal Damage	
441	Animal browse
444	Beaver damage
445	Porcupine damage
446	Sapsucker damage
447	Other animal damage
Borers and Insects	
707	Asian long-horned beetle
101	Balsam woolly adelgid
104	Beech bark scale only
111	Defoliation >20%
103	Hemlock woolly adelgid
710	Sirex wood wasp
108	Sugar maple borer
110	Other bark beetles
711	Emerald ash borer
109	Other borers
Cankers Conks and Diseases	
106	Beech bark disease symptoms
201	Butternut canker
206	European larch canker
203	Eutypella canker
204	Hypoxylon canker
202	Nectria canker
207	Other canker
208	Conks and other indicators of decay
209	Dwarf mistletoe
210	White pine blister rust
Human-related	
702	Logging damage > 20% of circumference
Weather-related	
708	Cracks and seams
501	Wind-thrown/uprooted
505	Other weather damage

Table A2: List on invasive plants and their codes for the Forest Health Monitoring program (Wilmot et al. 2019).

Code	Common name	Scientific name
1	Barberry: Japanese or common	*Berberis thunbergii, B. vulgaris*
2	Buckthorn: common or glossy	*Rhamnus cathartica, Frangula alnus*
3	Bittersweet: oriental	*Celastrus orbiculatus*
4	Honeysuckle: bell, Japanese, amur, Morrow or tartarian	*Lonicera* X *bella, L. japonica, L. maackii, L. morrowii, L. tatarica*
5	Multiflora rose	*Rosa multiflora*
6	Norway maple	*Acer platanoides*
7	Autumn or Russian olive	*Elaeagnus umbellate, E. angustifolia*
8	Japanese knotweed	*Fallopia japonica (Polygonum cuspidatum)*
9	Garlic mustard	*Alliaria petiolata (A. officinalis)*
10	Privet	*Ligustrum vulgare*
11	Tree of heaven	*Ailanthus altissima*
12	Wild chervil (cow parsnip)	*Anthriscus sylvestris*
13	Burning bush or winged euonymus	*Euonymus alatus*
14	Goutweed	*Aegopodium podagraria*
15	Amur maple	*Acer ginnala*
99	Other	

Table A3. Percentage of special damages recorded on live trees across the six states in the 154 FEMC FHM plots in 2021. Damages are shown as the percent affected per species per state. Note that not all damages were recorded if damages were not obvious or visible from the ground. For example, many eastern hemlock trees that were surveyed appeared discolored and showed symptoms of hemlock woolly adelgid (HWA), but often we cannot confirm the presence of HWA.

Species	***Regional***	***CT***	***MA***	***ME***	***NH***	***RI***	***VT***
red maple	13	10	12	13	13	15	16
sugar maple	12	7	2	12	5		18
balsam fir	9			5	5		13
eastern hemlock	6		8	11	1		8
red spruce	6		8	9	8		3
yellow birch	10		6	4	5	50	18
American beech	81	86	61	96	82	50	80
eastern white pine	2		<1	1	1	29	
northern red oak	3	3	4	2	2		5
black birch	10	11	6	18		16	6
paper birch	14		6	27	10		14
eastern redcedar	18			18			
white ash	12		3		8	16	40
quaking aspen	27		100	28	66		
northern white-cedar	17			18			
black cherry	7		7				10
black oak	4		4			100	
gray birch	2			16			
green ash	27			8	53		
eastern hophornbeam	4			20			
American mountain-ash	11						22
striped maple	55			81			20
blackgum	5					20	
bigtooth aspen	15			9			50
alders	100		100				
pin cherry	100				100		

FEMC

Forest Ecosystem Monitoring Cooperative

VERMONT AGENCY OF NATURAL RESOURCES

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