REGIONAL FOREST HEALTH MONITORING PROGRAM

2022 Report

Forest Ecosystem Monitoring Cooperative

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Regional Forest Health Monitoring Program: 2022 Report

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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 also can help ensure the sustained provisioning of key ecosystem services in the face of a changing climate.

By the 2022 field season, the Forest Ecosystem Monitoring Cooperative (FEMC) had worked with state partners in Connecticut, Maine, New Hampshire, Massachusetts, New York, and Rhode Island to expand the Forest Health Monitoring (FHM) network outside of Vermont to include permanent plots in each of the seven northeastern states. In most cases, 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 existing FIA or CFI plots.

In 2022, FEMC visited 193 plots from CT (15), MA (23), ME (35), NH (25), NY (39), RI (7), and VT (49). Results from the 2022 monitoring season indicate that the most abundant species across the 193-plot network are red maple (*Acer rubrum*; 17%), sugar maple (*Acer saccharum*; 13%), and balsam fir (*Abies balsamea*; 10%). From the 6,624 trees (≥5 inch DBH) measured, average live overstory tree density in 2022 was 180 stems per acre (SPA) and 127 ft^2/ac basal area. Regeneration assessments show sapling densities of 486 live SPA with balsam fir and American beech (*Fagus grandifolia*) representing the most abundant species. Red maple was the most abundant seedling tallied in 2022 (20% composition, 3,782 SPA), followed by sugar maple (16%, 2,979 SPA), and balsam fir (15%, 2,810 SPA; Table 10).

While there is a wide range of stressors and vulnerabilities impacting northeastern forests, data from the 2022 season suggest that the region's forests are overall diverse, vigorous, and healthy. However, there were notable exceptions that should continue to be monitored. From the 2022 crown health assessments, we identified black oak (*Quercus velutina*), quaking aspen (*Populus tremuloides*), and bigtooth aspen (*Populus grandidentata*) as species of concern. Average vigor ratings for these species were 1.8, 1.7, and 1.5 respectively, where 1 is healthy and 4 is severe decline (Table 2) and defoliation ratings were 0.8, 0.3, and 0.7, respectively, 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 12%, 15%, and 8% of the tree crown, respectively. With the recent spongy moth outbreaks across the Northeast, we recorded 10% of oaks with >30% defoliation. Seedling regeneration (Table 10) was also sparse for pitch pine (*Pinus rigida*; 0 SPA), slippery elm (*Ulmus rubra*; 0 SPA), and shagbark hickory (*Carya ovata*; 1 SPA). 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, each measuring 7.32 m (24 feet) 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 (Gillespi, 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 more detailed 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 spanning Vermont's forest types and biophysical regions between 1991 and 2018. 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 FEMC 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 expanded 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 and private lands to add to its annual FHM network. In 2020 and 2021 the FEMC expanded to CT (15 plots), RI (7 plots), ME (35 plots), NH (25 plots), and NY (39 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 and private 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 2022 FEMC FHM field season.

Methods

Plot selection

All plots were in place prior to the 2022 season (Figure 1). Previous reports can be referenced for a more detailed look at how those plots were selected and established (Wilmot et al. 2019; Sirch et al. 2020; Porter et al. 2022).

In expanding the FHM Network, FEMC opted to create a sampling concentration similar to the plot network in Vermont. FEMC partnered with various organizations and agencies within each of the seven regional states to gather existing long-term monitoring plot information. Nesting FHM plots on top of or adjacent to these existing networks when available allows for temporal comparisons of metrics monitored at the site.

While 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.

The final plot selections were then sent to state partners for review, and 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 feed-back from the field crew and review of the data.

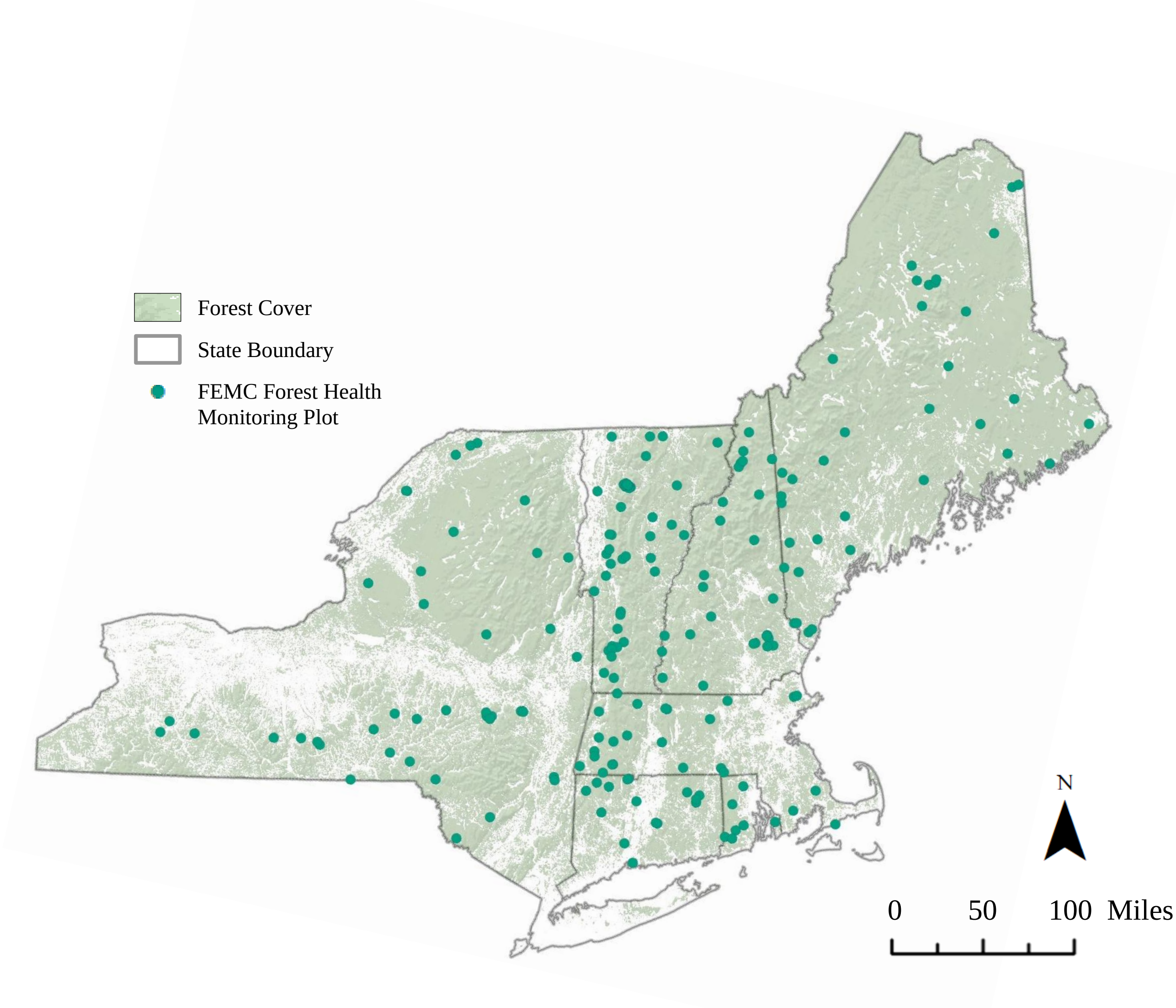

Figure 1. One hundred and ninety-three (193) plot locations of the FEMC Forest Health Monitoring program in 2022.

Plot layout

Clustered (FIA) Style

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

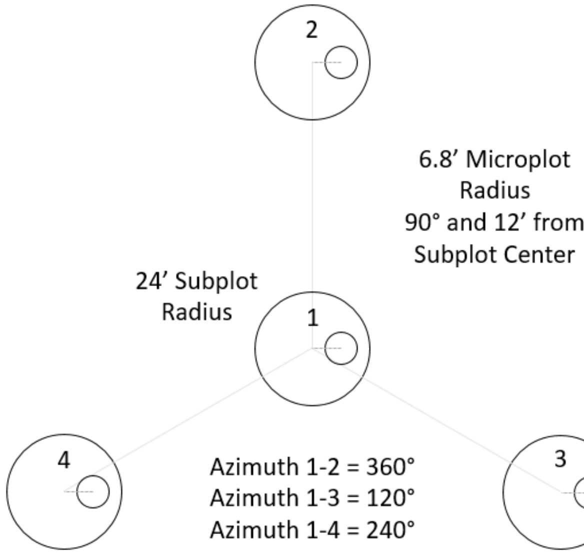

Figure 2. Layout of Clustered-Style FIA and FEMC FHM plots showing the 4 clustered sub-plots and four regeneration micro-plots within each.

Larger Nested (CFI) Plot Style

Connecticut, Massachusetts, Maine, and New York FHM plots are laid out based on the larger nested style. The large plot style consists of one large overstory plot, with a radius of 52.7 feet and area of 8,725.11 ft^2, and four nested regeneration microplots each with a radius of 6 feet and an area of 113.1 ft^2 (Figure 3). The four regeneration microplots are 26 feet 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 the plots with fiberglass or wooden dowel stakes.

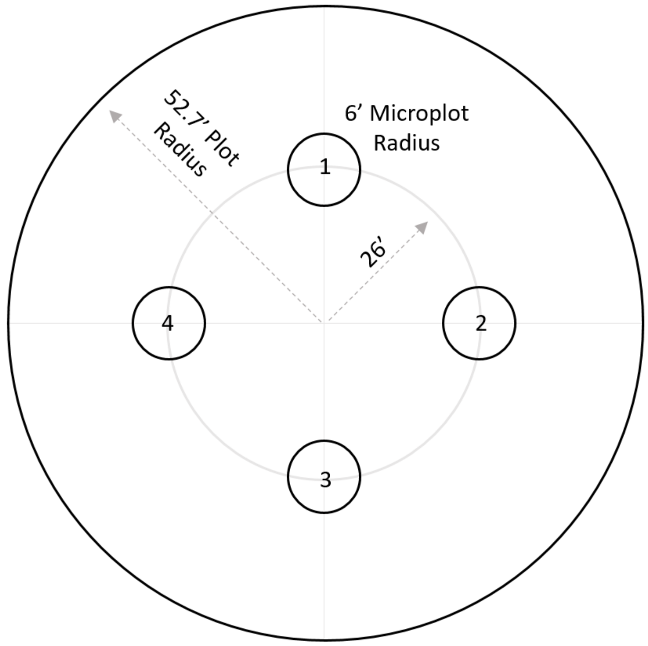

Figure 3. Layout of Nested-Style CFI and FEMC FHM plots showing the overstory plot (large circle) and four nested regeneration micro-plots (small circles at cardinal directions; MA DCR 2014).

Field metrics

In 2022 FEMC inventoried all 193 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 subplots. Other metrics, like animal browse, invasive plants, and forest composition (prism plots) were collected at the overstory plot level. Detailed methods for 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 are to 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 this damage assessment is not comprehensive and some damages may not have been recorded if they were not obvious to a technician from the ground. Damage categories assessed included: 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 9 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 were recorded as vigors 5, 6, 7 and 8. Vigor was assessed on all trees in the overstory plot. 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 and standing, natural caused; tree is dead and still standing ; phloem under bark has brown streaks; few epicormic shoots may be present on the bole; record the dead tree's height and DBH.
6	Dead and down, human caused; tree cut, or removed. Only record vigor/status
7	Dead and standing, human caused; tree is standing dead and there are signs of human cause (i.e. girdled or damaged by equipment). Record DBH and height
8	Dead and down, natural caused: tree is dead and on the ground or a snag less than 4.5' (DBH). Only record vigor/status.
9	Missing: Tree cannot be located, Only record vigor/status.

Crown health assessments

Ocular crown health assessments were conducted on all trees inventoried in the fixed radius overstory plot. Prior to the field season, training and calibration of crew members conducting crown health assessments were led by Vermont Forest Parks and Recreation (FPR) forest health specialists to ensure standardization of ratings from year-to-year. Assessments were conducted by two trained technicians using binoculars to distinguish seeds from leaves and detect the presence of insect defoliation. When the technicians conducting crown health assessments disagree on the rating, they discussed the estimates and moved around the tree to view it from different angles until an agreement could 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 was 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 0-5% dieback it was 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 outer* branches where dieback is likely a result of stress and not due to self- pruning or shading (Figure 3).

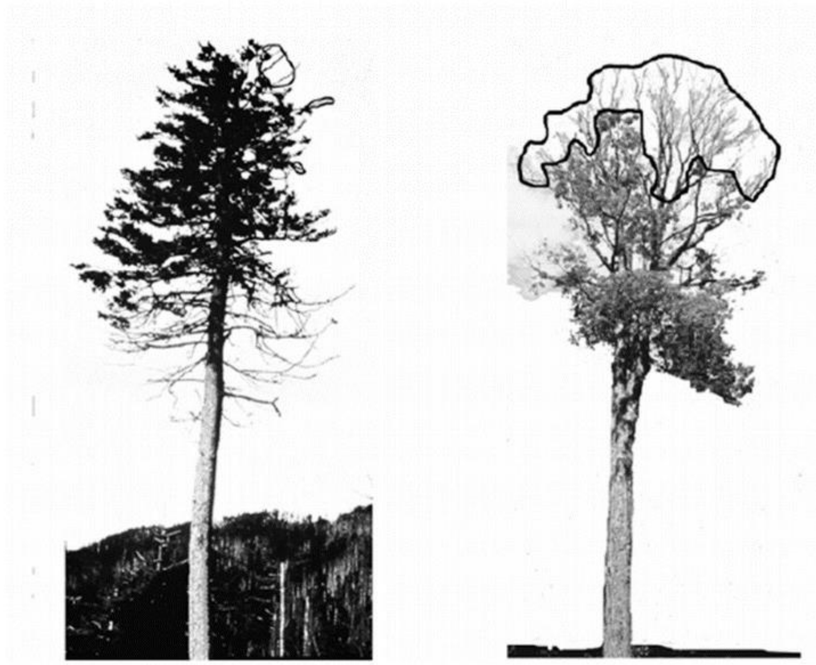

Figure 4. Crown dieback rating outline examples (Randolph, 2010). Dieback of left tree: 5%. Dieback of right tree: 30%. Note that self-pruning of lower branches is not included in the assessment.

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 were not included. Defoliation was 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 was estimated in the same four percentage classes as defoliation (Table 3). Only foliated portions of the crown were assessed. Foliage was considered discolored when the overall appearance of a leaf is more yellow, red, or brown than green (Wilmot et al. 2019). Binoculars were strongly 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 was 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 in 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). 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.

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

Forest composition

A 10 basal area factor wedge prism was used to assess the forest composition of the larger forest stand. The prism is 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.

Data entry, quality control, and analysis

Data were collected on paper field forms and entered into a custom online browser based web form following field collection. All paper field forms were scanned and digitally archived. Original physical copies were also retained. The online web form was designed by FEMC web developers to allow for transition to electronic data collection in the field as well as provide quality control to reduce data entry errors. The online web form was built using the open source ODK standard and hosted on an open source ODK server implementation. A custom REST component was also developed allowing data to be automatically submitted to FEMC servers and databases.

Quality assurance

Standard field quality assurance (QA) was performed on field data collection for 10% of plots assigned to each field crew regionally. In other words, 10% of the plots assigned to each regional field crew were chosen for QA field visits to check 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 were re-collected for a randomly selected subplot. A QA subplot was said to have failed the data-entry QA protocol if more than 10% of its metrics were 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 new protocols were followed to ensure accuracy of data entry via the online data entry tool. Quality checks were built into the form to identify erroneous errors, typos, large changes to metrics from previous years' data, and duplicate entries. The following are a few examples of features implemented that act as quality control:

- A technician enters a new tree found on the plot as ingrowth (a sapling has become a tree) but enters a DBH of 12.5cm. The form highlights the DBH with an error warning stating that the minimum DBH of a tree must be 12.7cm or greater to be considered a tree.
- A technician enters a DBH of a tree that is smaller than last year's tree. A warning message appears and asks the user to double check the measurement.

The online and paper forms also show previous years' data so the technicians collecting and entering data can compare their data in real time to check for typos and errors.

Following the automated quality checks, we identified any outlier data that needed to be reviewed once everything had been submitted to our database. These outliers were identified by querying the data for any measurements outside of a typical range for that metric. These standards were based on the database QA procedures from the VT FEMC FHM program.

The following queries were run on the data:

- Tree heights that exceeded 35 m in total
- DBH measurements greater than 75cm
- 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
- Plot, seedling, sapling, tree, and prism counts compared to previous years' data
- Checking for major changes in dieback, transparency, or other crown health metrics from previous year
- Additional queries to check that spatial measurements were within the plot boundaries, including tree and sapling distance from plot center and azimuths that exceeded the range of 0-360 degrees

Where outliers or errors were found, 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 2022 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 a 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 2022, FEMC FHM crews measured 6,455 live trees, 1,091 saplings, and tallied 42,233 seedlings across the 193 FEMC FHM plots. Below, we provide summaries of these data.

Overstory composition

We found that species composition across the 193 plots was similar to the state-wide composition for each state, according to FIA data (USFS 2021, Figure 5).

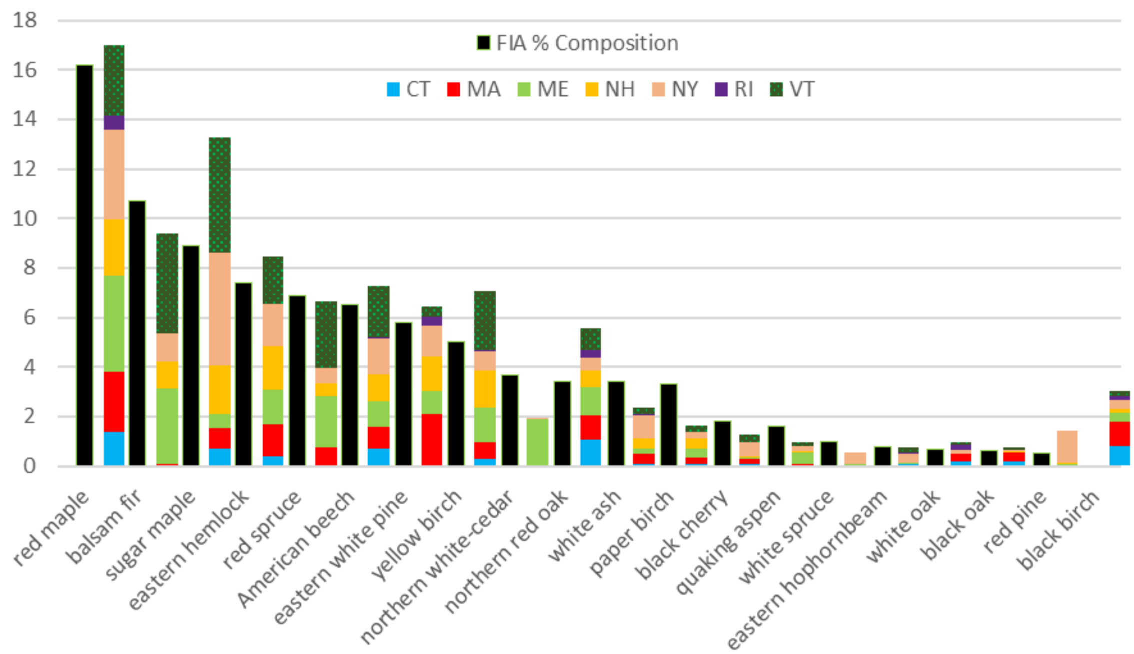

Figure 5. Percent live species composition for CT, MA, ME, NH, NY, RI, and VT from the FEMC Forest Health Monitoring plots from the 2022 season alongside FIA estimates of live growing stock (≥5 inch DBH; USFS 2021).

Across the 193 FEMC FHM plots, there were a total of 6,455 live and 122 standing dead trees (though it is important to note that dead trees are removed from the datasheets after 5 years and are not re-recorded). For live trees, this equated to an average of 180 live stems per acre (SPA) and basal area (BA) of 127 ft^2/ac basal area. Standing dead trees averaged 3 SPA and a BA of 2 ft^2/ac. The total BA (live and standing dead) was 129 which may be too high to encourage regeneration, especially for shade-intolerant species. Only 2% of standing trees sampled were dead snags.

Across the survey area, hardwoods comprised 65% of the total overstory composition by live stem count. Red maple represented the greatest live SPA (30), followed by sugar maple (24 SPA) and balsam fir (17 SPA; Table 6). Red maple also had the highest live Importance Value with an IV of 15.2% and BA of 17 ft^2/ac across all plots. Sugar maple had the second highest live IV (13.3%) with a BA of 17 ft^2/ac, followed by eastern hemlock (*Tsuga canadensis*; 9.1%, BA 12 ft^2/ac) and eastern white pine (*Pinus strobus*; 8.9%, BA 14 ft^2/ac).

Table 6. Overstory composition of trees from the FEMC FHM plot network in 2022 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	1089	19	30	17	0	15
sugar maple	853	9	24	17	13	13
eastern hemlock	542	9	15	12	8	9
eastern white pine	415	28	12	14	6	9
northern red oak	356	7	10	14	6	8
yellow birch	449	5	13	9	7	7
balsam fir	602	34	17	5	9	7
red spruce	424	15	12	7	7	6
American beech	466	12	13	6	7	6
black birch	193	1	5	3	3	3
white ash	150	3	4	3	2	2
red pine	92	0	3	3	1	2
northern white-cedar	121	2	3	2	2	2
black cherry	78	3	2	2	1	1
paper birch	105	4	3	1	2	1
quaking aspen	60	8	2	2	<1	1
white oak	59	1	2	1	<1	1
black oak	43	2	1	1	<1	<1
white spruce	35	1	<1	<1	<1	<1
American basswood	27	0	<1	<1	<1	<1
bigtooth aspen	31	1	<1	<1	<1	<1
eastern hophornbeam	42	0	1	<1	<1	<1
shagbark hickory	23	0	<1	<1	<1	<1
green ash	27	1	<1	<1	<1	<1

gray birch	28	0	<1	<1	<1	<1
Other hardwood	<1	2	<1	1	1	1
Other softwood	<1	2	<1	1	<1	<1
Total	6,455	169	180	127	100	100

The distribution of size classes across the FEMC FHM plot network in 2022 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 of eastern white pine (*Pinus strobus*), northern red oak (*Quercus rubra*), and eastern hemlock (*Tsuga canadensis*). As these stands continue to age, we can expect to see the number of large stems increase, particularly for late successional species such as eastern hemlock and sugar maple (Figure 6).

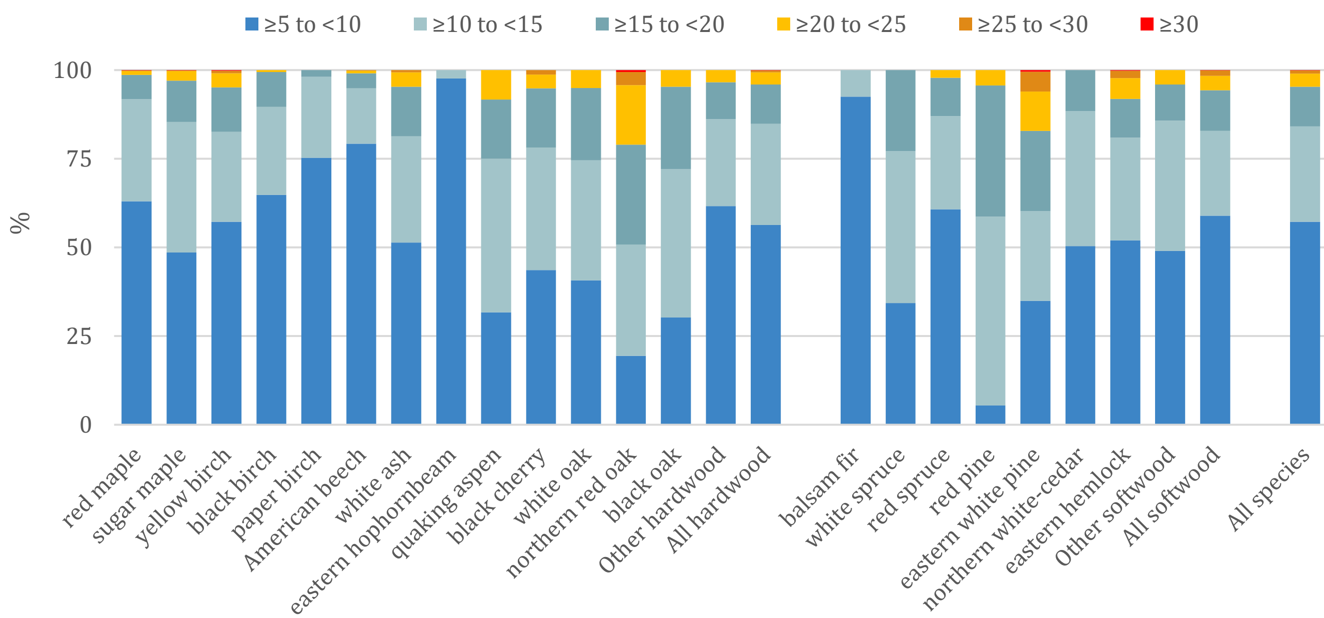

Figure 6. Size classes of live trees by diameter at breast height (DBH; inches) across the FEMC FHM plot network in 2022.

Tree health

Across the 193 FEMC FHM plots assessed in 2022, live tree vigor (mean ± SD) was 1.3 ± 0.6, or between 'healthy' and 'light decline.' Of live trees measured, we found that 6,093 trees (94.4%) had vigor ratings corresponding to 'healthy' and 'light decline' (vigor 1 and 2, respectively) and 362 trees (5.6%) were in 'moderate' to 'severe decline' (vigor 3 and 4, respectively).

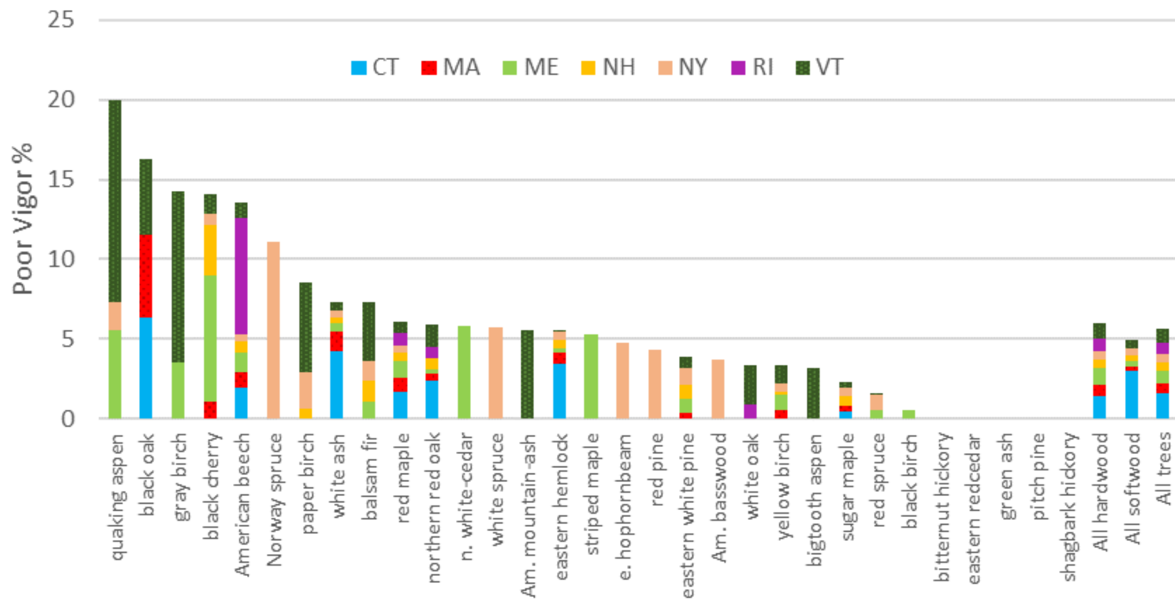

Figure 7. Percentage of trees with a 'poor vigor rating' sampled in 2022 across the seven states in the FEMC Forest Health Monitoring plot network where at least 10 individuals of each species were measured. Percent poor vigor is the proportion of live trees per species that were classified to be 'in decline' (vigor ratings of 3 or 4).

For tree species with more than 10 individuals measured, crown health assessments show black oak with lower vigor rating (average vigor of 1.8, where 1 is healthy and 4 is severe decline), average crown dieback of 12%, and defoliation of 0.8 (where 1 is less than 30 percent crown defoliated and 2 is 30-60% defoliation). Two other species of concern were quaking aspen with vigor 1.7, dieback 15%, and defoliation of 0.3; and bigtooth aspen with vigor 1.5, dieback 8%, and defoliation of 0.7. These numbers do not indicate an urgent concern, but that these species may be more vulnerable to threats and should be monitored closely in future years.

The overstory trees with the highest average rates of moderate or severe decline were gray birch (*Betula populifolia*; 7.1%), eastern hophornbeam (*Ostrya virginiana*; 4.8%), paper birch (*Betula papyrifera*; 4.8%), northern white-cedar (*Thuja occidentalis*; 4.1%), and American beech (4.1%) (Figure 7). 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 8.5%. Quaking aspen had the highest mean dieback at 15.1%, while black cherry (*Prunus serotina*) and black oak had 12.6% and 12.2% 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 2022 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 categories 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*
quaking aspen	20	15	10	28	25	0.3	0	0 to trace	0.3	0	0 to trace
black oak	16	12	10	26	20	0	0	0 to trace	0.8	1	0 to trace
gray birch	14	11	5	26	25	0.2	0	0 to trace	0.3	0	0 to trace
black cherry	14	13	10	24	25	0.1	0	0 to trace	0.4	0	0 to trace
American beech	14	12	5	24	20	0.2	0	0 to trace	0.3	0	0 to trace
paper birch	9	10	5	24	25	0.2	0	0 to trace	0.5	0	0 to trace
white ash	7	10	5	24	25	0	0	0 to trace	0.3	0	0 to trace
red maple	6	9	5	22	20	0.2	0	0 to trace	0.5	0	0 to trace
northern red oak	6	9	5	25	20	0.1	0	0 to trace	0.6	0	0 to trace
Am. mountain-ash	6	10	10	22	22.5	0.2	0	0 to trace	0.3	0	0 to trace
striped maple	5	7	5	19	15	0.2	0	0 to trace	0.4	0	0 to trace
e. hophornbeam	5	8	5	20	20	0	0	0 to trace	0.5	0	0 to trace
Am. basswood	4	10	10	19	20	0	0	0 to trace	0.7	1	0 to trace
white oak	3	8	5	19	20	0.1	0	0 to trace	0.6	1	0 to trace
yellow birch	3	7	5	20	20	0.1	0	0 to trace	0.7	1	0 to trace
bigtooth aspen	3	8	5	27	25	0.1	0	0 to trace	0.7	1	0 to trace
sugar maple	2	7	5	19	20	0.2	0	0 to trace	0.4	0	0 to trace
black birch	1	6	5	19	20	0	0	0 to trace	0.4	0	0 to trace
All hardwood	6	9	5	22	20	0.2	0.2	0 to trace	0.5	0	0 to trace
Norway spruce	11	11	5	21	20	0	0	0 to trace	0.2	0	0 to trace
balsam fir	7	9	5	17	15	0.1	0	0 to trace	0	0	0 to trace
N. white-cedar	6	9	5	26	25	0.3	0	0 to trace	0	0	0 to trace
white spruce	6	10	5	17	15	0	0	0 to trace	0	0	0 to trace
eastern hemlock	6	9	5	21	20	0.1	0	0 to trace	0.2	0	0 to trace
red pine	4	9	5	19	15	0	0	0 to trace	0	0	0 to trace
eastern white pine	4	8	5	21	20	0.1	0	0 to trace	0	0	0 to trace
red spruce	2	7	5	19	20	0.1	0	0 to trace	0.1	0	0 to trace
All softwood	**3**	**8**	**5**	**20**	**20**	**0.1**	**0.1**	**0 to trace**	**0.1**	**0**	**0 to trace**
All live trees	**6**	**9**	**5**	**21**	**20**	**0.1**	**0**	**none to trace**	**0.3**	**0**	**none to trace**

Across all live trees, average foliar transparency ranged from 17% to 28% (Table 7). Transparency was rated the same way across all species, however, each species has a slightly different range of commonly observed transparency ratings due to the general structure of each species crown, which may explain certain discrepancies. Bigtooth aspen, black oak, and gray birch had mean transparency >25%.

Foliar discoloration impacted quaking aspen and northern white cedar the most with a mean discoloration estimate of 0.3 (Table 7), which indicates both exhibited no 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).

Defoliation rates were highest among black oak with mean defoliation rates of 0.8 (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 2022, damage related to beech bark disease (BBD) was the most common damage agent recorded across plots. In total, 38% of the plots (73) were impacted by BBD and approximately 71% 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 or other stressors. This damage was present on 37% of plots (72) and impacted 2% of live trees (Table 8). Asian longhorned beetle, emerald ash borer, hemlock woolly adelgid, and sapsucker damage was observed on <2% of trees. Of the other damages recorded, defoliation >20% was the most common damage agents. Evidence of browse was recorded on 78% of plots (151), which may negatively impact regeneration success. For invasive species, we found 3% of plots (6) with buckthorn (*Rhamnus cathartica* or *Frangula alnus*) present, 3% of plots (6) containing honeysuckle (*Lonicera spp.*), and 2% of plots (3) containing barberry (*Berberis spp.*).

Table 8. Special damages recorded on live trees across the 193 FEMC FHM plots in 2022. 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 (%)
eastern cottonwood	1							100	100
willows	1							100	100
American beech	466		71	4				12	80
striped maple	19			26				36	57
bigtooth aspen	31			6				45	51
eastern redcedar	12			8				33	41
American basswood	27			7			3	14	29
white ash	150			4	16		1	4	26
northern white-cedar	121			1				23	24
shagbark hickory	23			4				4	17
American mountain-ash	18			11				11	16
northern red oak	356			<1			<1	9	16
bitternut hickory	13							7	15
quaking aspen	60			6				3	15
yellow birch	449			2			<1	7	12
black oak	43							9	11
balsam fir	602			<1				10	11
sugar maple	853			3			<1	6	11
chestnut oak	9								11
red maple	1089			2				8	10
eastern hemlock	542			<1		6	<1	2	9
black cherry	78			3				5	8
paper birch	105							7	8
white oak	59							6	8
black birch	193			1				4	8
eastern white pine	415			<1				7	7
gray birch	28							7	7
red spruce	424			2				1	4
white spruce	35			2					2
All live trees	6,455	0	5	2	<1	<1	<1	7	16

Tree regeneration

Saplings

Sixteen (16) out of 193 plots did not contain any saplings within the plot's four microplots. There were 1091 living saplings across the remaining 177 plots, with 486 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 48 tree species and 48 seedling species. The number of sapling species recorded per plot ranged from 0 to 7. The most abundant species in the sapling layer were balsam fir (27% of the total sapling composition, 128 SPA), American beech (20%, 20 SPA), and red spruce (12%, 12 SPA)(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 2022 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	287	128	5	27
American beech	220	98	3	20
red spruce	129	57	2	12
red maple	99	44	2	9
yellow birch	51	23	<1	5
eastern hemlock	44	20	<1	4
striped maple	37	16	<1	3
sugar maple	37	16	<1	3
eastern hophornbeam	36	16	<1	3
black spruce	25	11	<1	2
black birch	19	8	<1	2
eastern white pine	19	8	<1	2
white ash	12	5	<1	1
northern red oak	9	4	<1	<1
black cherry	6	3	<1	<1
paper birch	6	3	<1	<1
white oak	6	3	<1	<1
green ash	4	2	<1	<1
northern white-cedar	4	2	<1	<1
American mountain-ash	3	1	<1	<1
Other hardwood	20	9	<1	2
Other softwood	2	<1	<1	<1
All species	**1075**	**479**	**17.6**	**100**

Seedlings

In total, 42,233 seedlings (<1-inch DBH) were tallied across the FEMC FHM regeneration microplots in 2022. Of all seedlings counted, 86% (36,514) were classified as class 1 (hardwood seedlings <12 inches tall and softwood seedlings <6 inches tall) while 14% (36,514) were classified as class 2 (more established, with hardwood ≥12" and softwood ≥6 inches tall). Seedling counts per plot ranged from 0 seedlings to 1,199 seedlings per plot. There was an average density of 18,823 stems per acre (SPA) across the entire 193-plot network in 2022.

Seedling diversity was high within microplots with seedlings identified for 39 species, and 9 genera where species identification was not clear. Species diversity per plot ranged from zero to 13 unique species, and there did not appear to be a relationship between the number of species in the overstory trees and the number of species in the understory (paired t-test using R; $t(192) = 0.17482$, $p = 0.8614$).

Red maple was the most abundant seedling tallied in 2022 (20%, 3,782 SPA), followed by sugar maple (16%, 2,979 SPA), and balsam fir (15%, 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 2022 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	8,486	7,985	501	3,782	20
sugar maple	6,683	6,443	240	2,979	16
balsam fir	6,305	4,772	1,533	2,810	15
eastern hemlock	4,372	4,245	127	1,949	10
striped maple	2,673	2,135	538	1,191	6
American beech	1,815	924	891	809	4
red spruce	1,220	840	380	544	3
American mountain-ash	1,197	1,177	20	534	3
eastern white pine	1,115	876	239	497	3
yellow birch	1,033	936	97	460	2
northern red oak	599	540	59	267	1
white ash	466	283	183	208	1
black cherry	431	335	96	192	1
eastern hophornbeam	402	247	154	179	1
black birch	190	114	76	85	0.4
northern white-cedar	153	53	100	68	0.4
mountain maple	147	80	67	66	0.3
black spruce	133	24	109	59	0.3
white oak	130	89	41	58	0.3
American elm	91	88	3	41	0.2
quaking aspen	86	44	42	38	0.2
paper birch	53	36	17	24	0.1
chestnut oak	48	45	3	21	0.1
bitternut hickory	47	27	20	21	0.1
black oak	38	38	0	17	<0.1
Other hardwood	4,312	4,132	180	1,922	10
Other softwood	8	6	2	3	<0.1
All species	**42,233**	**36,514**	**5,718**	**18,824**	**100**

Conclusions

Annual forest monitoring offers valuable insights into subtle changes in forest conditions resulting from prolonged weather events like drought, as well as stress factors such as low-level pests and pathogens. It also helps identify subtle alterations in composition and overall health due to long-term changes in climate. Assessing crown health can serve as an early warning system for identifying hidden or widespread 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 across the entire Northeast region and sub-regionally. Specifically, we can analyze changes in seedling and sapling survival rates from year to year, as well as variations in crown health between different states, which may indicate persistent decline issues. These insights are crucial for forest managers aiming to ensure the future health, productivity, and resilience of these ecosystems.

Although northeastern forests face a broad range of stressors and exhibit significant vulnerabilities, preliminary indicators suggest that they are in a relatively diverse, robust, and healthy state. Species diversity is apparent across all three strata, encompassing overstory trees, saplings, and seedlings, although it is slightly lower in the sapling layer. On average, the overstory trees were vigorous with healthy crowns. Despite a widespread outbreak of spongy moth infestation in southern New England, the defoliation levels of our most affected species, black oak, remain below 30% throughout the region. While regeneration is observed in all monitored areas, sixteen plots lack saplings, which necessitates continuous monitoring and investigation. While the baseline data from 2021 and 2022 are significant, we hope to expand our analysis in 2023 to include more comprehensive comparisons between states and over time. As we continue to gather annual data, our aim is to track shifts in forest health and responses to disturbances in both spatial and temporal dimensions.

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	

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