



Forest Health Monitoring in the Northeast Temperate Network

2014 Summary Report

Natural Resource Report NPS/NETN/NRR—2015/973



ON THE COVER

Camilla Seirup and Mary Short sampling a forest plot in Acadia National Park
Photograph by: Kate Miller, NPS

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Executive Summary

The 2014 field season marked the Northeast Temperate Network (NETN) Inventory and Monitoring Program's 9th consecutive year of forest health monitoring and the start of the 3rd sampling cycle (i.e., 3rd visit to permanent monitoring plots). This report contains an ecological integrity scorecard for the parks that were sampled in 2014, along with a section that summarizes tree recruitment, growth, and mortality metrics for all of the parks covered by the forest health program. Parks included in this report are Acadia National Park (ACAD), Marsh-Billings-Rockefeller National Historical Park (MABI), Minute Man National Historical Park (MIMA), Morristown National Historical Park (MORR), Roosevelt-Vanderbilt National Historic Sites (ROVA), Saint-Gaudens National Historic Site (SAGA), Saratoga National Historical Park (SARA) and Weir Farm National Historic Site (WEFA).

Ecological Integrity

Acadia National Park

Ecological integrity metrics related to forest structure suggest that forests in ACAD are beginning to reach mature stages, but continue to lack late-successional structure such as medium to large snags. Tree regeneration in ACAD was rated Good for abundance, and impacts from deer browse were minimal. Patterns of regeneration compared to late-successional forest were indicative of young and mature spruce-fir forest, and ACAD was rated Caution for regeneration patterns due to a high sapling:small seedling ratio. As long as forest composition metrics remain stable, late-successional structure is expected to develop over time. Tree growth rates were slightly lower than regional averages, and may be due to a higher proportion of mature and late-successional plots than the regional Forest Inventory and Analysis (FIA) dataset. Poor site quality (e.g., thin acidic soils and rocky substrates) may also explain the lower growth rates. ACAD continues to be the least invaded NETN park, with only three out of 176 plots containing indicator invasive exotic plant species. Damage from beech bark disease (BBD) and balsam woolly adelgid (*Adelges piceae*) were the only major tree condition issues reported during the last 4 years of monitoring.

Marsh-Billings-Rockefeller National Historical Park

Ecological integrity metrics indicate that while over half of the plots in MABI are classified as late-successional, MABI forests lack late-successional structure such as medium to large snags and coarse woody debris. Medium to large snags were especially lacking in tree plantations. These results are consistent with forests managed for timber production. Tree growth rates were slightly lower than regional averages, and may be due to a higher proportion of mature and late-successional plots than the regional FIA dataset. Invasive exotic species are present at low levels throughout MABI, and are more common in tree plantations than natural stands. Beech bark disease was the only reported exotic pest/pathogen during the last 4 years of monitoring.

Minute Man National Historical Park

Metrics of ecological integrity indicate that a number of stressors are impacting forest health in MIMA. Forest plots in MIMA had the lowest coarse woody debris volume and ratio of all NETN parks. Invasive exotic species were abundant, and exotic shrub thickets are likely impacting forest structure and composition. Heavy defoliation was detected on hardwoods in both 2012 and 2014, and

the exotic winter moth (*Operophtera brumata*) was likely the primary defoliator. Tree growth and mortality rates for canopy trees were within expected ranges. However, if the heavy defoliation continues, we expect to see reduced growth, followed by increased tree mortality.

Saint-Gaudens National Historic Site

While coarse woody debris volume and snag abundance were higher in SAGA than most network parks, levels were still lower than those expected for late-successional hardwood stands. As long as park management efforts continue to control invasive exotic plants, and exotic pests (especially hemlock woolly adelgid) do not invade, we expect ecological integrity structural metrics to improve with time. Tree growth rates were slightly lower than regional averages, potentially due to a higher proportion of mature and late-successional plots than the regional FIA dataset. Invasive exotic plant species were present, but do not appear to be greatly impacting understory diversity or forest structure. Beech bark disease was the only pest/pathogen detected over the last 4 years of monitoring.

Saratoga National Historical Park

A number of factors are impacting forest health in SARA, including forest pests, invasive exotic species, and potentially excessive deer browse. Exotic shrubs, particularly bush honeysuckles (*Lonicera* spp.), have invaded large areas of the park, and are suppressing forest succession of old-field habitats. Invasive exotic plant species are especially abundant in stands that have succeeded from old-field since 1927. Emerald ash borer (EAB; *Agrilus planipennis*) poses a considerable threat to these early successional habitats, as white ash (*Fraxinus americana*) is one of the few tree species with seedlings capable of penetrating the thicket and forming a canopy. Deer browse may also be impacting forest regeneration and understory species, particularly in early successional stands. Late successional structure, including coarse woody debris and large snags, is lacking but will likely improve as forests are left to mature. Tree growth and mortality rates for canopy trees were comparable with regional patterns.

Ecological Integrity Scorecard: 2011-2014

Park	Structural Stage Distribution	CWD Ratio	Snag Abundance	Invasive Exotic Plants	Deer Browse Indicator Species	Tree Condition/ Forest Pests ¹	Tree Regen ²	Tree Growth and Mortality
ACAD	Caution	Caution	Caution	Good	Good		Good Caution	Good
MABI	Caution	Caution	Caution	Caution	Caution			Good
MIMA	Good	Sign. Conc. ³	Caution	Sign. Conc.	Caution			Caution
SAGA	Caution	Caution	Caution	Caution	Caution			Caution
SARA	Good	Caution	Caution	Caution	Caution			Good

¹Pie charts represent the proportion of plots in each ecological integrity rating category.

²ACAD regen is rated overall for abundance (Good) and pattern compared to late-successional forests (Caution).

³Significant Concern is abbreviated as Sign. Conc.

Tree Recruitment, Growth, and Mortality

The metrics in this section differ slightly from the tree growth metrics used in the ecological integrity scorecard. In this analysis we include all trees ≥ 10 cm diameter at breast height (DBH), not just canopy trees. Metrics are based on all plots except stunted woodlands in ACAD (not just mature and late-successional). We focus more on the increment growth rate in this section, whereas the scorecard uses the percent of basal area (%BA) growth rate. We also report on tree recruitment rates for the first time, which is a measure of the percentage of trees that gain tree status (i.e., grow to ≥ 10 cm DBH) between sampling cycles.

Acadia National Park

Tree recruitment, growth and mortality metrics reflect the different stand histories across ACAD. On Schoodic Peninsula (Schoodic), tree growth and recruitment rates are low, and mortality rates are relatively high. Plots at Schoodic are either in mature spruce-fir forest, or in woodlands on thin, exposed soils. These patterns are expected in woodlands due to the harsh growing environment. In spruce-fir forests, the patterns reflect mature forests that are developing late-successional structure. Isle au Haut (IAH) and western Mount Desert Island (MDI) had similar recruitment, growth and mortality rates, suggesting that forests in these subunits are at similar successional stages (i.e., mature to late-successional). Eastern MDI had the highest recruitment and growth rates. With red spruce (*Picea rubens*) as the primary recruit, our data continue to suggest that the stands that originated after the 1947 fire on eastern MDI are following expected trajectories of succession, and are at the stage of birch die-back and spruce replacement.

Marsh-Billings-Rockefeller National Historical Park

Patterns of tree recruitment, growth and mortality in MABI are indicative of selectively managed forests. Recruitment and growth are relatively high and mortality is low compared to the predominantly unmanaged forests in other NETN parks. European larch (*Larix decidua*), a species confined to Plantations, had the highest annual incremental growth rates among MABI tree species. One of the plots in the European larch plantation was harvested between the second and third cycle, and this may partially explain the high growth rate. White ash (*Fraxinus americana*) had a relatively high growth rate, which may prove to be a useful baseline for tracking the spread of EAB.

Recruitment rates for MABI were relatively high and highest in tree plantations that were harvested before the last survey. The highest recruitment rates were of yellow birch (*Betula alleghaniensis*) and sugar maple (*Acer saccharum*), and these are the primary species regenerating in both natural stands and plantations. European larch and red pine, which are common plantation species, are not regenerating in MABI, and may need to be planted if these species are to be maintained in the plantations.

Minute Man National Historical Park

MIMA had moderate increment growth and recruitment and relatively high mortality compared to other NETN parks. MIMA's forests are dominated by species (oak and maple) that are vulnerable to winter moth, which has been at outbreak levels in eastern Massachusetts in recent years. The high mortality in MIMA, which primarily involved subcanopy trees, may partially be the result of winter moth. Green ash (*Fraxinus pennsylvanica*) had the highest overall mortality rate in MIMA, and

mortality was relatively high for American elm (*Ulmus americana*), gray birch (*Betula populifolia*), and black oak (*Quercus velutina*). A number of tree conditions were recorded for these trees during the first cycle, including excessive leaf loss, insect leaf herbivory and epicormic branching, indicating health concerns existed before the observed mortality. The cause of the green ash mortality is not clear, and this should be closely monitored in MIMA, especially as EAB moves into the region.

Oak species consistently had very low or no recruitment, whereas red maple, white ash and American elm had multiple recruits. If these patterns continue, the canopy that is currently dominated by oak species will likely be replaced by more mesic hardwood species.

Morristown National Historical Park

Recruitment in MORR was exceptionally low compared to the rest of NETN. Recruitment only occurred with American beech (*Fagus grandifolia*), a species that is relatively resistant to deer browse. Poor recruitment is very likely the result of decades of deer overabundance, and is a great concern for the future health of MORR's forest. Recruitment may increase as forests respond to the canopy gaps created by Hurricane Sandy, but only if deer browse pressure is reduced.

The mortality rate in MORR was the highest reported for NETN, with mortality higher in successional stands than in mature stands. Tree mortality may actually be higher than our data indicate, because trees that were blown down by Hurricane Sandy in late 2012 were still alive in spring of 2013. We expect to see even higher mortality during the 2015 and 2017 surveys, as many of the wind-thrown trees that were alive in 2013 will likely have died. Given exceptionally low tree recruitment and relatively high mortality in MORR, forest canopies may become more open over time. Reducing deer browse pressure and controlling invasive species are necessary to prevent this from happening. Recruitment and growth rates also suggest that forest composition may be shifting from an oak-dominated canopy to a more mesophytic, American beech and red maple (*Acer rubrum*) dominated canopy.

Roosevelt-Vanderbilt National Historic Sites

Increment growth in ROVA was intermediate compared to other NETN parks. Tulip poplar (*Liriodendron tulipifera*) had the highest increment growth. The invasive species tree-of-heaven (*Ailanthus altissima*) and Norway maple also had relatively high growth rates. Overall tree recruitment rates were in the lower tier for the network. American beech and black gum (*Nyssa sylvatica*) had the highest recruitment rate in ROVA, followed by red maple and black birch (*Betula lenta*).

ROVA had intermediate mortality rates, compared with other NETN parks. White ash and American elm had the highest mortality rates in the park. White ash mortality may be due to EAB and American elm mortality may be from Dutch elm disease. Norway spruce and red pine, which also had relatively high mortality, are primarily in plantations in ROVA which may be over mature.

Saint-Gaudens National Historic Site

Annual increment growth rate in SAGA was among the lowest of NETN parks. Much of the forests in SAGA are mature or late-successional stages, which may partially explain the slow growth. The

growth rate for eastern hemlock in SAGA is lower than in MABI, but higher than ROVA where Hemlock Woolly Adelgid (HWA; *Adelges tsugae*) is present. The current growth rate for eastern hemlock is an important baseline for detecting future impacts from HWA in SAGA.

Recruitment in SAGA was relatively low. Structural stage is likely the primary driver in the low recruitment at SAGA, as mature and late-successional stands are not expected to have high recruitment rates. Beech bark disease, which is present in SAGA, may also be influencing recruitment by creating thickets of beech sprouts that suppress regeneration of other tree species. Mortality rates in SAGA were moderate compared with other parks in the network. Tree growth, recruitment, and mortality rates suggest that forests in SAGA are relatively stable, and reflective of mature and late-successional hardwood forests. HWA poses a major threat to the stability of forests in SAGA, and declines in eastern hemlock growth will be an early indicator of HWA infestation.

Saratoga National Historical Park

SARA had the highest annual increment growth of all NETN parks, and plots that were open field in 1927 had higher growth rates than plots that were forest by 1927. High growth rates in SARA are likely due to good site conditions such as soil fertility and light availability (e.g. open grown trees). SARA recruitment rates were also highest in NETN, with higher recruitment in plots that were forest in 1927 than plots that were open field in 1927. SARA had an intermediate overall tree mortality rate compared to other NETN parks. Among the different tree species, black cherry (*Prunus serotina*) and American elm had relatively high mortality rates. High rates of elm mortality are likely the result of Dutch elm disease. Mortality of black cherry may be due to forest succession.

The high growth and recruitment rates that we observed are suggestive of rather dynamic forests in SARA. As American elms reach about 20 cm diameter at breast height (DBH), they begin to die back and are replaced by new, fast-growing recruits of American elm. White ash also commonly occurs in American elm stands, and it is unclear how EAB will affect the structure and composition of these forests. Current rates of growth, recruitment and mortality serve as an important baseline, and changes in these rates may indicate the presence of a new pest (e.g., EAB) or forest health issue.

Weir Farm National Historic Site

WEFA annual increment growth was average and tree mortality was low when compared to other NETN parks. White ash had the lowest observed growth rate in WEFA, and this was also the lowest growth rate recorded for white ash in NETN. EAB has been found in the county where WEFA is located, and this could be an indication of EAB presence in the park.

Tree recruitment in WEFA was relatively low, and American beech, a species resistant to deer browse, had the highest recruitment. This may be a sign of deer browse impacts. As more cycles of data are collected and our sample size increases, the underlying drivers for low growth and recruitment may become clearer. Current rates are an important baseline to track threats to forest health, including EAB, deer overabundance, and climate change.

Conclusions

Forest condition in NETN parks is threatened by a range of stressors, including invasive exotic plants, exotic pests and pathogens, high deer densities, and lack of late-successional structure. Current indicators suggest that most parks could benefit from heightened invasive species control. Early detection of exotic forest pests and plants combined with rapid response control measures are important to maintaining forest condition. NETN parks often lack late-successional structure compared with benchmark conditions. As long as forests are left to mature and management activities do not reduce the potential for development of late-successional structure (e.g., cutting and/or removing coarse woody debris), we expect these metrics to improve in NETN parks over time.

Tree growth, recruitment and mortality rates in NETN parks reflect diverse forest types at different stages of succession. These data are an important baseline to track future impacts to forest health, such as forest pests, deer overabundance, invasive species, and climate change.

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Introduction

The Northeast Temperate Network (NETN) of the National Park Service (NPS) Inventory and Monitoring Program developed a long-term monitoring program for forest resources in response to the identification of Forest Vegetation as a high-priority vital sign for the network (Mitchell et al. 2006). This program also provides data for three additional high-priority vital signs: Forest Soil Condition, White-tailed Deer Herbivory, and Landscape Context. The overall goal of the forest monitoring program is to assess status and trends in the composition, structure, and function of NETN forested ecosystems.

Adapted from the U.S. Forest Service Forest Inventory and Analysis Program, the NETN forest protocol monitors a representative suite of site and vegetation measures in an extensive network of randomly located permanent plots (Tierney et al. 2014). The following parks are monitored in this program: Acadia National Park (ACAD), Marsh-Billings-Rockefeller National Historical Park (MABI), Minute Man National Historical Park (MIMA), Morristown National Historical Park (MORR), Roosevelt-Vanderbilt National Historic Sites (ROVA), Saint-Gaudens National Historic Site (SAGA), Saratoga National Historical Park (SARA), and Weir Farm National Historic Site (WEFA; Figure 1). Roosevelt-Vanderbilt National Historic Sites includes Eleanor Roosevelt National Historic Site (ELRO), Home of Franklin D. Roosevelt National Historic Site (HOFR), and Vanderbilt Mansion National Historic Site (VAMA). Currently NETN has resurveyed nearly all 351 of the plots that have been established throughout the network.

An Ecological Integrity Scorecard is used to facilitate reporting and interpreting forest condition in NETN parks. The Ecological Integrity Scorecard examines a suite of compositional, structural, and functional metrics in relation to their natural or historical range of variation (Tierney et al. 2009). NETN recognizes that “ecological integrity” may not be the primary goal of park resource management, particularly at historical parks and historic sites where cultural resource management may take precedence. Nevertheless, being able to compare the condition of park resources to ecological integrity benchmarks is valuable because it provides a deeper understanding of park condition, as well as a consistent baseline to assess management goals. NETN staff have started working with managers at several parks to develop scorecards that track progress towards park resource management goals and are open to working with managers at other parks.

This report contains an ecological integrity scorecard for the parks in NETN that were surveyed for forest health in 2014. An additional section examines tree recruitment, growth and mortality metrics in all NETN parks that are monitored for forest health. Quality Assurance/Quality Control results and issues related to the 2014 field season are summarized in Appendix A.

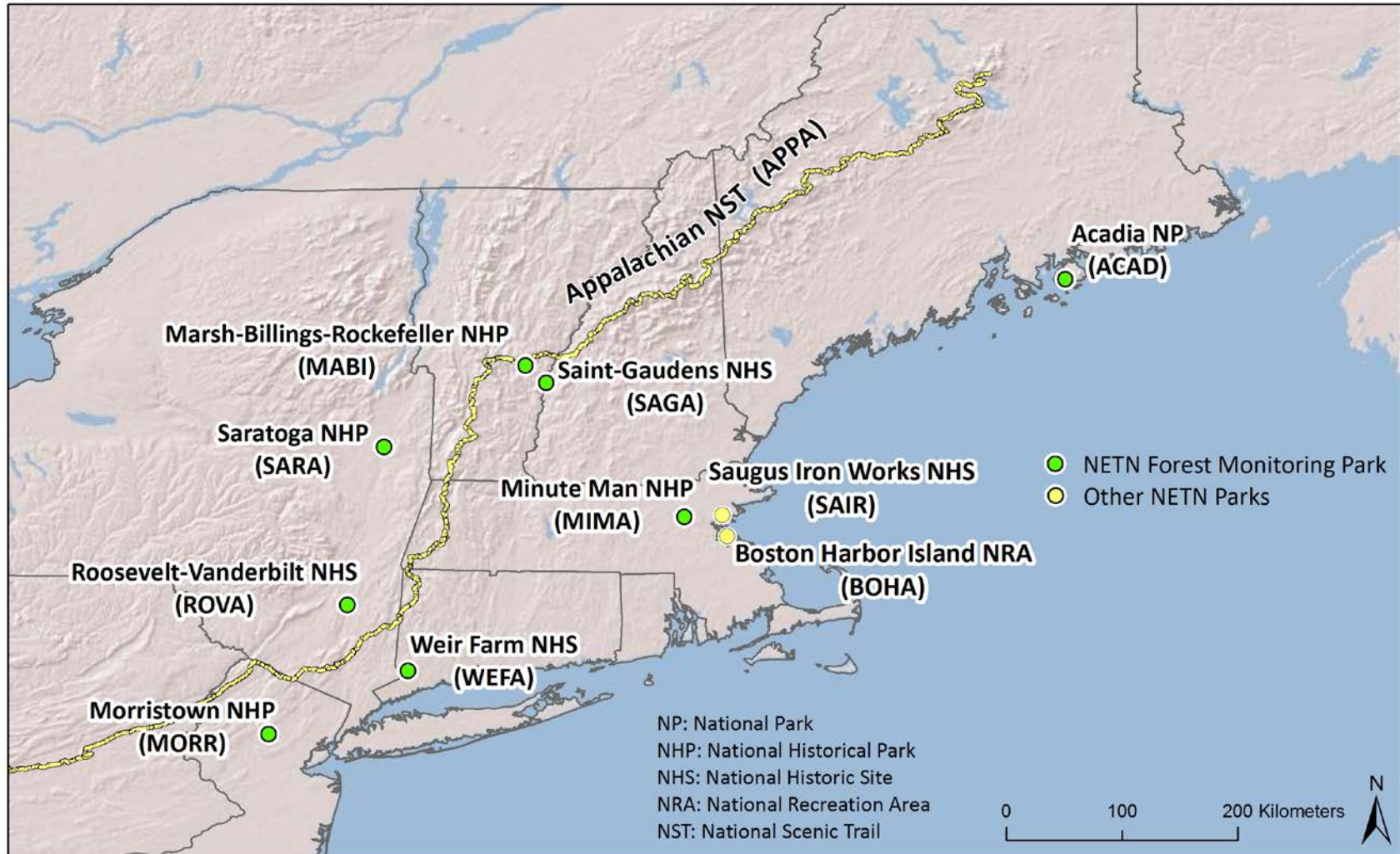


Figure 1. Map of the Northeast Temperate Network

Methods

Sampling Methods

Permanent forest plots have been installed and are sampled every 4 years using a rotating four-panel design (Table 1). One panel is sampled each year at ACAD (one-fourth of the plots are sampled during each of the four sampling panels) and in alternate years at the nine national historical parks and historic sites (one-half of the plots at each park are sampled during each of two sampling panels per park). Because ELRO and HOFR are adjacent park units, the sampling design treats them as a single unit. It is not possible to report on these parks individually because there is not a sufficient sample size at ELRO to support a stand-alone analysis.

Plots were randomly located within each park using generalized random tessellation stratified sampling (GRTS; Stevens and Olsen 2004). GRTS points which were located in areas that were primarily forested or succeeding to forest were established as forest plots, as long as they were ≥ 15 m from a road (including a carriage road), a perennial stream or water body large enough to create a canopy opening, a mowed area, or the park boundary. Plots in areas receiving management, such as logging and invasive species removal, are included in the target population as long as plots are not being specifically targeted for the management. That is, NETN forest plots should be representative of park forests and should not receive preferential treatment. In one case, a GRTS point was located in a 4 ha deer enclosure in MORR. Because this point was part of the random GRTS sample and met the pre-defined target population guidelines, it was not excluded from analyses. However, major differences between this plot and those outside of enclosures will be noted in ecological integrity metrics and trend analyses.

The permanent plot design is illustrated in Figure 2. Tree and stand measurements are made within fixed-area, square plots (15 m x 15 m at ACAD; 20 m x 20 m at the other parks). Square plots in ACAD are smaller because tree density is considerably higher. Tree regeneration is measured within three 2-m radius circular microplots embedded within each square plot (the area sampled by the microplots is 37.70 m²/plot). Coarse woody debris (CWD) is assessed using line intersect sampling along three 15-m transects originating at plot center. Understory diversity is monitored within eight 1-m² quadrats, and soil samples are obtained from a location adjacent to the plot. Plots are permanently marked and measured at the same location every cycle, but nested plots (e.g., quadrats) may shift slightly due to missing plot markers or misalignment along the plot boundary. For a more detailed description of the forest monitoring protocol, including background information, field methods, and sample design, refer to Tierney et al. (2014).

Table 1. Northeast Temperate Network forest monitoring panel design. Panel numbers are listed in the table. One-fourth of the plots in ACAD are sampled every year. One-half of the plots in MABI, MIMA, SAGA and SARA are sampled in panels 1 and 3. One-half of the plots in MORR, ROVA (HOFR, ELRO, VAMA), and WEFA are sampled in panels 2 and 4. A full census of all plots in the network, or one cycle, is completed every 4 years.

Park	Year								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
ACAD	1	2	3	4	1	2	3	4	1
MABI	1		3		1		3		1
MIMA	1		3		1		3		1
MORR		2		4		2		4	
ROVA		2		4		2		4	
SAGA	1		3		1		3		1
SARA	1		3		1		3		1
WEFA		2		4		2		4	

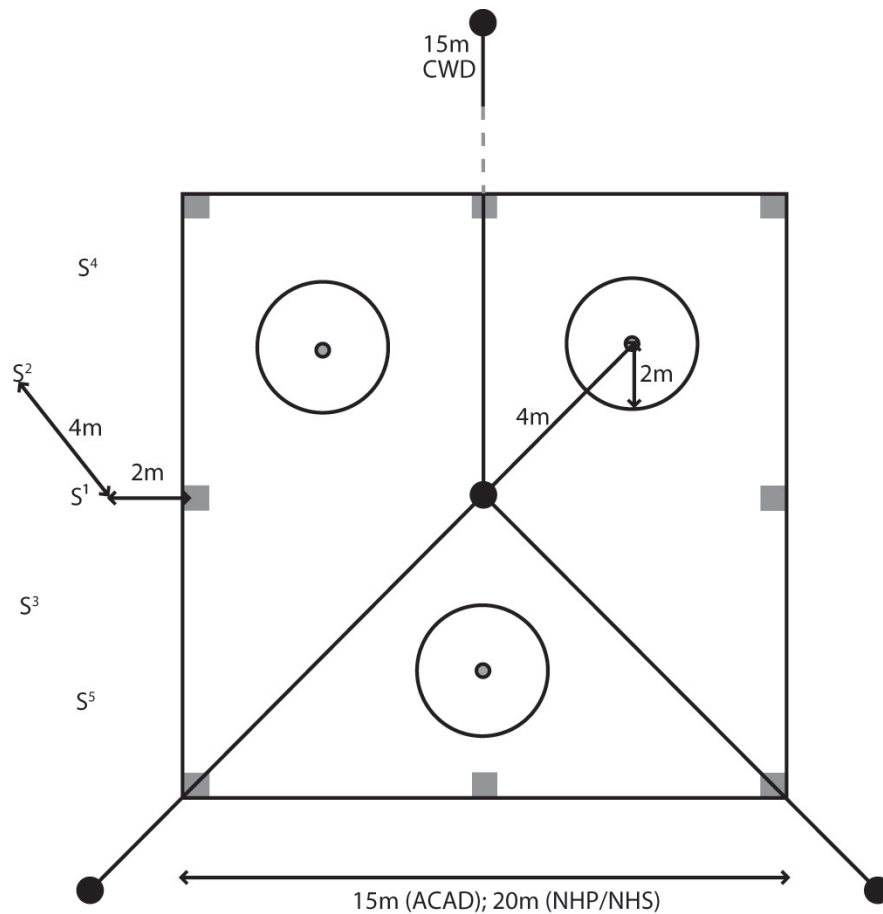


Figure 2. Plot layout showing square tree plot with three nested 2-m radius regeneration microplots (hollow circles), eight 1 m² vegetation quadrats (grey squares), and three 15-m coarse woody debris (CWD) transects. S_x is location of soil sample.

Ecological Integrity Scorecard

The Ecological Integrity scorecard uses the concept of “ecological integrity” to interpret the condition of forested ecosystems by assessing a suite of compositional, structural, and functional metrics in relation to their natural or historical range of variation (Tierney et al. 2009). For each metric, assessment points are defined that distinguish acceptable or expected conditions from undesired conditions based on current scientific understanding of their natural or historic range of variation (Bennetts et al. 2007). Integrity is interpreted for a broad audience using three categories: Good, Caution, and Significant Concern. “Good” represents desired or acceptable conditions, “Caution” indicates a problem may exist, and “Significant Concern” indicates undesired conditions that may need management action. For some metrics, NETN does not define conditions that merit Significant Concern because current knowledge is insufficient to justify this rating. Ecological integrity assessment points are summarized in Table 2. For a more detailed discussion of a metric’s justification, calculation and confidence, refer to the Ecological Integrity Reporting SOP in Tierney et al. (2014).

Metric ratings are based on the most recent full cycle (four panels, or one visit to each plot) of data collected from a given park. Thus, most metrics in ACAD are calculated every year for the most recent 4-year window of data, and may span two sampling cycles. Due to our alternating sampling schedule in national historical parks (NHP) and national historic sites (NHS), metrics for those parks are calculated every 2 years and may also span multiple sampling cycles.

The following metrics are included in this report: structural stage distribution, coarse woody debris, snag abundance, tree condition and forest pests, tree regeneration, deer browse indicator species, invasive exotic plant indicator species, and tree growth and mortality. Baseline results for forest patch size, anthropogenic land use and biotic homogenization metrics were reported in Miller et al. (2011) and baseline soil chemistry results were reported in Miller et al. (2014), and will not be included in this report.

In addition to reporting metrics at the park level, metrics were rated for groups within parks where sample size was sufficient (i.e., at least 10 plots per group). In ACAD, metrics were calculated overall and by the following park subunits: Isle au Haut (IAH), eastern section of Mount Desert Island (MDI), western section of MDI, and Schoodic Peninsula (Schoodic). In MABI, metrics were rated overall and by “Natural” and “Plantation” stand types. Natural stands are second growth forests that are primarily composed of naturally regenerated hardwood species. Plantations consist of forests that were planted with conifer species. In MORR, metrics were rated overall and by “Mature” and “Successional” stand types. Mature stands were defined as second growth stands that originated from areas cleared by General Washington’s forces around 1779 to 1780.

Table 2. Metrics and ratings for evaluating the ecological integrity of forest ecosystems.

Metric type	Metric	Metric Rating		
		Good	Caution	Significant Concern
Landscape structure	Forest patch size	> 50 ha	10-50 ha	0.5 to < 10 ha
	Anthropogenic land use	< 10%	10 - 40%	> 40%
Structure	Structural stage	≥ 70% (MABI, SAGA), ≥ 50% (ACAD), and ≥ 25% (MIMA, MORR, ROVA, SARA and WEFA) late-successional structure	< 70% (MABI, SAGA), < 50% (ACAD), and < 25% (MIMA, MORR, ROVA, SARA and WEFA) late-successional structure	< 70% (MABI, SAGA), < 50% (ACAD), and < 25% (MIMA, MORR, ROVA, SARA and WEFA) combined mature and late-successional structure
Composition	Snag abundance	≥10% standing trees are snags and ≥ 10% med-lg trees are snags ¹	< 10% standing trees are snags or < 10% med-lg trees are snags	< 5 med-lg snags/ha
	Coarse woody debris ratio ²	> 15% live tree volume	5 - 15% live tree volume	< 5% live tree volume
	Tree regeneration	NHP and NHS: Seedling ratio ≥ 0	NHP and NHS: Seedling ratio < 0	NHP and NHS: Stocking index < 25 ³
		ACAD: Stocking index ≥ 20 and sapling: small seedling ratio ≤ 0.11	ACAD: Stocking index ≥ 20 and sapling: small seedling ratio > 0.11	ACAD: Stocking index < 20
	Tree condition and forest pests	Foliage problem < 10% and no Priority 1 or Priority 2 pests ⁴ and BBD ⁴ ≤ 2	Foliage problem 10 - 50% or Priority 2 pest present or BBD > 2	Foliage problem > 50% or Priority 1 pest present
	Biotic homogenization ⁵	No change	Increasing homogenization ⁵	
	Indicator species: invasive exotic plants	< 0.5 indicator species per plot	0.5 to < 3.5 indicator species per plot	3.5 or more indicator species per plot
Function	Indicator species: deer browse	No decrease in frequency of most browse-sensitive species	Decrease in frequency of most browsed species or increase in frequency of browse-avoided species	Decrease in frequency of most browsed species and increase in frequency of browse-avoided species
	Tree growth and mortality rates ⁵	Growth ≥ 60% mean and Mort ≤ 1.6%	Growth < 60% mean or Mort > 1.6%	
	Soil chemistry: acid stress	Soil Ca:Al ratio > 4	Soil Ca:Al ratio 1 - 4	Soil Ca:Al ratio < 1
	Soil chemistry: nitrogen saturation	Soil C:N ratio > 25	Soil C:N ratio 20 - 25	Soil C:N ratio < 20

¹ Med-large trees are ≥ 30 cm diameter-at-breast-height.

² CWD metric ratings were developed for forested habitats, and do not include plots in woodland habitats in ACAD.

³ Assessment point is only applicable to MORR, ROVA and WEFA.

⁴ Priority 1 pests are Asian longhorned beetle, emerald ash borer, hemlock woolly adelgid, and sudden oak death. Priority 2 pests are balsam woolly adelgid, butternut canker, elongate hemlock scale, and beech bark disease (BBD).

⁵ Significant Concern rating has not been defined for these metrics.

While these stands may have been repeatedly or selectively logged, they have never been plowed or cultivated, and are thought to have returned directly to forest after the end of the encampment (Ehrenfeld 1982, Shaw and Patterson 2006). The successional category represents younger stands that originated on abandoned field or pasture around 1927 or later. Soils in successional stands have likely been plowed, and forests are mostly even-aged (Shaw and Patterson 2006). In SARA, forest plots were stratified post-sampling based on land use history. The “Field” category represents areas that were open field in 1927 when the park was established, and the soils in these areas were likely plowed and some soil amendment (e.g., manure, liming) may have occurred. Many of these areas have since succeeded to forest, including areas where forest plots are located. The “Forest” category includes sites that were forest or woodland in 1927 and have been continuously forested since 1927. Field and Forest configurations were delineated by SARA and NPS staff from rubber-sheeted georeferenced aerial photos. Note that all but one plot was cleared at some point between 1777 and 1927.

Structural Stage Distribution

Background

Prior to European settlement, the northern hardwood and spruce-fir forests of the northeastern US were predominantly in late-successional and old-growth stages of forest succession (Frelich and Lorimer 1991, Lorimer and White 2003). Natural disturbance regimes consisted primarily of frequent, small-scale disturbances (< 20% canopy removal), such as single tree-fall. Stand replacing disturbances were rare, with return intervals as high as 1,000-7,500 years for inland northern hardwood forests (Lorimer and White 2003). Presettlement forests were primarily composed of shade-tolerant tree species and characterized by a multi-aged or multi-cohort age structure, abundant standing dead and down trees at varying stages of decay, and an understory composed of advanced regeneration of shade-tolerant tree species (Mosseler et al. 2003, Fraver et al. 2009). The onslaught of logging and land-clearing for agriculture post-European settlement constituted a major disruption in the natural processes and disturbance regimes of these forests (Foster et al. 1998, Hall et al. 2002), and the second-growth forests of today are structurally and compositionally different from late-successional and old-growth forests (Scheller and Mladenoff 2002, Mosseler et al. 2003, Burton et al. 2009). While natural disturbance rates in eastern oak forests were higher due to greater fire disturbance, roughly 25-40% of the presettlement Eastern oak forests were old-growth (Lorimer and White 2003).

The distribution of structural stages is important for maintaining a full complement of native species, which vary in their dependence upon different successional stages. Human alteration and management have greatly changed the structural stage distributions of eastern forests such that younger forests are far more abundant, and the amount of late-successional and old-growth forest has been greatly reduced compared to presettlement times (Lorimer and White 2003, Mosseler et al. 2003, Whitman and Hagan 2007). These distributions will be further affected by altered disturbance regimes coincident with global climate change and outbreaks of exotic pests and pathogens (Dale et al. 2001). Comparison of existing distributions with those expected under natural disturbance regimes provides an indicator of altered disturbance regimes as well as habitat availability.

Structural stage distribution is calculated from tree size and canopy position measurements, using a method similar to that of Frelich and Lorimer (1991), but substituting basal area for exposed crown area (Goodell and Faber-Langendoen 2007). Plots are classified as pole, mature, or late-successional based on relative basal area of live canopy trees within pole, mature, and large size classes. For all parks except ACAD, size classes are 10-25.9 cm diameter at breast height (DBH; pole), 26-45.9 cm DBH (mature), and ≥ 46 cm DBH (large). Dominant trees of coastal Maine (balsam fir and red spruce) are typically smaller in diameter than dominant trees at the other NETN parks, and ACAD size classes have been adjusted to be 10-19.9 cm DBH (pole), 20-34.9 cm DBH (mature), and ≥ 35 cm DBH (large).

We assign assessment points based on the expected percentage of late-successional forest stages across the landscape as compiled by Frelich and Lorimer (1991) and Lorimer and White (2003), and ratings are based on the proportion of plots that are late-successional and mature forest. Plots classified in the field as early successional forest (i.e., $\leq 60\%$ canopy cover and dominated by open-grown trees) were not reclassified as pole, mature or late-succession, but were included to calculate proportion of plots in mature and late-successional stages. Plots classified in the field as woodland, which have $\leq 60\%$ canopy cover due to harsh growing conditions, were not included in this metric. Expected structural stage distributions vary among forest ecosystem types; thus assessment points vary among parks and are based on the matrix forest ecosystem dominant at each park. Assessment points were based on the following matrix forest ecosystems at each park: Acadian Low-Elevation Spruce-Fir-Hardwood Forest at ACAD; both Appalachian Hemlock-Northern Hardwood Forest and Laurentian-Acadian Northern Hardwoods Forest at MABI; Northeastern Interior Dry-Mesic Oak Forest at MIMA; both Appalachian Hemlock-Northern Hardwood Forest and Northeastern Interior Dry-Mesic Oak Forest at ELRO/HOFR and VAMA; Northeastern Interior Dry-Mesic Oak Forest at MORR and WEFA; Appalachian Hemlock-Northern Hardwood Forest at SAGA; and both Appalachian Hemlock-Northern Hardwood Forest and Northeastern Interior Dry-Mesic Oak Forest at SARA. At parks with more than one matrix forest ecosystem type, assessment points were based on the matrix type with the lowest expected proportion of late-successional structure. Assessment points are defined in Table 2.

Results and Discussion

Desired levels of late-successional forest were only met in MIMA and SARA (Table 3). While MABI and SAGA had proportionately more plots in late-successional forest than MIMA and SARA, they also have higher expected levels of late-successional forest due to differences in the dominant forest type, and both parks were rated Caution. Only a small percentage of plots were in late-successional forest in ACAD (Figure 3), and ACAD was also rated Caution. Eastern MDI continues to have a higher proportion of plots in the pole stage due because of the 1947 fire, and due to a lack of late successional forest, was rated Significant Concern. As long as forests are left to succeed under natural disturbance regimes, this metric is expected to improve for all parks over time.

We recently began collecting tree cores outside of plots to better understand age dynamics of park forests, and this will help us validate and refine the structural stage metric. Given time and staffing

Table 3. Summary of plot structural stage distributions in NETN parks for 2011-2014. “Succ.” stands for “Successional”.

Park	Group	% Late-succ.	% Mature and Late-succ.	Rating
ACAD	Overall	11.3	64.1	Caution
	IAH	0.0	58.3	Caution
	MDI East	8.8	48.5	Significant Concern
	MDI West	17.5	80.7	Caution
	Schoodic	0.0	100.0	Caution
MABI	Overall	58.3	91.7	Caution
	Natural	61.5	84.6	Caution
	Plantation	54.5	100.0	Caution
MIMA		30.0	75.0	Good
SAGA		42.9	100.0	Caution
SARA	Overall	25.0	62.5	Good
	Field	20.0	56.0	Caution
	Forest	42.9	85.7	Good

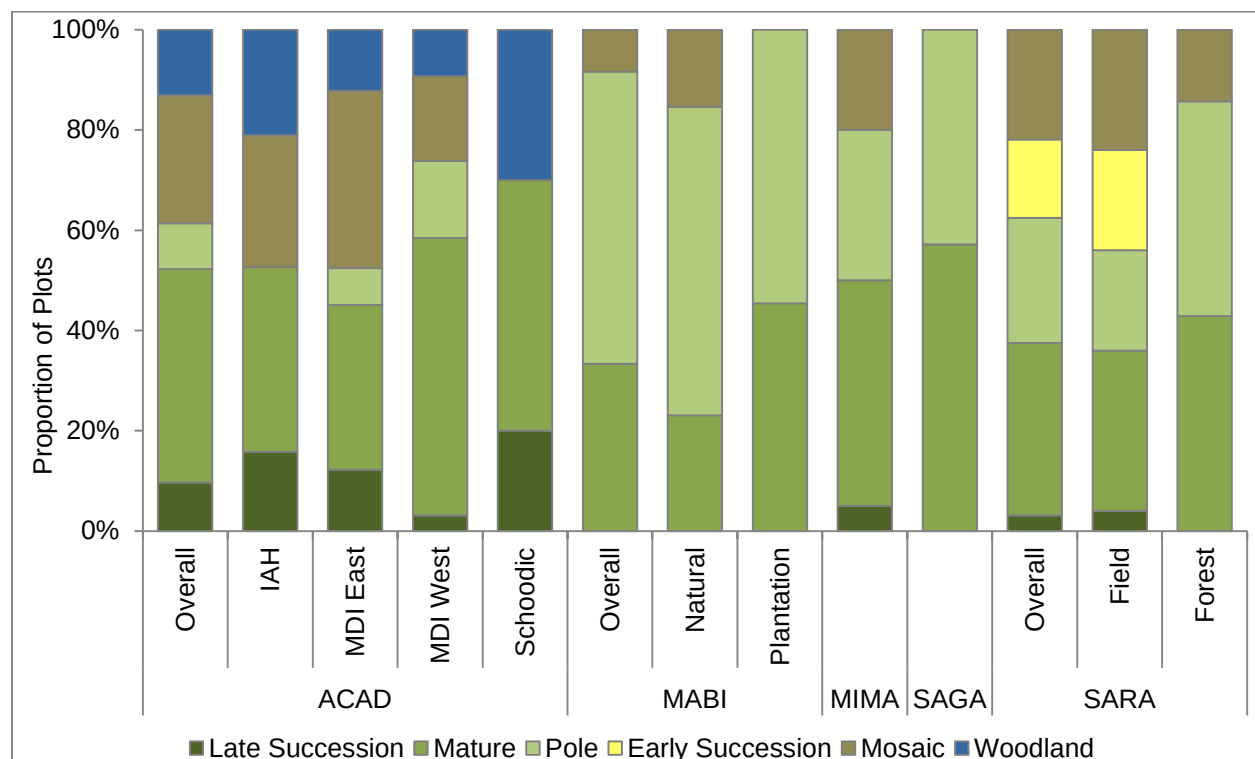


Figure 3. Proportion of plots in each structural stage (Late-succession, Mature, and Pole) and field stand structure class (Early Succession, Mosaic, and Woodland) for plots sampled between 2011-2014. Structural stages are assigned post-field and are based on proportion of basal area by size class. Field stand structure classes (Early Succession, Mosaic and Woodland) are determined in the field and plots in these classes are not assigned structural stages. Woodlands are not included in the metric rating.

constraints, we are only able to core plots in two parks per year, but we will eventually have age estimates for each plot in NETN. Preliminary results from coring indicate that the structural stage metric in SARA needs refinement, as stands classified as pole are often a similar age as stands classified as late-successional. The issue primarily relates to compositional differences, with young, small hardwoods often classified as pole, and young, large eastern white pine stands classified as mature or late-successional. We will refine this metric as more plots are cored and more cycles of data are available. We will also examine how diameter distributions change over time, and may consider other methods, such as the Departure Index, to assess forest structure (Menning et al. 2007).

Coarse Woody Debris and Snag Abundance

Background

Dead wood, in the form of fallen coarse woody debris (CWD) and standing dead trees (snags), is an important structural feature of forests that provides habitat for many taxonomic groups, including mammals, birds, fungi, herpetofauna, and insects. In addition, tip-up mounds caused by wind-throw contribute to forest soil turnover and create important microhabitats for tree seedlings and bryophytes (Jonsson and Esseen 1990, Ulanova 2000, Samonil et al. 2010). Silviculture, land management, and hazard tree removal can reduce the quantity or quality of these features. However, thoughtful land management can maintain or enhance snags and CWD (Keeton 2006).

Density of snags and volume of CWD vary substantially across ecosystems, with site conditions, and with stand age (Tyrrell et al. 1998). However, studies have documented positive relationships between live and dead tree density and between live tree volume and CWD volume (Sippola et al. 1998, Ferguson and Archibald 2002, and Stewart et al. 2003). Therefore live tree density (for snags) and live tree volume (for CWD) can control for site differences in determining expected levels of snag abundance and CWD volume (Tierney et al. 2014). In addition, large-diameter snags provide habitat for a greater number of vertebrate species (Cline et al. 1980, Wynne and Sherburne 1984, DeGraaf and Shigo 1985) and persist longer than smaller-diameter snags (Morrison and Raphael 1993, Garber 2005). Therefore density of large-diameter snags is also an important indicator of habitat quality and availability. These metrics assess the density of snags and volume of CWD in relation to live tree density and volume.

CWD metric ratings are based on a CWD ratio, which is the ratio of CWD volume to live tree volume and is expressed as a percent. The CWD ratio is calculated for each plot and is then averaged for a park or group. The CWD metric calculation requires a stand height measurement for each plot to calculate live tree volume. Therefore, early successional plots, which do not have a stand height measurement, and plots missing stand height measurements are excluded from this metric calculation. Plots in woodland habitats (ACAD only) are also excluded from the CWD metric, as expected ratios of CWD volume to live tree volume in woodlands are unknown.

Snag abundance metric ratings are based on the percent of standing trees that are snags and are calculated on all plots to distinguish between Good and Caution ratings. The assessment point for Significant Concern is based on best management practices developed by the US Forest Service, which recommends leaving 5-10 medium or large ($\geq 30\text{cm DBH}$) snags per ha for wildlife needs (USFS 1980). Since NETN plots are not large enough to accurately estimate rare features such as

snags, snag abundance is evaluated at the scale of the park or park subunit, and requires at least 10 plots to be adequately estimated. To facilitate comparisons of our CWD metric calculations with other studies, we report volume of CWD using both metric and English units.

At the request of MABI staff, we began recording the presence of small and large tree cavities on live and dead trees as a tree condition in 2012 for all NETN parks. While cavity data are not used to rate the tree condition metric, tree cavities are important wildlife habitat that are often lacking in younger and managed forests. Cavity data are summarized as the average number of live and dead trees with at least one small or one large cavity per hectare. Small cavities are 3 to 5 cm diameter, and large cavities are over 5 cm diameter.

Results and Discussion

With the exception of MIMA, all parks were rated Caution for CWD (Table 4). MIMA was rated Significant Concern, and had the lowest CWD ratio and CWD volume of all the parks sampled in NETN. The CWD ratio on western MDI in ACAD was very close to the 15% assessment point that distinguishes between Good and Caution, and has fluctuated around 15% during the last 5 years of reporting. The switch between Good and Caution does not likely represent an actual trend in CWD, but rather reflects variability in the data. Despite a relatively high volume of CWD, MABI and SAGA were rated Caution because live tree volume was also relatively high in these parks.

Ratings for Snag Abundance were more variable across NETN parks (Table 5). ACAD continues to have the highest snag density of all parks sampled in NETN. However, due to a lack of medium to large snags (diameter at breast height [DBH] ≥ 30 cm), the eastern section of MDI and Schoodic were rated Significant Concern. Western MDI and IAH were the only subunits to receive a Good rating, and ACAD Overall was rated Caution. Snag density and percent of trees as snags continue to be lower for MABI than other parks. The Plantation group had a slightly higher abundance of snags than Natural stands, but was rated Significant Concern due to the lack of snags ≥ 30 cm DBH.

In MABI, snag abundance and CWD volume continue to be lower than levels indicative of high ecological integrity, and this is a common issue in forests managed for timber production (Goodburn and Lorimer 1998). Adapting forest management approaches to encourage more snag and CWD retention may be necessary to improve these important structural components.

Pattern and abundance of tree cavities varied by park (Table 6). Small cavities on live trees were most abundant in ACAD, and least abundant in MABI. Large cavities on live trees were most abundant in SAGA and SARA. Small and large cavities on dead trees were most abundant in ACAD, SAGA, and SARA. The probability of detecting tree cavities, particularly small cavities, decreases with tree height and density of the canopy. It is possible in MABI, where trees are relatively tall and the canopy is multilayered, that true cavity densities are higher than our data suggest. These data are only based on plots sampled from 2012 to 2014, and it will be important to examine how much this metric varies over time and how repeatable the data are.

Table 4. Coarse woody debris (CWD) metric ratings, ratios, and volume calculations for NETN parks based on data collected from 2011 to 2014. Metric ratings are based on CWD ratio, which is the ratio of coarse woody debris volume to live tree volume and is expressed as a percent. The CWD ratio is calculated for each plot in a group and then averaged, and will differ from the mean CWD divided by the mean live tree volume. Only plots with complete stand height data are included in the analysis (i.e., no early successional plots). Groups with fewer than 10 plots were not rated for CWD, and woodland plots are not included in the ACAD ratings. SE refers to 1 standard error around the mean.

Park	Group	# Plots	Rating	CWD Ratio (%)		Metric CWD Volume (m ³ /ha)		English CWD Volume (ft ³ /acre)		Live Tree Volume (m ³ /ha)	
				Mean	SE	Mean	SE	Mean	SE	Mean	SE
ACAD	Overall	151	Caution	12.00%	1.23%	23.75	2.27	339.36	32.46	217.66	9.79
	IAH	15	Caution	10.60%	2.15%	20.15	4.81	287.93	68.77	180.73	29.16
	MDI East	72	Caution	10.53%	1.90%	16.75	2.81	239.37	40.10	191.75	15.70
	MDI West	58	Caution	14.02%	2.04%	32.88	4.24	469.88	60.59	259.39	12.04
	Schoodic	6	---	13.60%	4.41%	28.43	10.93	406.23	156.25	217.38	52.52
MABI	Overall	23	Caution	9.84%	1.91%	40.62	7.20	580.50	102.91	473.49	39.63
	Natural	12	Caution	11.73%	3.05%	40.70	11.84	581.68	169.16	382.26	47.24
	Plantation	11	Caution	7.77%	2.20%	40.53	8.39	579.21	119.92	573.02	51.45
MIMA		19	Sign. Conc.	4.27%	1.39%	10.78	4.00	154.09	57.17	360.42	60.31
SAGA		21	Caution	8.54%	2.62%	37.67	7.30	538.43	104.36	577.25	67.34
SARA	Overall	26	Caution	12.32%	3.85%	22.35	5.07	319.43	72.50	290.41	33.81
	Field	19	Caution	13.26%	4.96%	21.05	5.82	300.77	83.16	266.34	37.14
	Forest	7	---	9.79%	5.22%	25.89	10.94	370.07	156.35	355.74	74.09

Table 5. Snag abundance ratings and calculations for NETN parks based on data collected from 2011 to 2014. Metric ratings are based on the percent of standing trees (i.e., ≥ 10 cm diameter at breast height) that are snags. M-L Snags refers to medium to large (≥ 30 cm diameter at breast height) diameter snags. Groups with fewer than 10 plots were not rated for this metric. SE refers to 1 standard error around the mean.

Park	Group	# Plots	Rating	# of Snags/ha		# of M-L Snags/ha		% of Trees as Snags	
				Mean	SE	Mean	SE	All Sizes	M-L Snags
ACAD	Overall	176	Caution	171.46	10.83	7.83	1.59	15.77%	8.81%
	IAH	19	Good	114.62	15.69	11.70	5.73	12.37%	13.89%
	MDI East	82	Sign.Conc.	147.42	14.43	4.88	1.73	14.45%	6.67%
	MDI West	65	Good	201.71	19.90	11.62	3.27	16.62%	10.43%
	Schoodic	10	Sign.Conc.	280.00	48.71	0.00	0.00	24.90%	0.00%
MABI	Overall	24	Caution	42.71	10.26	5.21	2.12	9.40%	3.47%
	Natural	13	Caution	38.46	15.40	7.69	3.33	8.44%	6.25%
	Plantation	11	Sign.Conc.	47.73	13.67	2.27	2.27	10.55%	1.25%
MIMA		20	Caution	53.75	11.51	6.25	2.48	11.08%	4.90%
SAGA		21	Caution	76.19	17.38	10.71	2.77	12.19%	5.36%
SARA	Overall	31	Caution	77.34	14.86	7.03	2.80	16.72%	6.72%
	Field	24	Caution	74.00	16.17	7.00	3.39	16.59%	7.37%
	Forest	7	---	89.29	38.13	7.14	4.61	17.12%	5.13%

Table 6. Tree cavity summary statistics for each park from 2012 - 2014.

	# Plots	Small Cavities				Large Cavities			
		# Live Trees/ ha		# Dead Trees/ ha		# Live Trees/ ha		# Dead Trees/ ha	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
ACAD	132	5.72	1.39	9.43	2.09	5.05	1.41	10.10	2.12
MABI	24	1.04	1.04	2.08	1.44	1.04	1.04	2.08	1.44
MIMA	20	3.75	2.05	6.25	2.48	3.75	2.05	0.00	0.00
SAGA	21	4.76	2.20	11.90	4.09	3.57	2.61	10.71	5.05
SARA	32	3.13	1.86	14.06	4.19	4.69	2.08	10.16	2.94

Forested systems in most NETN parks are relatively young, and are likely to fall short of desired late successional levels of CWD and snags for some time (decades to centuries). As long as forests are left to mature and management activities (e.g., cutting and/or removing coarse woody debris) do not reduce the potential for development of CWD and large diameter snags, we expect these metrics to improve with time.

Tree Regeneration

Background

This metric assesses the quantity and composition of tree regeneration in the forest understory, which will impact future canopy structure and composition. Regeneration can be affected by a variety of stressors, including invasive species, acid deposition, and climate change. Most notably, sustained, selective browsing by a historically high population of white-tailed deer is currently impacting seedling establishment, growth, and composition in parts of the Midwest and Northeast U.S. (Cote et al. 2004). Significant impacts on forest tree regeneration are associated with deer densities ≥ 8.5 per km^2 , well above pre-settlement estimates of 3-4 deer per km^2 in the northeastern U.S. (Russell et al. 2001, Augustine and deCalesta 2003).

In most of the network, this metric is rated using a seedling ratio and stocking index. The seedling ratio considers preferential browse of deer on particular seedling species and size classes (Cornett et al. 2000) and uses a ratio developed by Sweetapple and Nugent (2004). This ratio takes the species richness in the tall, preferentially browsed size class (30-100 cm) minus species richness in the short, un-browsed (15-30 cm) size class and divides this by the sum of species richness in the tall and short size classes. This metric only considers the preferred browse species listed in Appendix B. Negative ratios suggest that deer browse is reducing diversity of the tall, preferentially browsed size class. While this ratio is useful in detecting moderate impacts of deer browse, it is less effective in systems that lack browse-preferred species for reasons other than deer browse (e.g., spruce-fir forests in ACAD), and may be less effective in systems with relatively low tree diversity (e.g., northern hardwood forests in MABI, MIMA, and SAGA).

The stocking index developed by McWilliams et al. (2005) quantifies whether current seedling numbers are sufficient to restock a mid-Atlantic hardwood forest stand. This index awards and sums points for native tree seedlings by size class within 2-m radius circular microplots as follows: one point for each seedling 15-30 cm, two points for each seedling 30-100 cm, 20 points for each seedling 100-150 cm, and 50 points for each seedling or sapling > 150 cm tall but less than 10 cm DBH. The stocking index in NETN plots is averaged over three 2-m radius microplots. A stocking index less than 25 is considered inadequate for mid-Atlantic hardwood stands with low deer densities and is the assessment point that distinguishes Caution from Significant Concern for MORR, ELRO/HOFR, VAMA, and WEFA. While this stocking index is a useful baseline, the stocking target (25) is based on experimental data collected in oak/hickory forests in Pennsylvania, and it is unknown whether these numbers are appropriate for the northern hardwood forests common in northern NETN parks.

The deer browse index is a qualitative assessment of deer browse impact at each plot based on the presence of browse-preferred and non-preferred woody and herbaceous species (Table 7). This

method was adapted from Brose et al. (2008) and Perles et al. (2010), and was initially implemented in 2009. Starting in 2010, the browse index was modified for ACAD to account for the absence of browse-preferred species for reasons other than deer browse and relies more on signs of deer (e.g., scat, deer trails, browse, etc.) than presence of browse-preferred species. The deer browse index in this report has not been incorporated into regeneration metric calculations.

Table 7. Index of deer browse impacts assessed for each plot in national historical parks (NHP) and historic sites (NHS) and ACAD (adapted from Brose et al. 2008 and Perles et al. 2010).

Parks	Level	Browse Impact	Description
NHP and NHS	1	None	Plot located inside deer exclosure, and no browse.
	2	Low	No observed browse; browse-preferred species present.
	3	Moderate	Evidence of browse; browse-preferred regeneration present but with little height variability; non-preferred and browse-resistant species common.
	4	High	Browse evidence common; browse-preferred species rare to absent; non-preferred or browse-resistant vegetation limited in height by browsing.
	5	Very High	Browse evidence omnipresent; browse-preferred species absent; browse-resistant plants show signs of heavy browsing and browse line evident.
ACAD	1	None	Plot located inside deer exclosure, and no browse.
	2	Low	No observed browse or sign of deer activity on plot.
	3	Moderate	Evidence of browse and signs of deer activity on the plot.
	4	High	Browse evidence common; and non-preferred species show signs of browse.
	5	Very High	Browse evidence omnipresent; browse-resistant and non-preferred species show signs of heavy browsing and browse line evident.

As more data are collected and deer density data are available, we will assess if the deer browse index is appropriate to incorporate into the tree regeneration metric. NETN recently developed a tree regeneration metric for ACAD using data collected in late-successional spruce-fir stands (Miller et al. 2013a). The regeneration metric for ACAD evaluates whether current patterns and abundance of regeneration are consistent with those expected in late-successional forests. The metric uses the stocking index to assess regeneration abundance for all stand types and the ratio of saplings to small (15-100 cm) seedling density to assess regeneration patterns for upland forests. The expectation is that regeneration in late-successional stands is abundant and, while both are present, small seedlings are more abundant than saplings. To account for the high spatial variability in regeneration, this metric requires a minimum of 10 plots to be rated and will be summarized at the group level, rather than by proportion of plots in each rating. The assessment points for tree regeneration in ACAD are defined in Table 1.

In the absence of data that can distinguish healthy from impacted condition in northern hardwood forests, we will examine the seedling ratio, stocking index, seedling densities and deer browse index

collectively to assess tree regeneration in the parks currently without a Significant Concern assessment point (MABI, MIMA, SAGA, and SARA). In ACAD, we will examine regeneration using the stocking index and the sapling:seedling ratio, as described in Miller et al. (2013a)

Results and Discussion

Over half of the plots in MABI, SAGA, and SARA were rated Caution due to negative seedling ratios (Figure 4). The average deer browse index was fairly low in MABI and SAGA, and other factors such as stand development may be behind the negative seedling ratios (Table 8). Stand development and invasive species may explain the plots that were rated Caution in MIMA. While overall seedling densities are fairly high in SARA, small seedlings (i.e., below 100 cm tall) made up the bulk of the seedling density (Figure 5), and the average deer browse index was close to 3 (Table 8). These results indicate moderate impacts to tree regeneration may be occurring in SARA.

Forests across all subunits and successional stages in ACAD have sufficient levels of regeneration, but patterns of regeneration reflect those of earlier stages of forest succession (Table 9). Therefore, all units of ACAD were rated Good for the stocking index, and Caution for the sapling:small seedling density ratio. As the park's forests mature and move towards more uneven-aged stands, we expect the sapling:seedling density ratios across ACAD subunits to approach the ratio observed in old-growth and late-successional stands.

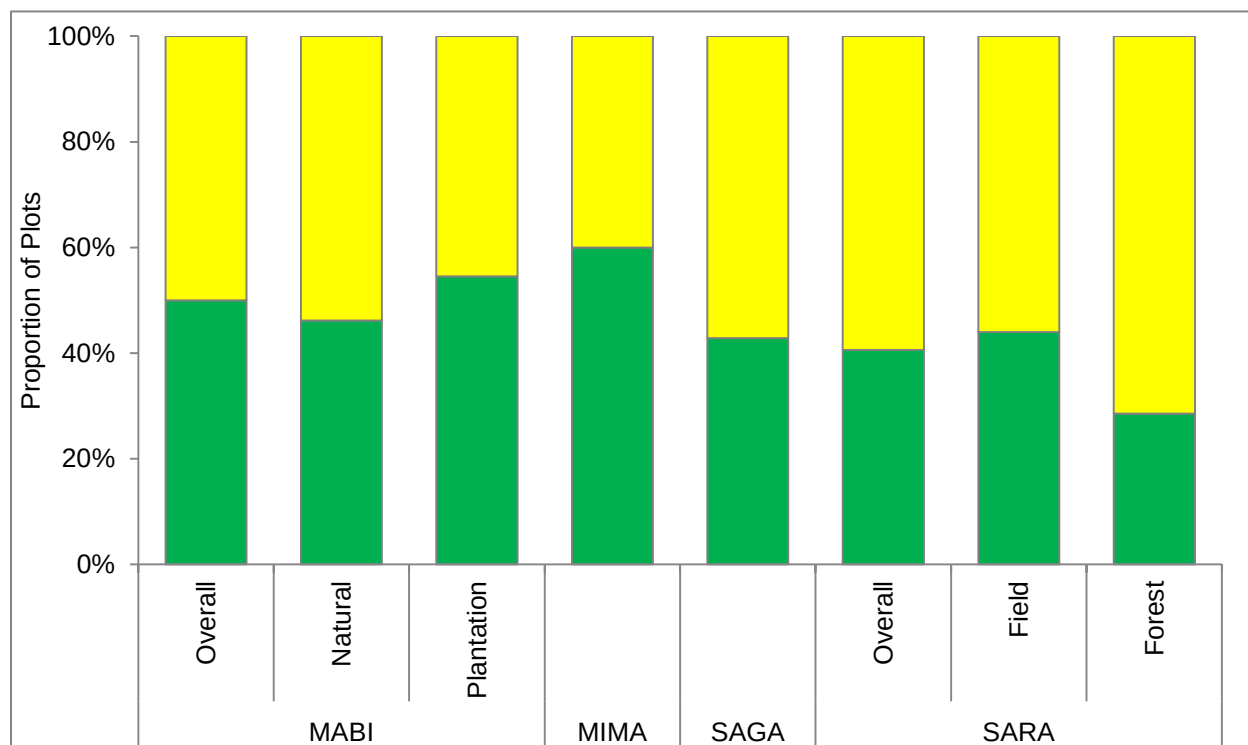


Figure 4. Proportion of plots in NHPs receiving Good (green), and Caution (yellow) ratings for tree regeneration based on data from 2011-2014. An assessment point for Significant Concern has not been defined for this group of parks.

Table 8. Mean stocking index and seedling ratio averaged over three 2-m radius microplots, and based on data collected from 2011-2014 for the NHPs. Plots without browse preferred species are not included in the seedling ratio summaries. The deer browse index was not used to rate the regeneration metric.

		Stocking Index			Tall : Short Seedling Richness Ratio			Deer Browse Index		
		Mean	SE	N	Mean	SE	N	Mean	SE	N
	Overall	68.35	22.56	24	-0.14	0.14	22	2.58	0.17	24
MABI	Natural	94.05	40.62	13	-0.16	0.21	12	2.31	0.17	13
	Plantation	37.97	6.64	11	-0.11	0.19	10	2.91	0.28	11
MIMA		47.87	11.96	20	0.04	0.15	18	2.75	0.16	20
SAGA		70.32	15.90	21	0.11	0.16	15	2.62	0.18	21
	Overall	45.82	20.82	32	-0.18	0.11	32	2.97	0.12	32
SARA	Field	27.61	7.85	25	-0.11	0.13	25	3.04	0.15	25
	Forest	110.86	91.97	7	-0.45	0.16	7	2.71	0.18	7

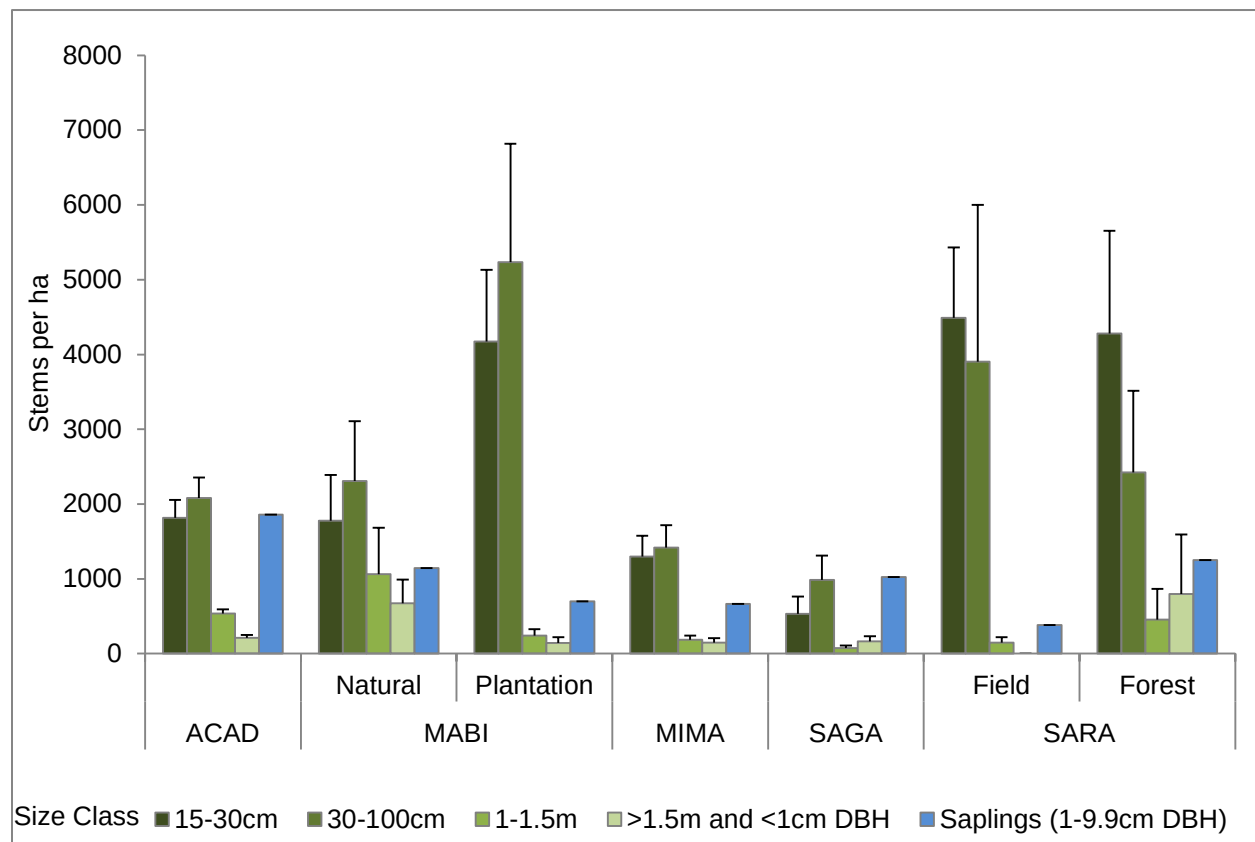


Figure 5. Mean seedling (green) and sapling (blue) densities based on data collected from 2011-2014.

Table 9. Regeneration metric summaries for ACAD, based on data collected from 2011-2014. Standard error (SE) for the ratio accounts for the uncertainty in the estimates of sapling and seedling abundance. Only upland forests were included in the sapling:small seedling density ratio. The deer browse index was not used to rate the regeneration metric.

Group	Stocking Index				Sapling: Small Seedling Ratio				Deer Browse Index	
	Mean	SE	N	Rating	Mean	SE	N	Rating	Mean	SE
Overall	138.39	13.78	176	Good	0.46	0.08	141	Caution	2.38	0.04
IAH	137.02	30.20	19	Good	0.68	0.25	12	Caution	2.32	0.15
MDI East	109.37	13.94	82	Good	0.52	0.16	65	Caution	2.40	0.06
MDI West	177.44	30.93	65	Good	0.41	0.11	54	Caution	2.34	0.07
Schoodic	125.13	31.93	10	Good	0.19	0.09	7	N/A	2.60	0.22

Tree Condition and Forest Pests

Background

This metric assesses tree condition based on qualitative observations of specific tree health problems and canopy foliage condition. As the season progresses, most trees develop minor foliage problems. However, more extensive damage to canopy foliage may be indicative of tree health problems within a species or across a region, and could be related to any combination of soil chemistry, climate, pathogens, or other drivers and stressors. In particular, exotic pests and pathogens have the potential to severely impact forest tree composition as well as structure and function. Several species of exotic pests and pathogens pose serious threats to northeastern forests if they advance into the region; these NETN “Priority 1” pests are Asian longhorned beetle (ALB; *Anoplophora glabripennis*), emerald ash borer (EAB; *Agrilus planipennis*), hemlock woolly adelgid (HWA; *Adelges tsugae*), and sudden oak death (*Phytophthora ramorum*; SOD; Appendix C). Other forest pests can cause problems that are not quite as severe, and/or may already be widespread in the NETN region. These NETN “Priority 2” pests are balsam woolly adelgid (BWA; *Adelges piceae*), beech bark disease (BBD), butternut canker (BC; *Sirococcus clavigignenti-juglandacearum*), and elongate hemlock scale (EHS; *Fiorinia externa*). As we learn more about the distribution and impacts of winter moth (WM; *Operophtera brumata*), a recently introduced pest in the Northeast, we may add this species to one of the priority lists. In addition, we record tree conditions related to native pests and pathogens, such as spruce budworm (*Choristoneura fumiferana*), forest tent caterpillars (*Malacosoma disstria*), and needlecast fungi, but only the damage resulting from these native pests/pathogens (e.g., foliage herbivory) is included in the metric ratings. We also look for signs of white pine blister rust (*Cronartium ribicola*), and may include this on the priority list as we learn more about the recent resurgence of this pathogen in New England (Frederick et al. 2011).

To calculate this metric, specific tree health problems are tallied per plot, and average percent foliage condition is calculated for the plot and for each tree species represented by two or more individuals. Good condition is defined as minor foliage problems (< 10%) averaged across a plot and within individual species, minor damage from BBD (BBD index ≤ 2), and no evidence of damage by Priority 1 or other Priority 2 pests and pathogens. More extensive foliage problems (10-50%), more extensive BBD damage (BBD index > 2), or evidence of damage by one of the other Priority 2 pests and pathogens indicate cause for concern, and are rated Caution. Foliage damage above 50%

averaged across a stand or within an individual species (represented by at least two individuals) indicates a more serious problem, and is the assessment point that distinguishes between Caution and Significant Concern. Likewise, evidence that Priority 1 pests have reached NETN forests, which might still be controlled by management action, also warrants a Significant Concern rating.

It is important to note that after the last reporting cycle (2006-2009), HWA was changed from a Priority 2 pest to a Priority 1 pest. While HWA has been in the southern region of NETN for over a decade, eastern hemlock remains a significant component of forests in ROVA and the northern NETN parks. The loss of eastern hemlock due to HWA can result in cascading effects throughout the ecosystem, and is a major threat to these parks (Orwig and Foster 1998, Jenkins et al. 1999, Eschtruth et al. 2006). Therefore, we felt it was more appropriate to treat HWA as a Priority 1 pest. This change means that plots where HWA is detected are automatically rated Significant Concern.

Results and Discussion

Tree condition was similar between the 4-year average and 2014 in ACAD, MABI, SAGA and SARA, and only a few plots in these parks were rated Significant Concern (Figure 6). Necrosis and leaf loss in conifers were the most common reasons for Significant Concern ratings in ACAD, and often these were in marginal sites (e.g., bedrock outcrops or conifer swamps). Elevated herbivory on hardwoods was the main cause of Caution ratings in ACAD and SARA, and Significant Concern ratings in MABI, SAGA and SARA. Caution ratings in MABI and SAGA were often due to BBD.

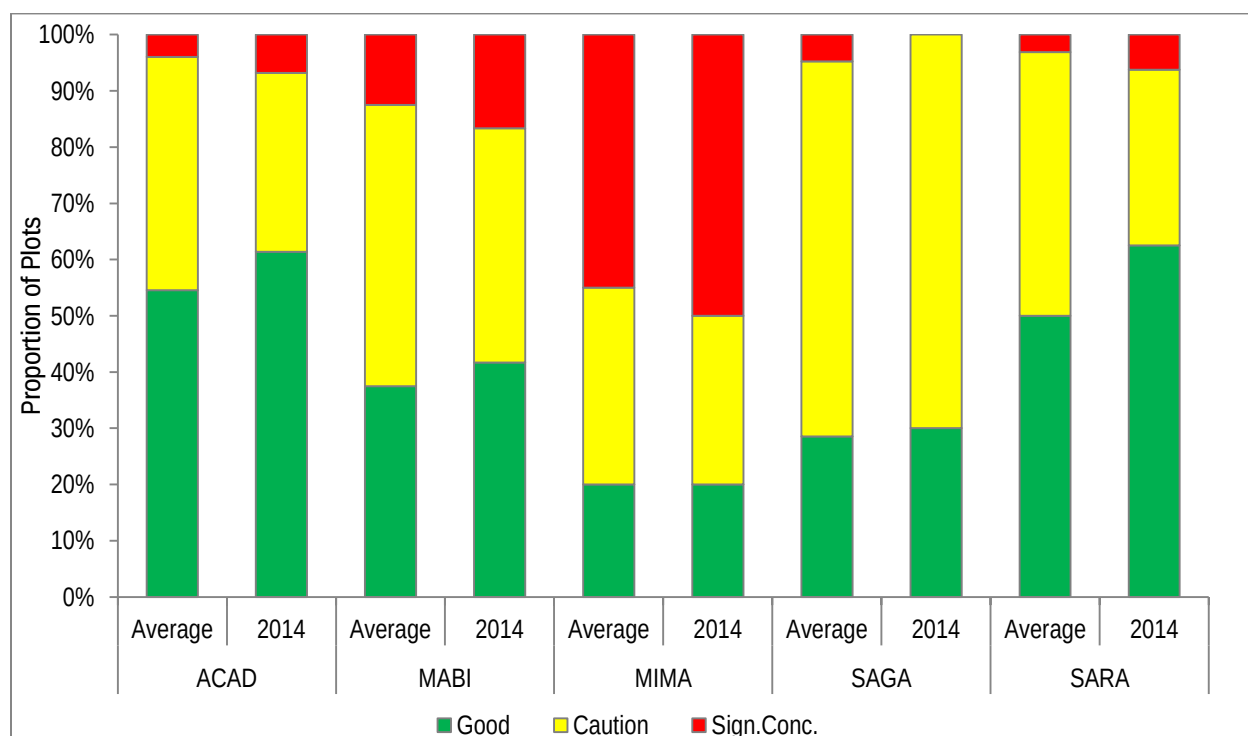


Figure 6. Proportion of plots receiving Good (green), Caution (yellow), and Significant Concern (red) ratings for tree condition for each park sampled in 2014. Average bars include 4 years (2011 – 2014) of data for ACAD, and 2012 and 2014 data for remaining parks. 2014 bars only include data collected in 2011.

Both 2012 and 2014 were years of high insect herbivory in MIMA and nearly half of the plots in MIMA were rated Significant Concern in both years. We observed especially heavy defoliation of hardwoods in 2014, and suspect WM as the primary cause. Continued heavy defoliation will likely result in reduced tree growth and eventually in increased mortality rates in MIMA (Simmons et al. 2014). We will continue to monitor herbivory with special attention to known WM infestations in MIMA and near ACAD.

Pests and pathogens detected in forest plots included BWA in ACAD, and BBD in all NETN parks. Dutch elm disease, which is not on the priority pest/pathogen lists because it has been widespread in the Northeastern US since the 1950s, continues to cause mortality in SARA. While not detected in forest plots, HWA and EHS have been identified in MIMA. HWA and WM have also recently been detected on MDI, but their presence has not been verified in ACAD forests (Figure 7).

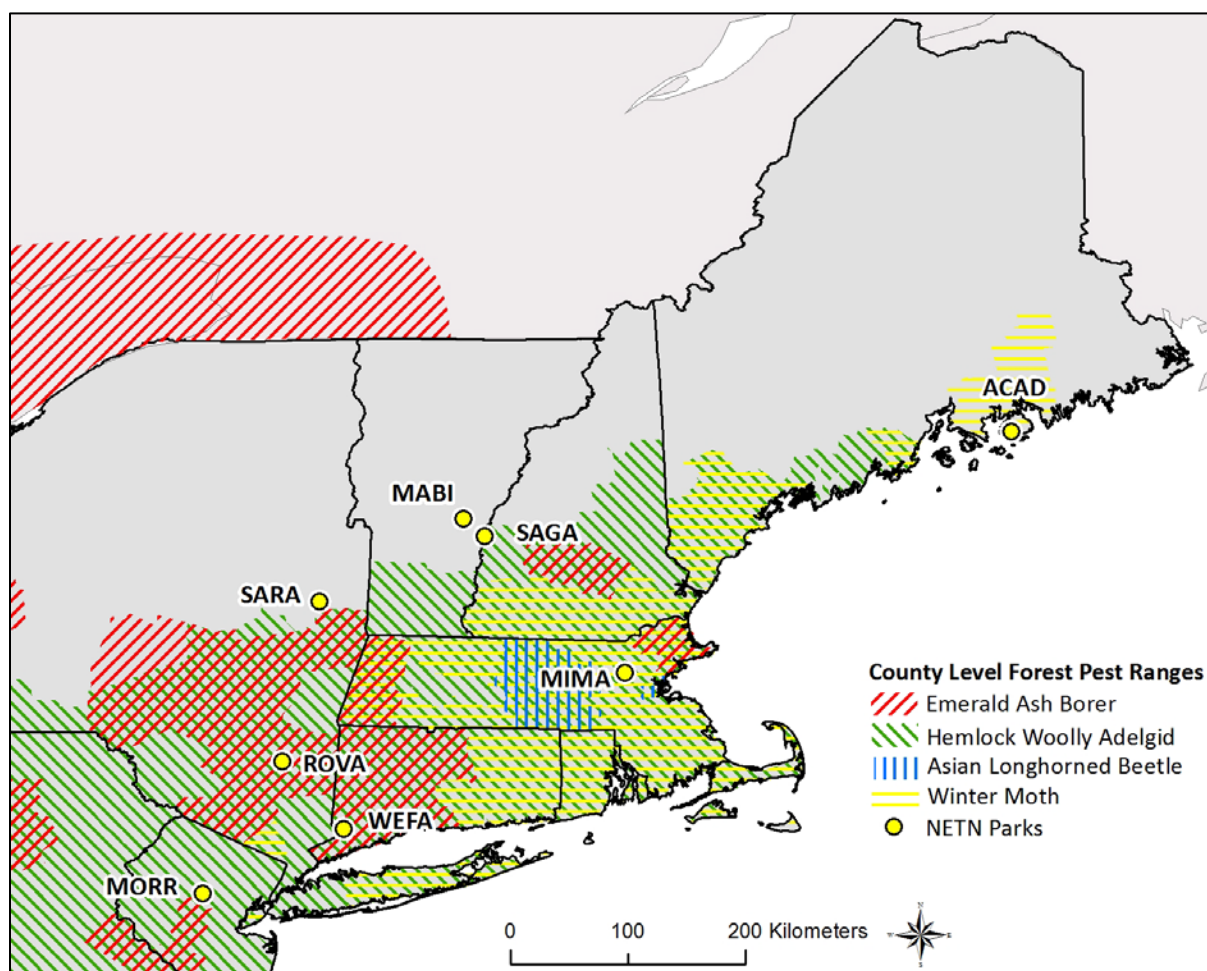


Figure 7. Exotic forest pest detections near NETN parks. Pest ranges were mapped at the county level and were downloaded from the Alien Forest Pest Explorer (<http://www.nrs.fs.fed.us/tools/afpe/maps/>), and the Collaborative EAB Project (<http://www.emeraldashborer.info>). The EAB range in Canada was estimated from maps on the Collaborative EAB Project website. Asian Longhorned Beetle range only reflects the most recent detection that has not yet been eradicated.

The range of Emerald ash borer continues to expand in the eastern US (Figure 7). A sizeable infestation of EAB is located in southern Canada and will likely lead to infestations in northern NY and VT. While EAB has not yet been detected in Saratoga County, EAB has been detected in the nearby county of Albany. EAB is a significant threat to SARA, where white ash (*Fraxinus americana*) is a common forest species and one of the few tree species capable of penetrating and persisting in the exotic shrub thickets. EAB has also moved closer to MORR and WEFA, although EAB has not yet been detected in these parks. Continued vigilance for detection and outreach for prevention by park staff, cooperators and volunteers is important to slow the spread of EAB. For more information on EAB, and strategies for slowing the spread of EAB, check the Collaborative Emerald Ash Borer Program website (<http://www.emeraldashborer.info>).

Invasive Exotic Plant Indicator Species

Background

Invasive exotic species have the potential to impact structure, composition, and function of forested ecosystems, and are one of the leading threats to biodiversity and ecological integrity of ecosystems worldwide (Mooney et al. 2005). Early detection of invasive exotic plants is an important NETN vital sign that has been incorporated into several long-term monitoring protocols. NETN is monitoring status and trends of invasive exotic species in forest plots, and is implementing a separate protocol for early detection of invasive exotic species and forest pests. To better understand the threat posed by invasive exotic plants, we developed a list of 22 indicator plant species that are highly invasive in northeastern forest, woodland, and successional habitats (Appendix D). Included species are those that may dominate and/or persist under shaded conditions (i.e., in forest or woodland), or that may disrupt succession to forest or woodland. Several exotic species such as knapweeds (*Centaurea* spp.) and greater celandine (*Chelidonium majus*) were not used as indicator species, despite being present in several parks, because they have not been found to suppress forest succession or to dominate under a shaded canopy. Thus, total abundance of exotic species may be higher than reported here for indicator species. In addition to the average number of indicator invasive exotic species per plot, we calculated average percent cover and average number of species at the quadrat level to assess degree of invasion in each park.

Results and Discussion

ACAD continues to have the lowest incidence of invasive exotic species, with all subunits rated Good (Table 10). MABI and SAGA had low levels of indicator invasive species, and both were rated Caution. Natural stands in MABI tended to have lower abundance and richness of invasive exotic species than Plantations. Indicator invasive species were more widespread in MIMA and SARA. Despite having a similar percent cover of invasive exotic species, MIMA was rated Significant Concern, and SARA was rated Caution. However, the Field group in SARA had higher rates of invasion than the Forest group, and was rated Significant Concern. This metric is based on the average number of invasive exotic species per plot, and does not consider overall abundance of invasive exotic species. Therefore, the high cover of invasive species in SARA is a concern to forest health, even though SARA was rated Caution overall.

The list of the top five most frequent indicator invasive exotics for each park demonstrates that NETN parks have a lot of invasive exotic species in common (Table 11). Common buckthorn (*Rhamnus cathartica*) and exotic bush honeysuckles (*Lonicera* spp.) are the most frequent indicator invasive species across NETN parks. Japanese barberry (*Berberis thunbergii*), glossy buckthorn (*Rhamnus frangula*), oriental bittersweet (*Celastrus orbiculatus*), and multiflora rose (*Rosa multiflora*) are also relatively common. These species represent some of the most invasive species in the Northeast, and it is critical that park managers continue to detect, manage and prevent the introduction and spread of these species in their parks.

In addition to ecosystem impacts, recent studies have suggested that exotic shrub thickets can have an indirect effect on human health. By creating a more favorable humid microclimate, exotic shrub thickets can harbor higher densities of blacklegged ticks (*Ixodes scapularis*) than uninvaded forests (Elias et al. 2006, Williams and Ward 2010). Research has also found higher incidences of blacklegged ticks that are infected with human pathogens, such as Lyme disease (*Borrelia burgdorferi*), in exotic shrub thickets due to altered movement and habitat use by mammals that disperse ticks (Williams et al. 2009, Allan et al. 2010). Blacklegged tick populations and infection rates dramatically decreased when the exotic shrub thickets were removed (Williams et al. 2009).

Table 10. Indicator invasive exotic plant species ratings for NETN parks. Metric ratings are based on the mean number of indicator species found per plot from 2011 to 2014. Average indicator invasive exotic percent cover (Mean % Cover / Quad), and mean number of indicator invasive exotic species per quadrat (Mean # / Quad) were used to interpret this metric, but were not involved in the metric rating.

Park	Group	N	# Species/Plot		% Cover / Quad		# Species/Quad		Rating
			Mean	SE	Mean	SE	Mean	SE	
ACAD	Overall	176	0.02	0.01	<0.01	<0.01	<0.01	<0.01	Good
	IAH	19	0	0	0	0	0	0	Good
	MDI East	82	0.05	0.03	<0.01	<0.01	<0.01	<0.01	Good
	MDI West	65	0	0	0	0	0	0	Good
	Schoodic	10	0	0	0	0	0	0	Good
MABI	Overall	24	0.92	0.18	<0.01	<0.01	0.02	<0.01	Caution
	Natural	13	0.62	0.24	0	0	<0.01	<0.01	Caution
	Plantation	11	1.27	0.24	0.02	0.02	0.03	0.02	Caution
MIMA		20	5.00	0.46	13.52	2.73	1.23	0.12	Sign. Conc.
SAGA		21	0.81	0.27	1.05	1.04	0.11	0.05	Caution
SARA	Overall	32	3.38	0.26	16.32	3.54	1.09	0.11	Caution
	Field	25	3.60	0.25	19.83	4.26	1.23	0.13	Sign. Conc.
	Forest	7	2.57	0.75	3.79	1.83	0.63	0.18	Caution

Deer Browse Indicator Species

Background

A recurring trend that has been observed throughout eastern U.S. forests is a compositional shift in forest understories in response to sustained high deer densities (Horsley et al. 2003, Rooney et al. 2004, Mudrak et al. 2009). This shift is characterized by losses in deer-preferred species such as

native perennial forbs and increases in browse-resistant or non-preferred species such as grasses and sedges, ferns, and exotic species (Rooney 2009). Negative browse impacts have been documented where deer densities are as low as 8 per km² for 10 or more years, and severe impacts have been observed with deer densities ≥ 20 per km² (Horsley et al. 2003, Augustine and deCalesta 2003).

Table 11. Most frequent indicator invasive exotic species in NETN forest plots by park from 2011 to 2014. Number of plots is listed below the park level and group level. MDI-East is the only subunit of ACAD where invasive exotic species have been found in a forest plot.

Park	Group	Latin	Common	# Plot Occurrences
ACAD n=176	MDI-East n=82	<i>Berberis thunbergii</i>	Japanese barberry	1
		<i>Lonicera</i> spp.	exotic bush honeysuckle	1
		<i>Rhamnus frangula</i>	glossy buckthorn	1
MABI n=24	Natural n=13	<i>Berberis vulgaris</i>	common barberry	2
		<i>Celastrus orbiculatus</i>	oriental bittersweet	1
		<i>Lonicera</i> spp.	exotic bush honeysuckle	3
		<i>Rhamnus cathartica</i>	common buckthorn	2
	Plantation n=11	<i>Alliaria petiolata</i>	Garlic mustard	1
		<i>Berberis vulgaris</i>	common barberry	1
		<i>Lonicera</i> spp.	exotic bush honeysuckle	7
		<i>Rhamnus cathartica</i>	common buckthorn	5
MIMA n=20		<i>Acer platanoides</i>	Norway maple	9
		<i>Celastrus orbiculatus</i>	oriental bittersweet	18
		<i>Lonicera</i> spp.	exotic bush honeysuckle	10
		<i>Rhamnus frangula</i>	glossy buckthorn	19
		<i>Rosa multiflora</i>	multiflora rose	16
SAGA n=21		<i>Acer platanoides</i>	Norway maple	4
		<i>Berberis thunbergii</i>	Japanese barberry	2
		<i>Celastrus orbiculatus</i>	oriental bittersweet	1
		<i>Euonymus</i> spp.	burningbush	1
		<i>Lonicera</i> spp.	exotic bush honeysuckle	7
		<i>Rhamnus cathartica</i>	Common buckthorn	1
SARA n=32	Field n=25	<i>Alliaria petiolata</i>	Garlic mustard	11
		<i>Celastrus orbiculatus</i>	oriental bittersweet	4
		<i>Lonicera</i> spp.	Exotic bush honeysuckle	24
		<i>Rhamnus cathartica</i>	Common buckthorn	23
		<i>Rosa multiflora</i>	Multiflora rose	19
	Forest n=7	<i>Alliaria petiolata</i>	Garlic mustard	2
		<i>Celastrus orbiculatus</i>	Oriental bittersweet	2
		<i>Lonicera</i> spp.	Exotic bush honeysuckle	5
		<i>Rhamnus cathartica</i>	Common buckthorn	4
		<i>Rosa multiflora</i>	Multiflora rose	4

This metric measures the change in quadrat frequency of indicator herbaceous species over time. The indicator list of species includes 15 common, highly-visible herbaceous species that are preferred by deer and/or have been shown or predicted to be intolerant of deer browsing due to life history traits (Augustine and deCalesta 2003). Also included on the list are three species and one genus considered unpalatable to deer and that have been shown to increase in abundance under heavy deer browse pressure. Frequency is calculated for each indicator species, based on presence or absence in eight herbaceous quadrats per plot, and is summarized at the park unit or group level for each survey cycle.

Note that this metric relies on change in species frequency of species present in at least one plot, and therefore has limited value for sites already highly impacted by deer browse. Indicator species for this metric are listed in Appendix E. Metric ratings are based on the change in frequency of indicator species between time periods and therefore only include data from plots that have been sampled more than once. This metric is very sensitive to small changes in quadrat frequency, which may be due to sample variability (e.g., different quadrat placements) rather than actual changes. Therefore a change in quadrat frequency that represents less than 1% of quadrats will be considered no change for metric ratings. Furthermore, with only two cycles for comparisons, the results are preliminary, and we will not assign a Significant Concern rating until we have more cycles of data to assess trends.

Results and Discussion

ACAD only showed slight changes in browse-preferred and browse-avoided species and was rated Good for this metric (Table 12). Half or more of the browse preferred species in MABI, MIMA, SAGA, and SARA decreased in frequency between cycles, and half of the deer-avoided species increased in frequency in SARA. All four parks were rated Caution. However, the decline in browse-preferred species frequency in these parks was typically represented a decline in only a few quadrats for each species (Appendix F). If this trend continues for multiple cycles in a park, then it would warrant more concern. We will also examine change in other metrics, such as average percent cover of browse-preferred and browse-avoided species, to assess deer impacts to forest understories.

Table 12. Deer browse indicator species ratings for plots resampled during 2011-2014. % Decrease Browse-Preferred is the proportion of browse-preferred species that declined in frequency between survey cycles. % Increase Browse-Avoided is the proportion of browse-avoided species that increased in quadrat frequency between survey cycles.

Park	% Decrease Browse-Preferred Species	% Increase Browse-Avoided Species	Rating
ACAD	0.0	33.3	Good
MABI	50.0	25.0	Caution
MIMA	100.0	33.3	Caution
SAGA	66.7	33.3	Caution
SARA	50.0	50.0	Caution

Tree Growth and Mortality Rates

Background

Tree growth and mortality rates are important indicators of tree health and vitality. Growth rates can decline in response to environmental factors or anthropogenic stress, and mortality is often preceded

by some years of reduced tree growth (Ward and Stephens 1997, Pedersen 1998, Dobbertin 2005). Decreased growth or elevated mortality rates in trees of a particular species can indicate a particular health problem for that species (Duchesne et al. 2003, Hyink and Zedeker 1987), while altered growth and mortality rates for multiple species across a region may indicate a regional environmental stress, such as acid deposition (Steinman 2004, Dobbertin 2005). Growth and mortality rates are also influenced by structural stage (Frelich and Reich 1995, Lutz and Halpern 2006).

To account for differences in growth and mortality rates due to site characteristics, stand structural stage, and by tree species, size, and crown class (i.e., tree position in canopy), both rates will be calculated for canopy trees (i.e., dominant, co-dominant, or intermediate crown classes) in stands that have succeeded to a mature or late-successional stage (based on the structural stage metric). To examine patterns of tree growth, we use relative basal area growth (% basal area / year), which is calculated as the percent change in basal area from successive diameter at breast height (DBH) measurements on individual trees, converted to an annual rate. Relative basal area growth rate is then averaged for canopy trees across the plot, and also by species within the plot. The average growth rate of each plot, or species within a plot, is then averaged by park or group of plots. Metric ratings are based on regional growth rates and derived from U.S. Forest Service Forest Inventory and Analysis (FIA) data collected from plots in the same Ecological Subsection as each NETN park. FIA growth and mortality rates are calculated using the same metric calculations and subset of plots (mature and late-successional) and trees (e.g., only canopy trees) from each plot. We determined the subset of plots by calculating the same structural stage metric with the FIA plot data as we calculate for NETN plots in the Ecological Integrity scorecard. As more cycles are sampled, we will examine growth rates within plots and across NETN parks in more detail.

Annual mortality rate is calculated from successive observations as the percent of stems that died between sample events (not including trees that were cut) and is converted to an annual basis. Annual mortality rate is calculated for each plot and for individual species within a plot, and then averaged by park or group of plots. Assessment points for this metric are based on annual mortality rates that have been documented in old-growth forests, which range from 0.3 to 1.6% (Busing 2005, Runkle 2000, Woods 2000).

Growth and mortality rates presented in this section represent mature and late-successional plots that were sampled in both cycles. Species growth and mortality rates were only calculated for species with five or more individuals in a park, and overall growth and mortality rates include all species. It is also important to note that DBH measurements were checked for potential errors that could skew growth rate calculations. Trees that differed more than 6 cm between surveys were likely the result of a data entry error, and were omitted from the analysis. Trees with large vines on the bole were also excluded from growth rate calculations, because DBH at the first census was often measured over the vine with a diameter tape, and DBH in cycle 2 was often measured using calipers. This resulted in artificially negative growth rates on several plots, and especially influenced growth rates in WEFA, where poison ivy vines were common.

Results and Discussion

Average growth rates were lower for NETN parks than FIA average growth rates (Table 13). MIMA and SAGA had overall growth rates below 60% of the FIA growth rate, and were rated Caution. Growth rates in NETN parks were based on a higher proportion of late-successional stands compared to FIA (Miller et al. 2013b). Trees in late-successional stands tend to have slower growth rates than trees in younger stands, and since NETN parks tend to have proportionately more late-successional forest plots than FIA, this may explain at least some of the differences in growth and mortality rates. Differences in species composition and management regimes (e.g., timber harvesting) may also explain the higher growth rates in FIA plots.

Several species in NETN had particularly high growth rates, including black walnut (*Juglans nigra*) in MIMA, and white ash (*Fraxinus americana*) in SARA. The black walnut growth rate is based on five trees from a plot in a historic walnut orchard, and is only relevant to this area. The high growth rate of white ash in SARA is of more interest. White ash can occupy early-successional habitats as a pioneer species, and the species is a gap exploiter in later successional stands. With the anticipated arrival of EAB, white ash may be eliminated from old field sites where exotic shrubs are most dominant and inhibit the growth of other tree species.

A number of the plots we sampled in MABI in 2014 had been recently harvested, but we did not see a dramatic increase in growth rates. This may be partially because the harvests were too recent to observe a response and partially because only mature and late-successional plots were included in this metric. European larch (*Larix decidua*) had a relatively high growth rate, and this was primarily from a plot that had been harvested. We examine tree growth in more detail in the next section of this report, including response of tree growth to harvesting in MABI.

Average mortality rates were within expected levels for all NETN parks and all were rated Good (Table 14). The highest mortality rates of individual species were striped maple (*Acer pensylvanicum*) and balsam fir (*Abies balsamea*) in ACAD. BWA is likely the main cause for the elevated mortality of balsam fir. Tamarack (*Larix laricina*) and paper birch (*Betula papyrifera*) had moderately high mortality rates in ACAD. The elevated mortality of paper birch and striped maple is likely due to succession. The mortality rate for tamarack may be due to environmental conditions, as this species tends to grow in acidic, water-logged soils. Scotch pine (*Pinus sylvestris*) in MABI had a moderately high mortality rate, and may be due to stem exclusion in over-stocked Plantations. We examine patterns of mortality in the next section in more detail.

Table 13. Average growth rates (% basal area / year) overall, and by tree species in each park. The growth rate calculation includes canopy trees (i.e., dominant, co-dominant, or intermediate crown classes) in stands that have succeeded to a mature or late-successional stage (based on the structural stage metric). U.S. Forest Inventory and Analysis (FIA) data were derived from plots located within the same Ecological Subsection as each park. Common names of tree species are listed in Appendix G. --- indicates less than five individuals of the species on the plots.

Species	ACAD		MABI		MIMA		SAGA		SARA	
	Park	FIA	Park	FIA	Park	FIA	Park	FIA	Park	FIA
<i>Abies balsamea</i>	3.02	4.21	---	---	---	---	---	---	---	---
<i>Acer platanoides</i>	---	---	---	---	0.96	---	---	---	---	---
<i>Acer rubrum</i>	1.73	2.40	1.73	2.08	1.23	2.22	1.06	2.08	2.21	2.81
<i>Acer saccharum/ A. nigrum</i>	---	---	1.56	2.41	---	---	0.96	2.41	1.50	2.55
<i>Betula alleghaniensis</i>	0.58	---	1.50	1.79	---	---	1.33	1.79	---	---
<i>Betula lenta</i>	---	---	---	2.56	---	2.65	1.37	2.56	---	---
<i>Betula papyrifera</i>	0.84	1.48	---	1.55	---	2.09	---	1.55	---	---
<i>Carya cordiformis</i>	---	---	---	---	---	---	---	---	3.11	5.75
<i>Carya ovata</i>	---	---	---	---	---	---	---	---	2.29	---
<i>Fagus grandifolia</i>	---	---	1.60	2.98	---	2.55	1.81	2.98	---	---
<i>Fraxinus americana</i>	2.03	---	1.91	6.26	0.37	3.85	1.96	6.26	4.22	4.16
<i>Juglans nigra</i>	---	---	---	---	3.30	---	---	---	---	---
<i>Larix decidua</i>	---	---	3.16	---	---	---	---	---	---	---
<i>Larix laricina</i>	2.05	---	---	---	---	---	---	---	---	---
<i>Picea mariana</i>	0.98	---	---	---	---	---	---	---	---	---
<i>Picea rubens</i>	1.83	3.14	---	---	---	---	---	---	---	---
<i>Pinus resinosa</i>	2.46	---	0.78	---	---	---	---	---	---	---
<i>Pinus strobus</i>	2.80	---	1.99	2.27	1.76	2.41	0.87	2.27	2.45	2.82
<i>Pinus sylvestris</i>	---	---	1.34	---	---	---	---	---	---	---
<i>Populus grandidentata</i>	2.17	2.50	---	---	---	---	---	---	---	---
<i>Populus tremuloides</i>	---	2.52	---	---	---	---	---	---	4.17	3.08
<i>Quercus alba</i>	---	---	---	---	0.68	1.56	---	---	---	---
<i>Quercus rubra</i>	2.12	---	2.26	3.07	2.32	3.12	1.89	3.07	---	2.72
<i>Quercus velutina</i>	---	---	---	---	1.22	2.97	---	---	2.68	---
<i>Robinia pseudoacacia</i>	---	---	---	---	0.64	---	---	---	---	---
<i>Thuja occidentalis</i>	1.14	1.84	---	---	---	---	---	---	---	---
<i>Tsuga canadensis</i>	---	---	1.45	2.81	---	3.57	1.38	2.81	---	1.62
<i>Ulmus americana</i>	---	---	---	---	---	---	---	---	2.78	5.86
Overall	1.80	2.84	1.61	2.57	1.48	2.59	1.31	2.57	3.03	3.10
Park Rating	Good		Good		Caution		Caution		Good	

Table 14. Average annual percent mortality rate by tree species in each park. The mortality rate calculation includes only plots in mature and late-successional stands, and only canopy trees (i.e., dominant, co-dominant and intermediate crown class). U.S. Forest Service Forest Inventory and Analysis (FIA) data were derived from plots located in the same Ecological Subsection as each park. Common names of tree species are listed in Appendix G. --- indicates less than five individuals of the species on the plots.

Species	ACAD		MABI		MIMA		SAGA		SARA	
	Park	FIA	Park	FIA	Park	FIA	Park	FIA	Park	FIA
<i>Abies balsamea</i>	3.91	4.91	---	---	---	---	---	---	---	---
<i>Acer pensylvanicum</i>	8.33	---	---	---	---	---	---	---	---	---
<i>Acer platanoides</i>	---	---	---	---	0.00	---	---	---	---	---
<i>Acer rubrum</i>	0.38	0.68	0.00	0.56	0.00	0.80	1.47	0.56	0.00	1.16
<i>A. saccharum/ A. nigrum</i>	---	---	0.77	0.14	---	---	0.00	0.14	0.00	0.00
<i>Betula alleghaniensis</i>	0.00	---	0.00	0.31	---	---	0.00	0.31	---	---
<i>Betula lenta</i>	---	---	---	0.00	0.00	0.00	0.00	0.00	---	---
<i>Betula papyrifera</i>	2.73	2.75	---	5.87	---	0.88	---	5.87	---	---
<i>Carya cordiformis</i>	---	---	---	---	---	---	---	---	0.00	0.00
<i>Carya ovata</i>	---	---	---	---	---	---	---	---	0.00	---
<i>Fagus grandifolia</i>	0.00	---	1.79	4.71	---	0.33	1.00	4.71	---	---
<i>Fraxinus americana</i>	0.00	---	0.00	0.06	0.00	1.15	0.00	0.06	0.00	2.78
<i>Juglans nigra</i>	---	---	---	---	0.00	---	---	---	---	---
<i>Larix decidua</i>	---	---	0.00	---	---	---	---	---	---	---
<i>Larix laricina</i>	2.78	---	---	---	---	---	---	---	---	---
<i>Ostrya virginiana</i>	---	---	0.00	---	---	---	---	---	---	---
<i>Picea mariana</i>	1.11	---	---	---	---	---	---	---	---	---
<i>Picea rubens</i>	1.00	0.54	---	---	---	---	---	---	---	---
<i>Pinus resinosa</i>	0.00	---	0.00	---	---	---	---	---	---	---
<i>Pinus strobus</i>	0.00	---	0.00	3.13	1.79	1.14	2.19	3.13	0.94	0.00
<i>Pinus sylvestris</i>	---	---	2.50	---	---	---	---	---	---	---
<i>Populus grandidentata</i>	1.83	0.95	---	---	---	---	---	---	---	---
<i>Populus tremuloides</i>	---	0.36	---	---	---	---	---	---	0.00	2.08
<i>Prunus serotina</i>	---	---	---	---	---	---	---	---	---	2.78
<i>Quercus alba</i>	---	---	---	---	0.00	0.00	---	---	---	---
<i>Quercus montana</i>	---	---	---	---	---	0.00	---	---	---	---
<i>Quercus rubra</i>	1.44	---	0.00	0.00	0.00	0.51	0.00	0.00	---	0.00
<i>Quercus velutina</i>	---	---	---	---	0.00	0.57	---	---	0.00	---
<i>Robinia pseudoacacia</i>	---	---	---	---	0.00	---	---	---	---	---
<i>Thuja occidentalis</i>	0.28	0.58	---	---	---	---	---	---	---	---
<i>Tsuga canadensis</i>	---	---	0.00	0.00	---	0.72	0.82	0.00	---	0.00
<i>Ulmus americana</i>	---	---	---	---	0.00	---	---	---	1.39	8.33
Overall	1.23	1.16	0.67	0.99	0.48	0.61	1.05	0.99	0.91	0.51
Park Rating	Good		Good		Good		Good		Good	

Management Implications
Ecological Integrity Scorecard:
2011-2014

Park	Structural Stage Distribution	CWD Ratio	Snag Abundance	Invasive Exotic Plants	Deer Browse Indicator Species	Tree Condition/ Forest Pests ¹	Tree Regen ²	Tree Growth and Mortality
ACAD	Caution	Caution	Caution	Good	Good		Good Caution	Good
MABI	Caution	Caution	Caution	Caution	Caution			Good
MIMA	Good	Sign. Conc. ³	Caution	Sign. Conc.	Caution			Caution
SAGA	Caution	Caution	Caution	Caution	Caution			Caution
SARA	Good	Caution	Caution	Caution	Caution			Good

¹Pie charts represent the proportion of plots in each ecological integrity rating category.

²ACAD regen is rated overall for abundance (Good) and pattern compared to late-successional forests (Caution).

³Significant Concern is abbreviated as Sign. Conc.

Acadia National Park

Ecological integrity metrics related to forest structure (e.g., coarse woody debris and snag abundance) suggest that forests in ACAD are beginning to reach mature stages, but still lack late-successional structure such as medium to large snags and a low sapling to seedling ratio. As long as forest composition metrics remain stable (e.g., no new invasive species, stable tree condition/forest pests, and continued regeneration), late-successional structure is expected to develop over time. Invasive species and forest pests are the major controllable threats to forest health in ACAD and ongoing exotic plant management is vitally important to maintaining forest health there. Continued vigilance and outreach are equally important to preventing the spread of forest pests such as hemlock woolly adelgid, winter moth, and emerald ash borer.

Marsh-Billings-Rockefeller National Historical Park

As is common in managed forests, coarse woody debris and snag abundance are lower than expected for late-successional hardwood stands. MABI also has the lowest density of trees with cavities in the network. Adapting forest management approaches to encourage more snag and CWD retention and to identify trees with cavities may be necessary to improve these important structural components.

Continued efforts to eradicate invasive species, particularly in plantation stands slated for harvesting, are important for maintaining forest health in MABI. Eradication of exotic shrub species is especially important, as they have caused significant impacts to forest condition in other network parks, and once established eradication is costly and labor intensive. Continued vigilance and outreach are important for preventing the spread of forest pests such as hemlock woolly adelgid, winter moth, and emerald ash borer. Efforts to slow the spread of earthworms, such as cleaning tires on logging equipment before moving into uninvaded areas, are recommended, particularly in hardwood stands

dominated by sugar maple (*Acer saccharum*). Continuing to monitor deer densities in the park is also helpful to determine how deer may be impacting forest health.

Minute Man National Historical Park

Invasive species, particularly thickets of exotic shrubs, are negatively impacting forest condition and may be increasing in MIMA. Without management efforts, these exotic shrub thickets are expected to persist and spread into new areas, especially recently disturbed areas. Forest pests pose a significant threat to forest health in MIMA, and the high defoliation rates observed by crews in 2012 and 2014 are concerning. Winter moth was likely the primary cause of the defoliation, and continued defoliation will lead to reduced tree growth and increased mortality. Early detection and rapid response to detections of Asian longhorned beetle and emerald ash borer are important, not just for the health of forests in MIMA, but for hardwood forests throughout the northeastern US.

Saint-Gaudens National Historic Site

Ecological integrity metrics related to forest structure (e.g., coarse woody debris and snag abundance) suggest that forests in SAGA lack late-successional structure such as medium to large snags. As long as forest composition metrics remain stable (e.g., no new invasive species, stable tree condition/forest pests, and continued regeneration), late-successional structure is expected to develop over time. While invasive species are present in SAGA, they do not appear to be greatly impacting forest condition. Management should continue its efforts to eradicate invasive species, especially exotic shrub species. Hemlock woolly adelgid may pose the greatest threat to forests and cultural landscapes in SAGA. Early detection efforts should focus on surveillance for hemlock woolly adelgid in and around the park.

Saratoga National Historical Park

The combined impacts of invasive species and deer herbivory appear to be altering forest condition in SARA. While we encourage the continued eradication efforts by park staff, reduction in deer densities may be an important part of the solution. Emerald ash borer poses a significant threat to forests in SARA. Early detection and outreach efforts to prevent spread of emerald ash borer into SARA are extremely important, especially considering its continued spread in NY. Eradication efforts focused on managing and slowing the spread of exotic shrub species are equally important to create and maintain conditions where tree species can regenerate.

Tree Recruitment, Growth, and Mortality

Background

Growth and mortality rates are important indicators of tree health and vitality and can be influenced by a number of factors, such as environmental stressors or forest successional stages. Average increment growth rates for trees in old-growth Appalachian forests can range from 0.25–0.45 cm / year (Runkle 1998, Runkle 2000), whereas average relative basal area growth rate for trees in similar forests can range from 3–5% (Runkle 2000). In eastern old-growth forests, annual mortality typically ranges from 0.3–1.6% (Runkle 1998, Runkle 2000, Busing 2005), and mortality rates of more than 1.6% for canopy trees in late-successional or mature stands may indicate forest health problems (Tierney et al. 2014). Using this benchmark, we designated tree species with mortality rates above 1.6% as having elevated mortality in this analysis. While benchmark recruitment rates are unknown, and depend on a number of factors related to stand structure and forest composition, lack of recruitment may indicate a forest health concern. The compositional patterns of tree recruitment are also important indicators of the future composition of the canopy (Foré et al. 1997).

Our approach in this analysis differed from the tree growth metrics used in the ecological integrity scorecard. First, we are reporting on tree recruitment in addition to tree growth and mortality rates. We also focus more on the increment growth rate and species-level rates in this section, whereas the scorecard uses the %BA growth rate and focuses more on park-level rates. In this analysis we included all trees ≥ 10 cm DBH (not just canopy trees), and all plots (not just mature and late-successional).

Mortality, recruitment, and growth rates were calculated by comparing data collected on the same trees during consecutive sampling visits for all plots in NETN. The rates reported here were computed by comparing data collected between 2007 through 2010 with data from the same trees in 2011 through 2014, respectively (panels two through four of the first and second sampling cycles, and panel one of the second and third sampling cycle). Tree mortality and recruitment are relatively rare events and one repeat sample is not enough to fully capture mortality and recruitment rates. For example, we did not observe mortality or recruitment of several fairly common species in NETN parks. This does not mean that the mortality or recruitment rate for those species is 0, but rather that these rates are below current detection levels (i.e., < 1 tree/4 years). As more trees recruit and die over time, our sample size will also improve, and will result in better estimates of tree recruitment and mortality rates.

Tree growth was measured in two ways, increment growth and percent basal area (%BA) growth. The increment growth rate was calculated for each tree as the difference (in cm) between the diameter at breast height (DBH) in the first census and the DBH in the second census, and converted to an annual rate (cm/year). The %BA growth rate was calculated for each tree as the percent change in basal area from successive DBH measurements, converted to an annual rate (%BA/year). To calculate park-level increment and %BA growth rates, we first averaged growth rates of all trees on a plot, then averaged plot growth rates by parks or groups of plots within parks. Species-level growth rates were calculated only for species with greater than five individuals, and were averaged overall,

rather than by plot. Park-level standard error was based on the plot-level average growth rates, such that plots were treated as the sample unit. Species-level standard error treated each individual tree as a sample unit, and did not account for spatial autocorrelation (i.e., correlation of individuals on the same plot). Therefore, the species-level standard error is likely an underestimate of the true error of the population, but is useful for comparisons among species. In addition, rare tree species may have resulted in high rates of recruitment or mortality driven by only a few individuals (e.g. striped maple in ACAD had only 4 individuals out of 20 die between cycles). These results should be interpreted with caution and are pointed out in each Park section.

As with the scorecard tree growth metric, DBH measurements were checked for potential errors that could skew growth rate calculations. Trees that differed more than 6 cm between surveys were likely the result of a data entry error, and were omitted from the analysis. Trees with large vines on the bole in MIMA, ROVA and WEFA were also excluded from growth rate calculations due to data quality issues. DBH in cycle 1 was often measured over the vine with a diameter tape and DBH in cycle 2 were often measured using calipers. This resulted in artificially negative growth rates on several plots, and especially influenced growth rates in WEFA, where poison ivy vines (*Toxicodendron radicans*) were common. Stunted woodlands at ACAD were also excluded from tree growth analyses.

Annual mortality rate (%trees/year) was calculated from successive observations as the percent of stems that died between sample events (not including trees that were cut) and was converted to an annual basis. Annual mortality rate was calculated for each plot and for individual species within a plot, and then averaged by park or group of plots. Species-level mortality rates were only calculated for species with more than five individuals. Annual recruitment rate (%trees/year) was calculated as the percent of trees on a plot that grew to tree status (≥ 10 cm DBH) after the initial census, divided by the number of live trees on a plot during the initial census, and then converted to an annual basis. Recruitment rate was calculated for each plot and for individual species within a plot, and then averaged by park and by species.

Results and Discussion

Mean %BA growth ranged from 1.38 - 3.30%/year and increment growth rates ranged from 0.17 – 0.37 cm/year within NETN (Figure 8). SARA had the highest %BA growth of all other parks. Increment growth was also highest in SARA, with MABI and MIMA as the next highest (Figure 8). Both %BA and increment growth rates in SAGA were the lowest among NETN parks, and this is likely due to site condition and stand structure (i.e., mature forests). High overall growth rates in SARA may be due to fast growing species and relatively good site conditions. Much of SARA is on deep, loam-clayey Hudson soils which can be quite productive (Silverman 2004), and many of the plots in SARA are located in areas with a sparse canopy and open-grown trees. Because %BA is reported in the Ecological Integrity Scorecard section, we will focus on increment growth rates for the rest of this section.

Red maple (*Acer rubrum*), white ash (*Fraxinus americana*), eastern white pine (*Pinus strobus*), and northern red oak (*Quercus rubra*) were the four most commonly found tree species in the network, which allowed for comparisons across the parks. Where present, eastern white pine increment growth

was similar across most parks, except for SAGA with just over half the growth rate of other NETN parks (Figure 9). Northern red oak growth was both higher and more variable in SARA and MORR than other parks, while growth rates remained substantially lower in ACAD. Red maple and white ash growth rates were more variable. Red maple growth rates were only 0.04 cm/year in SAGA, whereas considerably higher rates were reported for SARA (0.32 cm/year), ROVA (0.29 cm/year) and MABI (0.27 cm/year). The growth rate for white ash was markedly lower in WEFA (0.07 cm/year) compared to other parks.

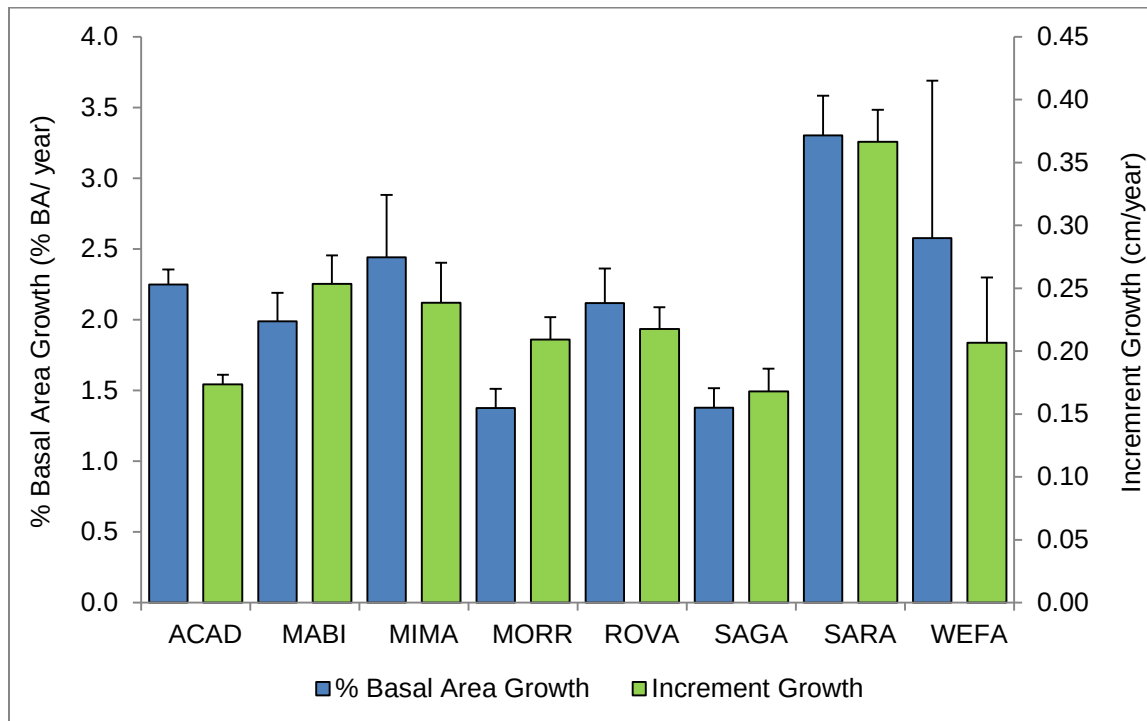


Figure 8. Mean annual %BA growth and increment growth rates for NETN parks based on all live trees and all forested plots. Error bars represent 1 SE above the mean.

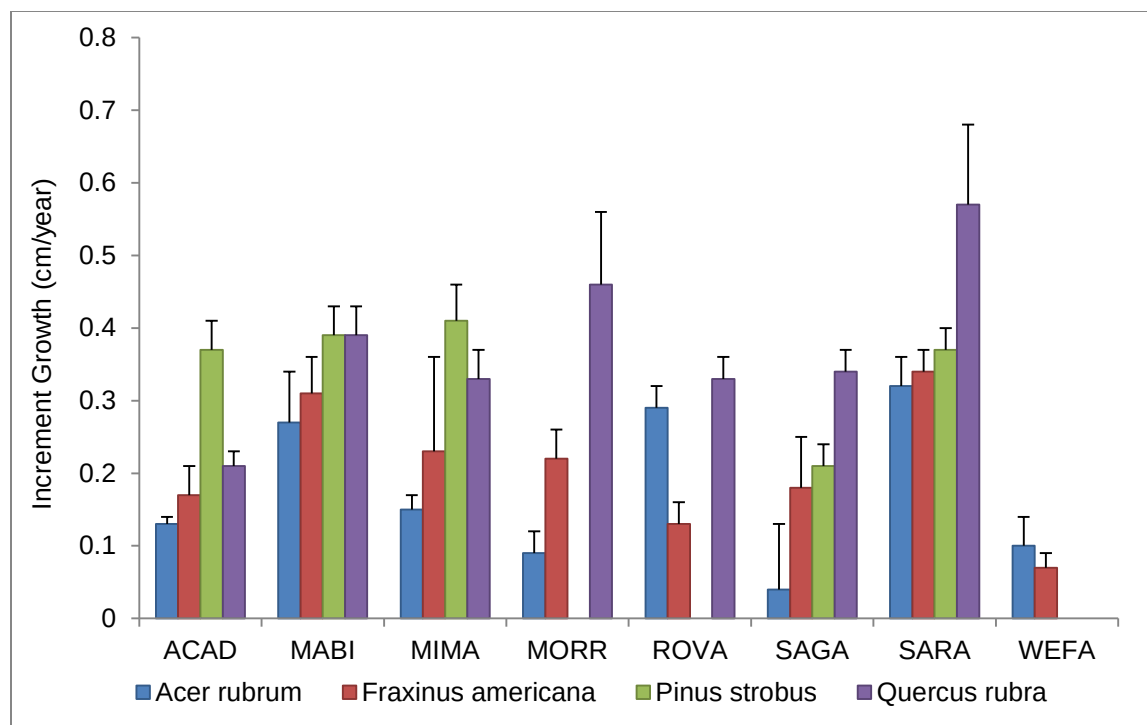


Figure 9. Average annual increment growth rates for most common species in NETN parks based on all live trees and all forested plots. Error bars represent 1 SE above the mean.

Common species that consistently exhibited high increment growth rates across network parks were northern red oak (0.21-0.57 cm/year), eastern white pine (0.21-0.41 cm/year) and black oak (*Quercus velutina*) (0.20-0.40 cm/year). Tulip poplar (*Liriodendron tulipifera*) and black walnut (*Juglans nigra*) also showed large increment growth rates, but these tree species were restricted to the southern-most parks in NETN.

Recruitment rates in NETN were highest for SARA, ACAD, MABI and MIMA (Figure 10). The tree species with the highest recruitment rates across the NETN were American elm (*Ulmus americana*) in SARA, yellow birch (*Betula alleghaniensis*) in MABI, American beech (*Fagus grandifolia*) in WEFA, and red spruce (*Picea rubens*) in ACAD. Recruitment rates in MORR, ROVA, and SAGA were the lowest in NETN. The low recruitment rate in MORR is likely the result of decades of intense deer browse pressure that has reduced regeneration directly while also enhancing invasive shrub cover throughout the understory. A similar pattern, although less extreme, may be occurring in ROVA. The relatively closed canopy forest in MORR and ROVA, which can shade out less shade-tolerant tree seedlings (e.g., oak species) may be a secondary contributing factor (Shaw and Patterson 2006). The low recruitment in SAGA is less of a concern since the parks' mature and late-successional stands are not expected to have high recruitment rates.

Mortality rates in NETN were highest in MORR and MIMA (Figure 10). Elevated levels of mortality in MORR are likely due in part to recent disturbances, including ice storms, heavy autumn snows and

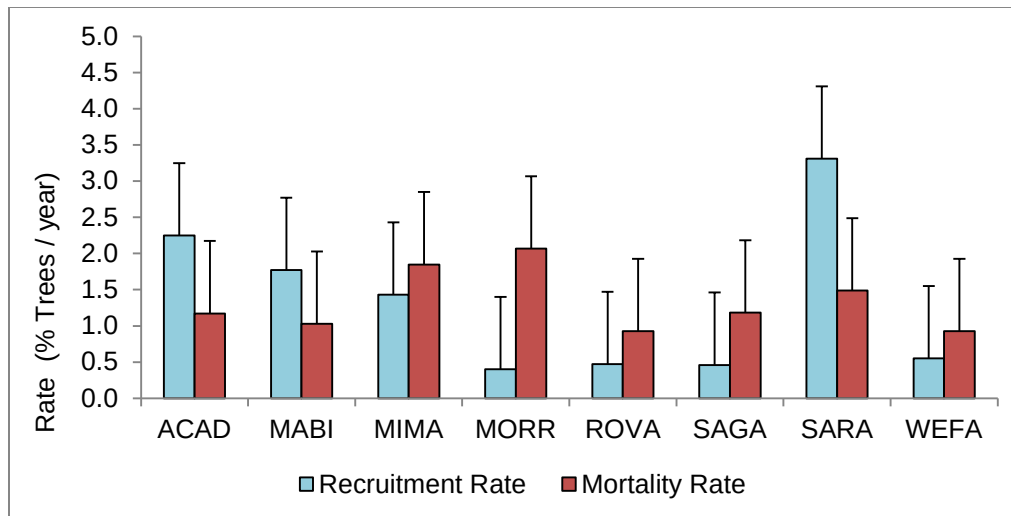


Figure 10. Average annual tree recruitment and mortality rates (%trees/year) for NETN parks based on all trees and all forested plots. Error bars represent 1 SE above the mean.

Hurricane Sandy. While it is unclear what the underlying causes of the elevated mortality are in MIMA, we suspect that repeated outbreaks of forest pests (e.g. winter moth [*Operophtera brumata*] and gypsy moth [*Lymantra dispar*]), along with pathogens (e.g. Dutch elm disease [*Ophiostoma novo-ulmi*]), may be at least partially to blame. The lowest mortality rates were found in WEFA and ROVA. However, mortality rates in ROVA may increase in the near future, as hemlock woolly adelgid (HWA; *Adelges tsugae*) and emerald ash borer (EAB; *Agrilus planipennis*) impact eastern hemlock (*Tsuga canadensis*) and ash (*Fraxinus* spp.) species in the park.

At 8.3%, the highest species mortality rate observed across the network was green ash (*Fraxinus pennsylvanica*) in MIMA. American elm had consistently high mortality rates across the network, including in MIMA, ROVA, and SARA, and this is likely due to Dutch elm disease. Other species with elevated mortality were striped maple (*Acer pensylvanicum*) in ACAD, eastern white pine in MABI and SAGA, and black cherry (*Prunus serotina*) in MIMA. Many of the species with elevated mortality rates correspondingly have little to no observed recruitment. If trends continue, these species are likely to decrease in abundance in the canopy.

Average mortality rates for MIMA and MORR were below 1.6% trees/year (Table 15). Looking only at canopy trees and plots in mature and late-succession, seventeen tree species had elevated mortality in at least one park, with white ash, eastern white pine and black oak having elevated mortality in two different parks (Table 15). If these patterns continue, this could indicate trouble across a broader landscape for these species. As more data are collected, we will have a better understanding of how species and park mortality rates are changing over time and whether they are a forest health concern.

Tree mortality and recruitment are relatively rare events and one repeat sample is not enough to fully capture mortality and recruitment rates. For species where we did not observe mortality or recruitment (e.g., black birch in WEFA), this event does not mean that the mortality or recruitment rate for those species is 0. Rather, it likely means that these rates are below current detection levels

(i.e., < 1 tree/4 years). As more trees recruit and die over time, our sample size will also improve, and will result in better estimates of tree recruitment and mortality rates.

Acadia National Park

At 0.17 cm/year, the average annual increment growth rate in ACAD was among the lowest in the network (Figure 8). Given the short growing season and thin, acidic soils that are common in ACAD, the comparatively slow growth is somewhat expected. Increment growth was highest on eastern MDI and lowest on Schoodic (Appendix H: Figure 1). Eastern white pine had the highest increment growth rate in ACAD, at almost twice the rate of other species (Figure 11). The next fastest growth rates were northern red oak, big-toothed aspen (*Populus grandidentata*), red pine (*Pinus resinosa*) and American beech (Figure 11). ACAD's slowest growing species, jack pine (*Pinus banksiana*) and mountain paper birch (*Betula cordifolia*), are primarily found on poor sites with thin soils and exposed bedrock. White birch species had some of the lowest growth rates in the park. The white birch species (*Betula cordifolia*, *B. papyrifera*, and *B. populifolia*) are shade-intolerant, early successional species that can grow quickly following a stand replacing disturbance, but tend to slow their growth as the canopy closes in. In contrast, big-toothed aspen, another early-successional species common in the area that burned in 1947, still has moderate increment growth (Figure 11).

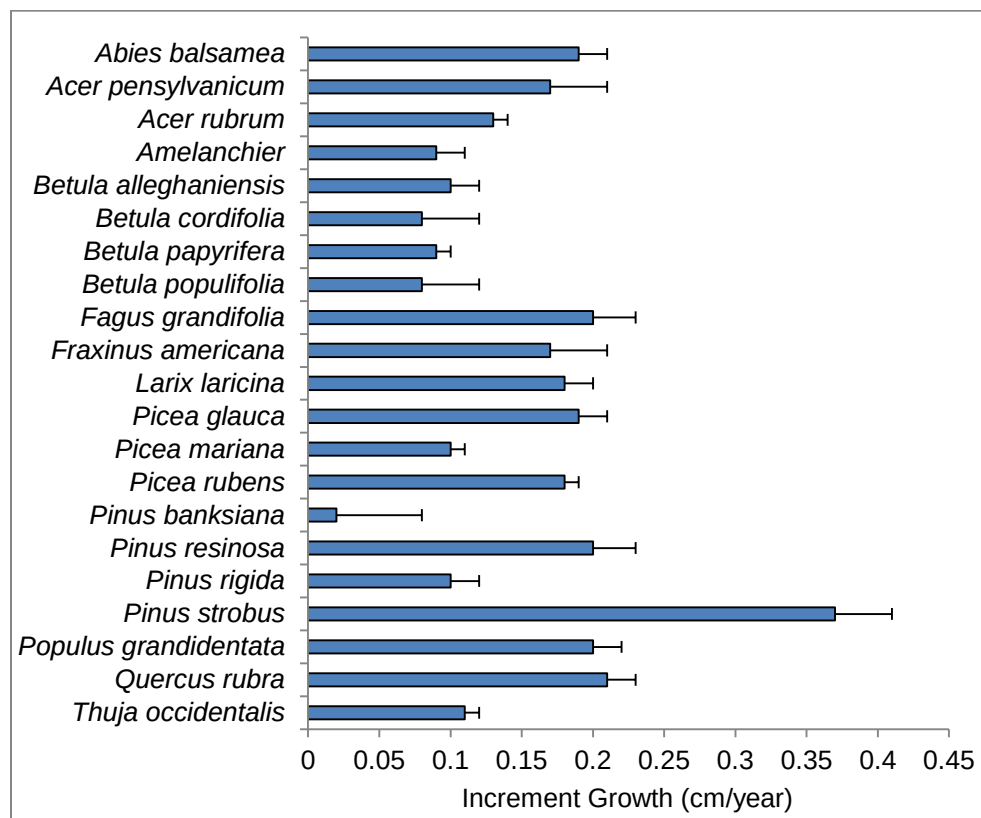


Figure 11. Average annual increment growth (cm/year) for tree species in Acadia National Park. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean ($N \geq 5$). Common names of tree species are listed in Appendix G.

With a rate of 2.25% trees/year, recruitment in ACAD was higher than all parks but SARA (Figure 10). Recruitment was highest on eastern MDI and lowest on Schoodic (Appendix H: Figure 2). The high recruitment rate across ACAD was primarily driven by large numbers of red spruce (*Picea rubens*) growing into tree status since the previous cycle (Figure 10). The recruitment rate for red spruce was more than double the mortality rate, a rare occurrence among NETN tree species. Other top species recruits include eastern white pine, balsam fir (*Abies balsamea*) and red maple. Eastern white pine, pitch pine, American beech and yellow birch (*Betula alleghaniensis*) all had positive recruitment along with no observed mortality between cycles.

Schoodic district had the highest mortality rate and this was primarily driven by red spruce mortality (Appendix H: Figure 2). Serviceberry (*Amelanchier* spp.), tamarack (*Larix laricina*), and big-toothed aspen had relatively high mortality rates and low recruitment, indicating that they may be declining in abundance (Figure 12). There were several species throughout ACAD with elevated mortality, including shorter lived species that tend to drop out as forests mature, such as striped maple (*Acer pensylvanicum*), paper birch, and big-toothed aspen (Table 15). Mortality rates were the result of very few individuals dying since the first cycle for striped maple (4 out of 20), serviceberry (2 out of 14) and tamarack (3 out of 30) and should be interpreted with caution. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for these rarer tree species.

Breaking ACAD down into subunits, we can see clear differences in forest dynamics (Appendix H). On Schoodic, tree growth and recruitment rates are low, and mortality rates are relatively high. Plots at Schoodic are either in mature spruce-fir forest, or in woodlands on thin, exposed soils. These patterns are expected in woodlands due to the harsh growing environment. In spruce-fir forests, the patterns reflect mature forests that are developing late-successional structure. IAH and western MDI had similar recruitment, growth and mortality rates, suggesting that forests in these subunits are at similar successional stages (i.e., mature to late-successional). Eastern MDI had the highest recruitment and growth rates, with the rates primarily driven by stand dynamics in the area that burned in 1947. These stands are at the stage of birch die-back and spruce replacement (Miller et al. 2014). This is an expected pattern of succession where early successional species slow growth as the canopy closes, and more shade-tolerant, climax species increase growth and dominance in the understory and canopy.

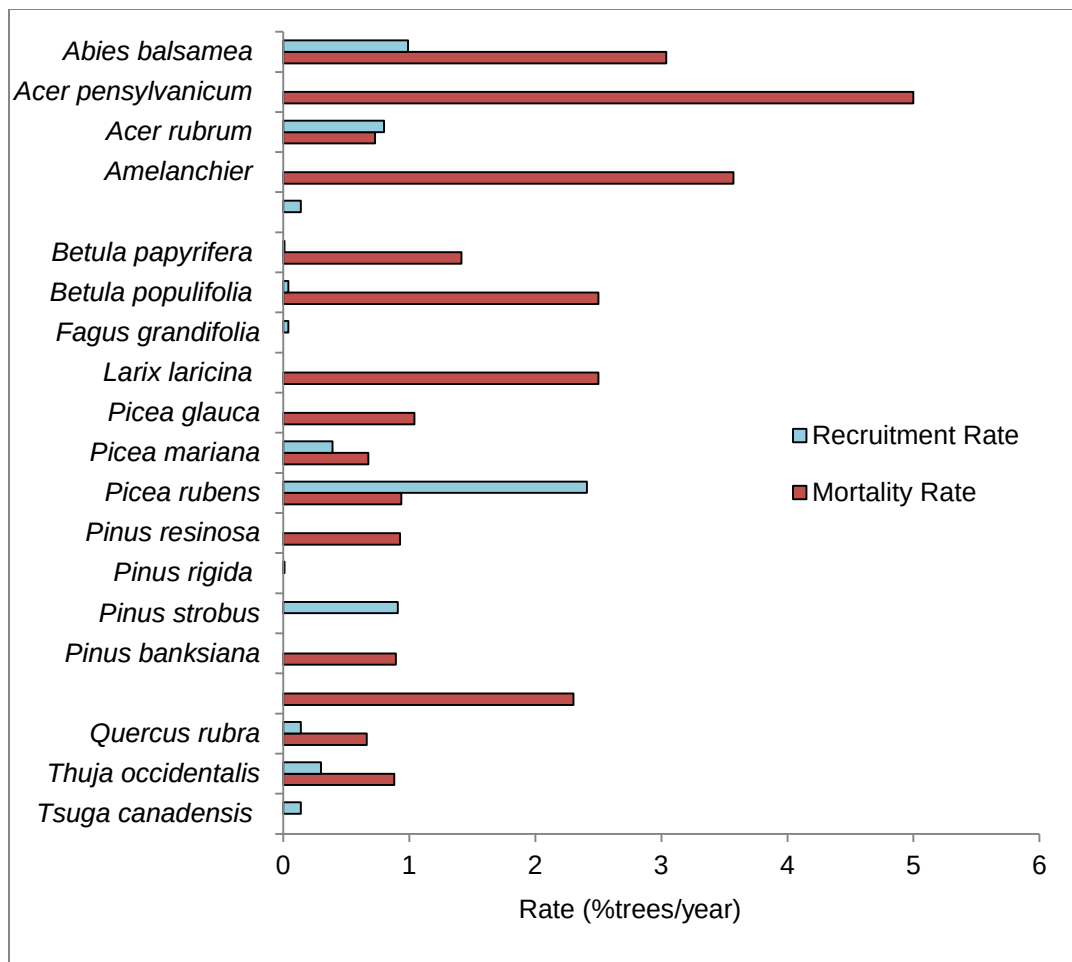


Figure 12. Average recruitment and mortality rate (%trees/yr) for tree species measured in Acadia National Park. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Marsh-Billings-Rockefeller National Historical Park

Given that MABI is the only park in NETN with active forest management, it is no surprise that increment growth rates are second only to SARA, where trees are commonly open grown (Figure 8). European larch (*Larix decidua*), a species confined to plantations, had the highest annual incremental growth rates among MABI tree species (Figure 13). One of the plots in the European larch plantation was harvested between the second and third cycle, and this may explain the high growth rate. Northern red oak (*Quercus rubra*), eastern white pine (*Pinus strobus*) and white ash (*Fraxinus americana*) had the next highest growth rates in MABI, and these top growing species are an important component of the naturally regenerated forest in the park. The high growth rate for white ash is a useful baseline for tracking the spread of EAB, as several years of slow growth are often observed before mortality occurs from EAB. The slowest growing trees in MABI were hophornbeam (*Ostrya virginiana*), yellow birch, and American beech (Figure 13). Hophornbeam is a short-stature species that rarely reaches the canopy, and growth rates are likely slow from shading by the canopy.

Table 15. Tree species with elevated mortality rates (>1.6%trees/yr) for NETN. The mortality rate calculation includes only trees in Mature and Late-Successional stages as well as canopy trees of dominant, co-dominant and intermediate crown classes. Common names of tree species are listed in Appendix G.

Tree Species	ACAD	MABI	MIMA	MORR	ROVA	SAGA	SARA	WEFA	# Dead / Previously Alive
<i>Abies balsamea</i>	X								10 / 64
<i>Acer pensylvanicum</i>	X								2 / 6
<i>Acer rubrum</i>								X	3 / 41
<i>Acer saccharum</i>								X	1 / 13
<i>Betula papyrifera</i>	X								6 / 55
<i>Carya glabra</i>				X					1 / 5
<i>Carya tomentosa</i>				X					1 / 7
<i>Fagus grandifolia</i>		X							1 / 14
<i>Fraxinus americana</i>				X	X				2 / 23 (MORR), 1 / 5 (ROVA)
<i>Larix laricina</i>	X								3 / 27
<i>Picea abies</i>					X				2 / 10
<i>Pinus resinosa</i>					X				2 / 17
<i>Pinus strobus</i>			X			X			1 / 14 (MIMA), 5 / 57 (SAGA)
<i>Pinus sylvestris</i>		X							1 / 10
<i>Populus grandidentata</i>	X								3 / 41
<i>Quercus velutina</i>				X	X				1 / 11 (MORR), 1 / 11 (ROVA)
<i>Robinia pseudoacacia</i>				X					1 / 8

American beech growth rates are likely influenced by the presence of beech bark disease.

Recruitment rates for MABI were relatively high (Figure 10), and higher in plantations than natural stands (Appendix H: Figure 2). Most of the recruitment is driven by two plots (017 and 002), both of which were harvested prior to the third sample cycle. The highest species recruitment rates were of yellow birch and sugar maple (*Acer saccharum*), the latter contributing to more than 1/3 of all recruits at MABI (Figure 14). Sugar maple is the most common tree species in the canopy in MABI, and dominance of sugar maple in regeneration and young tree groups is expected for mesic hardwood forests.

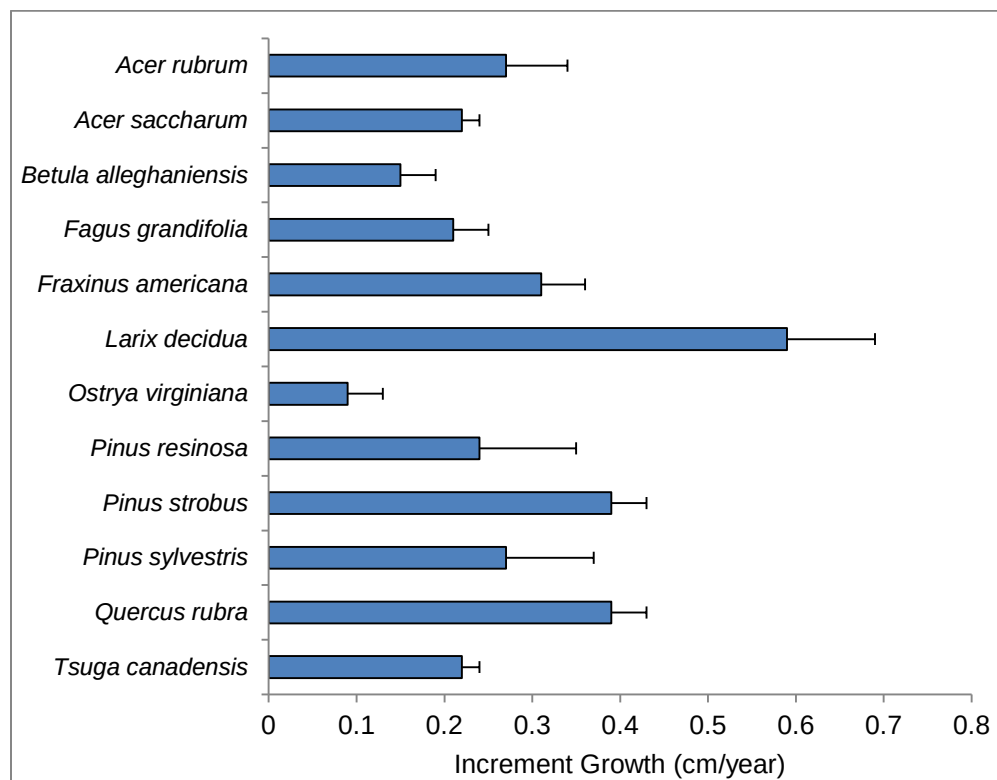


Figure 13. Average annual increment growth (cm/year) for tree species in Marsh-Billings-Rockefeller National Historical Park. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean (N≥5). Common names of tree species are listed in Appendix G.

Although yellow birch is not as abundant in the canopy, this prolific seeder appears to be regenerating well in the mid story and has not seen any tree mortality between cycles. Eastern hemlock had modest recruitment rates while sustaining zero mortality between cycles. A number of species common in MABI experienced no observed recruitment or mortality between 2008-2010 and 2012-2014, including red maple (*Acer rubrum*), white ash, European larch, and red pine. Red maple and white ash are common in mature hardwood stands. As these stands are harvested, recruitment of red maple and white ash may increase. European larch and red pine are primarily only in plantations, several of which have been harvested. Lack of recruitment and regeneration of these species suggested that they may need to be planted in stands that are harvested, if these species are to be maintained.

Mortality rates in MABI, which did not include harvested trees, were among the lowest in NETN (Figure 10). These patterns are typical of forests that are managed with selective harvesting, with stands typically being thinned before mortality from stem exclusion occurs. Eastern white pine and hophornbeam had the highest mortality rates in MABI (Figure 14). Hophornbeam and Scotch pine experienced mortality but no observed recruitment between cycles, although the rates are only represented by one dead individual out of 10 for hophornbeam and 11 for Scotch pine (*Pinus sylvestris*). In addition, eastern white pine had two individuals die out of 20 and these results should be interpreted with caution due to low sample size. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for these rarer tree species.

Patterns of tree recruitment, growth and mortality in MABI are indicative of selectively managed forests. Recruitment and growth are relatively high and mortality is low compared to the predominantly unmanaged forests in other NETN parks. It will be important to track how these rates change as forests respond to timber harvests.

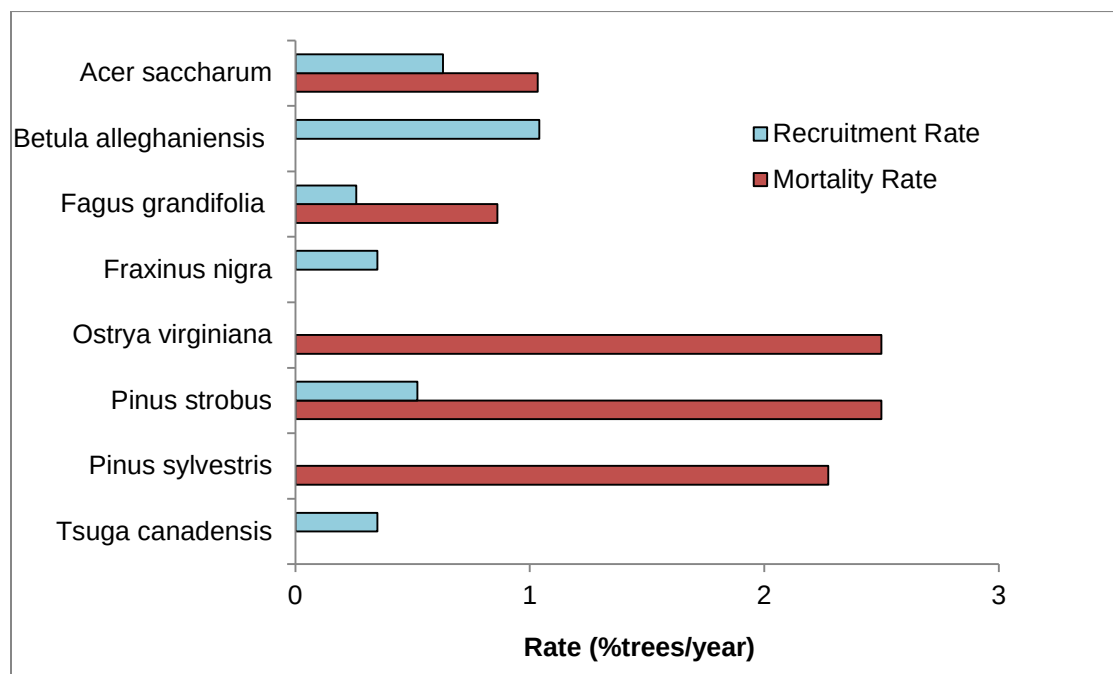


Figure 14. Average recruitment and mortality rate (%trees/year) for tree species measured in Marsh-Billings-Rockefeller National Historical Park. Mortality rate does not include harvested trees. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Minute Man National Historical Park

The average increment growth rate in MIMA was intermediate when compared with rates in other NETN parks. The species with the highest average increment growth were black walnut (*Juglans nigra*) and eastern white pine (Figure 15). American elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica*) and northern red oak also had relatively high growth rates. While the moderate growth of American elm indicates suitable growing conditions, Dutch elm disease is likely affecting

this species' ability to increase in abundance or grow into larger size classes. The slowest growing species in MIMA were gray birch (*Betula populifolia*), Norway maple (*Acer platanoides*), red maple (*Acer rubrum*) and black oak (*Quercus velutina*). Red maple and black oak are major components of MIMA's forest. The exact reasons for the slow growth are not clear. However, oak and maple species are preferred hosts to winter moth (*Operophtera brumata*), which has been at outbreak levels in the region in recent years. In southeastern Massachusetts, many broadleaved tree species, especially oaks, are displaying signs of decline after multiple years of defoliation by winter moth, forest tent caterpillar and gypsy moth (Simmons et al. 2014). MIMA's forests are dominated by species that are vulnerable to these pests and will experience a decline in tree growth with increased mortality if the heavy defoliation continues.

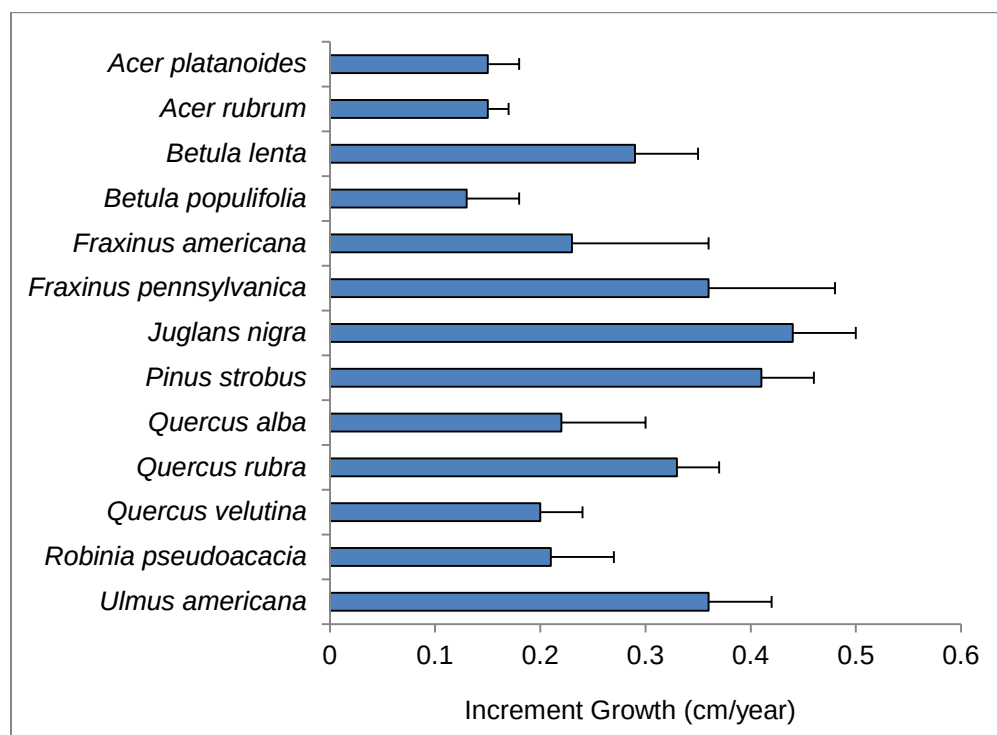


Figure 15. Average annual increment growth (cm/year) for tree species in Minute Man National Historical Park. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean (N≥5). Common names of tree species are listed in Appendix G.

Recruitment in MIMA was intermediate compared to other NETN parks (Figure 10). Recruitment rates were highest for American elm, red maple and white ash (Figure 16). Eastern white pine and black locust (*Robinia pseudoacacia*) were the only other two species with observed recruitment rates. Oak species consistently had very low recruitment. If these patterns continue, the canopy that is currently dominated by oak species will likely be replaced by more mesic hardwood species, such as red maple.

Tree mortality in MIMA was the second highest in NETN (Figure 10). Green ash had the highest overall mortality rate (Figure 16). Mortality was also relatively high for American elm, gray birch, and black oak. All of the green ash mortality occurred on plot 013 where half of the green ash on the

plot died between cycles. A number of tree conditions were recorded for these trees during the first cycle, including excessive leaf loss, insect leaf herbivory and epicormic branching, an indicator of stress. This indicates that health concerns existed before the observed mortality. The cause of the green ash mortality is not clear, and this should be closely monitored in MIMA, especially as EAB moves into the region. Relatively high mortality rates were produced by very few individuals dying since the first cycle for green ash (3 out of 6), American elm (2 out of 11) and gray birch (1 out of 9) and should be interpreted with caution. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for these rarer tree species.

Recruitment and mortality were not observed for a number of species in MIMA, including black birch (*Betula lenta*), black walnut, Norway maple, northern red oak, and white oak (*Quercus alba*). This suggests that these species are somewhat stable, although increased mortality could shift composition towards species with more recruitment. Black oak, gray birch and green ash all experienced mortality where no recruits were observed between cycles. We will continue to track tree recruitment and mortality rates in MIMA to assess how forest pests and other stressors influence patterns in forest composition and structure.

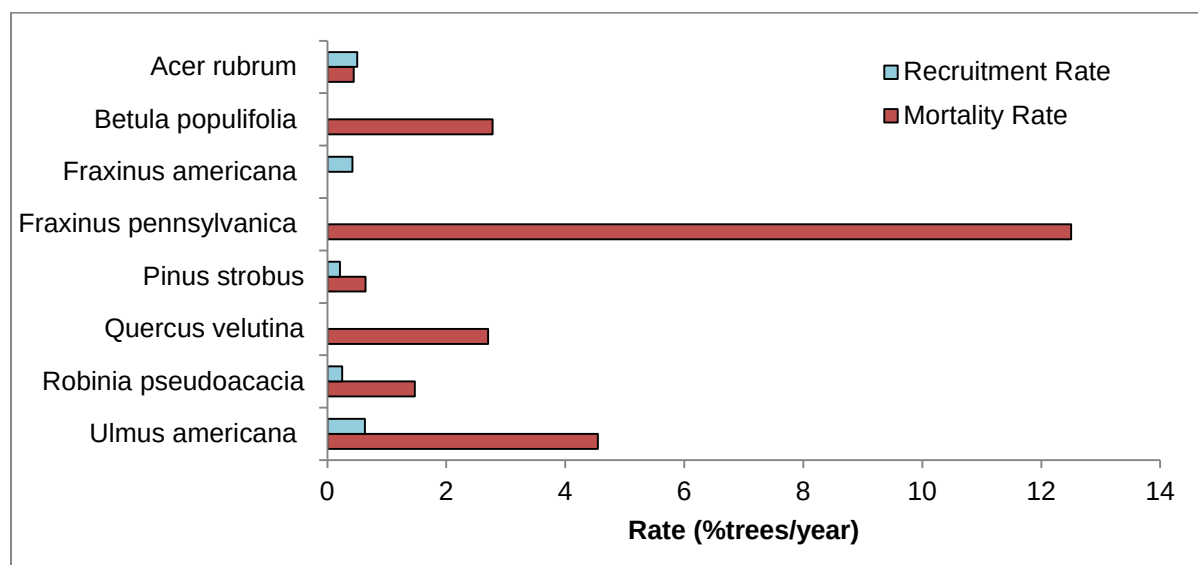


Figure 16. Average recruitment and mortality rate (%trees/year) for tree species measured in Minute Man National Historical Park. Mortality rate does not include harvested trees. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Morristown National Historical Park

The %BA growth rate in MORR was the lowest in NETN, although the increment growth was intermediate (Figure 8). The low %BA growth rate may be because trees in MORR are relatively large, compared to other NETN parks. Northern red oak and tulip poplar (*Liriodendron tulipifera*) were the fastest growing species averaging 0.46 cm/yr and 0.42 cm/yr, respectively (Figure 17). These values are similar to a 2006 study in MORR, where both species averaged 0.50 cm/yr (Shaw and Patterson 2006). Increment growth was also relatively high for chestnut oak (*Quercus montana*), white oak, and black oak, which are all common species in MORR. Yellow birch and black birch had

the slowest increment growth between cycles. Yellow birch in MORR tends to occur along streams where roots are frequently inundated, and slow growth can be expected for those habitats. The slow growth of black birch may be the result of shading from the oak-dominated canopy.

Recruitment in MORR was exceptionally low compared to the rest of NETN. Recruitment was only observed with American beech, a species that is relatively resistant to deer browse. Poor recruitment is very likely the result of decades of deer overabundance, and is a great concern for the future health of MORR's forest. Recruitment may increase as forests respond to the canopy gaps created by Hurricane Sandy, but only if deer browse pressure is reduced. A close watch in these areas over the next few years will provide valuable information.

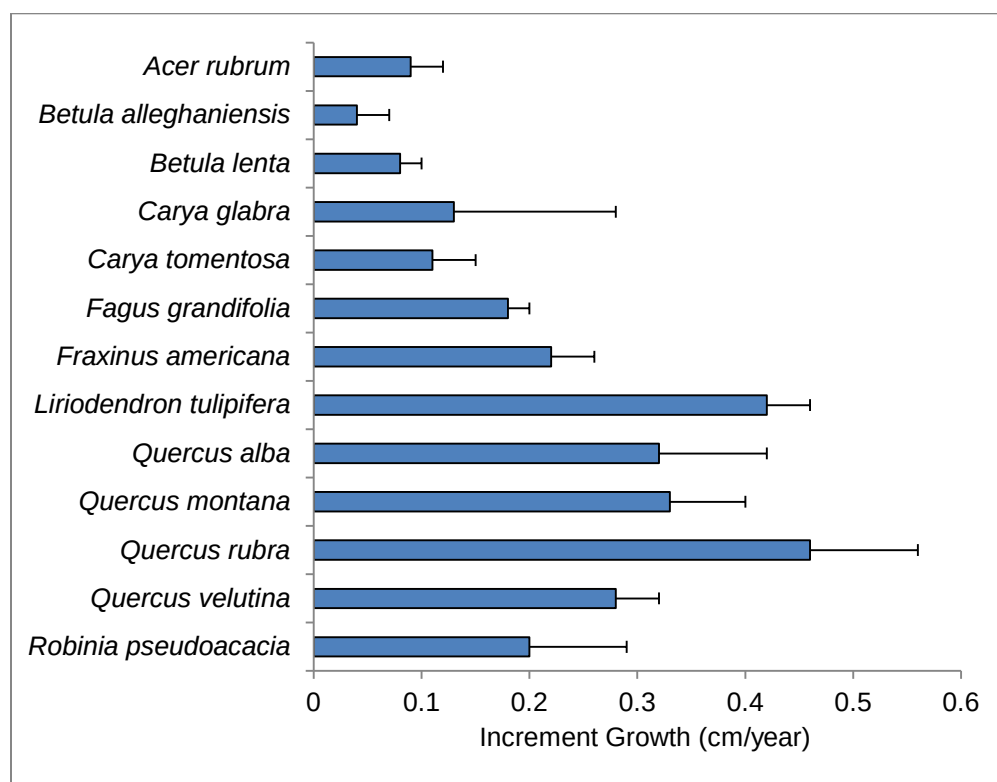


Figure 17. Average annual increment growth (cm/year) for tree species in Morristown National Historical Park. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean ($N \geq 5$). Common names of tree species are listed in Appendix G.

The mortality rate in MORR was the highest reported for NETN (Figure 10); mortality was higher in Successional stands than in Mature stands (Appendix H: Figure 2). Tree mortality may actually be higher than our data indicate, because trees that were blown down by Hurricane Sandy in late 2012 were still alive in spring of 2013. We expect to see even higher mortality during the 2015 and 2017 surveys, as many of the wind-thrown trees that were alive in 2013 will likely have perished. Black locust had the highest mortality rate (Figure 18). White ash was one of five species with elevated mortality (Table 15). Relatively high mortality rates were the result of very few individuals dying since the first cycle for black locust (4 out of 11), pignut hickory (*Carya glabra*) (1 out of 6) and mockernut hickory (*Carya tomentosa*) (1 out of 8) and should be interpreted with caution due to low

sample size. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for these rarer tree species. Species with no observed mortality between cycles were American beech, red maple, yellow birch, white oak, chestnut oak, and northern red oak. Of the species with no observed mortality, American beech and red maple were the most common.

Given exceptionally low tree recruitment and relatively high mortality in MORR, forest canopies may become more open over time. Reducing deer browse pressure and controlling invasive species are necessary to prevent this from happening. Recruitment and growth rates also suggest that forest composition may be shifting from an oak-dominated canopy to a more mesophytic, American beech and red maple dominated canopy.

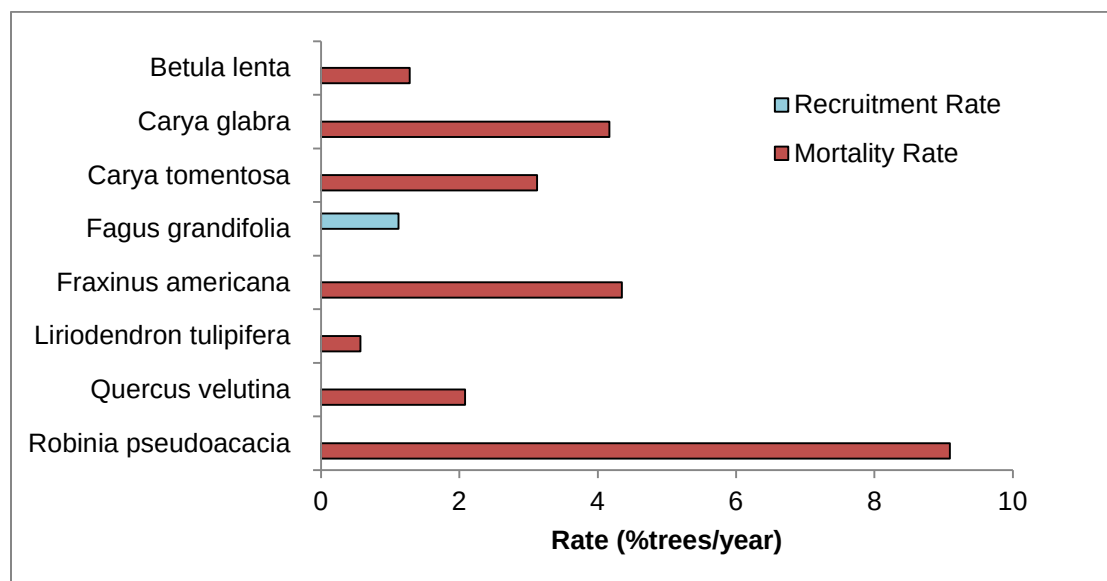


Figure 18. Average recruitment and mortality rate (%trees/year) for tree species measured in Morristown National Historical Park. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Roosevelt-Vanderbilt National Historic Sites

Increment growth in ROVA was intermediate compared to other NETN parks and very close to MORR and WEFA growth rates (Figure 8). Tulip poplar stood out with the highest increment growth (Figure 19). A number of species had very similar and relatively high growth rates, including tree-of-heaven (*Ailanthus altissima*), Norway maple, chestnut oak, northern red oak, and black oak. Tree-of-heaven and Norway maple are invasive exotic species that can outcompete native species, and this is potentially evidenced by their high growth rates in ROVA.

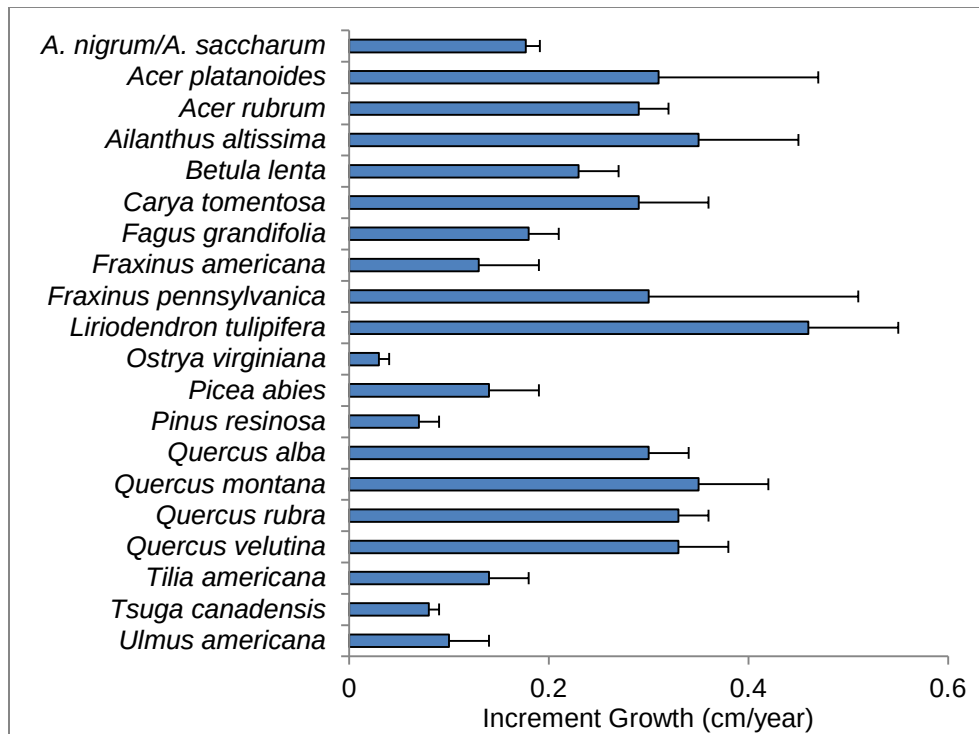


Figure 19. Average annual increment growth (cm/year) for tree species in Roosevelt-Vanderbilt National Historic Sites. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean ($N \geq 5$). Common names of tree species are listed in Appendix G.

While green ash had a relatively high growth rate, we expect this to decline as the species succumbs to EAB. The slowest growing species were hophornbeam, red pine and eastern hemlock. Hophornbeam is a low canopy species, and similarly slow growth was observed in MABI for this species. Given the presence of HWA in ROVA, the low growth rate for eastern hemlock is not a surprise. Red pine typically occurs in plantations in ROVA, where growth may be slow without repeated thinning.

Overall tree recruitment rates were in the lower tier for the network (Figure 10). American beech and black gum (*Nyssa sylvatica*) had the highest recruitment rate in ROVA, followed by red maple and black birch (Figure 20). Recruitment rates were similar across ROVA units (Appendix H: Figure 2).

ROVA had intermediate mortality rates, compared with other NETN parks (Figure 10), and mortality was similar across the units in ROVA (Appendix H: Figure 2). White ash and American elm had the highest mortality rates in the park (Figure 20) and were two of four tree species with elevated mortality (Table 15). White ash mortality may be due to EAB and American elm mortality may be from Dutch elm disease. However, the mortality rates for these two species are based on only a few individuals, white ash had 2 out of 7 and American elm had 1 out of 5 individuals die between cycles. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for these rarer tree species. Norway spruce and red pine are primarily in plantations in ROVA which may be over mature. American basswood (*Tilia americana*) mortality rates were produced by very few individuals dying since the first cycle (1 out of 6).

We will continue to track tree recruitment, growth and mortality in ROVA, with special attention towards species vulnerable to pests and pathogens, and invasive tree species capable of expanding into the canopy.

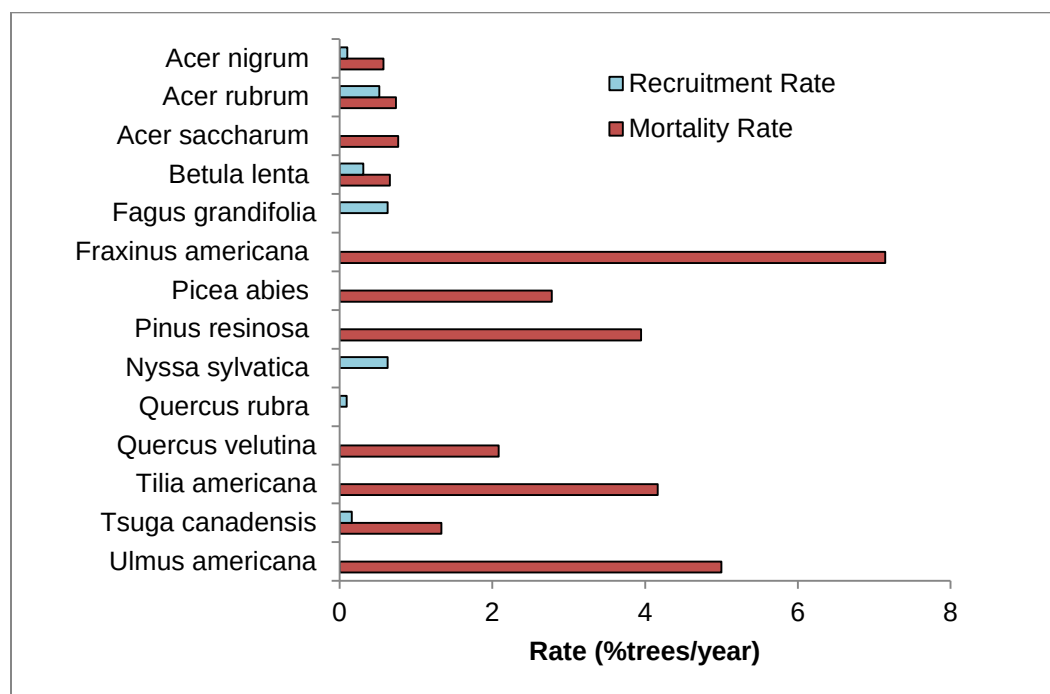


Figure 20. Average recruitment and mortality rate (%trees/year) for tree species measured in Roosevelt-Vanderbilt National Historic Sites. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Saint-Gaudens National Historic Site

Annual increment growth rate in SAGA was among the lowest of NETN parks (Figure 8). Much of the forests in SAGA are mature or late-successional stages, which may partially explain the slow growth. Tree growth may also be tempered by edaphic conditions, such as steep slopes or acidic soils that may limit nutrient availability. Northern red oak and American basswood had the highest increment growth rates (Figure 21). The growth rate for eastern hemlock in SAGA is lower than in MABI, but higher than ROVA where HWA is present. The current growth rate for HWA is an important baseline for detecting future impacts from HWA in SAGA.

Recruitment in SAGA was quite low at 0.46% trees/year (Figure 10). Only three tree species have advanced to tree status in SAGA: eastern hemlock, red maple and black birch (Figure 22). Moderate recruitment and low mortality of eastern hemlock is a good sign that HWA is not present in the park. Structural stage is the primary driver in the low recruitment at SAGA, as mature and late-successional stands are not expected to have high recruitment rates. Beech bark disease, which is present in SAGA, may also be influencing recruitment. A number of plots have a dense understory of American beech sprouts, which may not grow to tree size, but can suppress regeneration of other tree species.

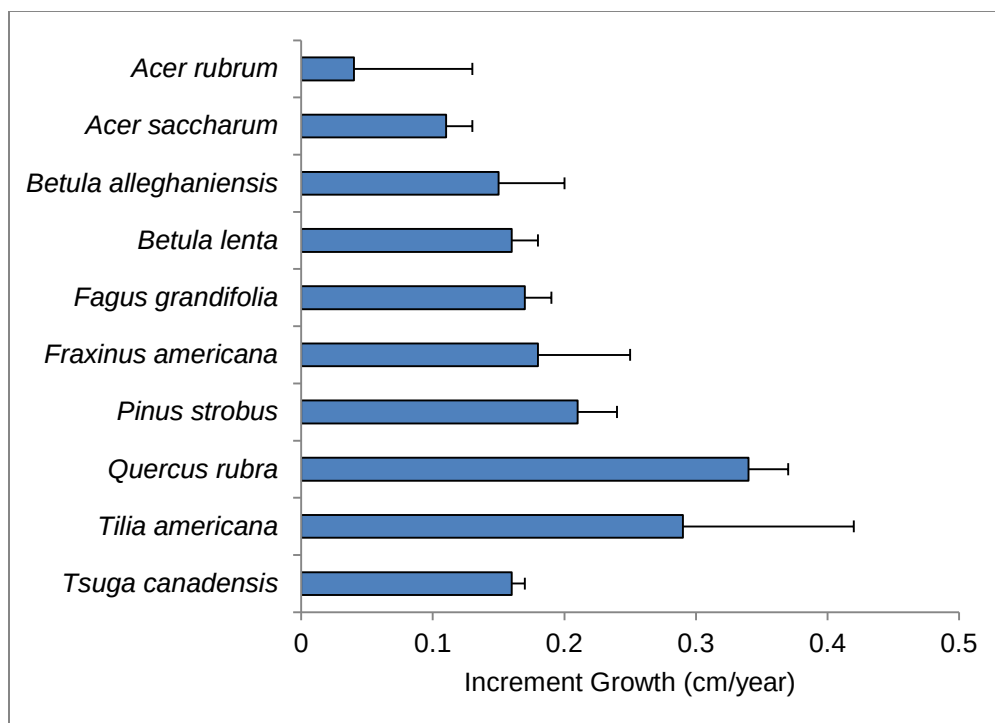


Figure 21. Average annual increment growth (cm/year) for tree species in Saint-Gaudens National Historic Site. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean ($N \geq 5$). Common names of tree species are listed in Appendix G.

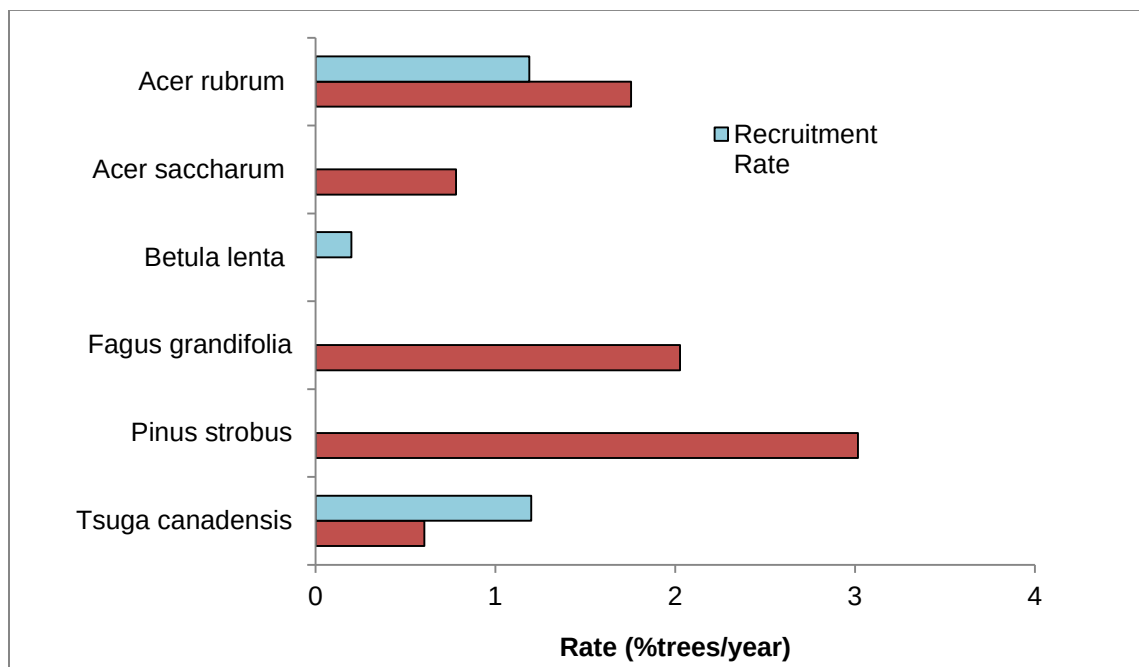


Figure 22. Average recruitment and mortality rate (%trees/year) for tree species measured in Saint-Gaudens National Historic Site. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Mortality rates in SAGA were moderate, compared with other parks in the network (Figure 10). Eastern white pine mortality was the highest for SAGA species (Figure 22) and the only species with elevated mortality (Table 15). The reasons behind eastern white pine mortality are not clear; however the increasing presence of white pine blister rust (*Cronartium ribicola*) in the region may be having an impact. Future surveys by field crews and park staff should look for symptomatic white pine and the presence of *Ribes* spp., an alternate host for this pathogen. The relatively high American beech mortality is likely due to BBD. Northern red oak and American basswood, the species with the highest growth rates in SAGA, had no observed mortality or recruitment. White ash and yellow birch also had no observed mortality or recruitment.

Tree growth, recruitment, and mortality rates suggest that forests in SAGA are relatively stable, and reflective of mature and late-successional hardwood forests. HWA poses a major threat to the stability of forests in SAGA, and declines in eastern hemlock growth will be an early indicator of HWA infestation.

Saratoga National Historical Park

Averaging 0.37 cm/year, SARA had the highest annual increment growth of all NETN parks (Figure 8). Interestingly, we found a very similar average growth rate (0.39 cm/year) by measuring ring widths from increment cores taken in 2014. This suggests that our tree diameter measurements are accurate and the high growth rates in SARA are real. Plots that were open field in 1927 had higher growth rates than plots that were forest by 1927 (Appendix H: Figure 1). Oak species had the highest incremental growth with northern red oak at 0.57 cm/year, swamp white oak (*Quercus bicolor*) at 0.44 cm/year, and black oak (*Quercus velutina*) with 0.40 cm/year (Figure 23). High growth rates in SARA could be explained by fast growing tree species and relatively good site conditions such as soil fertility and light availability for optimal growth. Many of these species can be expected to grow well in a landscape with nutrient rich, moist clay soils that were deposited from post-glacial Lake Albany. The slowest growing species were hawthorn (*Crataegus* spp.) and hophornbeam (*Ostrya virginiana*). Growth rates for hophornbeam are similar across NETN parks, and are reflective of its typically low canopy position. Hawthorns are old field species that do not generally grow under shade or reach canopy height.

SARA recruitment rates were highest among all network parks at 3.30% trees/year (Figure 8). Of the six tree species that advanced to tree status in SARA, American elm and white ash had the highest recruitment rates (Figure 24). Red maple and sugar maple also had moderate recruitment. Recruitment was considerably higher in plots that were forest in 1927 than in plots that were open field in 1927 (Appendix H: Figure 2).

SARA had an intermediate mortality rate (Figure 8). Hophornbeam had the highest mortality rate of 10.00% trees/year (Figure 24). However this rate is based on only 2 out of 5 individuals dying since the last cycle. Black cherry (*Prunus serotina*) and American elm also had relatively high mortality rates, but black cherry had only 1 out of 7 individuals die between cycles. Tracking how rates change over time, rather than evaluating a one-time rate, will be more meaningful in the long run, particularly for rarer tree species, such as hophornbeam and black cherry. (Figure 24). High rates of

elm mortality are likely the result of Dutch elm disease. Mortality of black cherry may be due to forest succession.

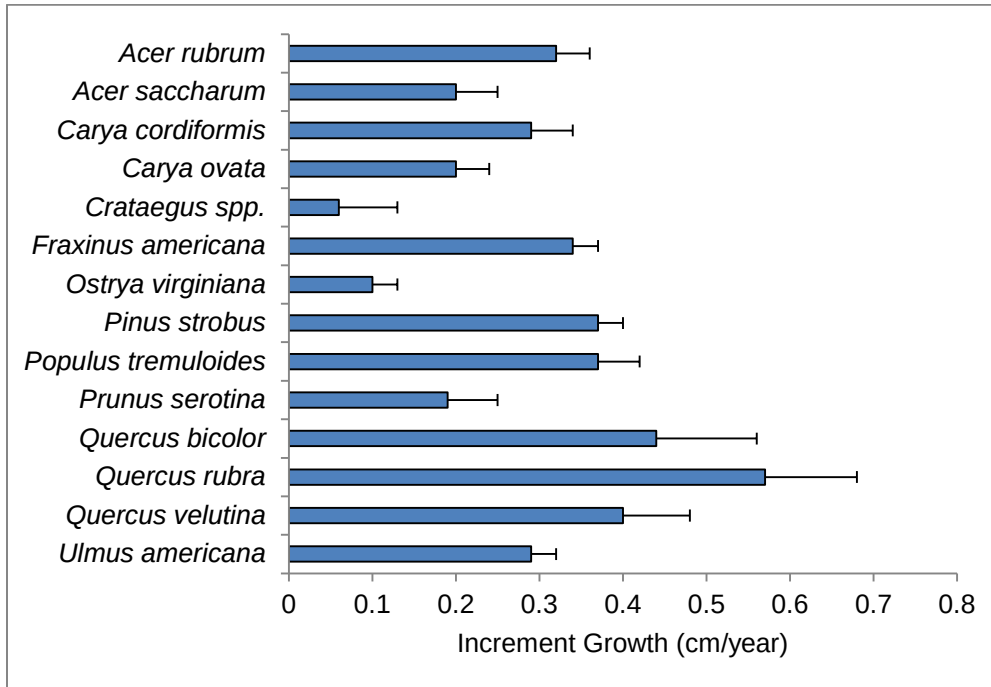


Figure 23. Average annual increment growth (cm/year) for tree species in Saratoga National Historical Park. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean ($N \geq 5$). Common names of tree species are listed in Appendix G.

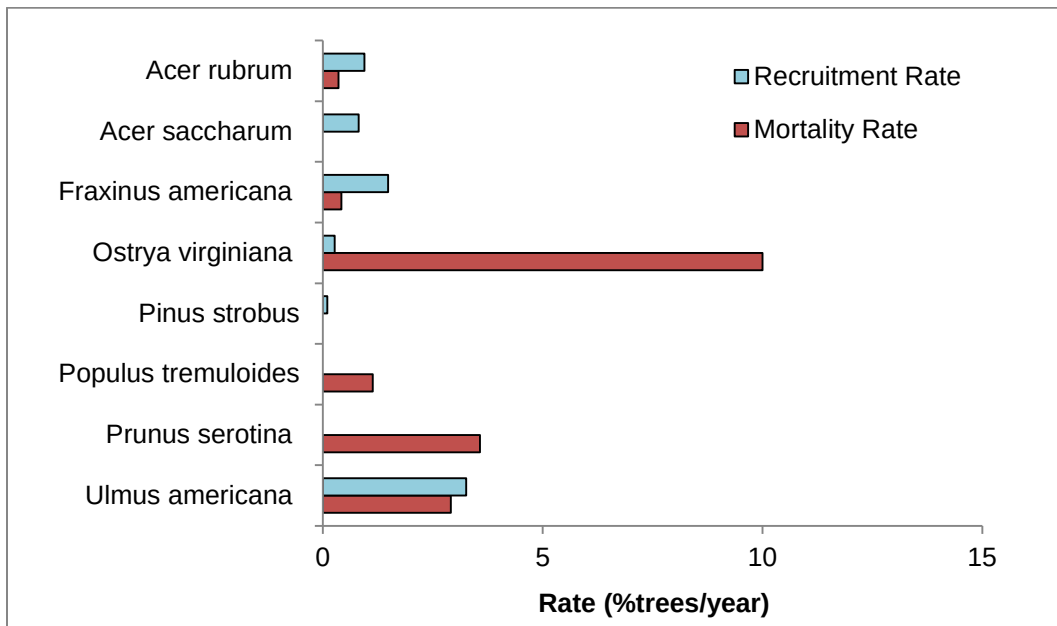


Figure 24. Average recruitment and mortality rate (%trees/year) for tree species measured in Saratoga National Historical Park. Species lacking recruitment and mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

The high growth and recruitment rates that we observed suggest that forests in SARA are quite dynamic. As American elms reach about 20 cm diameter at breast height (DBH), they begin to die back and are replaced by new recruits of American elm. White ash commonly occurs in American elm stands, and it is unclear how EAB will affect the structure and composition of these forests. White ash may be eliminated from old field sites where exotic shrubs are most dominant and are inhibiting the growth of other tree species. We also expect these rates to move closer to those observed in other NETN parks as forests mature.

Weir Farm National Historic Site

WEFA annual increment growth was average among NETN parks and similar to MORR and ROVA (Figure 8). The highest growth rates were observed for sugar maple, chestnut oak, and black oak (Figure 25). Yellow birch and red maple, which are commonly found growing in seeps and wet areas in WEFA, had relatively slow growth rates. White ash had the lowest observed growth rate in WEFA, and this was also the lowest growth rate recorded for white ash in NETN (Figure 9). EAB has been found in the county where WEFA is located (Fairfield County), and this could be an indication of EAB presence in the park. These results are preliminary, as many canopy trees with vines on the stem had to be excluded from growth rate calculations due to measurement inconsistencies between cycles.

Tree recruitment in WEFA was relatively low, compared with other NETN parks (Figure 10). American beech had the highest recruitment, followed by black oak and sugar maple (Figure 26). Mortality in WEFA was tied for the lowest among NETN parks (Figure 10).

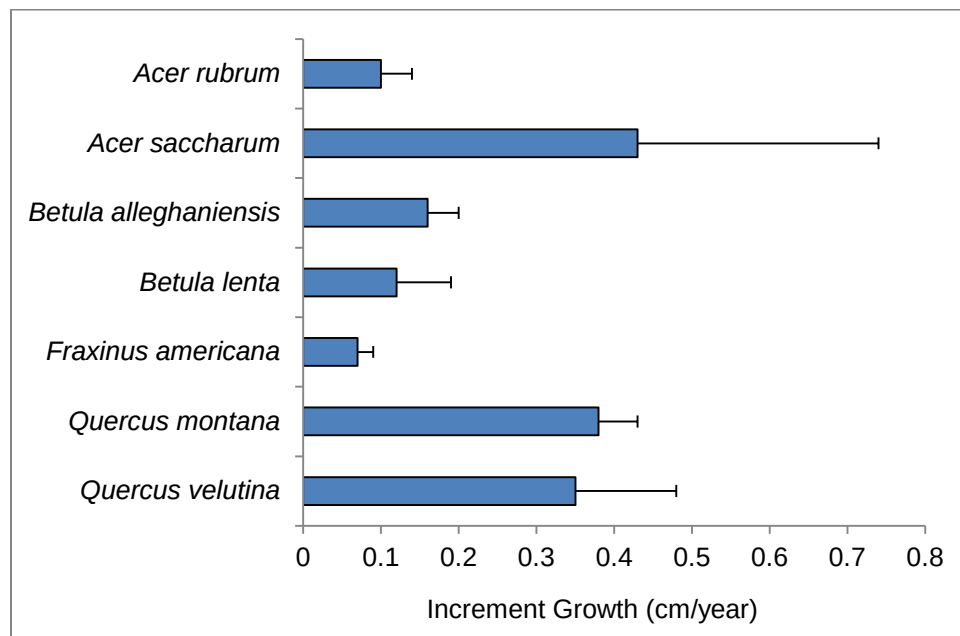


Figure 25. Average annual increment growth (cm/year) for tree species in Weir Farm National Historic Site. Growth rates include all trees and all crown classes. Error bars represent 1 SE above the mean (N≥5). Common names of tree species are listed in Appendix G.

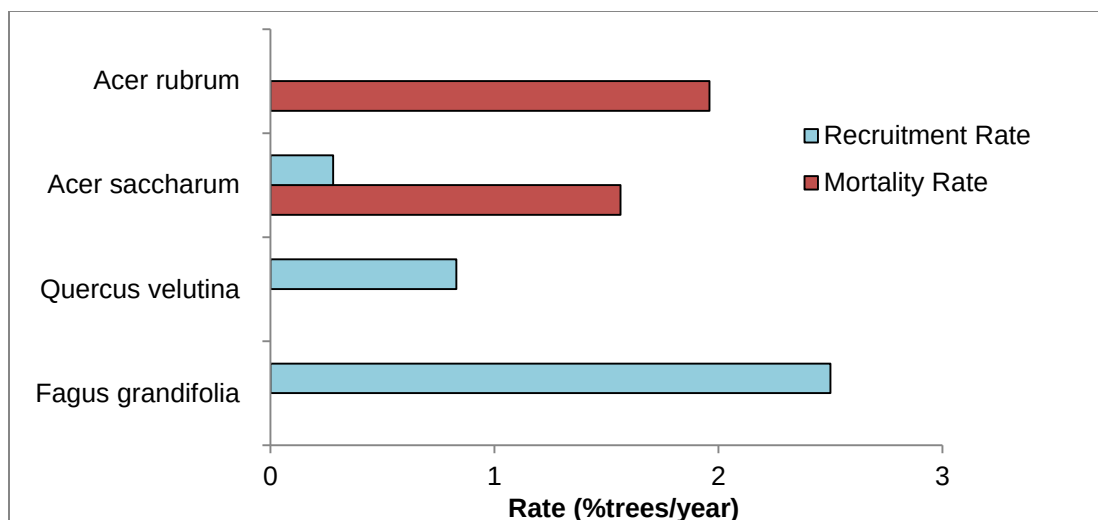


Figure 26. Average recruitment and mortality rate (%trees/year) for tree species measured in Weir Farm National Historic Site. Species with no recruits and no mortality are not shown. Common names of tree species are listed in Appendix G. Total number of live trees, recruits and deaths, are listed in Appendix I.

Sugar maple and red maple were the only tree species with observed mortality (Figure 26). Several common species in WEFA had no observed recruitment or mortality, including black birch, white ash, and chestnut oak.

These results could be reflecting a common pattern observed in Mature / Even-aged forests; however it is also possible that the small sample area could have missed rare events (e.g. mortality, recruitment) that exist in the forests of WEFA. As more cycles of data are collected and our sample size increases, the underlying drivers for low growth and recruitment may become clearer. Current rates are an important baseline to track threats to forest health, including EAB, deer overabundance, and climate change.

Conclusions

Tree growth, recruitment and mortality rates in NETN parks reflect diverse forest types at different stages of succession. These data are an important baseline to track future impacts to forest health, such as forest pests, deer overabundance, invasive species, and climate change. The advancement of forest pests in network parks will likely have a profound effect on recruitment and mortality rates, especially for target host species. Increased deer abundance and subsequent browse pressure on tree seedlings may lead to reduced recruitment rates for browse-preferred species, and possible increased recruitment rates for non-preferred tree species. Invasive plant species can inhibit colonization of many tree seedlings, while invasive vine species can impact tree growth rates and mortality. A changing climate may benefit the growth of some tree species, while disadvantaging others, especially those where species range limits overlap with network parks.

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Appendix A. Protocol implementation for the 2014 field season.

2014 Data Quality

Overall data quality for the 2014 field season was excellent. While an exceptional forest crew was no doubt a major reason for the high quality data, continued enhancements to the data checker function in the forest database were also important contributions. The forest crew was able to use the database for data entry for the vast majority of plots, and at the end of every week, we were able to merge the two crew backend databases. This allowed us to begin analyzing the data and to check for inconsistencies or issues within days of the crew sampling a plot.

Quality Control and Quality Assurance (QA/QC)

To verify data quality and quantify sampling error, we resample 5% (four plots) of the forest plots that crews sample every year. Plots are randomly selected for QA/QC, with two plots located in ACAD and two plots located in a randomly selected national historical park or national historic site. MABI plots 004 and 009, and ACAD plots 017 and 038 were sampled for QA/QC in 2014.

Data comparisons between the forest crew and the QA/QC crew were very close for most stand level assessments, photopoint scenes, regeneration microplot tallies, CWD pieces, tree condition and tree diameter at breast height (DBH) measurements. Stand height measurements continued to show improvement in accuracy from past years, but this remains one of the more variable measurements in our protocol. Microplot measurements commonly have 1 seedling or sapling that was measured by one team, but not the other. Usually these are stems on the microplot boundary. We will stress during future training that seedlings and saplings on the microplot boundaries be measured with a tape rather than the Sonin electronic distance measurers to improve accuracy. Photopoint comparisons also showed improvement, with remarkably close scenes photographed by the forest crew and QA/QC crew in MABI. The main differences in the photopoints in ACAD were due to weather, with the forest crew sampling on a sunny day and the QA/QC crew sampling in a downpour.

The QA/QC crew in MABI, which included the NETN Plant Ecologist, tended to pick up more species in the quadrats and the plot search than the forest crew in plot 004. Plot 017 in ACAD, an unusually diverse plot for ACAD, was similar with the more experienced crew picking up more species in the plot search. This has been a consistent pattern throughout our program, where teams with an experienced botanist tend to pick up a few more species. While not ideal, the species that are found by the more experienced botanists tend to be sparse, low cover graminoids, and are not likely to affect our ability to characterize and detect changes in major understory patterns. Another difference between the forest crew and the QA/QC crew was that the forest crew missed the presence of earthworms on plot 009, despite obvious impacts from earthworms, such as a thin leaf litter layer, earthworm castings, and exposed tree roots. This plot was not sampled for soils, which is where earthworms are usually observed. We will stress the importance of looking for and indicators of earthworms on plots without a soil sample during training.

Resampling and Protocol Revision

Few changes were made to existing procedures in the protocol. In NETN, we will begin marking saplings with green spray paint at DBH to improve sapling detection and measurements in

microplots. We also expanded the "Excluded" tree status code to distinguish between a tree that was excluded because it was determined to be outside of the plot (XP), a tree that was excluded because it shrank below 10 cm at DBH (XS), and a tree that was excluded for other reasons (XO).

We continued coring trees in plots sampled in 2014 on western MDI in ACAD, and started coring on IAH in ACAD and in SARA. The ages derived from the tree cores will improve our understanding of stand age dynamics in these parks.

Appendix B. Indicator species used for seedling ratio.

Species	Common Name	Potential Deer Impact	Cite ¹	Note
<i>Acer rubrum</i>	red maple	High	2	
<i>Acer saccharum</i>	sugar maple	High	2	
<i>Cornus florida</i>	flowering dogwood	High	1	
<i>Liriodendron tulipifera</i>	tulip poplar	High	2	
<i>Magnolia acuminata</i>	cucumber tree	High	2	
<i>Prunus pensylvanica</i>	pin cherry	High	2	
<i>Sassafras albidum</i>	sassafras	High	1	
<i>Sorbus americana</i>	mountain ash	High	1	
<i>Thuja occidentalis</i>	northern white cedar	High	1	
<i>Tilia americana</i>	basswood	High	1	
<i>Tsuga canadensis</i>	eastern hemlock	High	2	
<i>Betula alleghaniensis</i>	yellow birch	Medium	2	High preference but medium browse tolerance
<i>Betula lenta</i>	black birch	Medium	2	High preference but medium browse tolerance
<i>Carya</i> spp.	hickories	Medium	2	High preference but medium browse tolerance
<i>Fraxinus</i> spp.	ashes	Medium	2	High preference but medium browse tolerance
<i>Hamamelis virginiana</i>	witch hazel	Medium	1	
<i>Juglans cinerea</i>	butternut	Medium	1	
<i>Juglans nigra</i>	black walnut	Medium	1	
<i>Nyssa sylvatica</i>	black gum	Medium	3	Sprouts have medium to high palatability
<i>Quercus</i> spp.	oaks	Medium	2	High preference but medium browse tolerance
<i>Ulmus</i> spp.	elm	Medium	1	
<i>Abies balsamea</i>	balsam fir	Medium/Low	1	Low choice but heavily browsed if needed
<i>Acer pensylvanicum</i>	striped maple	Medium/Low	2	Medium preference but high browse tolerance
<i>Fagus grandifolia</i>	American beech	Medium/Low	2	Medium preference but high browse tolerance
<i>Pinus resinosa</i>	red pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus rigida</i>	pitch pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus strobus</i>	eastern white pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Pinus sylvestris</i>	Scotch pine	Medium/Low	1	Low choice but heavily browsed if needed
<i>Alnus</i> spp.	alder	Low	1	
<i>Betula papyrifera</i>	paper birch	Low	1	
<i>Betula populifolia</i>	gray birch	Low	1	
<i>Carpinus caroliniana</i>	musclewood	Low	1	
<i>Crataegus</i> spp.	hawthorn	Low	1	
<i>Juniperus virginiana</i>	red cedar	Low	1	

Appendix B. Indicator species used for seedling ratio (continued).

Species	Common Name	Potential Deer Impact	Cite ¹	Note
<i>Larix laricina</i>	tamarack	Low	1	
<i>Ostrya virginiana</i>	hophornbeam	Low	1	
<i>Picea</i> spp.	spruces	Low	1	
<i>Populus</i> spp.	aspens	Low	1	
<i>Prunus serotina</i>	black cherry	Low	2	
<i>Rhamnus cathartica</i>	common buckthorn	Low	1	
<i>Robinia pseudoacacia</i>	black locust	Low	1	

¹1 — New York State Department of Environmental Conservation (NYS DEC). A Preference List of Winter Deer Foods (www.dec.state.ny.us/website/dfwmr/wildlife/deer/foodlist.html); 2 — USFS 2003. Forest Inventory and Analysis. Northeast Field Guide, Version 1.7, App. 12; 3 — USFS Fire Effects Information System tree description. (www.fs.fed.us/database/feis/plants/index.html).

Appendix C. Priority pest and pathogen species.

Common Name	Latin Name	Code	Priority
Asian longhorned beetle	<i>Anoplophora glabripennis</i>	ALB	1
Emerald ash borer	<i>Agrilus planipennis</i>	EAB	1
Hemlock woolly adelgid	<i>Adelges tsugae</i>	HWA	1
Sudden oak death	<i>Phytophthora ramorum</i>	SOD	1
Balsam woolly adelgid	<i>Adelges piceae</i>	BWA	2
Beech bark disease	<i>Cryptococcus fagisuga/Nectria</i> spp.	BBD	2
Butternut canker	<i>Sirococcus clavigignenti-juglandacearum</i>	BC	2
Elongate hemlock scale	<i>Fiorinia externa</i>	EHS	2

Appendix D. Key indicator invasive exotic plant species of forest, woodland and successional ecosystems in the northeastern U.S. that were used in the NETN Ecological Integrity Scorecard.

Latin name	Common name	Habitat
<i>Acer platanoides</i>	Norway maple	Open & forest habitats
<i>Ailanthus altissima</i>	tree-of-heaven	Edges & successional habitats
<i>Alliaria petiolata</i>	garlic mustard	Open & forest habitats
<i>Berberis thunbergii</i>	Japanese barberry	Open & forest habitats
<i>Berberis vulgaris</i>	European barberry	Open & wooded habitats
<i>Cardamine impatiens</i>	narrowleaf bittercress	Open & wooded habitats
<i>Celastrus orbiculatus</i>	oriental bittersweet	Edges & successional habitats
<i>Euonymus alatus</i>	winged burning bush	Open, successional & wooded habitats
<i>Fallopia japonica</i> (= <i>Polygonum cuspidatum</i>)	Japanese knotweed	Riparian, open & successional habitats
<i>Ligustrum</i> spp. (<i>obtusifolium</i> , <i>vulgare</i>)	privet	Successional & forest habitats
<i>Lonicera japonica</i>	Japanese honeysuckle	Edges & successional habitats
<i>Lonicera</i> spp. (<i>morrowii</i> , <i>tatarica</i> , <i>x bella</i>)	exotic honeysuckles	Open & successional habitats
<i>Luzula luzuloides</i>	forest woodrush	Open & wooded habitats
<i>Microstegium vimineum</i>	Japanese stiltgrass	Open & forest habitats
<i>Persicaria posumbu</i> (= <i>Polygonum caespitosum</i>)	oriental ladythumb	Open & successional habitats
<i>Rhamnus cathartica</i>	common buckthorn	Riparian, open & successional habitats
<i>Rhamnus frangula</i> (= <i>Frangula alnus</i>)	glossy buckthorn	Wetland & successional habitats
<i>Rhodotypos scandens</i>	black jetbead	Open, successional & wooded habitats
<i>Rosa multiflora</i>	multiflora rose	Open & successional habitats
<i>Rubus phoenicolasius</i>	wineberry	Open, successional & wooded habitats
<i>Vincetoxicum</i> spp.	swallow-wort species	Open, successional and wooded habitats

Appendix E. Herbaceous indicator species of deer browse pressure in northeastern U.S. forests.

Latin name	Common Name	Deer Preference	Citations
<i>Ageratina altissima</i> var. <i>altissima</i> (formerly <i>Eupatorium rugosum</i>)	white snakeroot	Avoided	Augustine and Jordan 1998
<i>Aralia nudicaulis</i>	wild sarsaparilla	Browsed	Balگوoyen and Waller 1995
<i>Eurybia divaricata</i>	white wood aster	Browsed	Williams et al. 2000
<i>Carex</i> spp.	sedge	Avoided	Williams et al. 2000, Augustine and deCalesta 2003, Horsley et al. 2003
<i>Clintonia borealis</i>	blue bead lily	Browsed	Balگوoyen and Waller 1995
<i>Dennstaedtia punctilobula</i>	hayscented fern	Avoided	Horsley et al. 2003
<i>Maianthemum</i> (<i>Smilacina</i>) spp. (<i>racemosum</i> , <i>stellatum</i>)	Canada mayflower and false Solomon's seal	Browsed	Fletcher et al. 2001, Augustine and deCalesta 2003
<i>Polygonatum</i> spp. (<i>biflorum</i> , <i>pubescens</i>)	smooth Solomon's seal	Browsed	Augustine and deCalesta 2003, Webster et al. 2005, Kraft et al. 2004
<i>Sanguinaria canadensis</i>	bloodroot	Browsed	Augustine and deCalesta 2003
<i>Thelypteris noveboracensis</i>	New York fern	Avoided	Williams et al. 2000, Horsley et al. 2003
<i>Trillium</i> spp. (<i>cernum</i> , <i>erectum</i> , <i>grandiflorum</i> , <i>undulatum</i>)	trillium	Browsed	Anderson 1994, Augustine and Frelich 1998, Rooney 2001, Augustine and deCalesta 2003, Webster et al. 2005
<i>Uvularia</i> spp. (<i>grandiflora</i> , <i>perfoliata</i> , <i>sessifolia</i>)	bellwort	Browsed	Fletcher et al. 2001, Augustine and deCalesta 2003, Webster et al. 2005

Appendix F. Raw data for use to rate the deer browse indicator species metric.

Park	Browse Type	Latin Name	Quadrat Frequency			% Change	Trend
			Previous	Current	Change		
ACAD	Preferred	<i>Aralia nudicaulis</i>	82	73	-9	-0.65	No Change
ACAD	Preferred	<i>Uvularia</i> spp.	11	3	-8	-0.58	No Change
ACAD	Avoided	<i>Carex</i> spp.	183	199	16	1.16	Positive
ACAD	Avoided	<i>Dennstaedtia punctilobula</i>	22	12	-10	-0.72	No Change
ACAD	Avoided	<i>Thelypteris noveboracensis</i>	13	7	-6	-0.43	No Change
MABI	Preferred	<i>Aralia nudicaulis</i>	10	22	12	6.25	Positive
MABI	Preferred	<i>Eurybia divaricata</i>	36	31	-5	-2.60	Negative
MABI	Preferred	<i>Trillium</i> spp.	25	24	-1	-0.52	No Change
MABI	Preferred	<i>Uvularia</i> spp.	26	15	-11	-5.73	Negative
MABI	Preferred	<i>Mainthemum</i> spp.	20	15	-5	-2.60	Negative
MABI	Preferred	<i>Polygonatum</i> spp.	7	8	1	0.52	No Change
MABI	Avoided	<i>Ageratina altissima</i>	28	28	0	0.00	No Change
MABI	Avoided	<i>Carex</i> spp.	96	172	76	39.58	Positive
MABI	Avoided	<i>Dennstaedtia punctilobula</i>	50	51	1	0.52	No Change
MABI	Avoided	<i>Thelypteris noveboracensis</i>	29	21	-8	-4.17	Negative
MIMA	Preferred	<i>Eurybia divaricata</i>	3	1	-2	-1.25	Negative
MIMA	Preferred	<i>Uvularia</i> spp.	7	5	-2	-1.25	Negative
MIMA	Avoided	<i>Carex</i> spp.	54	74	20	12.50	Positive
MIMA	Avoided	<i>Dennstaedtia punctilobula</i>	9	3	-6	-3.75	Negative
MIMA	Avoided	<i>Thelypteris noveboracensis</i>	4	2	-2	-1.25	Negative
SAGA	Preferred	<i>Aralia nudicaulis</i>	10	11	1	0.60	No Change
SAGA	Preferred	<i>Eurybia divaricata</i>	20	11	-9	-5.36	Negative
SAGA	Preferred	<i>Trillium</i> spp.	15	9	-6	-3.57	Negative
SAGA	Preferred	<i>Uvularia</i> spp.	7	7	0	0.00	No Change
SAGA	Preferred	<i>Mainthemum</i> spp.	24	12	-12	-7.14	Negative
SAGA	Preferred	<i>Polygonatum</i> spp.	27	16	-11	-6.55	Negative
SAGA	Avoided	<i>Carex</i> spp.	45	85	40	23.81	Positive
SAGA	Avoided	<i>Dennstaedtia punctilobula</i>	21	12	-9	-5.36	Negative
SAGA	Avoided	<i>Thelypteris noveboracensis</i>	33	24	-9	-5.36	Negative
SARA	Preferred	<i>Eurybia divaricata</i>	18	5	-13	-5.24	Negative
SARA	Preferred	<i>Mainthemum</i> spp.	5	3	-2	-0.81	No Change
SARA	Preferred	<i>Polygonatum</i> spp.	10	8	-2	-0.81	No Change
SARA	Preferred	<i>Sanguinaria canadensis</i>	8	1	-7	-2.82	Negative
SARA	Avoided	<i>Ageratina altissima</i>	39	28	-11	-4.44	Negative
SARA	Avoided	<i>Carex</i> spp.	210	244	34	13.71	Positive
SARA	Avoided	<i>Dennstaedtia punctilobula</i>	6	2	-4	-1.61	Negative
SARA	Avoided	<i>Thelypteris noveboracensis</i>	14	19	5	2.02	Positive

Appendix G. Scientific and common names of tree species mentioned in the Tree Growth and Mortality metric and the Tree Recruitment, Growth, and Mortality chapter.

Scientific Name	Common Name
<i>Abies balsamea</i>	balsam fir
<i>Acer nigrum</i>	black maple
<i>Acer pensylvanicum</i>	striped maple
<i>Acer platanoides</i>	Norway maple
<i>Acer rubrum</i>	red maple
<i>Acer saccharum</i>	sugar maple
<i>Ailanthus altissima</i>	tree-of-heaven
<i>Amelanchier</i> spp.	serviceberry
<i>Betula alleghaniensis</i>	yellow birch
<i>Betula cordifolia</i>	mountain paper birch
<i>Betula lenta</i>	black birch
<i>Betula papyrifera</i>	paper birch
<i>Betula populifolia</i>	gray birch
<i>Carya cordiformis</i>	bitternut hickory
<i>Carya glabra</i>	pignut hickory
<i>Carya ovata</i>	shagbark hickory
<i>Carya tomentosa</i>	mockernut hickory
<i>Crataegus</i> spp.	hawthorn
<i>Fagus grandifolia</i>	American beech
<i>Fraxinus americana</i>	white ash
<i>Fraxinus pennsylvanica</i>	green ash
<i>Fraxinus nigra</i>	black ash
<i>Juglans nigra</i>	black walnut
<i>Larix decidua</i>	European larch
<i>Larix laricina</i>	tamarack
<i>Liriodendron tulipifera</i>	tulip poplar
<i>Nyssa sylvatica</i>	black gum
<i>Ostrya virginiana</i>	hophornbeam
<i>Picea abies</i>	Norway spruce
<i>Picea glauca</i>	white spruce
<i>Picea mariana</i>	black spruce
<i>Picea rubens</i>	red spruce
<i>Pinus banksiana</i>	jack pine
<i>Pinus resinosa</i>	red pine
<i>Pinus rigida</i>	pitch pine
<i>Pinus strobus</i>	eastern white pine
<i>Pinus sylvestris</i>	Scotch pine

Appendix G. Scientific and common names of tree species mentioned in the Tree Growth and Mortality metric and the Tree Recruitment, Growth, and Mortality chapter (continued).

Scientific Name	Common Name
<i>Populus grandidentata</i>	big-toothed aspen
<i>Populus tremuloides</i>	quaking aspen
<i>Prunus serotina</i>	black cherry
<i>Quercus alba</i>	white oak
<i>Quercus bicolor</i>	swamp white oak
<i>Quercus montana</i>	chestnut oak
<i>Quercus rubra</i>	northern red oak
<i>Quercus velutina</i>	black oak
<i>Robinia pseudoacacia</i>	black locust
<i>Thuja occidentalis</i>	northern white cedar
<i>Tilia americana</i>	American basswood
<i>Tsuga canadensis</i>	eastern hemlock
<i>Ulmus americana</i>	American elm

Appendix H. Tree recruitment, growth and mortality rate figures by park subunit or land use.

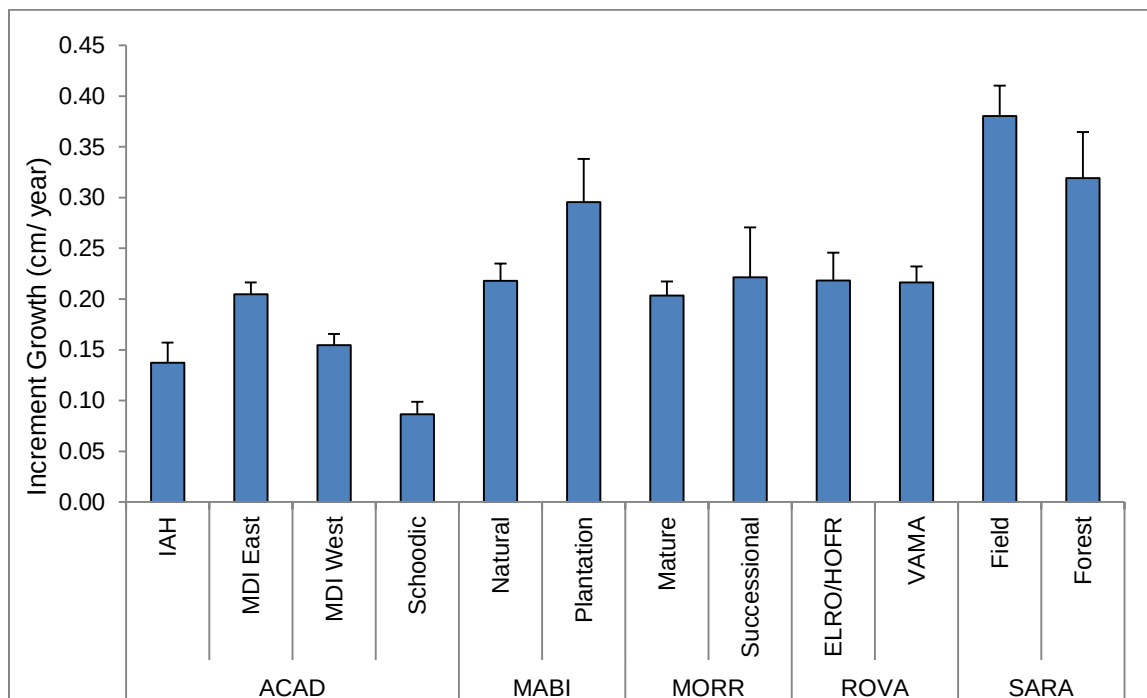


Figure G-1. Average annual increment growth rates by park subunit based on all live trees and all forested plots. Error bars represent 1 SE above the mean.

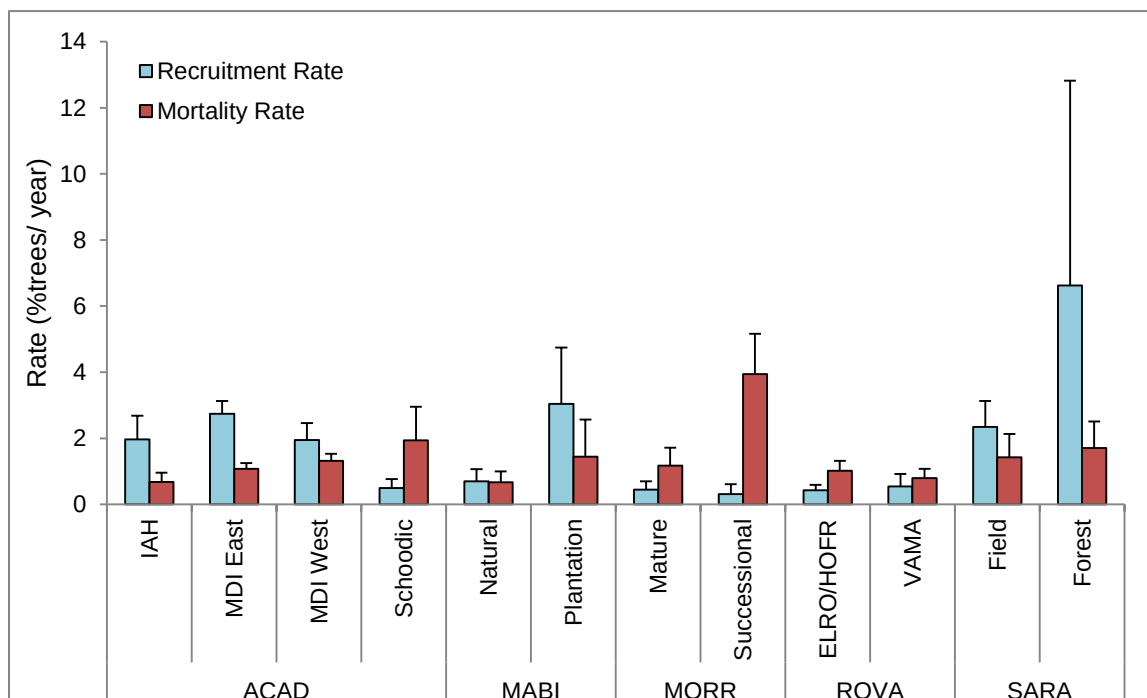


Figure G-2. Average annual recruitment and mortality rates by park subunit or land use.

Appendix I. Tree recruitment and mortality by species and park.

Park	Tree Species	Trees previously alive	Trees that died	Tree recruits
ACAD n=173	<i>Abies balsamea</i>	181	22	22
	<i>Acer pensylvanicum</i>	20	4	0
	<i>Acer rubrum</i>	378	11	19
	<i>Amelanchier</i>	14	2	0
	<i>Betula alleghaniensis</i>	57	0	6
	<i>Betula cordifolia</i>	8	0	0
	<i>Betula papyrifera</i>	159	9	1
	<i>Betula populifolia</i>	10	1	1
	<i>Fagus grandifolia</i>	29	0	1
	<i>Fraxinus americana</i>	16	0	0
	<i>Larix laricina</i>	30	3	0
	<i>Picea glauca</i>	24	1	0
	<i>Picea mariana</i>	185	5	11
	<i>Picea rubens</i>	1361	51	113
	<i>Pinus banksiana</i>	28	1	0
	<i>Pinus resinosa</i>	27	1	0
	<i>Pinus rigida</i>	67	0	3
	<i>Pinus strobus</i>	165	0	16
	<i>Populus grandidentata</i>	76	7	0
	<i>Quercus rubra</i>	113	3	4
	<i>Thuja occidentalis</i>	284	10	3
MIMA n=20	<i>Acer platanoides</i>	22	0	0
	<i>Acer rubrum</i>	113	2	2
	<i>Betula lenta</i>	10	0	0
	<i>Betula populifolia</i>	9	1	0
	<i>Fraxinus americana</i>	19	0	2
	<i>Fraxinus pennsylvanica</i>	6	3	0
	<i>Juglans nigra</i>	7	0	0
	<i>Pinus strobus</i>	39	1	1
	<i>Quercus alba</i>	5	0	0
	<i>Quercus rubra</i>	16	0	0
	<i>Quercus velutina</i>	37	4	0
	<i>Robinia pseudoacacia</i>	17	1	1
	<i>Ulmus americana</i>	11	2	1

Appendix I. Tree recruitment and mortality by species and park (continued).

Park	Tree Species	Trees previously alive	Trees that died	Tree recruits
MABI n=24	<i>Acer rubrum</i>	11	0	0
	<i>Acer saccharum</i>	121	5	3
	<i>Betula alleghaniensis</i>	17	0	1
	<i>Fagus grandifolia</i>	29	1	1
	<i>Fraxinus americana</i>	27	0	0
	<i>Larix decidua</i>	5	0	0
	<i>Ostrya virginiana</i>	10	1	0
	<i>Pinus resinosa</i>	22	0	0
	<i>Pinus strobus</i>	20	2	1
	<i>Pinus sylvestris</i>	11	1	0
	<i>Quercus rubra</i>	6	0	0
	<i>Tsuga canadensis</i>	73	0	2
SARA n=31	<i>Acer rubrum</i>	71	1	2
	<i>Acer saccharum</i>	17	0	1
	<i>Carya cordiformis</i>	17	0	0
	<i>Carya ovata</i>	15	0	0
	<i>Crataegus</i>	5	0	0
	<i>Fraxinus americana</i>	60	1	4
	<i>Ostrya virginiana</i>	5	2	1
	<i>Pinus strobus</i>	114	6	1
	<i>Populus tremuloides</i>	22	1	0
	<i>Prunus serotina</i>	7	1	0
	<i>Quercus bicolor</i>	6	0	0
	<i>Quercus rubra</i>	5	0	0
	<i>Quercus velutina</i>	12	0	0
	<i>Ulmus americana</i>	43	5	9

Appendix I. Tree recruitment and mortality by species and park (continued).

Park	Tree Species	Trees previously alive	Trees that died	Tree recruits
SAGA n=21	<i>Acer rubrum</i>	57	4	1
	<i>Acer saccharum</i>	32	1	0
	<i>Betula alleghaniensis</i>	13	0	0
	<i>Betula lenta</i>	48	0	1
	<i>Fagus grandifolia</i>	37	3	0
	<i>Fraxinus americana</i>	10	0	0
	<i>Pinus strobus</i>	58	7	0
	<i>Quercus rubra</i>	43	0	0
	<i>Tilia americana</i>	6	0	0
	<i>Tsuga canadensis</i>	124	3	5
MORR n=28	<i>Acer rubrum</i>	26	0	0
	<i>Betula alleghaniensis</i>	7	0	0
	<i>Betula lenta</i>	39	2	0
	<i>Carya glabra</i>	6	1	0
	<i>Carya tomentosa</i>	8	1	0
	<i>Fagus grandifolia</i>	49	0	2
	<i>Fraxinus americana</i>	23	4	0
	<i>Liriodendron tulipifera</i>	44	1	0
	<i>Quercus alba</i>	8	0	0
	<i>Quercus montana</i>	6	0	0
	<i>Quercus rubra</i>	9	0	0
	<i>Quercus velutina</i>	12	1	0
	<i>Robinia pseudoacacia</i>	11	4	0
WEFA n=10	<i>Acer rubrum</i>	51	4	0
	<i>Acer saccharum</i>	16	1	1
	<i>Betula alleghaniensis</i>	8	0	0
	<i>Betula lenta</i>	38	0	0
	<i>Fraxinus americana</i>	7	0	0
	<i>Quercus montana</i>	7	0	0
	<i>Quercus velutina</i>	5	0	1

Appendix I. Tree recruitment and mortality by species and park (continued).

Park	Tree Species	Trees previously alive	Trees that died	Tree recruits
ROVA n=40	<i>Acer</i>	7	0	0
	<i>Acer nigrum</i>	131	3	1
	<i>Acer platanoides</i>	6	0	0
	<i>Acer rubrum</i>	34	1	3
	<i>Acer saccharum</i>	98	3	0
	<i>Ailanthus altissima</i>	11	0	0
	<i>Betula lenta</i>	38	1	1
	<i>Carya tomentosa</i>	10	0	0
	<i>Fagus grandifolia</i>	17	0	1
	<i>Fraxinus americana</i>	7	2	0
	<i>Fraxinus pennsylvanica</i>	14	0	0
	<i>Liriodendron tulipifera</i>	9	0	0
	<i>Ostrya virginiana</i>	10	0	0
	<i>Picea abies</i>	18	2	0
	<i>Pinus resinosa</i>	19	3	0
	<i>Quercus alba</i>	19	0	0
	<i>Quercus montana</i>	8	0	0
	<i>Quercus rubra</i>	45	0	1
	<i>Quercus velutina</i>	12	1	0
	<i>Tilia americana</i>	6	1	0
	<i>Tsuga canadensis</i>	75	4	1
	<i>Ulmus americana</i>	5	1	0

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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