



Forest Health Monitoring in the Eastern Rivers and Mountains Network

2009–2012 Summary Report

Natural Resource Report NPS/ERMN/NRR— 2014/803



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Collecting forest health monitoring data in Delaware Water Gap National Recreation Area.
Photograph by: Stephen Murphy, NPS.

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Executive Summary

Completion of the 2012 field season marked the Eastern Rivers and Mountains Network (ERMN) Inventory and Monitoring Program's sixth year of sampling vegetation and soil monitoring plots. From 2007–2010, three hundred and sixty permanent plots were installed and sampled for the first time. From 2011–2012, half of the plots were sampled a second time. This report summarizes data collected from the latest full set of plot samples, from 2009–2012. Vegetation conditions described herein are based on all established monitoring plots, but only the latest visit to each plot; however, growth and mortality results in the Forest Dynamics section compare data from 2007 and 2008 with data from 2011 and 2012, respectively.

Nearly all plots occur in young or middle-aged forest stands, with very few plots capturing late-successional forest. As the parks' forests mature, more plots will be expected to attain late-successional structure; however, disturbances and stressors will strongly influence future forest structure.

Land use within the parks has important impacts on the parks' vegetation resources—since developed land (e.g. buildings and roads) and agricultural fields do not support native plant communities which are valued as important park natural resources. These land uses also fragment the parks' forests, creating edges which are susceptible to invasion by exotic species. Developed land and transportation corridors also facilitate the movement of people and their recreational impacts. Trails, in particular, act as conduits for the dispersal of invasive exotic species through forest communities. Recent trail construction in ALPO rendered two plots unsuitable for long-term monitoring by completely removing groundstory vegetation in much of the plots. Three additional plots in NERI were threatened by trail construction, but were spared through the efforts of park resource managers. Because the National Park Service's dual mandate, protecting the parks' natural resources from recreational impacts will be a persistent challenge.

Oak-dominated forests are an important resource in ERMN parks, covering large portions of the dry ridgetops and mesic side-slopes. Previous ERMN reports and numerous other studies in the eastern United States have documented the underrepresentation of oak seedlings and saplings in forests dominated by oaks. Furthermore, shade-tolerant species, such as maples that are capable of displacing oaks, have established in many oak forests. Using an oak sustainability indicator developed by the U.S. Forest Service, we show that oak regeneration in ERMN parks is similar to that of the surrounding region, with few to no oak seedlings and saplings present, or mortality of young oak trees surpassing the available oak seedlings and saplings. Given the dismal state of oak regeneration, managers should seek opportunities to conduct adaptive management in the parks' oak forests to experiment with and monitor the effects of fire, browse exclosures, and canopy thinning on oak regeneration.

There are numerous, often complex and interacting factors that influence tree regeneration. We use monitoring data to investigate which site characteristics most influence the amount of tree regeneration observed. In general, increased canopy closure, higher elevation, and drier forest types

contain more tree regeneration. Lower grass and fern cover and more plants sensitive to deer browse are also correlated with more tree regeneration.

ERMN monitoring protocols focus on a few plant species considered as preferred food for white-tailed deer. Very low levels of browse have been observed on these plants; however, browse is disproportionately observed on reproductive plants compared with non-reproductive plants. Furthermore, the number of reproductive individuals of these species may be suppressed in ERMN parks compared with populations not subjected to deer browse. The sustained low level of browse focused on reproductive plants may be affecting long-term viability of these species within the parks.

Park-Specific Management Implications

Allegheny Portage Railroad National Historic Site (ALPO)

For most forest health metrics reported herein, ALPO falls in the middle of the range of values observed among network parks. In general, trees in ALPO experienced less branch dieback and had healthier vigor rankings than in other parks, suggesting that park forests may be experiencing fewer stressors such as extreme weather, harsh site conditions, or insect and disease outbreaks. However, the park's beech and hemlock trees are being negatively affected by beech bark disease and hemlock woolly adelgid, respectively. Park managers should also be vigilant for signs of emerald ash borer which is known to occur in the park's counties and is likely already in the park. Invasive exotic plant species continue to impact forest health, with multiflora rose and Japanese barberry as the most commonly observed species. Ongoing exotic plant management and early detection efforts of both plants and pests are vitally important to maintaining forest health in the park.

Bluestone National Scenic River (BLUE)

Of the network parks, the highest tree mortality rate, as well as the highest proportion of plots experiencing elevated levels of tree mortality, occurs in BLUE. In addition, trees in BLUE are growing more slowly than in many other network parks. These forest metrics should be closely reexamined after all plots have been resampled to determine if these elevated levels of mortality and slow tree growth are of management concern or are due to normal competition among trees in a mature forest canopy. Invasive exotic plant species and forest pests are important threats to the park's forest. Invasive exotic species are twice as common in BLUE as in NERI and GARI. Multiflora rose and wineberry are the most common species, occurring in about half of the park's plots. Of the known forest pests, hemlock woolly adelgid and emerald ash borer are currently serious threats to the park's hemlock and ash trees, respectively. Ongoing exotic plant management and early detection efforts of both invasive plants and pests are vitally important to maintaining forest health in the park.

Delaware Water Gap National Recreation Area (DEWA)

Several forest health metrics in DEWA are influenced by early successional vegetation types that occur in old fields, wet meadows, and floodplains. Approximately half the plots in DEWA do not contain sufficient tree regeneration to replace current canopy. This is likely caused by a combination of high browse pressure and presence of young successional habitats which typically do not contain many tree seedlings. Among the network parks, DEWA has the highest average tree recruitment due to several plots located in early successional habitats where many saplings are reaching the minimum

threshold to be tallied as mature trees. The rapid growth of trees in these early successional habitats leads to a high average tree growth rate for the park.

Although approximately 30% of the plots in DEWA showed elevated tree mortality, many other of the park's plots have low (or 0%) tree mortality. Thus, the park-wide average is similar to that of other parks in the network. Tree mortality in DEWA should be examined closely after all plots have been resampled to determine if the elevated levels of mortality are of management concern or are due to normal competition among trees in a mature forest canopy. Thus far, plots with elevated mortality are scattered throughout the park in many different habitat types.

Invasive exotic plant species and forest pests continue to be serious threats to the park's forest. Compared to other network parks, DEWA contains relatively high levels of nonnative and invasive exotic plant species. This underscores the importance of ongoing exotic plant management and early detection efforts that are critical to maintaining forest health. Varying among years, 30–66% of the park's plots contained important forest pests and pathogens, with hemlock woolly adelgid and elongated hemlock scale the most commonly observed pests.

Fort Necessity National Battlefield (FONE)

For most forest health metrics reported herein, FONE falls in the middle of the range of values observed among network parks. In general, trees in FONE experienced less branch dieback and had healthier vigor rankings than in other parks, suggesting that park forests may be experiencing fewer stressors such as extreme weather, harsh site conditions, or insect and disease outbreaks. Only one occurrence of a forest pest was observed over the four-year sampling interval, the second lowest incidence of forest pests in the network. However, park managers should be vigilant for signs of emerald ash borer, which is known to occur in the park's county and may occur in the park. Invasive exotic plant species continue to be a serious threat to the park's forest, especially multiflora rose, Japanese barberry, and Morrow's honeysuckle, which occur in 60–85% of park plots, depending on the species. Ongoing exotic plant management and early detection efforts of both invasive plants and pests are vitally important to maintaining forest health in the park.

Friendship Hill National Historic Site (FRHI)

Several forest health metrics in FRHI are influenced by early successional forest established on former agricultural land. Approximately half of the plots in FRHI do not contain sufficient tree regeneration to replace current canopy. This is likely caused by a combination of high browse pressure and the abundance of young successional habitats which typically do not contain many tree seedlings. These early successional forests are characterized by rapid tree growth, but also by the presence of nonnative and invasive exotic plant species, which leads to lower floristic quality in the forest groundstory. In particular, invasive plant species are one of the most pressing threats to forest health in FRHI. On average, FRHI contains the most invasive plant species (5.5 species/plot and 20% of total plant cover) of any network park. Without concerted management efforts, invasive plant species will continue to expand within the park, further degrading forest health. There were no detections of targeted forest pests and pathogens in FRHI plots; however, park managers should be vigilant for hemlock woolly adelgid, emerald ash borer, and gypsy moth, as these pests will likely be introduced to the park in the coming years.

Gauley River National Recreation Area (GARI)

GARI contains the most fallen logs (coarse woody debris) and the fewest standing dead trees (snags) of the ERMN parks. Many forest stands in GARI exhibit characteristics approaching old-growth forests, such as large downed trees. As evidenced by the park's high tree recruitment rate, young trees are now filling in gaps left by large fallen/downed trees. Also, the park's low tree mortality rate leads to low density of snags.

Invasive plant species are currently at relatively low levels within the park; however, they remain a major threat to forest health in GARI. Multiflora rose, tree of heaven, autumn olive, and Japanese stiltgrass are the most common invasive plant species, although five other invasive species were also found in monitoring plots. Ongoing exotic plant management and early detection efforts are vitally important to maintaining forest health and the current low incidence of these species. Similarly, forest pests were rarely observed in the monitoring plots; however, they are a serious threat to the park's forests. Notably, hemlock woolly adelgid and emerald ash borer are significant threats to the park's hemlock and ash trees, respectively. Continued vigilance and outreach to park neighbors and user groups are equally important in preventing the introduction and spread of new invasive plant and pest species.

Johnstown Flood National Memorial (JOFL)

Much of the forest at JOFL is relatively young, and the numerous small-diameter trees that died during the stem-exclusion phase of forest stand succession have not yet fallen to create coarse woody debris. As a result, JOFL contains the least amount of fallen logs (coarse woody debris) and the largest amount of standing dead trees (snags) of the ERMN parks. Very few detections of forest pests occurred over the sampling interval; however, park managers should be vigilant for signs of emerald ash borer which is known to occur in the park's county and is likely already in the park. Invasive exotic plant species continue to be a serious threat to the park's forest, especially multiflora rose and Morrow's honeysuckle, which occur in half of the park's plots. Ongoing exotic plant management and early detection efforts of both plants and pests are vitally important to maintaining forest health in the park.

New River Gorge National River (NERI)

For most forest health metrics reported herein, NERI falls in the middle of the range of values observed among network parks. Invasive plant species are currently at relatively low levels within the park; however, they remain a major threat to forest health in NERI. Multiflora rose and tree of heaven are the most common invasive plant species, although 13 other invasive species were found in the monitoring plots. Ongoing exotic plant management and early detection efforts are vitally important to maintaining forest health and the current low incidents of these species. Forest pests, another serious threat to the park's forests, were found in less than 20% of the park's plots each year. Notably, hemlock woolly adelgid and emerald ash borer are significant threats to the park's hemlock and ash trees, respectively. In light of the recent influx of visitors to the park and neighboring lands, protecting the park's forests from recreational impacts will be a challenge. Continued vigilance and outreach to park neighbors and user groups are equally important in preventing the introduction and spread of new invasive plant and pest species. Minimizing trail construction will also help protect forest communities from the dispersal of invasive exotic plants, pests, and diseases.

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Introduction

The Eastern Rivers and Mountains Network (ERMN) of the National Park Service (NPS) Inventory and Monitoring Program developed a long-term monitoring program for vegetation resources (Perles et al. 2014) in response to the identification of vegetation communities and soils as high-priority vital signs for the network (Marshall and Piekielek 2007) and as part of the nationwide NPS Inventory and Monitoring Program (Fancy et al. 2009). The ERMN Vegetation and Soil Monitoring Program provides information regarding the condition of these resources in the parks, and how this condition is changing through time. Data generated by this program contribute to the monitoring of several of the network's vital signs, including: Forest, Woodland, Shrubland, and Riparian Plant Communities; Status and Trends of Invasive/Exotic Plants, Animals, and Diseases; Early Detection of Invasive/Exotic Plants, Animals, and Diseases; and Soil Function and Dynamics. The overall goal of the Vegetation and Soil Monitoring Program is to assess status and trends in the composition, structure, and function of ERMN vegetation and soil resources in order to inform management decisions.

The ERMN includes nine parks in New York, New Jersey, Pennsylvania, and West Virginia (Figure 1), which together encompass nearly 91,000 ha (225,000 ac) of land area and over 965 km (600 mi) of streams and rivers within the parks' authorized boundaries. The network includes four smaller parks in central and southwestern Pennsylvania that have a primarily cultural or historical focus. The cultural parks are Allegheny Portage Railroad National Historic Site (ALPO), Johnstown Flood National Memorial (JOFL), Fort Necessity National Battlefield (FONE), and Friendship Hill National Historic Site (FRHI). The five larger parks preserve segments of large rivers and generally extend to the ridge tops surrounding the river section. The river parks are Upper Delaware Scenic and Recreational River (UPDE), Delaware Water Gap National Recreation Area (DEWA), New River Gorge National River (NERI), Gauley River National Recreation Area (GARI), and Bluestone National Scenic River (BLUE). In 2007, the ERMN began monitoring vegetation communities and soil in all of its parks except UPDE, which contains insufficient publically owned land on which to conduct long-term vegetation monitoring. The 2012 field season marked the sixth year of sampling the monitoring plots.

Numerous ecological and anthropogenic forces affect the parks' vegetation. Ecological factors such as geology, soil nutrient availability, weather, and disturbance patterns directly influence the structure, composition, and dynamics of the vegetation. Some anthropogenic stressors are easily identified, such as visitor overuse or loss and fragmentation of habitat due to development inside and outside the parks. However, many changes in forest vegetation are linked to several interacting ecological and anthropogenic factors. Exotic species, white-tailed deer (*Odocoileus virginianus*), atmospheric acid and nutrient deposition, climate change, altered disturbance regimes, and changes in land use are all important factors affecting the parks' vegetation (Rentch 2006, Perles et al. 2014).

Depending on the successional stage, disturbance history, and site conditions, there are certain parameters within which a terrestrial vegetation ecosystem can be described as "healthy" (Tierney et al. 2012). By measuring taxonomic, structural, and demographic features, an assessment can be made

as to whether or not the ecosystem's parameters fall within expected or accepted norms and ranges of variability. These measures serve as indicators of ecological integrity that can be explicitly linked to park management.

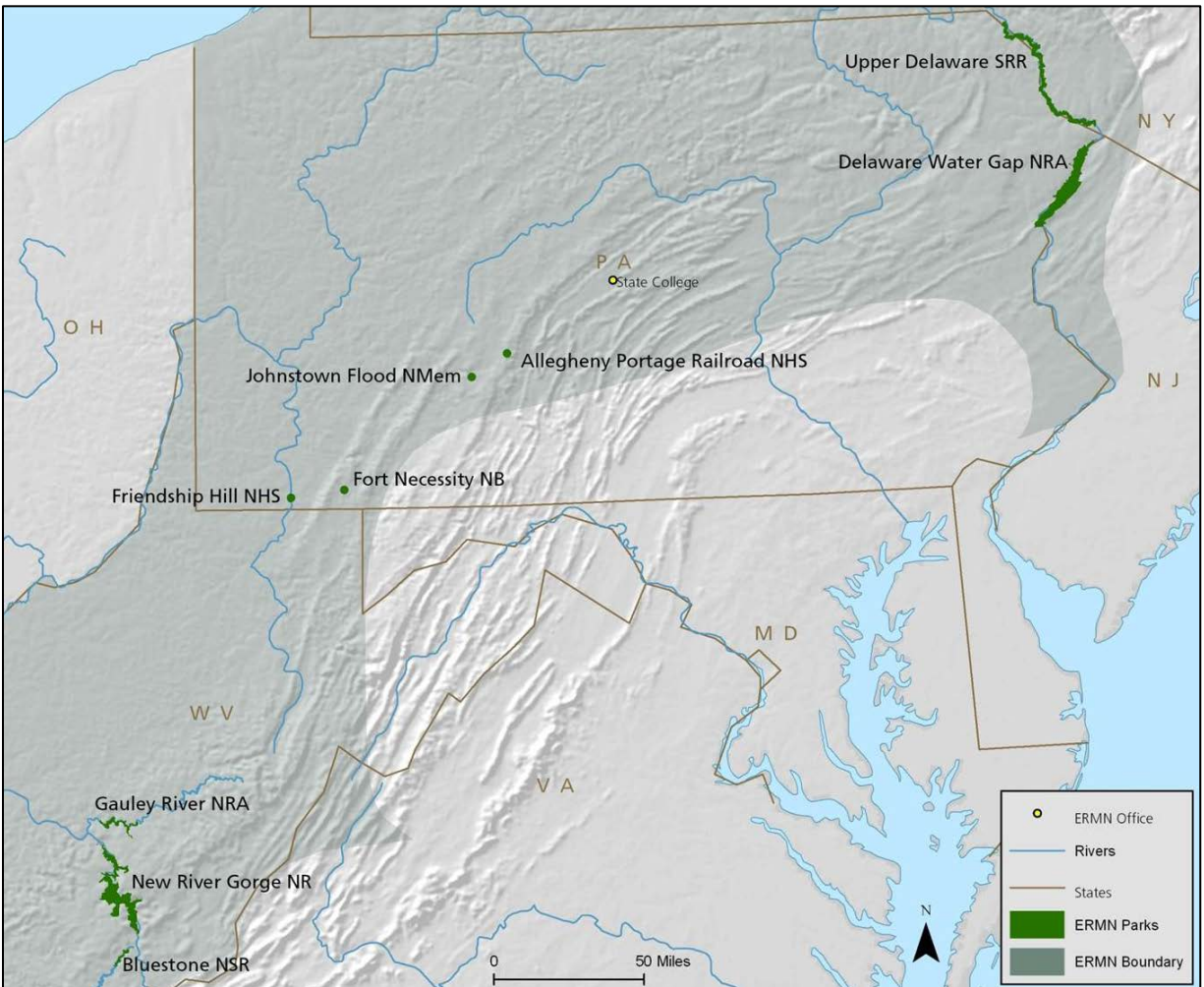


Figure 1. Locations of parks in the Eastern Rivers and Mountains Network.

Methods

Adapted from the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) Program and the vegetation monitoring protocols of four other NPS Inventory and Monitoring programs in the eastern United States (Sanders et al. 2008, Schmit et al. 2009, Comiskey et al. 2009, Tierney et al. 2012), the ERMN forest protocol monitors a representative suite of site and vegetation measures in an extensive network of randomly located permanent plots (Perles et al. 2014).

The sampling universe for vegetation and soil monitoring includes all area within each park's authorized boundary that is publically owned, vegetated, not intensively managed, and has a slope of less than 30° (see Appendix A for sampling universe maps by park). Since inferences derived from monitoring data cannot be applied to areas of the park outside the sampling universe, results presented in this report apply only to the areas shown in green in Appendix A.

Vegetation and soil are monitored at permanent plots, since the use of permanent plots increases the power to detect trends through time (Urquhart et al. 1998). For each park, a regular grid of potential plot locations was overlain on the park. Sampling locations were selected from the regular grid using a generalized random-tessellation stratified (GRTS) design (McDonald 2004, Stevens and Olsen 2004). Plots are sampled on a four-year panel design, in which one panel containing one-fourth of a park's total plots is sampled each year. On the fifth year, the first panel is re-sampled. From 2007–2010, three hundred and sixty permanent plots were installed and sampled for the first time (panels 1–4). From 2011–2012, half of the plots were sampled a second time (panels 1 and 2). The number of plots sampled in each park in each year is shown in Table 1.

Table 1. The number and type of monitoring plots sampled in ERMN parks from 2007–2012. Plots from panel 1 (2007 and 2011) are shown in blue. Plots from panel 2 (2008 and 2012) are shown in orange. Plots from panel 3 (2009) are shown in green. Plots from panel 4 (2010) are shown in purple.

	NERI	DEWA	JOFL	ALPO	FONE	FRHI	GARI	BLUE	Total
2007 – Panel 1	20	26	1	3	5	5	12	12	84
2008 – Panel 2	29	26	3	6	5	5	9	9	92
2009 – Panel 3	25	25	3	6	5	5	9	9	87
2010 – Panel 4	26	25	3	6	5	5	10	10	90
2011 – Panel 1	22 ^a	26	3 ^b	6 ^b	5	5	12	12	91
2012 – Panel 2	28 ^c	26	3	6	5	5	9	9	91

^a Two plots were added in NERI to panel 1 in 2011 on newly-acquired land with the park's authorized boundary. For more information on this sampling design see the vegetation and soil monitoring protocol (Perles et al. 2014)

^b Logistical issues prevented a full panel of plots from being established in ALPO and JOFL in 2007, so additional plots were added in 2011 to complete the panel.

^c Due to a resurveying of the park boundary, one plot from panel 2 that was established in 2008 was no longer within the park boundary in 2012; therefore, this plot was removed from the monitoring program.

Field Methods

At each plot, the ERMN monitors a suite of vegetation and soil variables. The plot design includes several embedded sampling units (Figure 2). Details of the sampling methods, in addition to data collection Standard Operating Procedures, can be found in the Vegetation and Soil Monitoring Protocol (Perles et al. 2014). Tree, stand, and site measurements are collected within fixed-area, circular plots, 15 m (49.2 ft) in radius. Tree regeneration and shrub measurements are collected on four 2-m (6.6 ft) radius circular microplots embedded within each plot. Data on coarse woody debris are collected using line intersect sampling along six 15-m (49.2 ft) transects. Data on understory plant composition are monitored using twelve 1-m² quadrats set along the six transects. A photograph of the plot is taken from the plot's southern edge to document change in vegetation structure through time. Three soil samples are collected from sampling frames located adjacent to the plot's northern edge.

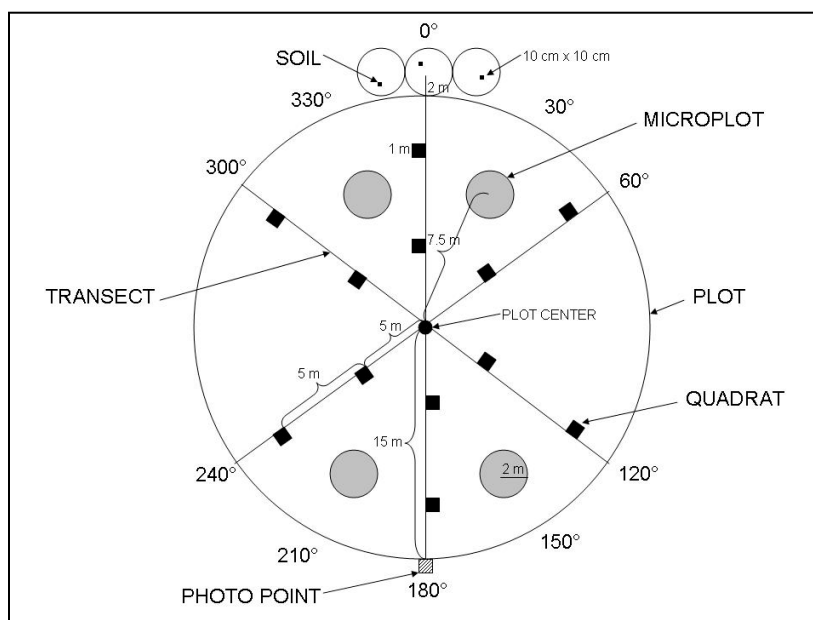


Figure 2. Plot design for Eastern Rivers and Mountains Network Vegetation Monitoring protocol. Tree, stand, and site measurements are collected within the plot. Tree regeneration and shrub measurements are collected in the microplots. Data on coarse woody debris are collected along transects. Data on understory plant composition and the diversity of understory species are collected in the quadrats. A photograph of the plot is taken from the plot's southern edge. Three soil samples are collected from sampling frames located adjacent to the plot's northern edge.

Data Analysis

This report summarizes data collected from the latest full set of four panels, from 2009–2012. Vegetation conditions described herein are based on all established monitoring plots, but only the latest visit to each plot. The Forest Dynamics section contains the only metrics in this report for which 2007 and 2008 data were used. The growth and mortality results were calculated by comparing data from 2007 and 2008 with data from 2011 and 2012, respectively.

Results and Discussion

The concept of “ecological integrity” interprets 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. 2012). Conditions reported herein are based on the most recent full cycle (2009-2012) of data collected from all plots in the parks. Specifically, we present findings on structural stage distribution, land use, forest composition, coarse woody debris volume, snag abundance, tree regeneration, forest dynamics, tree condition, invasive exotic plants, floristic quality, and deer browse indicators.

Structural Stage Distribution

Vegetation in ERMN parks is primarily forest, though forest stands vary greatly in age and land use history. A diversity of other vegetation types is also present, including successional old fields, riparian communities, and wet meadows. Distribution of vegetation types and forest structural stages within a park 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 distribution of vegetation types in eastern forests, and 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).

Monitoring the successional stage of the forests provides a picture of the shifting mosaic of stand structures within the parks. For each plot, we calculated the quadratic mean diameter (QMD), which is the “average” diameter for the plot (i.e., the diameter of a hypothetical tree with its basal area equal to the plot’s average basal area of live trees, Curtis and Marshall 2000). Plots were then classified into non-forested, pole, mature, and late-successional categories based on the following classification (adapted from Frelich and Lorimer 1991): non-forested = no trees (woody species with diameter at breast height ≥ 10 cm) in the plot; pole = $10 \text{ cm} \leq \text{QMD} < 26 \text{ cm}$; mature = $26 \text{ cm} \leq \text{QMD} < 46 \text{ cm}$; late-successional = $\text{QMD} \geq 46 \text{ cm dbh}$. Figure 3 shows examples of vegetation in the four successional stages. Figure 4 shows the proportion of plots in each park that fall into these stages.

The vast majority of the parks’ forests are young and middle-aged, and as a result, nearly all plots are located in pole-sized or mature stands. FONE contains the largest proportion of plots in mature forest, while JOFL contains the smallest proportion of mature forest plots. While many forest stands in GARI exhibit characteristics approaching old growth, no monitoring plots are classified as late-successional yet; though, GARI does contain the second highest proportion of plots in mature forest. Very few plots (two out of 359 plots) capture late-successional forest. As the parks’ forests mature, more plots will be expected to attain late-successional structure; however, disturbances and stressors will strongly influence future forest structure.



Figure 3. Examples of vegetation in four different structural stages: non-forested (upper left), pole (upper right), mature (lower left), and late-successional (lower-right).

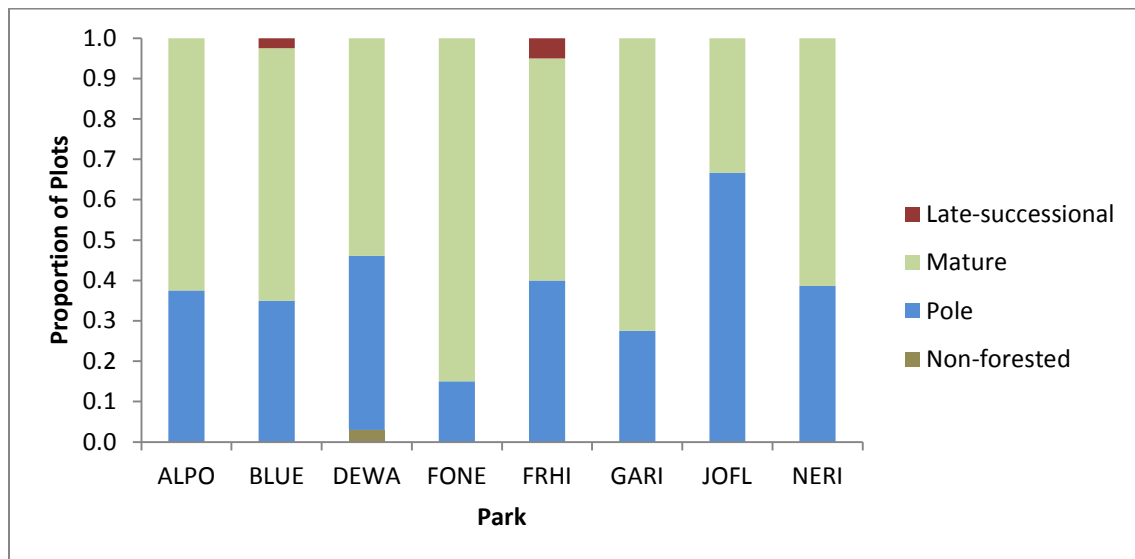


Figure 4. Proportion of plots in each structural stage (Late Successional, Mature, Pole and Non-forested) by park based on the calculated quadratic mean diameter for each plot.

Land Use

Land use within the parks has important impacts on the parks' vegetation resources. At the most basic level, developed land (e.g. buildings and roads) no longer supports native plant communities which are valued as important park natural resources. Similarly, agricultural fields, especially planted crop monocultures, do not contribute to the health of the parks' native vegetation communities. Furthermore, these land uses fragment the parks' forests, creating edges which are susceptible to invasion by exotic species (Honnay et al. 2002, Gonzalez-Moreno et al. 2012).

Figure 5 shows the percent of each park and the total hectares within each park that are currently developed or in agriculture (calculated from Perles et al. 2006a, b, c; Perles et al. 2007a, b; Vanderhorst et al. 2007; Vanderhorst et al. 2008; Vanderhorst et al. 2010). In particular, DEWA contains over 1,200 ha (2,965 ac) of active cropland (~5% of park area), primarily corn fields in the lowlands around the Delaware River (Perles et al. 2007b). From a forest health perspective, these monocultures are ecological deserts compared with the surrounding diverse mesic vegetation communities (Perles et al. 2007b). NERI contains over 1,600 ha (3,954 ac) of developed land (~6% of park area) due to the numerous small towns contained within the park (Vanderhorst et al. 2007). Due to the small size of the park, JOFL contains the highest percentage of developed land (15%), though this land supports the park visitor center, maintenance facilities, and interpretative stations (Perles et al. 2006c). In FRHI, 8% of the park is developed land, while an additional 9% of the park is maintained in agriculture (Perles et al. 2006b).

Not only are developed land and transportation corridors impacts to the parks' forest resources in and of themselves, they also facilitate the movement of people and their recreational impacts. Indeed, considerable impacts to forest communities occur quickly with only light recreational use, while recovery from these impacts requires longer periods without any use (Cole 1987). In many eastern forests where recreation occurs, the amount of visitation is the primary factor influencing deterioration of natural communities, with more visitor use leading to greater resource deterioration over a larger area (Bratton et al. 1976, Brown et al. 1977, Cole and Marion 1988).

A variety of natural resource impacts are associated with trails. For example, soil erosion and vegetation loss on and around trails are persistent problems, along with the proliferation and deterioration of visitor-created informal trails (Jewell 2001). Trails also act as conduits for dispersal of invasive exotic species through forest communities. Numerous studies report higher richness and cover of exotic species along trails than in the forest interior (Benninger-Truax et al. 1992, Campbell and Gibson 2001, Mortensen et al. 2009). Thus, trails are a source and a pathway of spread for invasive exotic plant species to expand into forest communities.

Since the ERMN vegetation monitoring program began in 2007, trail construction in ALPO has impacted two plots severely enough to render the plots unsuitable for long-term monitoring. Vegetation in numerous microplots and quadrats within these plots has been removed and those portions of the plot will likely persist as unvegetated due to continued trail use. Within NERI, three monitoring plots were nearly eliminated by proposed trail construction. In each of these cases, ERMN staff worked closely with NERI resource managers to ensure that the trails were re-routed to avoid the monitoring plots. Because the National Park Service has a dual mandate to "to conserve the

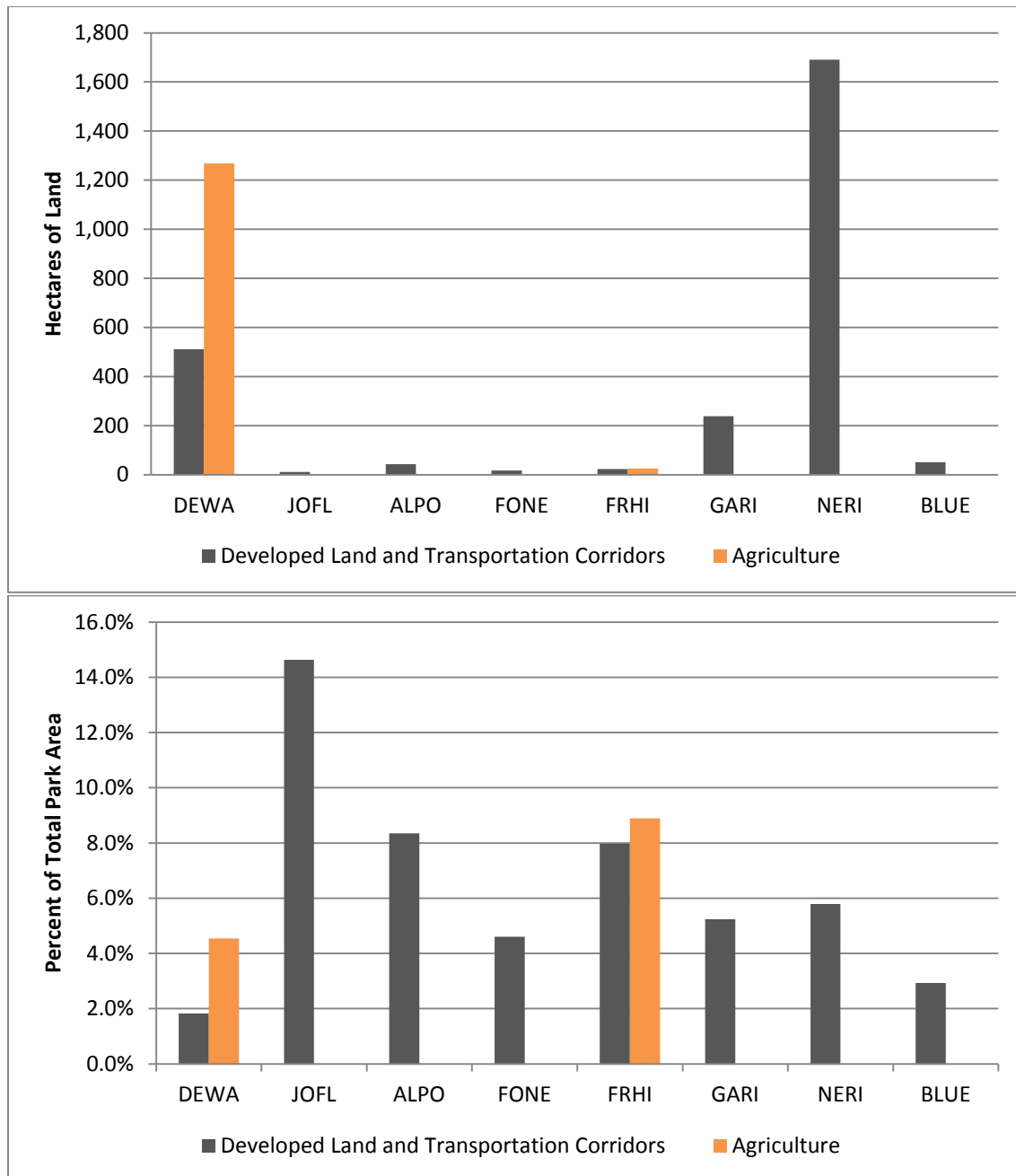


Figure 5. Total hectares of land and percent of total park area in developed land, transportation corridors, and agriculture in ERMN parks (calculated from Perles et al. 2006a, b, c; Perles et al. 2007a, b; Vanderhorst et al. 2007; Vanderhorst et al. 2008; Vanderhorst et al. 2010).

scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations” (NPS Organic Act 1916), protecting the parks’ natural resources from recreational impacts will be a persistent challenge.

Forest Composition

Oak-dominated forests are an important resource in ERMN parks, covering large portions of the dry ridgetops and mesic side-slopes. Previous ERMN reports and numerous other studies in the eastern United States have documented the underrepresentation of oak seedlings and saplings in forests with canopies dominated by oaks (*Quercus* spp.; Abrams 2003, Widmann and McWilliams 2007, Brose et al. 2008, Iverson et al. 2008, Perles et al. 2014). According to paleoecological studies, oak dominance has been relatively stable in most areas of the eastern United States over the long term (>9,000 years; Watts 1979, Maenza-Gmelch 1997). In presettlement land surveys, oak species comprised 35–75% of witness trees (Russell 1981, Abrams and Ruffner 1995, Black and Abrams 2001). However, in recent decades, shade-tolerant species (such as maples [*Acer* spp.]) that are capable of displacing oaks on mesic and dry-mesic sites have established in many oak forests (Abrams 1992, Abrams and Downs 1990, Abrams and Nowacki 1992).

To assess the future of oak forests, Woodall et al. (2008) developed an indicator of oak sustainability which incorporates the proportion of oaks present in the seedling and sapling layers with mortality of young oak trees. The indicator is calculated as:

$$\text{Indicator} = \text{Seed}_R + \text{Sap}_R - \text{TreeMort}_R$$

Where Seed_R is the ratio of oak seedlings to total seedlings per plot, Sap_R is the ratio of oak saplings to total saplings per plot, and TreeMort_R is the ratio of young (10 cm < diameter at breast height < 15 cm) oak tree mortality to total young tree mortality. The indicator has a maximum value of 2 when all seedlings and saplings are oak species with no mortality of young oak trees. A value of -1 indicates that no oak seedlings or saplings were present and all young tree mortality occurred on oaks.

We calculated the oak sustainability indicator for 131 plots that contained at least one oak tree in the canopy and that have been revisited allowing for the calculation of mortality rates. The distribution of the indicator is heavily skewed to the left, with most plots having a value close to zero (Table 2, Figure 6). The indicator equals zero when no oak seedlings and saplings are present, or mortality of young oak trees surpasses the available oak seedlings and saplings. This skewed distribution illustrates the failure of oak regeneration in ERMN oak forests. In the median plot, oak seedlings and saplings constituted only 11 percent of the stand's total seedling and saplings (assuming no mortality of young oak trees).

We compared the distribution of the oak sustainability indicator within ERMN parks with values calculated from USFS FIA plots in 24 states in the Midwest and Northeast (Figure 6, Table 2). The distributions are very similar, with most values close to 0. This suggests that, in general, oak regeneration in ERMN parks is similar to that of the surrounding region, with few to no oak seedlings and saplings present, or mortality of young oak trees surpassing the available oak seedlings and saplings. Given the dismal state of oak regeneration, managers should seek opportunities to conduct adaptive management in the parks' oak forests to experiment with and monitor the effects of fire, browse exclosures, and canopy thinning on oak regeneration.

Table 2. Order statistics for the oak sustainability indicator in ERMN parks and 24 Midwestern and Northeastern states studied by the USFS FIA program.

Statistic	Oak Sustainability Indicator	
	USFS FIA (from Woodall et al. 2008)	ERMN
Maximum (100%)	2.00	1.42
Quartile 3 (75%)	0.60	0.32
Median (50%)	0.20	0.10
Quartile 1 (25%)	0.02	0.02
Minimum (0%)	-0.53	-1.00
Mean	0.38	0.19
Number of Plots	5,729	131

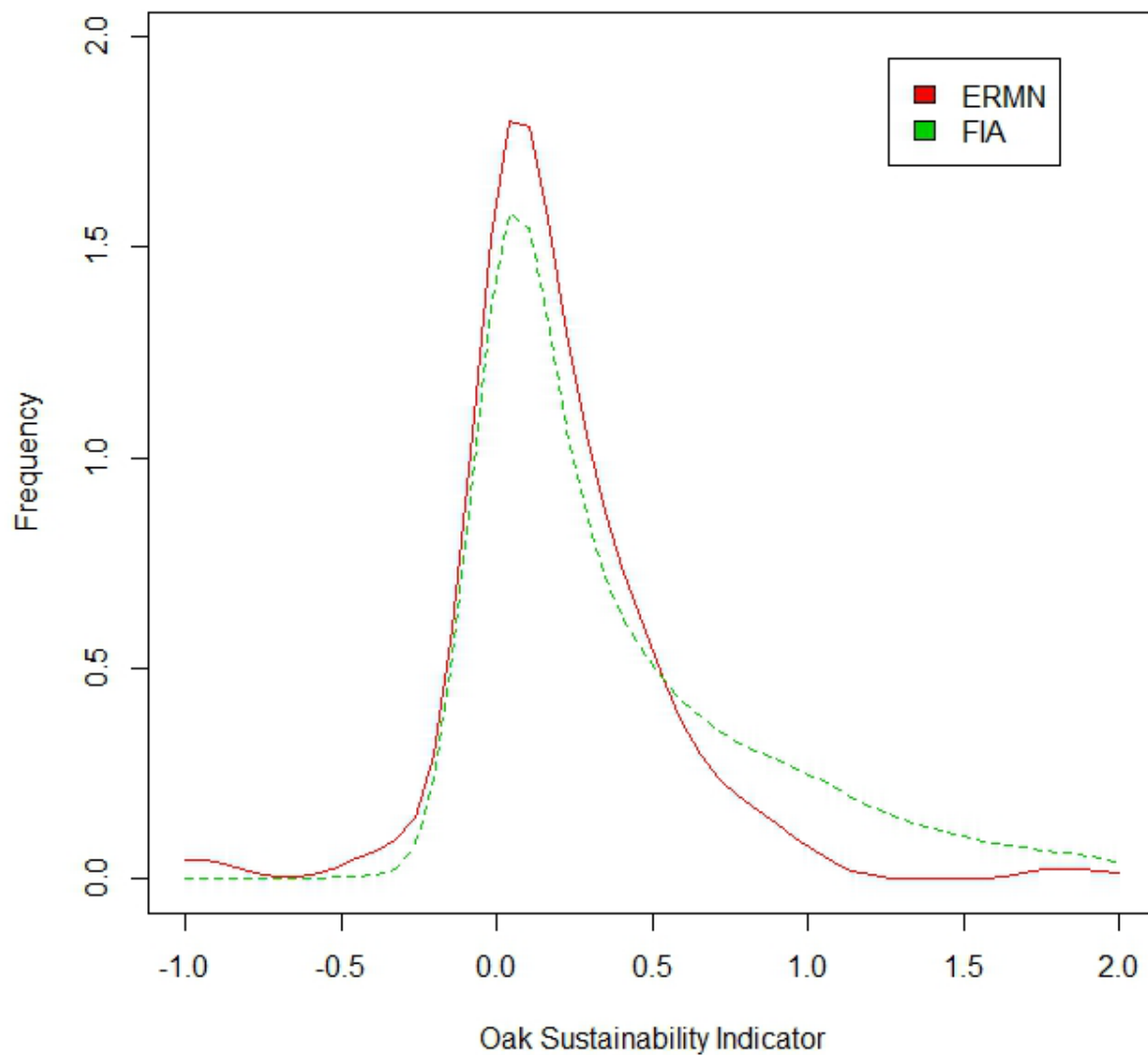


Figure 6. Histogram of oak sustainability indicator values in ERMN (n=131) and USFS FIA (n=5729) oak forest plots.

Coarse Woody Debris and Snag Abundance

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 taxa (Figure 7). Coarse woody debris provide important habitat for microbes, arthropods, amphibians, reptiles, small mammals, and fungi, while snags provide habitat for cavity-nesting birds and mammals (Hagan and Grove 1999). The density and size of snags are indicative of habitat availability for those species. In addition, tip-up mounds caused by windthrow contribute to forest soil turnover and create important microhabitats for tree seedlings and bryophytes (Jonsson and Esseen 1990, Ulanova 2000, McGee 2001, Samonil et al. 2010).



Figure 7. Measuring coarse woody debris (left) in Gauley River National Recreation Area and a flying squirrel (*Glaucomys* sp.) inhabits a snag (right) in New River Gorge National River.

We assess the dead wood resources of the parks using the volume of CWD and the density of snags which can vary substantially across ecosystems and with site conditions (Tyrrell et al. 1998). Volume of CWD in most ERMN parks ranges from 20.0–30.0 m³/ha (Figure 8, Table 3), within the range of variation observed for forests in the region. Coarse woody debris volume can range from 25 m³/ha in even-aged northern hardwood stands to 102 m³/ha in old-growth northern hardwood forests in northern Michigan and Wisconsin (Goodburn and Lorimer 1998). Other published values include 46–132 m³/ha for mixed oak forests (Harmon et al. 1983) and 48 m³/ha for old-growth forests in eastern Kentucky (Muller and Liu 1991).

Snag density in ERMN parks ranges from 50.0–80.0 snags/ha with snags representing 6–13% of the total trees and snag basal area ranging from 1.30–2.88 m²/ha (Figure 8, Table 3). These values also fall within the range of variation observed for eastern forests (Table 4).

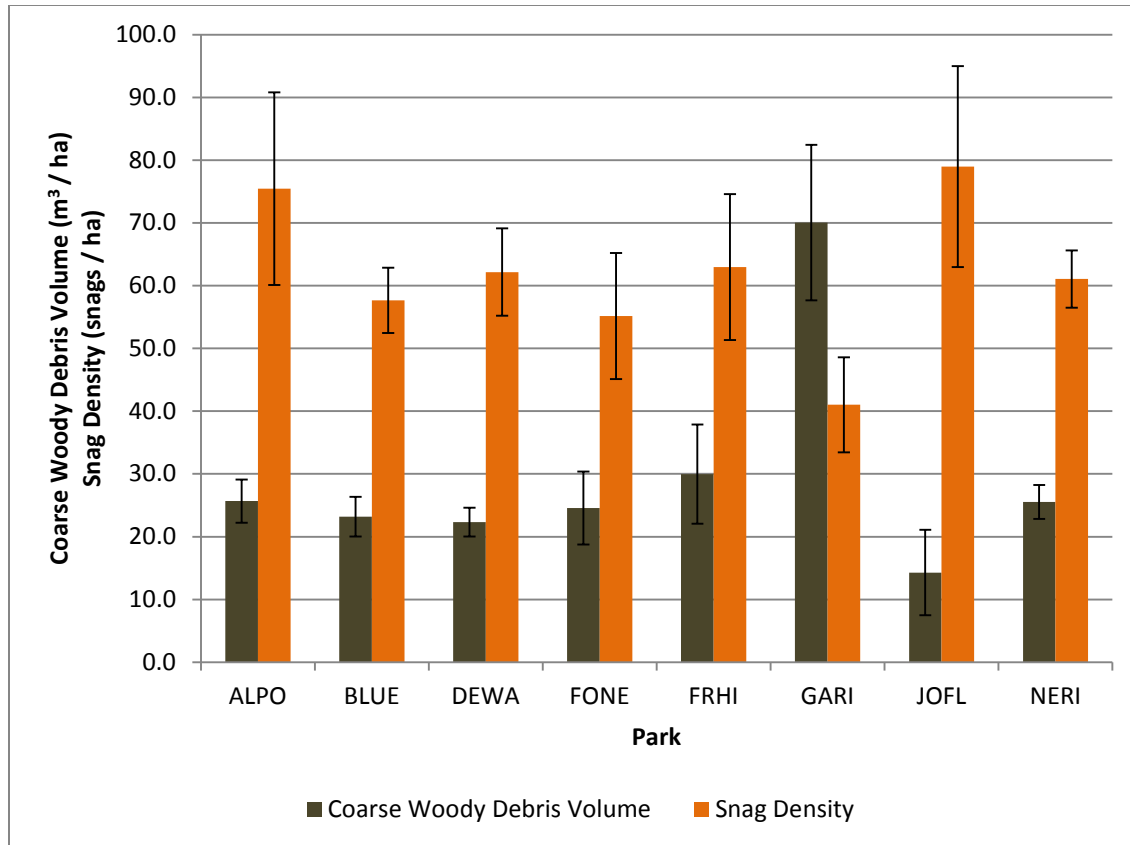


Figure 8. Coarse woody debris volume and snag density (mean ± standard error) for ERMN parks.

Table 3. Coarse woody debris volume and snag statistics by park.

Park	Coarse Woody Debris Volume (m ³ / ha)		Snag Basal Area (m ² /ha)		Percent of Trees as Snags		Snag Density (snags/ha)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
ALPO	25.68	3.43	2.88	0.54	13.16%	2.07%	75.44	15.34
BLUE	23.19	3.18	1.78	0.22	9.76%	0.86%	57.64	5.20
DEWA	22.35	2.29	2.34	0.27	11.31%	0.99%	62.15	6.96
FONE	24.56	5.80	2.06	0.42	10.70%	1.75%	55.16	10.05
FRHI	29.99	7.90	1.83	0.47	12.40%	2.02%	62.94	11.63
GARI	70.05	12.39	1.30	0.28	6.32%	0.89%	41.02	7.56
JOFL	14.28	6.81	2.21	0.53	11.39%	2.24%	78.97	16.00
NERI	25.54	2.68	1.71	0.15	9.84%	0.64%	61.06	4.56

Table 4. Published values for snag statistics in eastern forests.

Forest Type	Location	Snag Basal Area (m ² /ha)	Percent of Trees as Snags	Snag Density (snags/ha)	Citation
Oak-Hickory Forest	Connecticut	1.3-3.4	8-9%	47-109	1
Hemlock-Hardwood Forest	Pennsylvania	6.7	12%	49	1
Hardwood Forest	West Virginia			22-55	2
Oak-dominated Forest	Virginia			62-69	3
Old-growth Forest	Southern Appalachia			10-20	4, 5
Old-growth Forest	Kentucky			43	6
Old growth Northern-Hardwood Forest	Michigan and Wisconsin			39-73	7

1 - Tritton and Siccama 1990;

2 - Carey 1983;

3 - Rosenberg et al. 1998;

4 - Runkle 1998;

5 - Runkle 2000;

6 - McComb and Muller 1983;

7 - Goodburn and Lorimer 1998.

Though most ERMN parks contain similar amounts of coarse woody debris and snags, JOFL and GARI are notable outliers (Figure 8, Table 3). JOFL contains the least amount of coarse woody debris (14.3 m³/ha) and the largest amount of standing snags (78.97 snags/ha), while GARI contains the most coarse woody debris (70.05 m³/ha) and the fewest snags (41.02 snags/ha), only six percent of all trees. These values are reflective of the age of the parks' forests. The majority of JOFL plots are in young pole-sized forest stands, and the numerous small-diameter trees that died during the stem-exclusion phase of forest stand succession have not yet fallen to create CWD. Many stands in GARI are older and exhibit characteristics approaching late-successional forests. Large downed logs are frequent in GARI's forests, and the relatively few snags may be a result of the low mortality rate of canopy trees (see Forest Dynamics section).

Tree Regeneration

The quantity and composition of tree regeneration in the forest understory impacts 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 an 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 $\geq 8.5/\text{km}^2$, well above pre-settlement estimates of three to four deer per km^2 in the northeastern U.S. (Russell et al. 2001, Augustine and deCalesta 2003).

One approach to assessing forest regeneration quantifies whether current seedling quantities are sufficient to replace a forest stand's canopy trees (Figure 9). 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 assigns and sums points for native tree seedlings by height size class within 2-m radius circular microplots as follows: one point for each seedling 5–30 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.



Figure 9. Sampling tree regeneration in Delaware Water Gap National Recreation Area.

The deer browse index (Brose et al. 2008, Perles et al. 2014, Table 5) is a qualitative assessment of the impact of browse at each plot, based on the amount of observed browse damage and the presence of browse-preferred and non-preferred woody and herbaceous species. Depending on the assigned deer browse index, the regeneration stocking index must attain a benchmark level for the microplot to be considered “stocked” (i.e. contains sufficient tree regeneration to replace the forest canopy given the observed level of browse, Table 5). A plot is considered stocked if three of the four microplots are stocked (McWilliams et al. 2005).

Figure 10 shows the proportion of each park's plots that were assigned to different browse impact levels. The “Very Low” and “Very High” browse impact levels were not observed. In general, a higher proportion of plots in the Pennsylvania parks contain High browse levels when compared with the parks in West Virginia. BLUE and GARI plots contained the lowest browse levels, with more than 62% of the plots showing low browse impacts. FRHI and FONE contained the highest browse levels, with greater than 75% of the plots showing moderate to high browse impacts.

Table 5. Index of deer browse impacts and regeneration stocking index benchmarks for assessing tree regeneration in monitoring plots (adapted from McWilliams et al. 2005, Brose et al. 2008, and Perles et al. 2014).

Deer Browse Index	Browse Impact	Description	Regeneration Stocking Index Benchmark
1	Very Low	Plot located inside deer enclosure, and no browse observed.	15
2	Low	Browse is absent or scarce. Browse-preferred regeneration is abundant and of varying heights. Browse-preferred plants are present and able to flower and fruit. Stump sprouts, if present, have minimal evidence of browse.	30
3	Moderate	Browse evidence is observed but not common. Browse-preferred regeneration is present but with little variability in height. Stump sprouts, if present, are browsed. Nonpreferred browse and browse-resistant species are common and widespread.	50
4	High	Browse evidence is common, or browse-preferred regeneration is rare to absent. Nonpreferred and browse-resilient vegetation is limited in height growth by deer browsing.	100
5	Very High	Browse evidence is omnipresent, or browse-preferred regeneration is absent. The abundance of nonpreferred vegetation is reduced by browsing. Browse-resilient plants show signs of heavy repeated browsing and a browse line is evident.	200

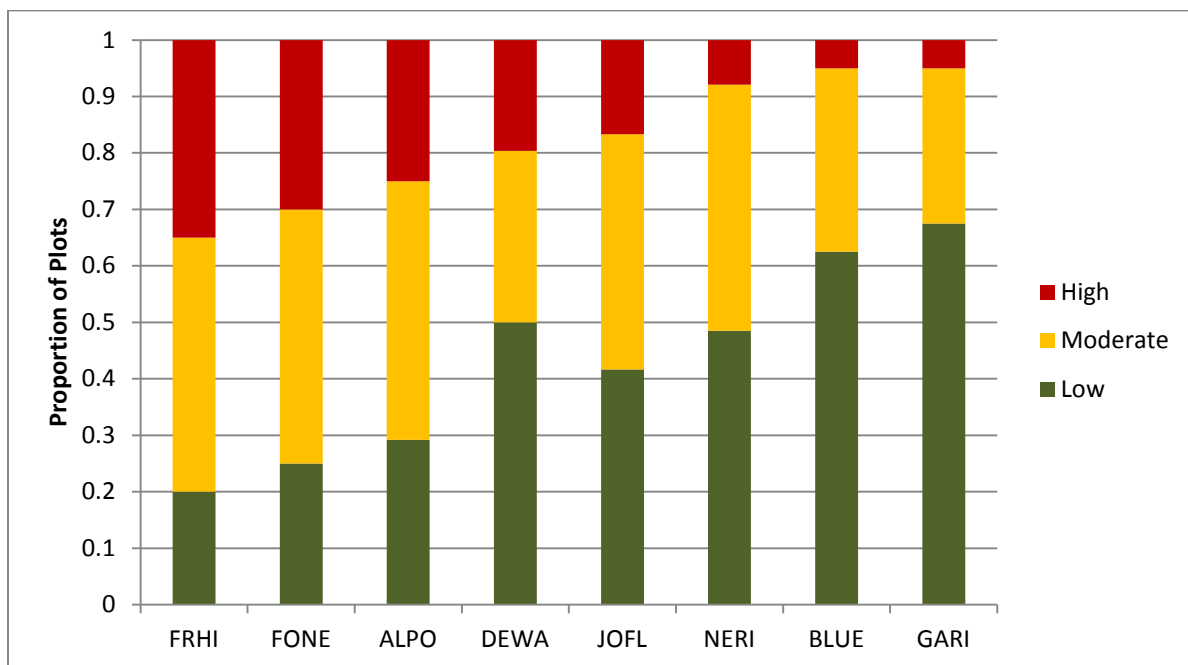


Figure 10. The proportion of the parks' plots that were assigned to different browse impact levels (Brose et al. 2008, Perles et al. 2014, Table 5).

Figure 11 shows the average regeneration stocking index for each park and the proportion of the parks' plots that are stocked based on the stocking and deer browse indices. In general, NERI, GARI, JOFL, FONE, and ALPO tend to have higher levels of tree regeneration, whereas BLUE, DEWA, and FRHI tend to contain less tree regeneration. Notably, approximately half of the plots in DEWA

and FRHI do not contain sufficient tree regeneration to replace the current canopy. This is likely caused by a combination of high browse pressure and the presence of young successional habitats which typically do not contain many tree seedlings.

There are numerous, often complex and interacting factors that influence tree regeneration. We used the monitoring data to investigate which site characteristics most influence the variation in tree regeneration observed among plots. Site characteristics included vegetation type, elevation, aspect, slope, canopy closure, tree basal area, tree density, observed deer browse index, number of indicator plants sensitive to deer browse (Appendix B), cover of ferns, cover of graminoids, and soil quality index. Regeneration was quantified by the natural log-transformed average regeneration stocking index for each plot since the distribution of stocking values was highly skewed towards zero. The number of indicator plants sensitive to deer browse, cover of ferns, and cover of graminoids was also natural-log transformed. We performed ANOVAs to compare regeneration within each categorical variable (e.g., vegetation type, aspect, canopy closure class, and observed deer browse index) in

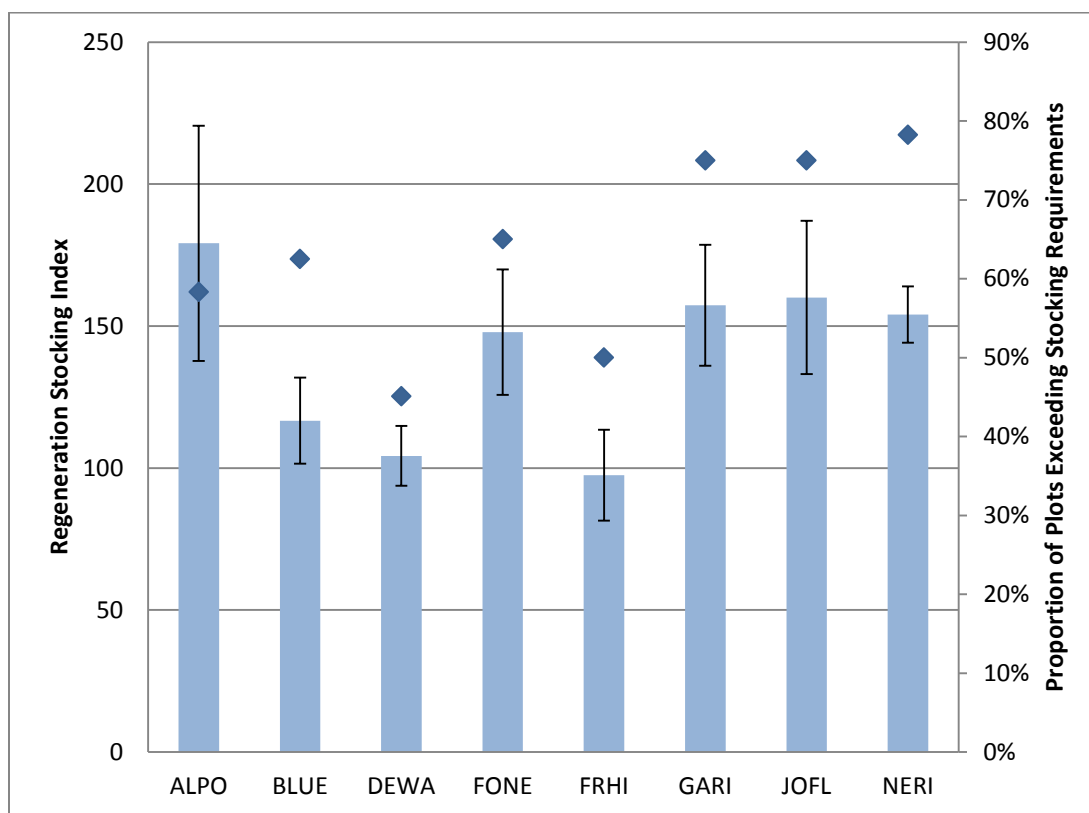


Figure 11. Blue bars represent average ($\pm$ standard error) regeneration stocking index for ERMN parks. Blue diamonds represent the proportion of the parks' plots which exceed the stocking requirements (see text for additional description of requirements).

R 2.15.2 (R Core Team 2012). We employed mixed effects models to determine which continuous variable most strongly influenced the amount of tree regeneration using the nlme package in R (Lindstrom and Bates 1990). We built numerous models using different combinations of site characteristics and then evaluated which model had the most statistical support. The most influential

factors are discussed below. Slope, tree basal area, tree density, and soil quality index did not strongly influence tree regeneration in our models.

Canopy Closure

As tree canopy cover increases, so does the regeneration stocking index. Plots with minimal tree canopy (<10%) have significantly lower regeneration ($p < 0.001$, $F = 5.36$) than plots with greater than 50% canopy closure. Open plots with little tree cover receive relatively few tree seeds compared with established forests. These non-forested sites tend to be dominated by dense herbaceous or shrubby species that prevent tree seedlings from establishing. In contrast, established forests generate abundant tree seeds and a diversity of microhabitats on the forest floor, providing suitable environments for seedling germination, especially for tree species whose seedlings are tolerant of shade.

Aspect

Though the aspect of sloped sites does not influence the amount of tree regeneration, flat sites without aspect contain significantly lower amounts of regeneration than sites with a detectable slope ($p = 0.002$, $F = 3.14$).

Elevation and Vegetation Type

The regeneration stocking index increases as the elevation of the site increases (Figure 12a). In general, ridgetop sites support more tree regeneration than sites in valleys. The amount of tree regeneration also differs by vegetation type (Figure 13), which is closely related to elevation in most ERMN parks. Xeric vegetation types contain significantly higher tree regeneration than all other vegetation types ($p < 0.001$, $F = 7.45$), including mesic, successional, and floodplain. These xeric types tend to occur at higher elevations and dominate the parks' ridgetops. Floodplain sites tend to contain less tree regeneration than other vegetation types; however, these differences among floodplain, mesic, and successional types were not significant. The large variation in regeneration stocking index observed among floodplain sites reflects the gradient of different floodplain vegetation that occurs in the parks, from floristically diverse, high-quality examples of globally unique communities to near monocultures of exotic invasive species on degraded sites.

Grass Cover

As the cover of grasses and other graminoid plants increases, the amount of tree regeneration decreases (Figure 12b). Previous studies have suggested that grasses and sedges compete with tree seedlings, such that high cover of grasses and sedges is detrimental to tree seedling establishment and growth (Marquis et al. 1992, Horsley et al. 2003).

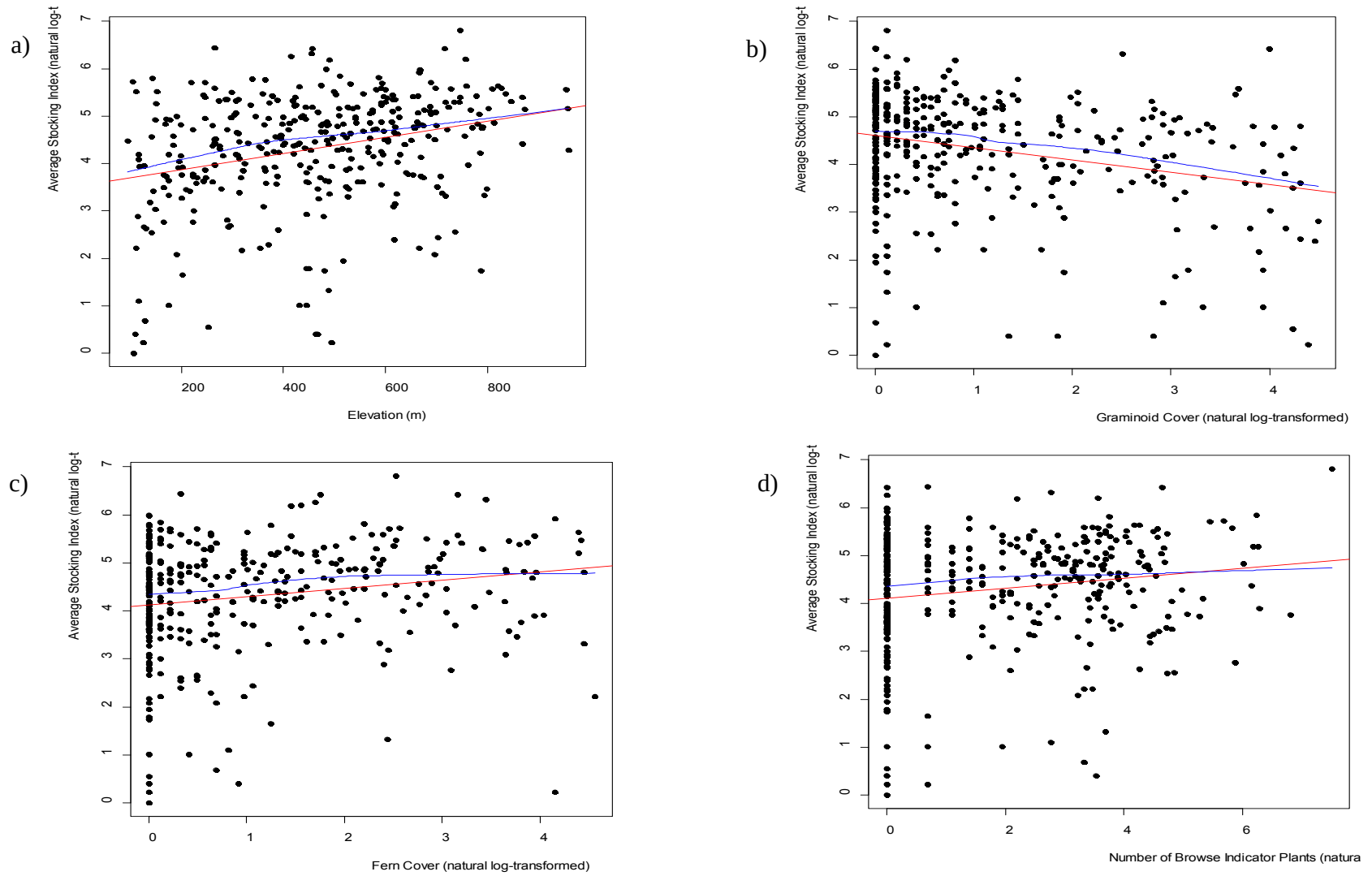


Figure 12. Scatterplots of the relationship between tree regeneration stocking index and a) elevation, b) cover of grasses, c) cover of ferns, and d) the number of plants sensitive to deer browse. Red lines show the linear regressions. LOWESS (locally weighted scatterplot smoothing) curves are shown in blue.

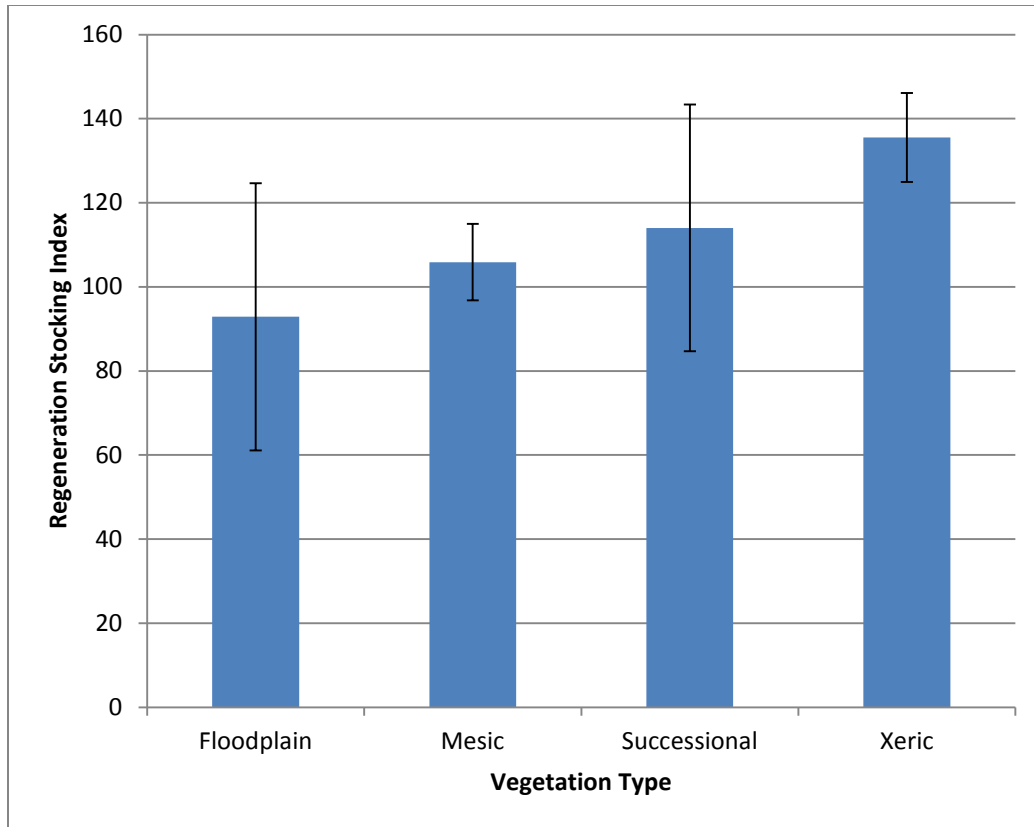


Figure 13. Tree regeneration stocking index (mean $\pm$ standard error) by vegetation type.

Fern Cover

Tree regeneration is also dependent on level of fern cover present (Figure 12c). Tree regeneration increases as cover of ferns increases—until fern cover reaches 15–20%. Above 20% fern cover, tree regeneration decreases as fern cover increases. Other studies have shown that high fern cover inhibits growth and establishment of tree seedlings (Maguire and Forman 1983, Horsley 1986, Marquis et al. 1992, de la Cretaz and Kelty 2002, Horsley et al. 2003). The increase in tree regeneration up to 20% fern cover probably relates to amount of tree canopy and age of forest. Open canopied sites and younger forests are less likely to have established ferns and typically have less tree regeneration.

Deer Browse

As the number of herbaceous plants sensitive to deer browse increases so does the amount of tree regeneration (Figure 12d). For a list of these herbaceous species, see Appendix B. Browse by deer is a serious stressor to tree regeneration in many places in the eastern United States (Russell et al. 2001, Augustine and deCalesta 2003, Cote et al. 2004, Latham et al. 2005). When browse on herbaceous indicator plants is lower, browse on tree regeneration is likely lower as well. In plots with low observed browse impacts, the average regeneration stocking index is higher than in plots with moderate or high observed browse impacts, though these differences were not statistically significant (Figure 14).

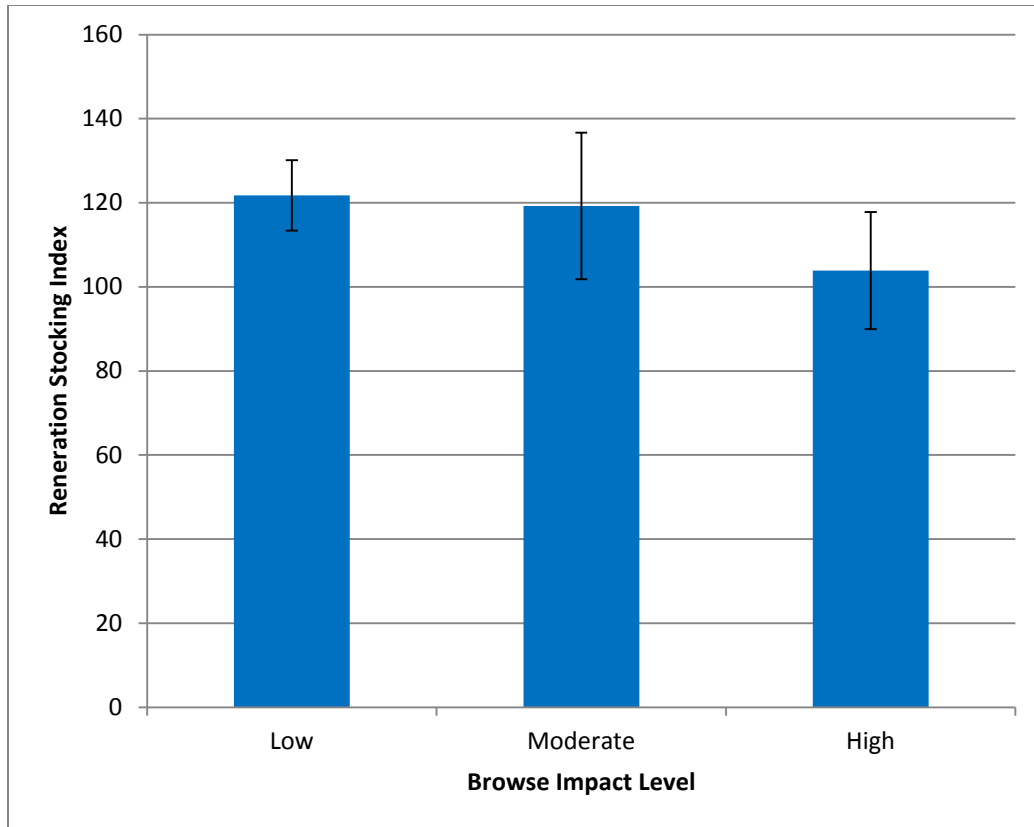


Figure 14. Tree regeneration stocking index (mean $\pm$ standard error) by browse impact level.

Forest Dynamics

Tree recruitment and mortality rates, as well as annual tree growth, are important indicators of tree health and vitality. Tree growth rates can decline in response to environmental factors or anthropogenic stress, and tree 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 health problem for that species (Hyink and Zedeker 1987, Duchesne et al. 2003); while altered vital rates for multiple species across a region may indicate a regional environmental stress, such as acid deposition (Steinman 2004, Dobbertin 2005).

Mortality, recruitment, and growth rates are calculated by comparing data collected on the same trees during two different sampling visits. The rates reported here were computed by comparing data from 2007 and 2008 with data from 2011 and 2012, respectively (panels 1 and 2). This data set represents only half of the established plots in the network; therefore, the results reported here may be revised after all four panels have been revisited.

Annual mortality rate (m ; % trees/year) is calculated from successive observations as the percent of trees that died between sample events, converted to an annual basis. Mortality is calculated as:

$$m = \frac{N_d \times 100}{N_o \times t}$$

where N_o is the number of trees in the previous census, and N_d is the number of trees that died after t years. In eastern old-growth forests, annual mortality typically ranges from 0.3–1.6% (Lorimer 1980, Runkle 1998, Runkle 2000, Busing 2005), such that mortality rates that exceed 1.6% may indicate forest health problems (Tierney et al. 2012).

Similarly, annual recruitment rate (r ; % trees/year) is calculated as the percent of trees that grew such that their diameters exceeded the minimum threshold for trees (10.0 cm). Recruitment is calculated as:

$$r = \frac{N_r \times 100}{N_o \times t}$$

where N_o is the number of trees in the previous census, and N_r is the number of recruited trees after t years. Recruitment and mortality rates were calculated by park and by tree species for species that occurred in two or more plots.

Tree growth is another important component of forest health that is measured in two ways: the mean annual diameter increment and relative basal area growth. The mean annual diameter increment (MADI) is the sum of the annual diameter increment (in cm) for all stems of a species or in a plot:

$$MADI = \frac{\sum(DBH_2 - DBH_1)/t}{n}$$

where DBH_1 is the diameter of the trees in the first census, DBH_2 is the diameter in the next census, with a census interval of t years, and n equals the total number of trees. Average MADI for trees in old-growth Appalachian forests can range from 0.25–0.45 cm (Runkle 1998, 2000).

Relative basal area growth (RBA; % basal area/year) is calculated as:

$$RBA = \frac{(DBH_2 - DBH_1) \times 100}{DBH_1 \times t}$$

Relative basal area growth rate is then averaged by park and by species. Species growth rates were calculated only for species with greater than ten individuals. Also, 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 human error, and were omitted from the analysis. Less than 1% of the approximately 7,000 trees used in this analysis were removed due to abnormal DBH change. Average relative basal area growth rate for trees in old-growth Appalachian forests can range from 3–5% (Runkle 2000).

Average recruitment and mortality rates by park are shown in Figure 15. Among the parks, DEWA has the highest average tree recruitment due to several plots in early successional habitats where many saplings are reaching the minimum threshold to be tallied as mature trees. These plots fall in the pole structural stage, due to the scattered young trees that occur in early successional habitats such as old fields, wet meadows, and on river islands. Although approximately 30% of plots in DEWA show elevated mortality, many other of the park's plots have low (or 0%) mortality, thus, the park-wide average is similar to other parks in the network. Tree mortality in DEWA should be examined closely after all plots have been resampled (2014) to determine if these elevated levels of mortality are of management concern, or are due to normal competition among trees in a mature forest canopy. Thus far, plots with elevated mortality are scattered throughout the park in many different habitats types. GARI has the second highest recruitment rate and the lowest mortality rate of the ERMN parks, as well as the lowest proportion of plots (<5%) with elevated mortality. This is consistent with the park's low density of snags and large volume of coarse woody debris. In general, trees are filling in gaps left by large fallen down trees, and the current low mortality rate leads to low density of snags. BLUE reports the highest mortality rate as well as the highest proportion of plots experiencing elevated levels of mortality. The mortality is primarily white pine (*Pinus strobus*, 2%/year) and eastern hemlock (*Tsuga canadensis*, 1.5%/year), as well as oaks (*Quercus* spp., 0.6–1%/year), and sugar maple (*Acer saccharum*, 0.9%/year). Mortality in BLUE should be examined closely after all plots have been resampled to determine if these elevated levels of mortality are parkwide and possibly of concern.

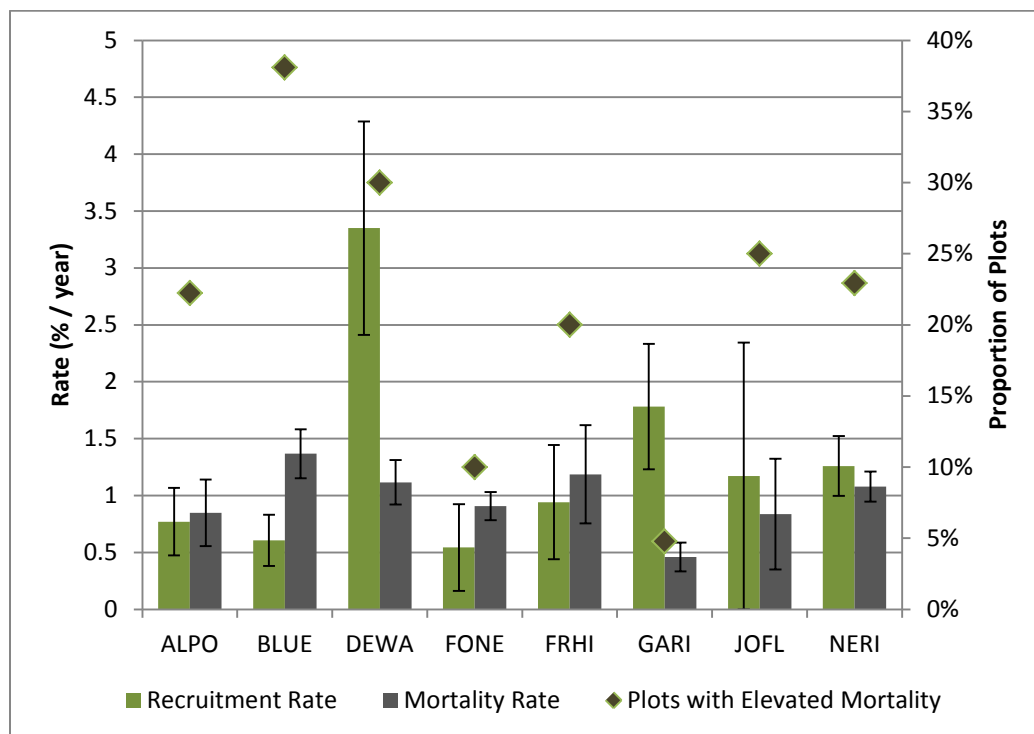


Figure 15. Tree recruitment and mortality rates (mean $\pm$ standard error) by park shown by green and brown bars, respectively. Brown diamonds indicate the proportion of plots with elevated mortality (>1.6%) within each park.

Mean annual diameter increment and relative basal area growth show similar trends for tree growth across network parks (Figure 16). FRHI and DEWA have the highest average rates of tree growth due to plots in the pole structural stage where young trees grow rapidly in these open early successional habitats. BLUE and FONE have the lowest average growth rates.

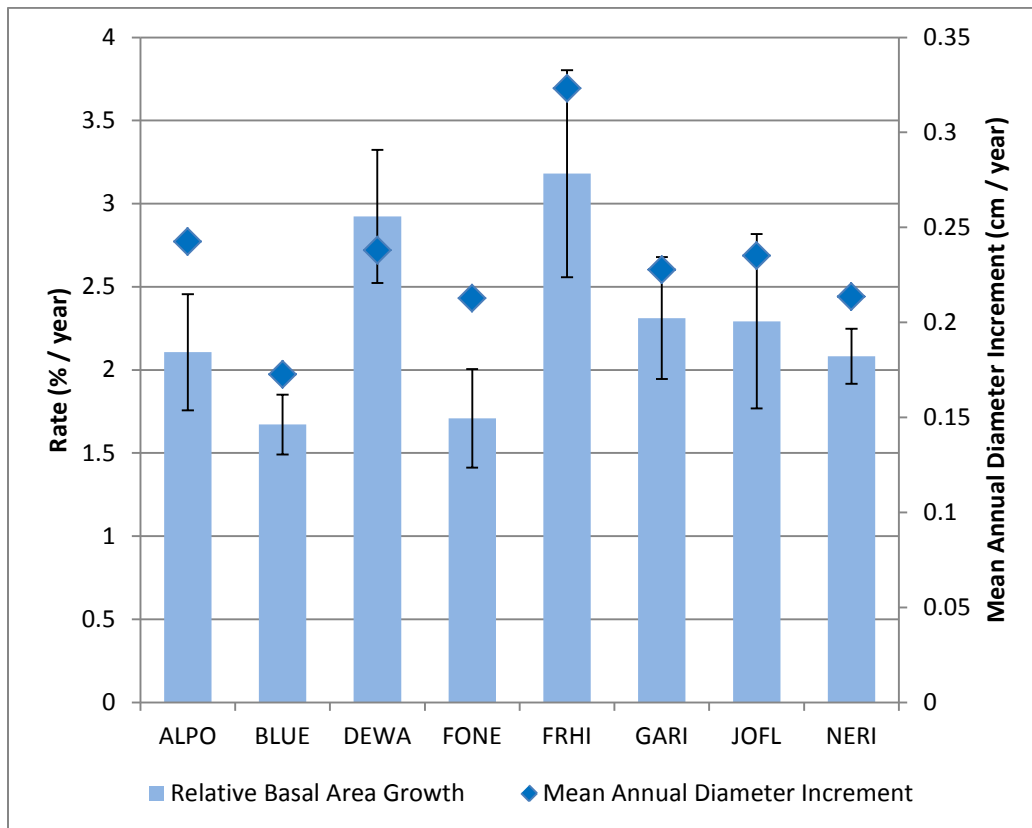


Figure 16. Blue bars represent average ($\pm$ standard error) relative basal area growth rate for ERMN parks. Blue diamonds represent the mean annual diameter increment by park.

Across the network as a whole, white pine (*Pinus strobus*), hornbeam (*Carpinus carolinana*), and box elder (*Acer negundo*) had among the highest recruitment and mortality rates, however, the standard errors were also quite large (Figure 17). Similarly, Virginia pine (*Pinus virginiana*) exhibited a high recruitment rate, but also a large standard error. These rates may become more precise as additional data are collected. Red maple (*Acer rubrum*), black birch (*Betula lenta*), and eastern hemlock (*Tsuga canadensis*) also exhibited higher recruitment rates. These species are typical understory and midstory species in many forest types in the parks and we would expect young individuals to be maturing to canopy trees. Species with high mortality rates network-wide include basswood (*Tilia americana*), chestnut oak (*Quercus prinus*), and river birch (*Betula nigra*).

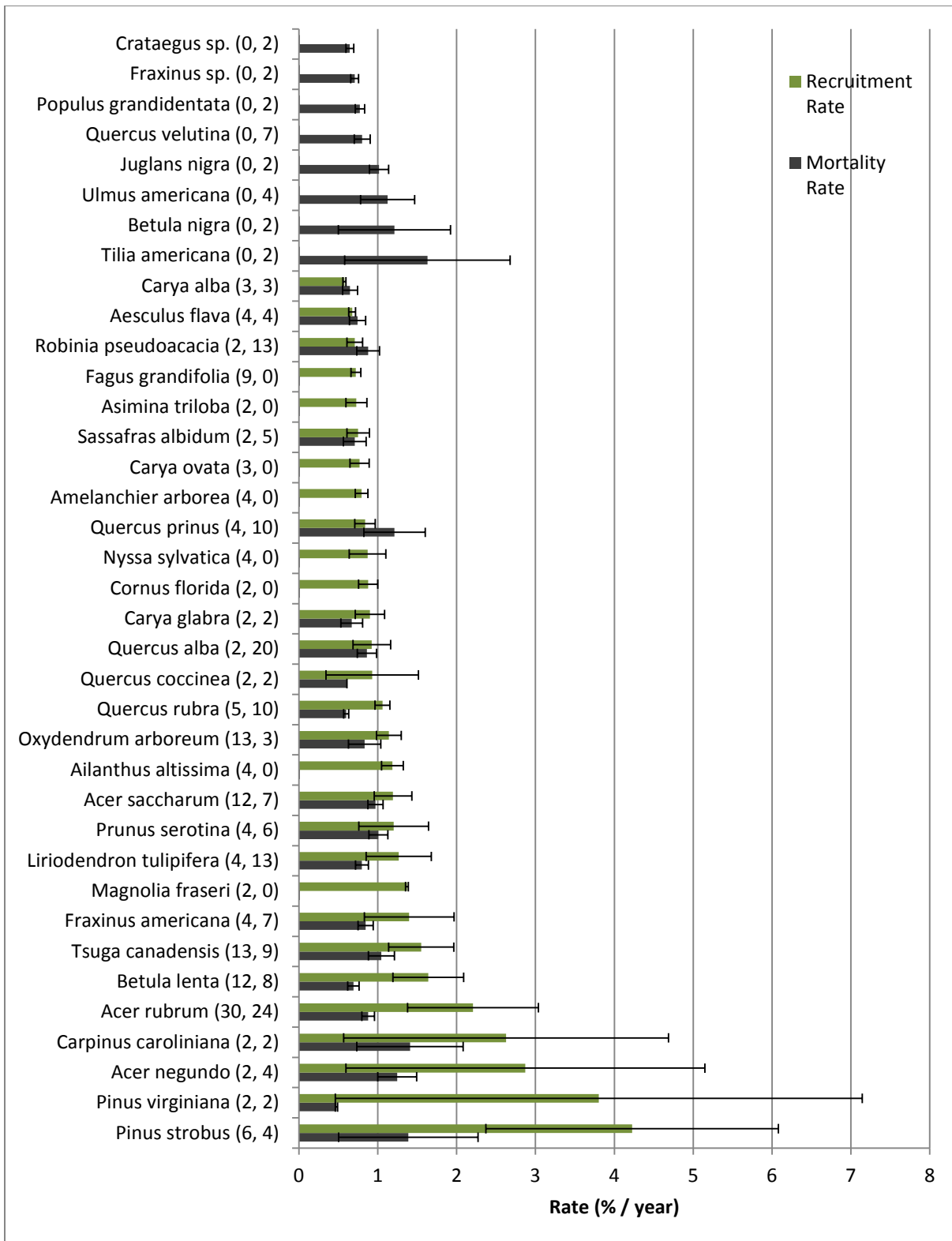


Figure 17. Recruitment and mortality rates (mean $\pm$ standard error) across the network by tree species shown by green and brown bars, respectively. No bar means the rate was zero. The number in parenthesis after the tree species name is the sample size (number of plots used to calculate recruitment rate, number of plots used to calculate mortality rate).

Average growth rates for common tree species are shown in Figure 18. Unfortunately, the species with the highest growth rate, nearly double that of most species, in the parks is the invasive, exotic species, tree of heaven (*Ailanthus altissima*). This fast-growing tree invades canopy openings and forest edges, reproducing through prolific seeds and vigorous root suckers. Because of this dramatically accelerated growth, tree of heaven is a serious threat to park forests when it colonizes canopy gaps after storm events, insect-caused canopy mortality, or other disturbances.

Some native species with faster growth rates include scarlet oak (*Quercus coccinea*), northern red oak (*Quercus rubra*), and bitternut hickory (*Carya cordiformis*). Species with the slowest growth rates include flowering dogwood (*Cornus florida*), river birch (*Betula nigra*), red bud (*Cercis canadensis*), eastern red cedar (*Juniperus virginiana*), and slippery elm (*Ulmus rubra*). Most of these slow-growing species are typically found as small trees, overtopped by the forest canopy and subcanopy. Their slow growth rate is likely a result of limited light availability and competition with canopy trees. However, the standard errors for these species are also large, such that additional data may yield a more precise growth rate.

Tree Condition and Forest Pests

The health of individual trees and tree species within the forest is an important component of overall forest health. We assess tree health by assigning vigor and dieback ratings to each tree within a plot and by recording the presence of important forest pests and pathogens.

In 2009, the ERMN began assessing vigor and dieback of individual trees based on established protocols (Millers et al. 1991) from the North American Sugar Maple Decline Project. The vigor assessment compares each tree in the plot to a species-specific “healthy” specimen growing in similar stand conditions, focusing on crown damage, snag branches, foliar damage, vines, and tree structure. Vigor rankings range from 1 (healthy) to 5 (functionally dead). Trees with vigorous, healthy crowns tend to have higher growth rates, while trees with damaged or degraded crowns have a reduced capacity for photosynthesis and slower growth rates (Morin et al. 2012). Dieback focuses on fine twig mortality, typically the result of short-term stresses such as seed production, weather extremes, or insect defoliation. Dieback is assessed in 10% cover categories and has been shown to be one of the most important metrics for predicting tree mortality in the USFS FIA program (Morin et al. 2012). After collecting pilot data in 2009, the vigor and dieback protocols were clarified to fit ERMN forest systems, thus, only 2010–2012 data are presented here.

Each tree is also inspected for signs of 11 important insects, pathogens, and diseases that affect trees in the region (some species shown in Figure 19; for complete list and details see Perles et al. 2014). These pests and pathogens have the capability of, and in many cases already are, causing wide-spread damage or mortality to trees in our region (Coulston et al. 2005, Keefer et al. 2010).

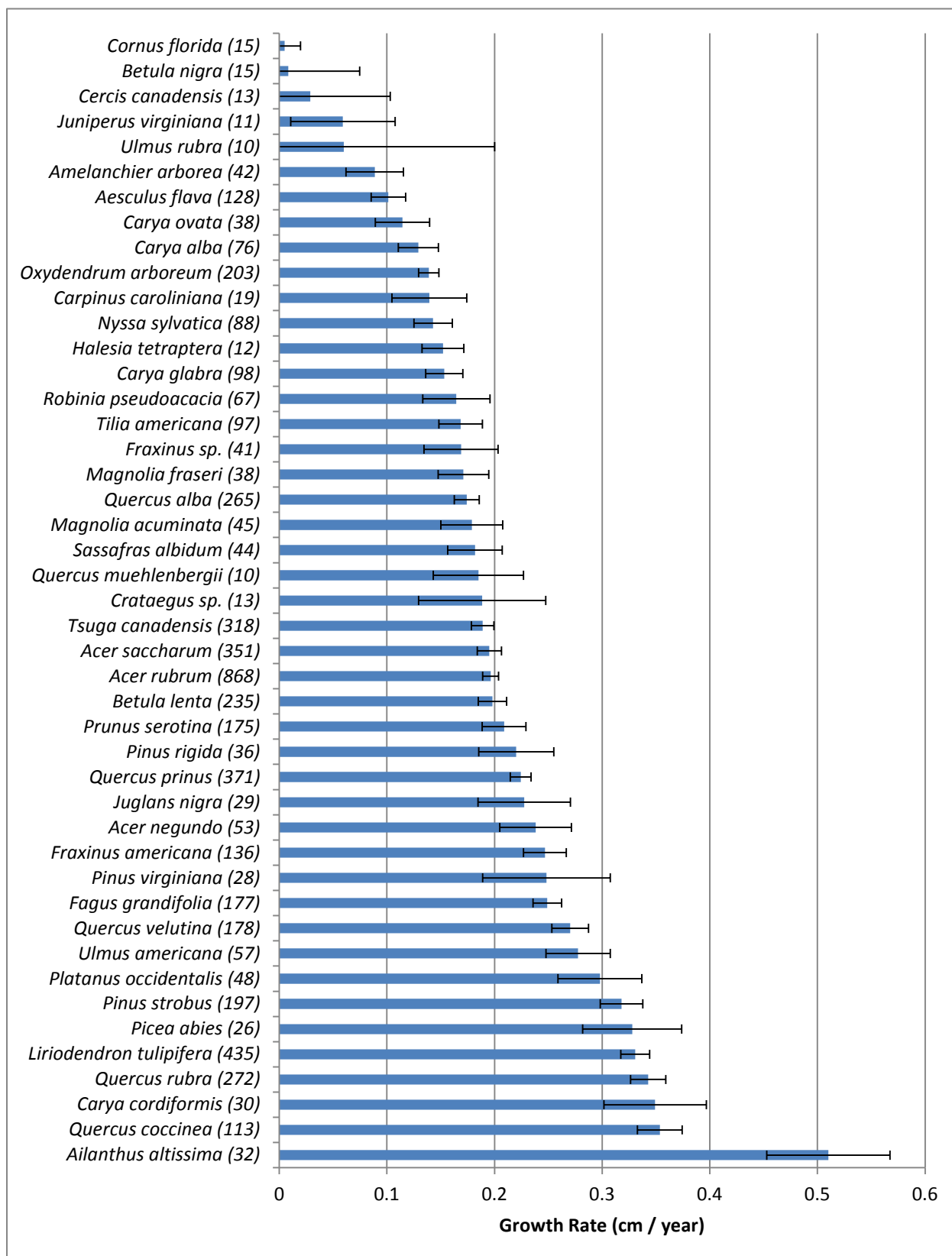


Figure 18. Growth rates (mean $\pm$ standard error) for common tree species in ERMN parks. Number in parenthesis after tree name is sample size.

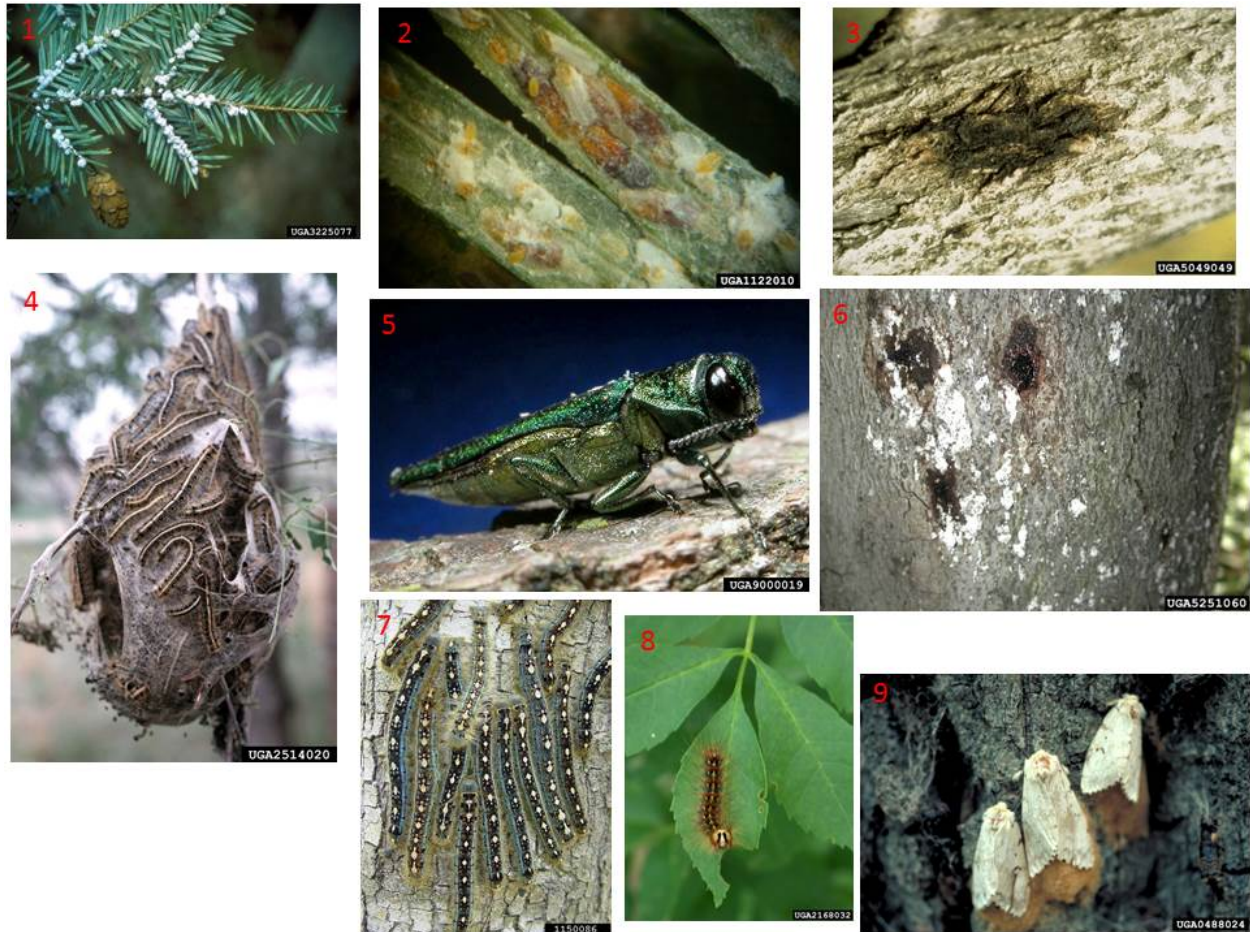


Figure 19. Some important insects, pathogens, and diseases targeted by the ERMN vegetation monitoring protocol. Photos include: 1. Hemlock woolly adelgid (*Adelges tsugae*). Citation: Connecticut Agricultural Experiment Station Archive, Connecticut Agricultural Experiment Station, Bugwood.org; 2. Elongate hemlock scale (*Fiorinia externa*). Citation: Eric R. Day, Virginia Polytechnic Institute and State University, Bugwood.org; 3. Butternut canker (*Sirococcus clavignenti-juglandacearum*). Citation: Joseph O'Brien, USDA Forest Service, Bugwood.org; 4. Eastern tent caterpillar (*Malacosoma americanum*). Citation: Jerry A. Payne, USDA Agricultural Research Service, Bugwood.org; 5. Emerald ash borer (*Agrilus planipennis*). Citation: David Cappaert, Michigan State University, Bugwood.org; 6. Beech bark disease (*Nectria coccinea*). Citation: Joseph O'Brien, USDA Forest Service, Bugwood.org; 7. Forest tent caterpillar (*Malacosoma disstria*). Citation: Herbert A. 'Joe' Pase III, None, Bugwood.org; 8. Gypsy moth caterpillar (*Lymantria dispar*). Citation: Haruta Ovidiu, University of Oradea, Bugwood.org; 9. Gypsy moths (*Lymantria dispar*). Citation: John H. Ghent, USDA Forest Service, Bugwood.org

Across all parks and years, tree species with “healthier” vigor and dieback rankings include birches (*Betula* spp.), magnolias (*Magnolia* spp.), American beech (*Fagus grandifolia*), hickories (*Carya* spp.), and American basswood (*Tilia americana*). Differences in vigor and dieback ratings have been observed among ERMN parks and among sampling years (Figure 20). In general, trees in ALPO, FONE and GARI experienced less dieback than in the other parks, while trees in ALPO, FONE, JOFL, and NERI had healthier vigor rankings on average than in the other ERMN parks. Network-wide, dieback increased from 2010 to 2012, while vigor was “healthiest” in 2012 and worst in 2011. With additional years of data, these metrics will provide important park- and species-specific information on tree health.

Dieback rankings include early successional species such as eastern red cedar (*Juniperus virginiana*), black locust (*Robinia pseudoacacia*), sassafras (*Sassafras albidum*), aspens (*Populus* spp.), pin cherry (*Prunus pensylvanica*), apple (*Malus* spp.), and Virginia pine (*Pinus virginiana*) (Table 6). As the parks’ predominantly middle-aged forests mature, we expect these early successional species to be out-competed by current canopy species. Similarly, elms (*Ulmus* spp.), flowering dogwood (*Cornus florida*), and eastern red bud (*Cercis canadensis*) usually occur as small trees overtopped by the canopy. These species also receive poor vigor and dieback ratings due to competition with taller trees; however, elms and flowering dogwood are further impacted by Dutch elm disease and dogwood anthracnose, respectively. Eastern hemlock (*Tsuga canadensis*) received poor vigor and dieback ranking primarily due to the effects of the hemlock woolly adelgid (*Adelges tsugae*) and elongate hemlock scale (*Fiorinia externa*) which have infested hemlocks throughout our region.

Of the forest pests and pathogens targeted by the monitoring protocol, hemlock woolly adelgid has been observed in the most plots (n=28) over the four-year sampling period. European gypsy moth (*Lymantria dispar*) and elongate hemlock scale were also regularly observed at 19 and 18 plots, respectively. Other pests and pathogens observed during this period include beech bark disease (three plots), eastern forest tent caterpillar (*Malacosoma americanum*, three plots), forest tent caterpillar (*Malacosoma disstria*, three plots), and butternut canker (one plot).

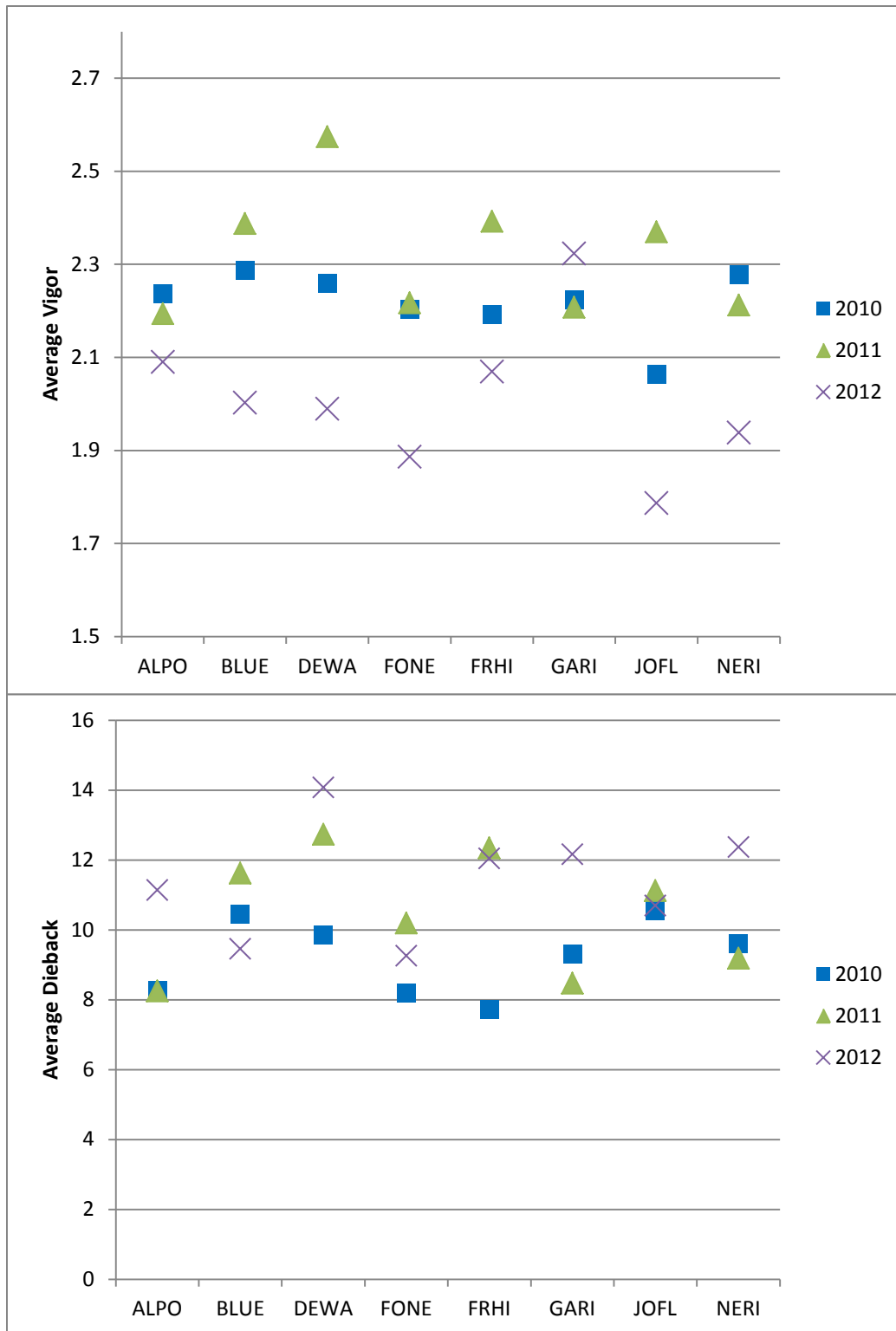


Figure 20. Tree vigor and dieback ratings averaged by park and by year.

Table 6. Average vigor and dieback for selected tree species (those with the largest and smallest values). Lower values for vigor and dieback indicate healthier trees. Only 39 species of the total 60 species assessed for vigor and dieback are reported here.

Species	Vigor			Species	Dieback		
	Average	Standard Error	Number of Trees		Average	Standard Error	Number of Trees
<i>Betula lenta</i>	1.78	0.02	465	<i>Betula alleghaniensis</i>	5.25	0.25	20
<i>Quercus palustris</i>	1.79	0.11	14	<i>Tilia americana</i>	5.50	0.35	159
<i>Ostrya virginiana</i>	1.81	0.23	16	<i>Betula lenta</i>	5.88	0.16	465
<i>Fagus grandifolia</i>	1.82	0.03	257	<i>Fagus grandifolia</i>	5.91	0.16	257
<i>Carya ovata</i>	1.84	0.06	79	<i>Magnolia acuminata</i>	5.91	0.28	82
<i>Tilia americana</i>	1.87	0.05	159	<i>Aesculus flava</i>	6.01	0.24	174
<i>Betula alleghaniensis</i>	1.90	0.07	20	<i>Acer saccharum</i>	6.46	0.21	625
<i>Celtis occidentalis</i>	1.90	0.18	10	<i>Carya ovata</i>	6.58	0.31	79
<i>Carya cordiformis</i>	1.90	0.08	51	<i>Magnolia fraseri</i>	6.69	1.47	59
<i>Magnolia fraseri</i>	1.93	0.10	59	<i>Liriodendron tulipifera</i>	7.18	0.24	730
<i>Carya sp.</i>	1.93	0.15	15	<i>Carya cordiformis</i>	7.25	0.49	51
<i>Acer saccharum</i>	1.95	0.02	625	<i>Carya sp.</i>	7.33	0.67	15
<i>Magnolia acuminata</i>	1.95	0.07	82	<i>Amelanchier sp.</i>	7.50	1.12	6
<i>Carya alba</i>	1.96	0.05	125	<i>Platanus occidentalis</i>	7.94	0.79	68
<i>Ulmus rubra</i>	2.56	0.18	18	<i>Carya alba</i>	7.96	0.37	125
<i>Cornus florida</i>	2.57	0.11	35	<i>Acer pensylvanicum</i>	16.67	6.01	6
<i>Juniperus virginiana</i>	2.58	0.14	36	<i>Quercus coccinea</i>	16.68	0.70	164
<i>Malus sp.</i>	2.59	0.15	17	<i>Pinus rigida</i>	16.76	1.43	37
<i>Prunus pensylvanica</i>	2.60	0.24	5	<i>Juniperus virginiana</i>	17.50	2.80	36
<i>Populus tremuloides</i>	2.61	0.12	23	<i>Prunus pensylvanica</i>	18.00	4.90	5
<i>Pinus virginiana</i>	2.71	0.13	31	<i>Cornus florida</i>	18.14	1.74	35
<i>Sassafras albidum</i>	2.71	0.10	66	<i>Halesia tetraptera</i>	19.17	4.84	12
<i>Acer negundo</i>	2.73	0.07	90	<i>Crataegus sp.</i>	20.18	3.30	28
<i>Robinia pseudoacacia</i>	2.81	0.09	120	<i>Pinus virginiana</i>	20.48	2.28	31
<i>Populus grandidentata</i>	3.00	0.00	6	<i>Sassafras albidum</i>	20.91	1.53	66
<i>Tsuga canadensis</i>	3.10	0.04	502	<i>Malus sp.</i>	21.47	3.20	17
<i>Cercis canadensis</i>	3.33	0.16	15	<i>Acer negundo</i>	21.94	1.57	90
				<i>Tsuga canadensis</i>	25.68	0.76	502

The proportion of plots in which priority pests or pathogens were observed between 2009 and 2012 is shown in Figure 21. There were no detections in FRHI plots during this time period. Likewise, no detections occurred in FONE, GARI, or JOFL until 2012. Pests and pathogens were observed in approximately 10% of the plots in BLUE every year. In DEWA, 30–66% of the plots contained priority pests and pathogens, while in NERI, less than 20% of the plots contained pests or pathogens each year. ALPO's plots showed the greatest variation with no detections in 2009 and nearly all (83%) of the plots containing a pest or pathogen in 2012.

The vegetation monitoring crew continues to be vigilant for signs of emerald ash borer (*Agilus planipennis*), which is known to occur in the counties containing NERI, GARI, BLUE, ALPO, and JOFL, and likely occurs in those parks. Given the recent spread of emerald ash borer, it will likely be in all ERMN parks in a few years. For more information on emerald ash borer and potential management strategies, check the Collaborative Emerald Ash Borer Program website (<http://www.emeraldashborer.info>).

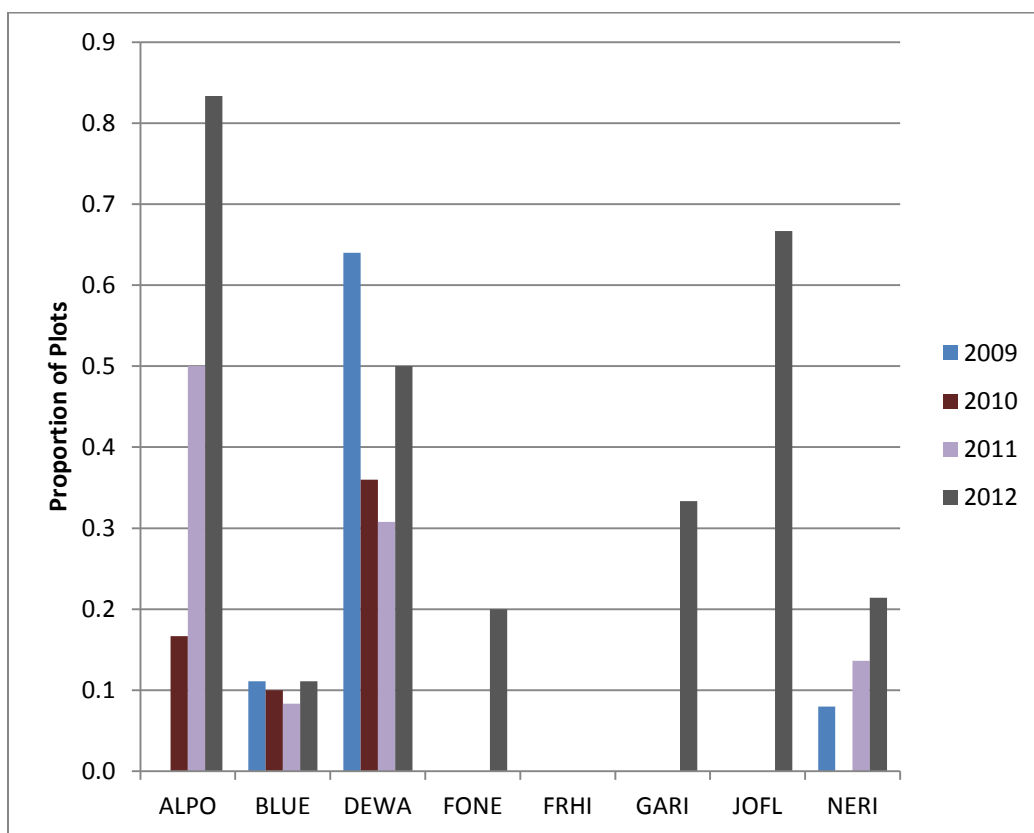


Figure 21. Proportion of plots containing at least one priority forest pest or pathogen between 2009 and 2012.

Invasive Exotic Plant Species

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). These nonnative species compete with native plant species and can dramatically change the vegetation structure of a site, often affecting wildlife habitat. Invasive plants can also disrupt ecosystem-level processes by altering resource utilization, trophic structures, and disturbance regimes. These disruptions may result in altered fire regimes, nutrient cycling, or soil development (Vitousek 1990; Mack et al. 2000; Pimentel et al. 2000).

For each park, a target list of exotic plants considered to be invasive in that park is maintained (Appendix C). From 2009–2012, forty-two of these invasive species were observed in the monitoring plots (Table 7). The most commonly observed species include: multiflora rose (*Rosa multiflora*), Japanese barberry (*Berberis thunbergii*), Morrow's honeysuckle (*Lonicera morrowii*), Japanese stiltgrass (*Microstegium vimineum*), and Oriental ladythumb (*Polygonum caespitosum*). We measured invasive exotic plant species abundance through three metrics: average number of invasive plant species per plot, proportion of total quadrat cover in invasive species, and proportion of total species richness held by invasive species in the quadrats. Considering all three of these metrics, FRHI contains the most invasive plant species (5.5 species/plot, Figure 22), with 20% of the plant cover occupied by invasive species on average. In contrast, NERI and GARI contain the least invasive plant species (approximately 1 species/plot, Figure 21), and only 1–1.5% of the cover and species present in the groundstory are invasive.

In addition to ecosystem impacts, recent studies suggest that exotic shrub thickets, especially of Japanese barberry (*Berberis thunbergii*), 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 in exotic shrub thickets due to altered movement and habitat use by mammals that disperse ticks. Fortunately, blacklegged tick populations and infection rates were both dramatically decreased when the exotic shrub thickets were removed (Williams et al. 2009, Allan et al. 2010).

Table 7. Percentage of plots in ERMN parks containing invasive exotic plant species, observed 2009-2012. Double slashes indicate that the species was not observed in that park.

Common Name	Scientific Name	ALPO	BLUE	DEWA	FONE	FRHI	GARI	JOFL	NERI
multiflora rose	<i>Rosa multiflora</i>	25%	60%	45%	85%	90%	28%	50%	31%
Japanese barberry	<i>Berberis thunbergii</i>	21%	--	56%	75%	25%	--	33%	--
Morrow's honeysuckle	<i>Lonicera morrowii</i>	13%	20%	33%	60%	20%	5%	50%	--
Japanese stiltgrass	<i>Microstegium vimineum</i>	17%	--	44%	5%	85%	13%	--	3%
Oriental ladythumb	<i>Polygonum caespitosum</i>	13%	8%	25%	25%	75%	8%	--	6%
Japanese honeysuckle	<i>Lonicera japonica</i>	--	13%	5%	--	90%	--	--	9%
garlic mustard	<i>Alliaria petiolata</i>	17%	20%	41%	--	20%	--	8%	1%
autumn olive	<i>Elaeagnus umbellata</i>	--	18%	25%	--	30%	18%	--	8%
tree of heaven	<i>Ailanthus altissima</i>	--	--	3%	--	55%	25%	--	10%
ground ivy	<i>Glechoma hederacea</i>	8%	20%	4%	10%	40%	--	--	7%
sweet vernalgrass	<i>Anthoxanthum odoratum</i>	13%	--	--	20%	10%	--	33%	--
wineberry	<i>Rubus phoenicolasius</i>	--	43%	6%	--	--	8%	--	8%
Oriental bittersweet	<i>Celastrus orbiculatus</i>	13%	--	35%	--	--	--	--	--
honeysuckle	<i>Lonicera sp.</i>	--	10%	5%	10%	10%	3%	--	--
giant knotweed	<i>Polygonum sachalinense</i>	13%	--	--	--	--	--	17%	--
burning bush	<i>Euonymus alatus</i>	--	--	9%	10%	--	--	--	--
creeping jenny	<i>Lysimachia nummularia</i>	--	18%	1%	--	--	--	--	--
dames rocket	<i>Hesperis matronalis</i>	13%	--	6%	--	--	--	--	--
narrowleaf bittercress	<i>Cardamine impatiens</i>	--	5%	4%	--	--	--	--	9%
privet	<i>Ligustrum sp.</i>	8%	3%	6%	--	--	--	--	1%
Amur honeysuckle	<i>Lonicera maackii</i>	8%	--	9%	--	--	--	--	--
Canada thistle	<i>Cirsium arvense</i>	4%	--	1%	5%	5%	--	--	--
Norway maple	<i>Acer platanoides</i>	4%	--	1%	--	--	--	8%	--
crown vetch	<i>Securigera varia</i>	--	3%	--	5%	--	--	--	--
Japanese hop	<i>Humulus japonicus</i>	--	8%	--	--	--	--	--	--
Japanese knotweed	<i>Polygonum cuspidatum</i>	--	--	4%	--	--	--	--	2%
European privet	<i>Ligustrum vulgare</i>	--	3%	1%	--	--	--	--	2%
Canada thistle	<i>Cirsium arvense</i>	--	--	--	5%	--	--	--	--
bull thistle	<i>Cirsium vulgare</i>	--	--	--	5%	--	--	--	--
princess tree	<i>Paulownia tomentosa</i>	--	--	--	--	--	3%	--	2%
Fuller's teasel	<i>Dipsacus fullonum</i>	4%	--	--	--	--	--	--	--
coltsfoot	<i>Tussilago farfara</i>	4%	--	--	--	--	--	--	--
purple loosestrife	<i>Lythrum salicaria</i>	--	--	3%	--	--	--	--	--
border privet	<i>Ligustrum obtusifolium</i>	--	--	2%	--	--	--	--	--
common buckthorn	<i>Rhamnus cathartica</i>	--	--	2%	--	--	--	--	--
Chinese yam	<i>Dioscorea oppositifolia</i>	--	--	--	--	--	--	--	1%
wild chervil	<i>Anthriscus sylvestris</i>	--	--	1%	--	--	--	--	--
star-mustard	<i>Coincya monensis</i>	--	--	1%	--	--	--	--	--
Russian olive	<i>Elaeagnus angustifolia</i>	--	--	1%	--	--	--	--	--
sericea lespedeza	<i>Lespedeza cuneata</i>	--	--	1%	--	--	--	--	--
Asiatic tearthumb	<i>Polygonum perfoliatum</i>	--	--	1%	--	--	--	--	--
spotted ladythumb	<i>Polygonum persicaria</i>	--	--	1%	--	--	--	--	--

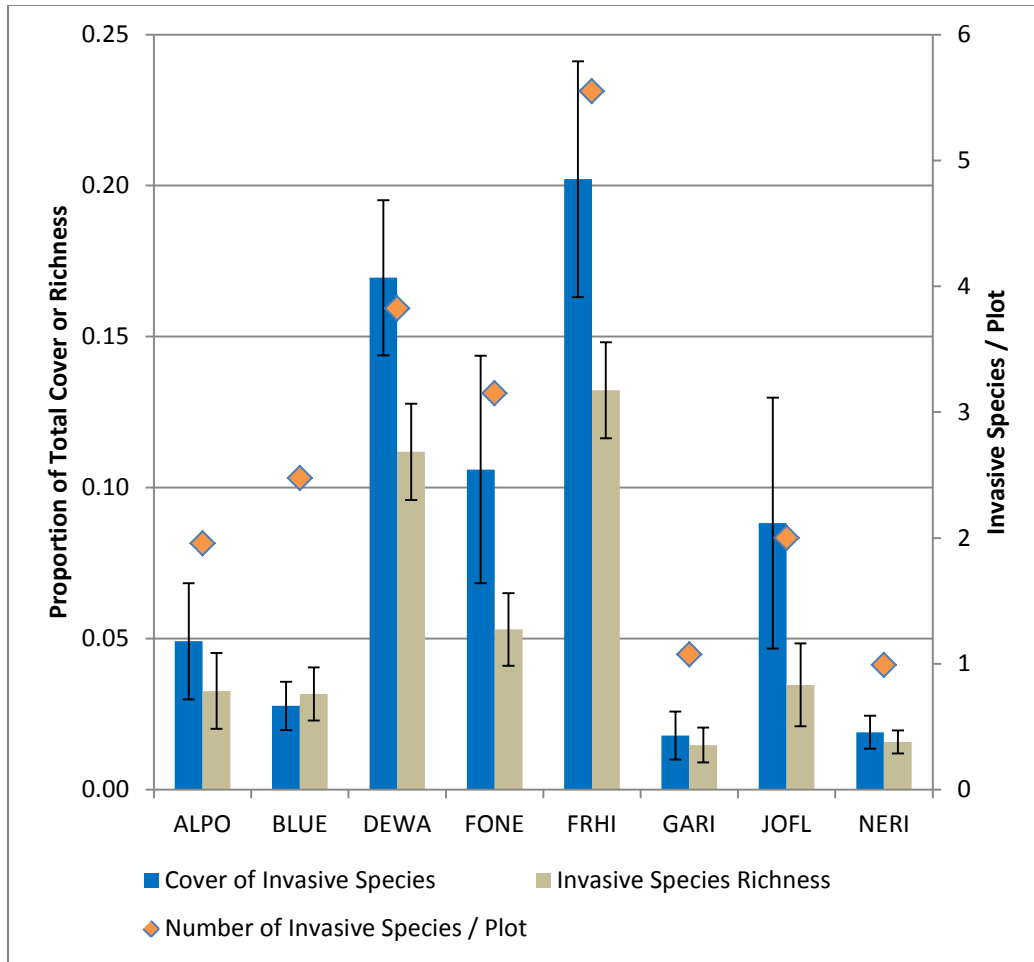


Figure 22. Average ($\pm$ standard error) proportion of the total cover (blue bars) and species richness (brown bars) held by invasive exotic plant species as measured in monitoring quadrats in ERMN parks. The orange diamonds show the average number of invasive species / plot for each park, using all species data collected on each plot.

Floristic Quality

The groundstory of forest stands often is the most diverse strata. Thus, diversity and nativity of the groundstory are important components of overall forest health. Although some nonnative species act invasively (as discussed above), most nonnative plant species co-exist alongside native species and do not spread aggressively. Approximately 41% of the plant species known to occur in Pennsylvania and West Virginia are nonnative species; however, only a small proportion of these roughly 1,400 species act invasively. However, the spread of all nonnative species, even those that co-exist with native species, leads to biotic homogenization, when a variety of different vegetation types become more similar to each other, shifting from specialized, unique vegetation communities towards a more generic, homogeneous species composition (Olden and Rooney 2006).

In this section, we consider all nonnative species, including those that are invasive and those that are not. Nonnative plant species make up a portion of the groundstory diversity (ranging from 0–84% of total species richness) and cover (ranging from 0–98% of total cover) as measured in the monitoring plot quadrats. On average, FRHI and DEWA contain larger proportions of nonnative species richness and cover than other ERMN parks (Figure 22). The parks in West Virginia, particularly NERI and GARI, contain the least nonnative species (2% of total diversity and cover on average). Figure 23 shows the average proportion of total richness and cover occupied by native and nonnative plant species in the groundstory of ERMN parks. Proportions do not add to one because some plants cannot be identified to species and therefore nativity cannot be assigned to those taxa.

One common metric used to measure the condition of vegetation communities is the floristic quality assessment index (FQAI), originally developed by Swink and Wilhelm (1979, 1994) and applied throughout eastern North America (Ladd 1993, Oldham et al. 1995, Herman et al. 1997, Taft et al. 1997, Bernthal 2003, Andreas et al. 2004). The FQAI incorporates the ecological conservatism of the present plant species and the species richness of the plant community to derive an estimate of habitat quality. Ecological conservatism is quantified as a coefficient of conservatism (C) value, ranging from 0 to 10, which is assigned a priori based on an individual plant species' fidelity to specific habitat types and its tolerance to both natural and anthropogenic disturbance (Chamberlain and Ingram 2012). Highly conservative plants (C values between 7–10) are only found in minimally degraded natural areas, while species that persist in or readily invade degraded areas are assigned lower numbers. Nonnative species are assigned a C value of zero. We calculate FQAI' following Miller and Wardop (2006) as:

$$FQAI' = \left(\frac{\bar{C}}{10} \frac{\sqrt{N}}{\sqrt{N+A}} \right) \times 100$$

where $\bar{C}$ is the average coefficient of conservatism, N is the number of native species and A is the number of nonnative species. This method of calculating FQAI is favored over previous methods because it includes nonnative species but reduces the influence of the species richness on the index. The maximum attainable FQAI' score is 100 and any departure from this optimal habitat condition can be interpreted as a diminishment of floristic quality.

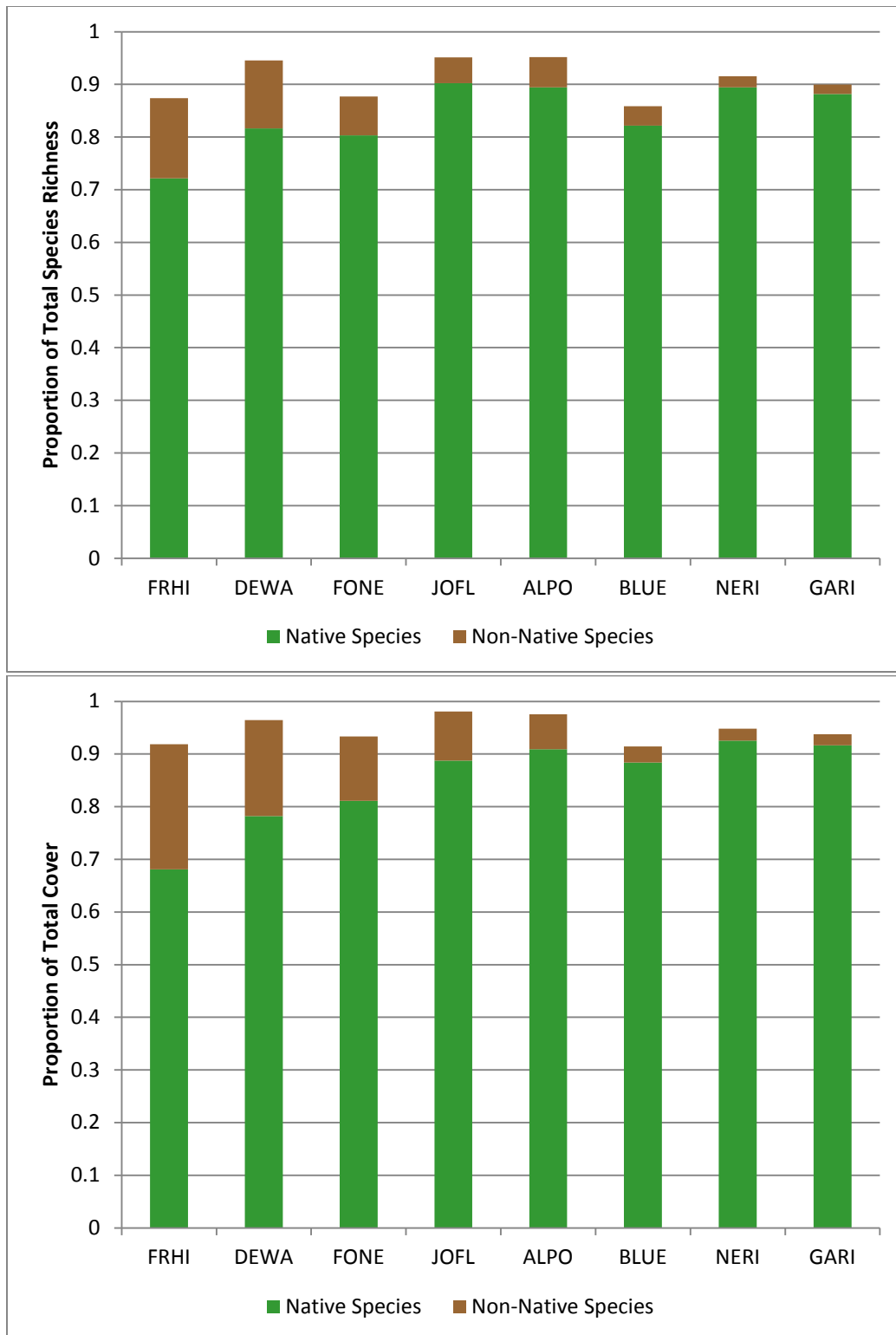


Figure 23. Proportion of total quadrat species richness and total quadrat cover occupied by native and nonnative plant species in ERMN parks. Proportions do not add to one because some plants cannot be identified to species and therefore nativity cannot be assigned to those taxa

Within ERMN, floristic quality differs by vegetation type (Figure 24). As expected, successional habitats such as old fields and young woodlands (Figure 25) have the lowest FQAI' since these habitats contain many generalist and nonnative species which tolerate the recent disturbance. Floodplain habitats, which are regularly disturbed from flood waters and ice scour, also receive lower FQAI' scores. In contrast, the mixed mesophytic forests (Figure 26) found on lower slopes in the West Virginia parks rank highly using the FQAI'. These forests are typically on steep (and thus often less disturbed) lower slopes with a lush diverse understory of native herbaceous species. Xeric habitats, which tend to occur on ridgetops in larger swaths of unfragmented forest, have the highest FQAI' score on average. The Tulip Poplar vegetation found primarily in NERI exhibits the widest variation in floristic quality. Some tulip poplar stands are more-recently disturbed and resemble young successional forests, while other mature tulip poplar stands resemble the rich mixed mesophytic forests.

Differences in floristic quality were also observed among the parks (Figure 26). Floristic quality is significantly lower in the Pennsylvania parks than in the West Virginia parks. In general, the West Virginia parks contain larger swaths of unfragmented forest and less proportion of the parks contains disturbed forest. The West Virginia parks also contain fewer nonnative and invasive exotic plant species, as well as host the diverse mixed-mesophytic forest types discussed above. Of particular note, floristic quality in FRHI is significantly lower than all other ERMN parks. The majority of vegetation in FRHI (aside from the actively managed fields) is young forest recently established on old fields, or floodplain forest which is frequently scoured by the adjacent large river. These recently disturbed successional habitats tend to contain many nonnative species and native species which can tolerate disturbance, thus resulting in a lower FQAI' score.

Deer Browse Indicator Species

A recurring trend 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, Webster et al. 2005, Wiegmann and Waller 2006, Mudrak et al. 2009, Heckel et al. 2010). 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, 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).

ERMN monitoring protocols focus on species in 10 genera that are considered preferred food for deer (Figure 27; see Appendix B for full species list). From 2009–2012, approximately 15,000 individuals of these species were observed in monitoring quadrats. Very low levels of browse (2.0% of all individuals) have been observed; however, this browse appears to be disproportionately observed on reproductive individuals (4.3% of reproductive individuals were browsed, whereas only 1.8% of unreproductive individuals were browsed). Furthermore, the number of reproductive individuals of these species may be suppressed in ERMN parks compared with populations that are not subjected to deer browse. Figure 28 compares the percent of reproductive individuals of three species observed in ERMN parks compared with values reported from 11 sites in Virginia (Fletcher

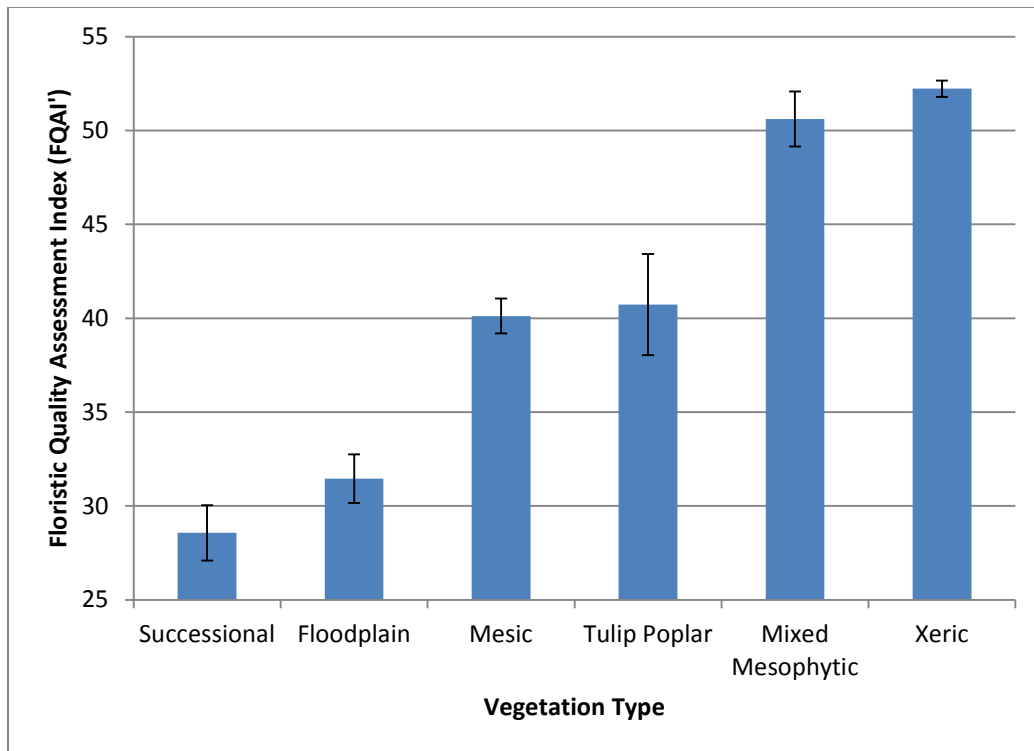


Figure 24. Floristic quality assessment index (FQAI') scores (average $\pm$ standard error) by vegetation type.

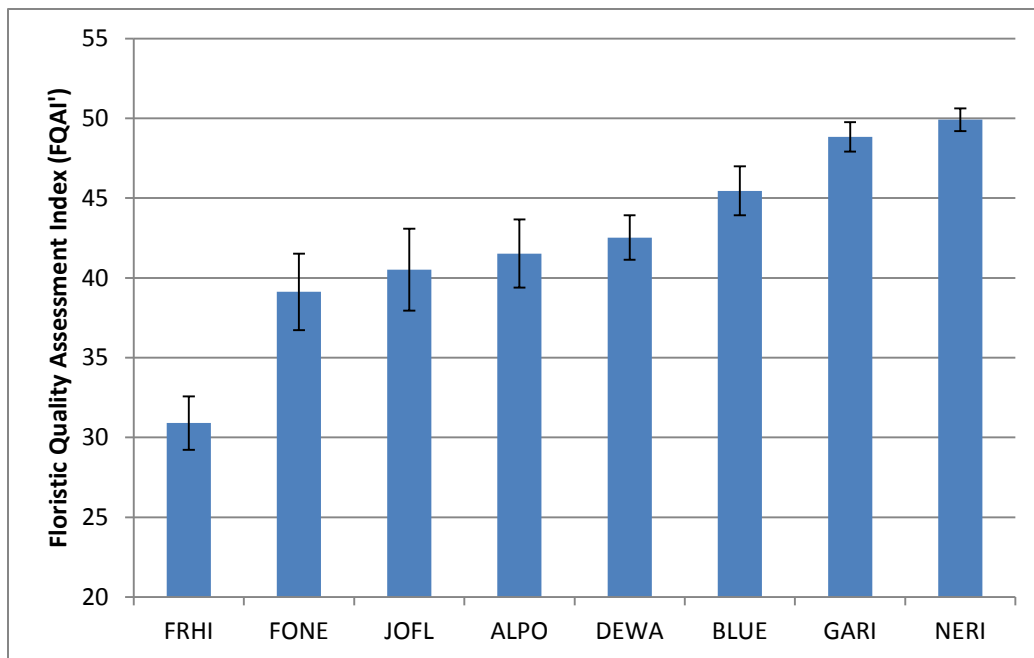


Figure 25. Floristic quality assessment index (FQAI') scores (average $\pm$ standard error) by ERMN park.



Figure 26. Disturbed forest (left) invaded by Japanese stilt grass, garlic mustard, and Japanese barberry in Delaware Water Gap National Recreation Area compared to an unfragmented closed-canopy mixed mesophytic forest (right) with a lush diverse understory in New River Gorge National River.



Figure 27. Four of the deer-browse indicator species (from left to right): false Solomon seal (Photo credit: Merel Black, University of Wisconsin Stevens Point), Jack-in-the-pulpit, sessile-leaved bellwort, true Solomon seal.

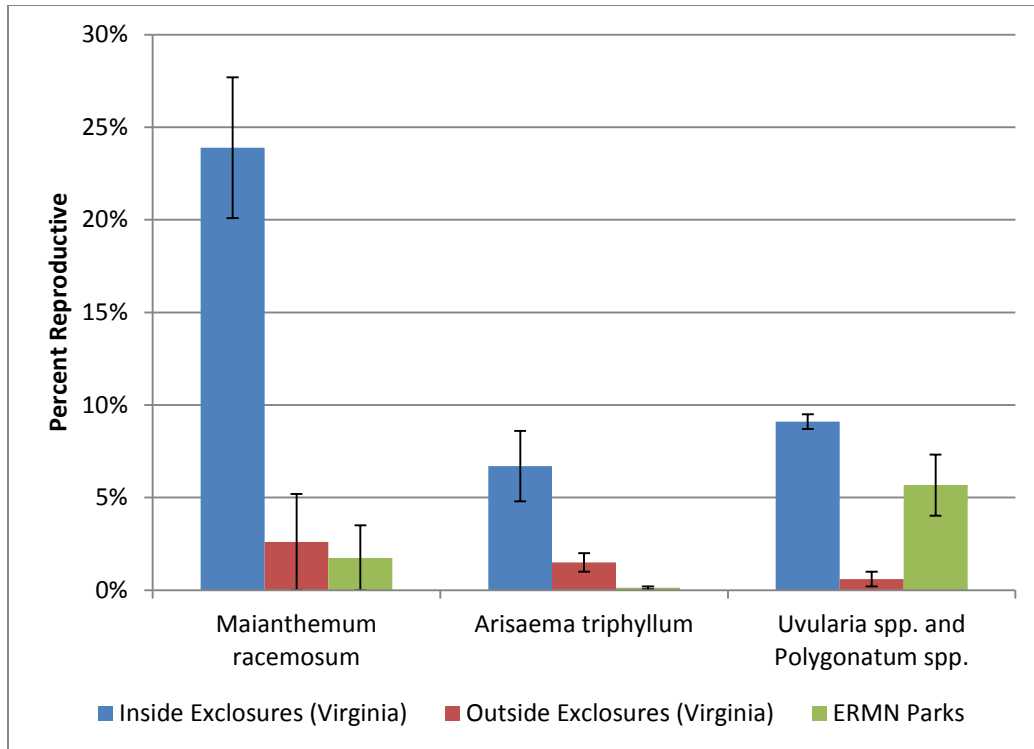


Figure 28. Percent of individuals that were reproductive (mean $\pm$ standard error) for three deer browse indicator species in ERMN parks compared with data from 11 sites in Virginia (values taken from Fletcher et al. 2001).

et al. 2001). For all three species, ERMN parks contain a much lower percent of reproducing individuals than observed within the deer exclosures that had been in place for seven years in Virginia. The sustained low level of browse focused on reproductive plants may be affecting the long-term viability of these species within the parks. Additional monitoring data will provide information on trends in these species populations.

Park-Specific Management Implications

Allegheny Portage Railroad National Historic Site

For most forest health metrics reported herein, ALPO falls in the middle of the range of values observed among network parks. In general, trees in ALPO experienced less branch dieback and had healthier vigor rankings than in the other parks, suggesting that park forests may be experiencing fewer stressors such as extreme weather, harsh site conditions, or insect and disease outbreaks. However, the park's beech and hemlock trees are being negatively affected by beech bark disease and hemlock woolly adelgid, respectively. Park managers should also be vigilant for signs of emerald ash borer which is known to occur in the park's counties and is likely already in the park. Invasive exotic plant species continue to impact forest health, with multiflora rose and Japanese barberry as the most commonly observed species. Ongoing exotic plant management and early detection efforts of both plants and pests are vitally important to maintaining forest health in the park.

Bluestone National Scenic River

Of the network parks, the highest tree mortality rate, as well as the highest proportion of plots experiencing elevated levels of tree mortality, occurs in BLUE. In addition, trees in BLUE are growing more slowly than in many other network parks. These forest metrics should be closely reexamined after all of the plots have been resampled to determine if these elevated levels of mortality and slow tree growth are of management concern, or are due to normal competition among trees in a mature forest canopy. Invasive exotic plant species and forest pests are important threats to the park's forest. Invasive exotic species are twice as common in BLUE as in NERI and GARI. Multiflora rose and wineberry are the most common species, occurring in about half of the park's plots. Of the known forest pests, hemlock woolly adelgid and emerald ash borer are currently serious threats to the park's hemlock and ash trees. Ongoing exotic plant management and early detection efforts of both invasive plants and pests are vitally important to maintaining forest health in the park.

Delaware Water Gap National Recreation Area

Several forest health metrics in DEWA are influenced by the early successional vegetation types that occur in old fields, wet meadows, and floodplains. Approximately half of the plots in DEWA do not contain sufficient tree regeneration to replace the current canopy. This is likely caused by a combination of high browse pressure and the presence of young successional habitats which typically do not contain many tree seedlings. Among the network parks, DEWA has the highest average tree recruitment due to several plots located in early successional habitats where many saplings are reaching the minimum threshold to be tallied as mature trees. The rapid growth of trees in these early successional habitats leads to a high average tree growth rate for the park.

Although approximately 30% of the plots in DEWA showed elevated tree mortality, many other of the park's plots have low (or 0%) tree mortality. Thus, the park-wide average is similar to that of other parks in the network. Tree mortality in DEWA should be examined closely after all of the plots have been resampled to determine if the elevated levels of mortality are of management concern, or are due to normal competition among trees in a mature forest canopy. Thus far, the plots with elevated mortality are scattered throughout the park in many different habitats types.

Invasive exotic plant species and forest pests continue to be serious threats to the park's forest. Compared to other network parks, DEWA contains relatively high levels of nonnative and invasive exotic plant species. This underscores the importance of ongoing exotic plant management and early detection efforts that are critical to maintaining forest health. Varying among years, 30–66% of the park's plots contained important forest pests and pathogens, with hemlock woolly adelgid and elongated hemlock scale the most commonly observed pests.

Fort Necessity National Battlefield

For most forest health metrics reported herein, FONE falls in the middle of the range of values observed among network parks. In general, trees in FONE experienced less branch dieback and had healthier vigor rankings than in the other parks, suggesting that park forests may be experiencing fewer stressors such as extreme weather, harsh site conditions, or insect and disease outbreaks. Only one occurrence of a forest pest was observed over the four-year sampling interval, the second-lowest incidence of forest pests in the network. However, park managers should be vigilant for signs of emerald ash borer which is known to occur in the park's county and may occur in the park. Invasive exotic plant species continue to be a serious threat to the park's forest, especially multiflora rose, Japanese barberry, and Morrow's honeysuckle which occur in 60–85% of the park's plots, depending on the species. Ongoing exotic plant management and early detection efforts of both invasive plants and pests are vitally important to maintaining forest health in the park.

Friendship Hill National Historic Site

Several forest health metrics in FRHI are influenced by early successional forest that has established on former agricultural land. Approximately half of the plots in FRHI do not contain sufficient tree regeneration to replace the current canopy. This is likely caused by a combination of high browse pressure and the abundance of young successional habitats which typically do not contain many tree seedlings. These early successional forests are characterized by rapid tree growth, but also by the presence of nonnative and invasive exotic plant species, which leads to lower floristic quality in the forest groundstory. In particular, invasive plant species are one of the most pressing threats to forest health in FRHI. On average, FRHI contains the most invasive plant species (5.5 species/plot and 20% of total plant cover) of any network park. Without concerted management efforts, invasive plant species will continue to expand within the park, further degrading forest health. There were no detections of targeted forest pests and pathogens in FRHI plots; however, park managers should be vigilant for hemlock woolly adelgid, emerald ash borer, and gypsy moth, as these pests will likely be introduced to the park in the coming years.

Gauley River National Recreation Area

GARI contains the most fallen logs (coarse woody debris) and the fewest standing dead trees (snags) of the ERMN parks. Many forest stands in GARI exhibit characteristics approaching old-growth forests, such as large downed trees. As evidenced by the park's high tree recruitment rate, young trees are now filling in the gaps left by the large fallen downed trees. Also, the park's low tree mortality rate leads to low density of snags.

Invasive plant species are currently at relatively low levels within the park; however, they remain a major threat to forest health in GARI. Multiflora rose, tree of heaven, autumn olive, and Japanese stiltgrass are the most common invasive plant species, although five other invasive species were also found in the monitoring plots. Ongoing exotic plant management and early detection efforts are vitally important to maintaining forest health and the current low incidence of these species. Similarly, forest pests were rarely observed in the monitoring plots; however, they are a serious threat to the park's forests. Notably, hemlock woolly adelgid and emerald ash borer are significant threats to the park's hemlock and ash trees, respectively. Continued vigilance and outreach to park neighbors and user groups are equally important in preventing the introduction and spread of new invasive plant and pest species.

Johnstown Flood National Memorial

Much of the forest at JOFL is relatively young, and the numerous small-diameter trees that died during the stem-exclusion phase of forest stand succession have not yet fallen to create coarse woody debris. As a result, JOFL contains the least amount of fallen logs (coarse woody debris) and the largest amount of standing dead trees (snags) of the ERMN parks. Very few detections of forest pests occurred over the sampling interval; however, park managers should be vigilant for signs of emerald ash borer which is known to occur in the park's county and is likely already in the park. Invasive exotic plant species continue to be a serious threat to the park's forest, especially multiflora rose and Morrow's honeysuckle which occur in half of the park's plots. Ongoing exotic plant management and early detection efforts of both plants and pests are vitally important to maintaining forest health in the park.

New River Gorge National River

For most forest health metrics reported herein, NERI falls in the middle of the range of values observed among network parks. Invasive plant species are currently at relatively low levels within the park; however, they remain a major threat to forest health in NERI. Multiflora rose and tree of heaven are the most common invasive plant species, although 13 other invasive species were also found in the monitoring plots. Ongoing exotic plant management and early detection efforts are vitally important to maintaining forest health and the current low incidence of these species. Forest pests, another serious threat to the park's forests, were found in less than 20% of the park's plots each year. Notably, hemlock woolly adelgid and emerald ash borer are significant threats to the park's hemlock and ash trees, respectively. In light of the recent influx of visitors to the park and neighboring lands, protecting the park's forests from recreational impacts will be a challenge. Continued vigilance and outreach to park neighbors and user groups are equally important in preventing the introduction and spread of new invasive plant and pest species. Minimizing trail construction will also help protect forest communities from the dispersal of invasive exotic plants, pests, and diseases.

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Appendix A. Sampling universes in ERMN parks.

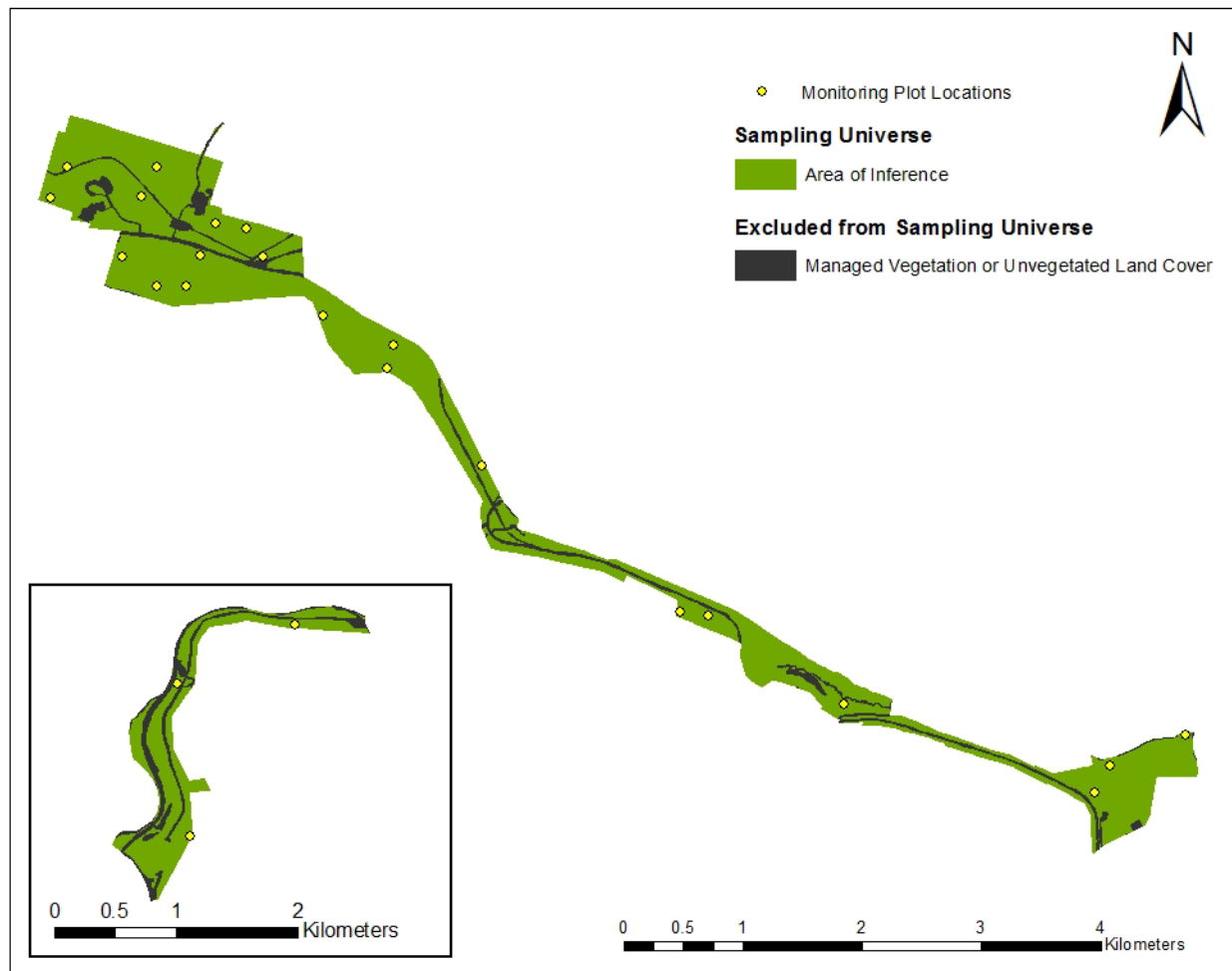


Figure A1. Sampling universe (91% of park area), area of inference (91% of park area) and plot locations for Allegheny Portage Railroad National Historic Site. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In ALPO, excluded areas are primarily developed land, transportation corridors, and the historic trace. Before sampling began in 2007, the park's natural and cultural resource managers reviewed every potential plot location and requested that two plots be excluded from the monitoring due to their proximity to significant cultural resources or safety hazards.

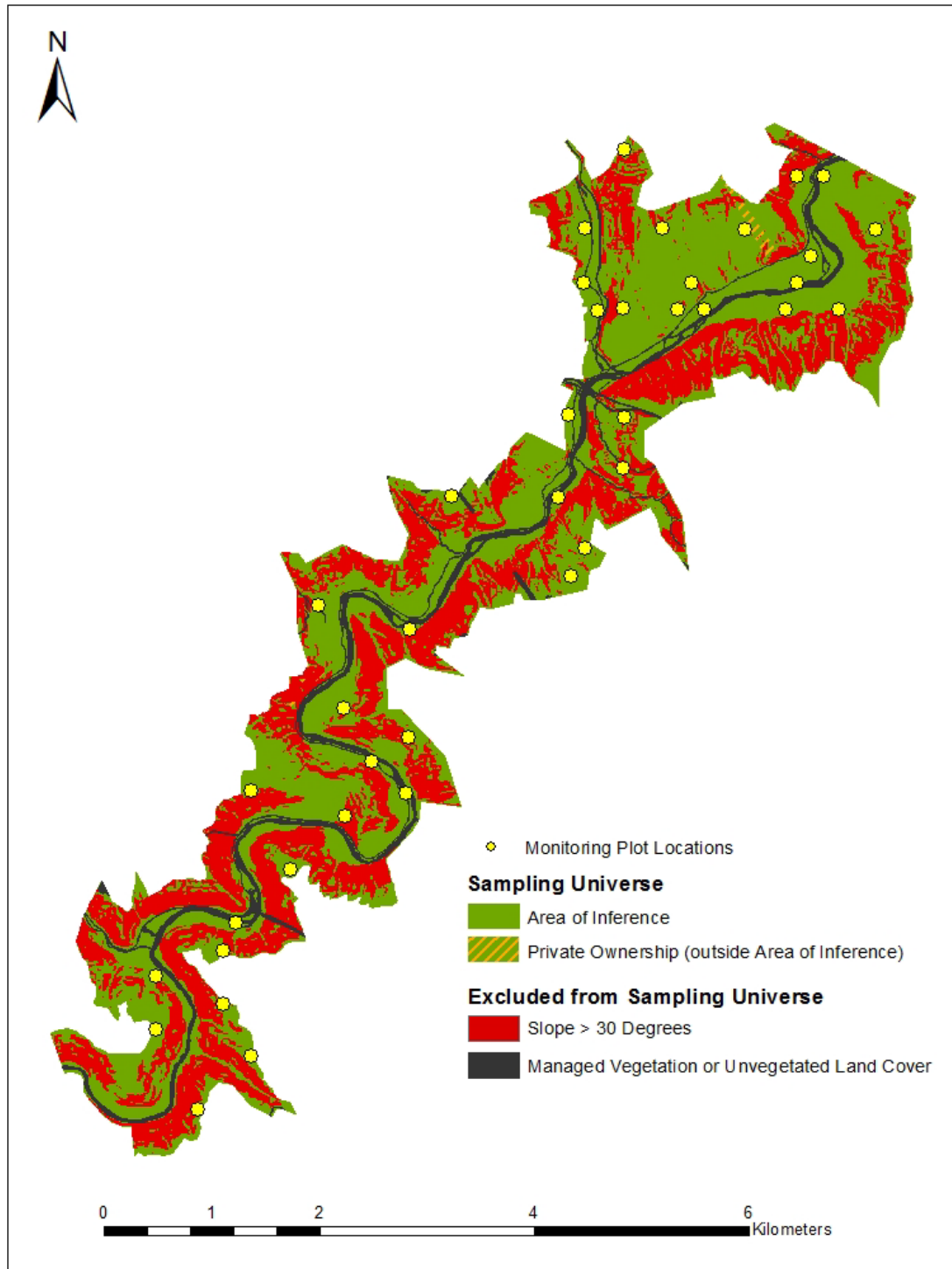


Figure A2. Sampling universe (57% of park area), area of inference (56% of park area) and plot locations for Bluestone National Scenic River. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In BLUE, excluded areas are primarily slopes steeper than 30°. Reducing the steep slope cut-off to 25° would have removed significantly more plots from the grid of potential plots in BLUE.

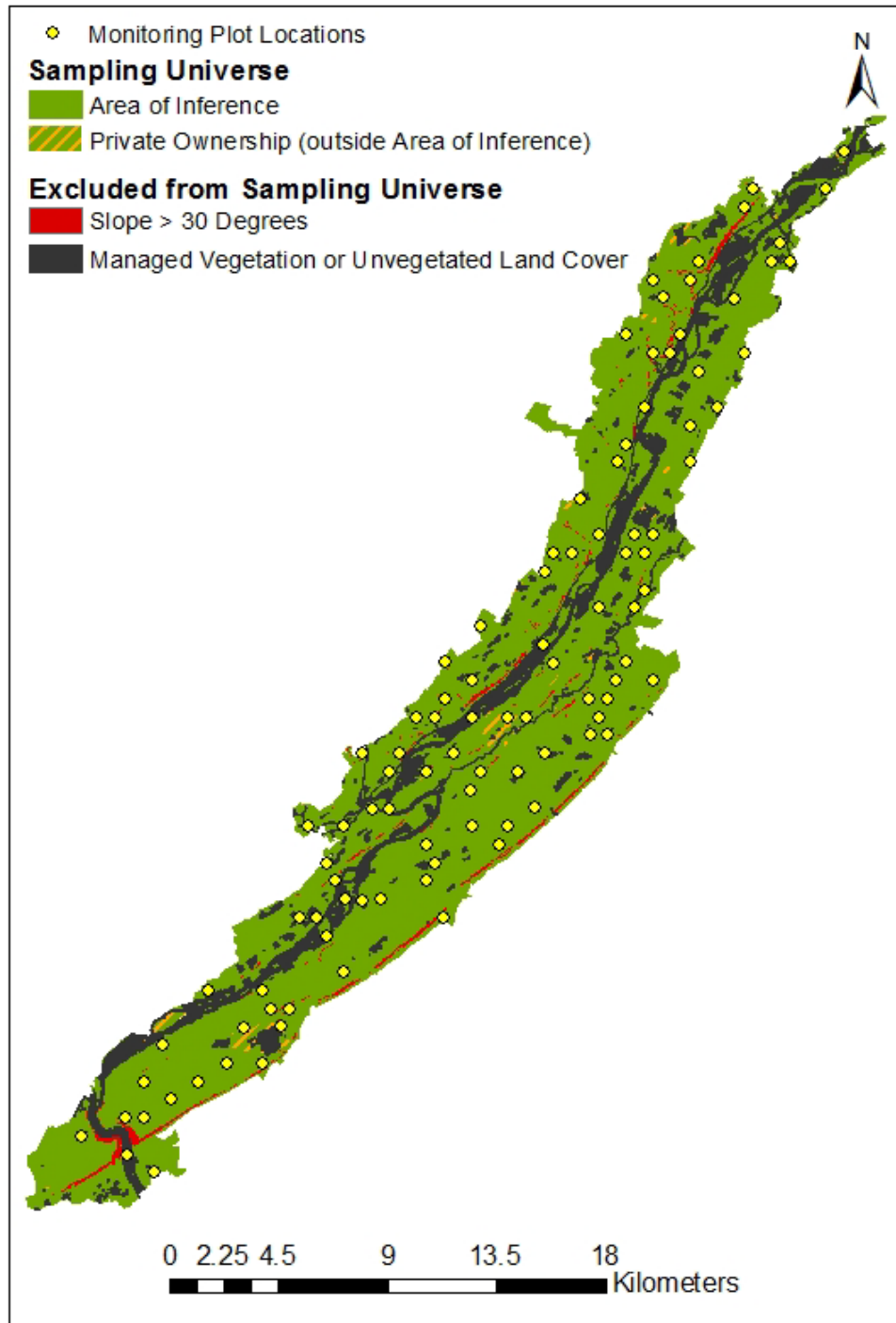


Figure A3. Sampling universe (86% of park area), area of inference (84% of park area) and plot locations for Delaware Water Gap National Recreation Area. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In DEWA, excluded areas are primarily agriculture, developed land, privately-owned land, open water, transportation corridors, and steep slopes.

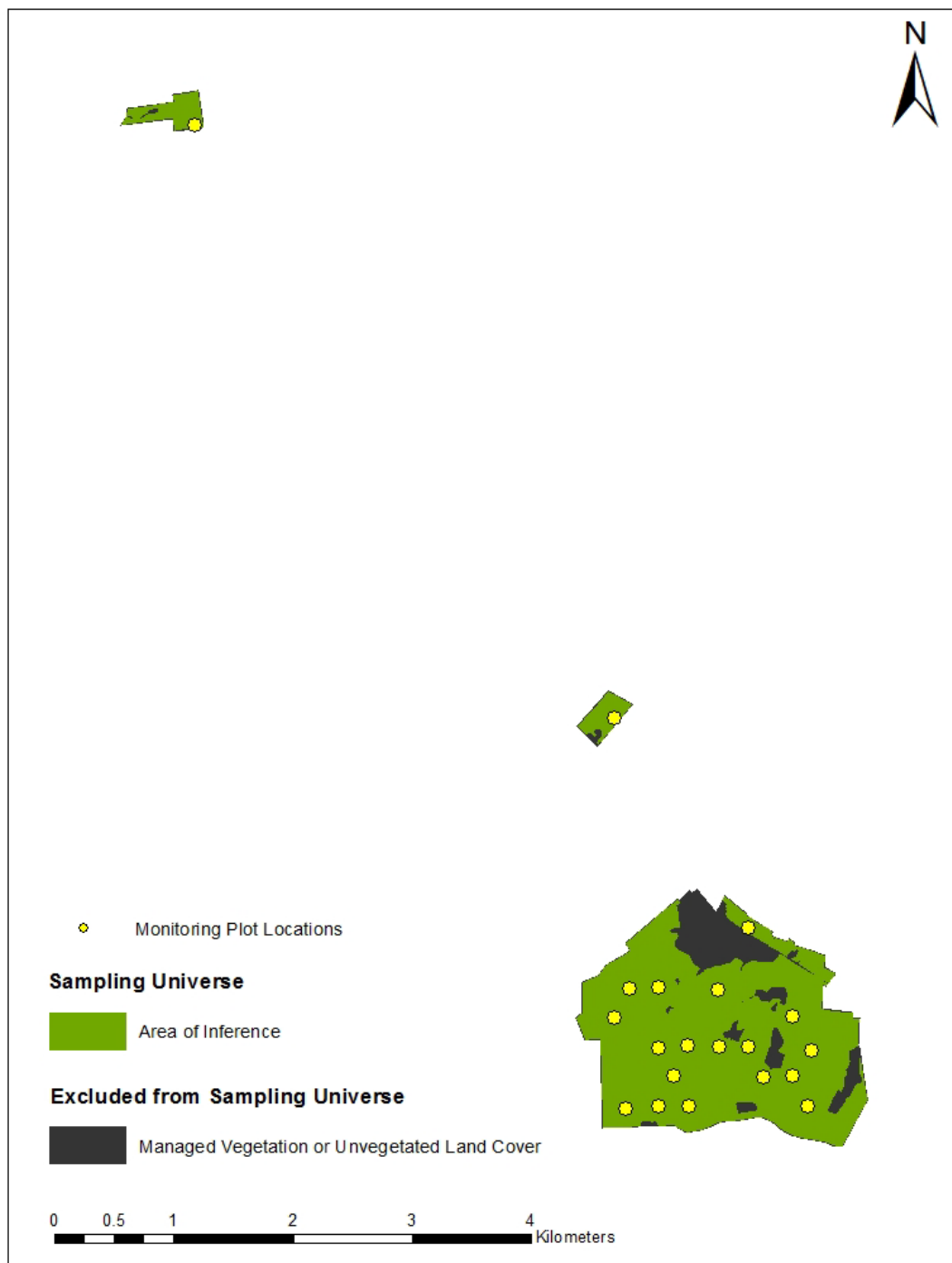


Figure A4. Sampling universe (86% of park area), area of inference (86% of park area) and plot locations for Fort Necessity National Battlefield. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In FONE, potential plots were excluded from the Great Meadow since that area will be maintained as open to retain its historical character and viewsheds. In addition, potential plots located in the hayfields on the Rush property were also excluded since these fields are regularly mowed.



Figure A5. Sampling universe (83% of park area), area of inference (83% of park area) and plot locations for Friendship Hill National Historic Site. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In FRHI, excluded areas are primarily managed fields, developed land, and rights-of-way.

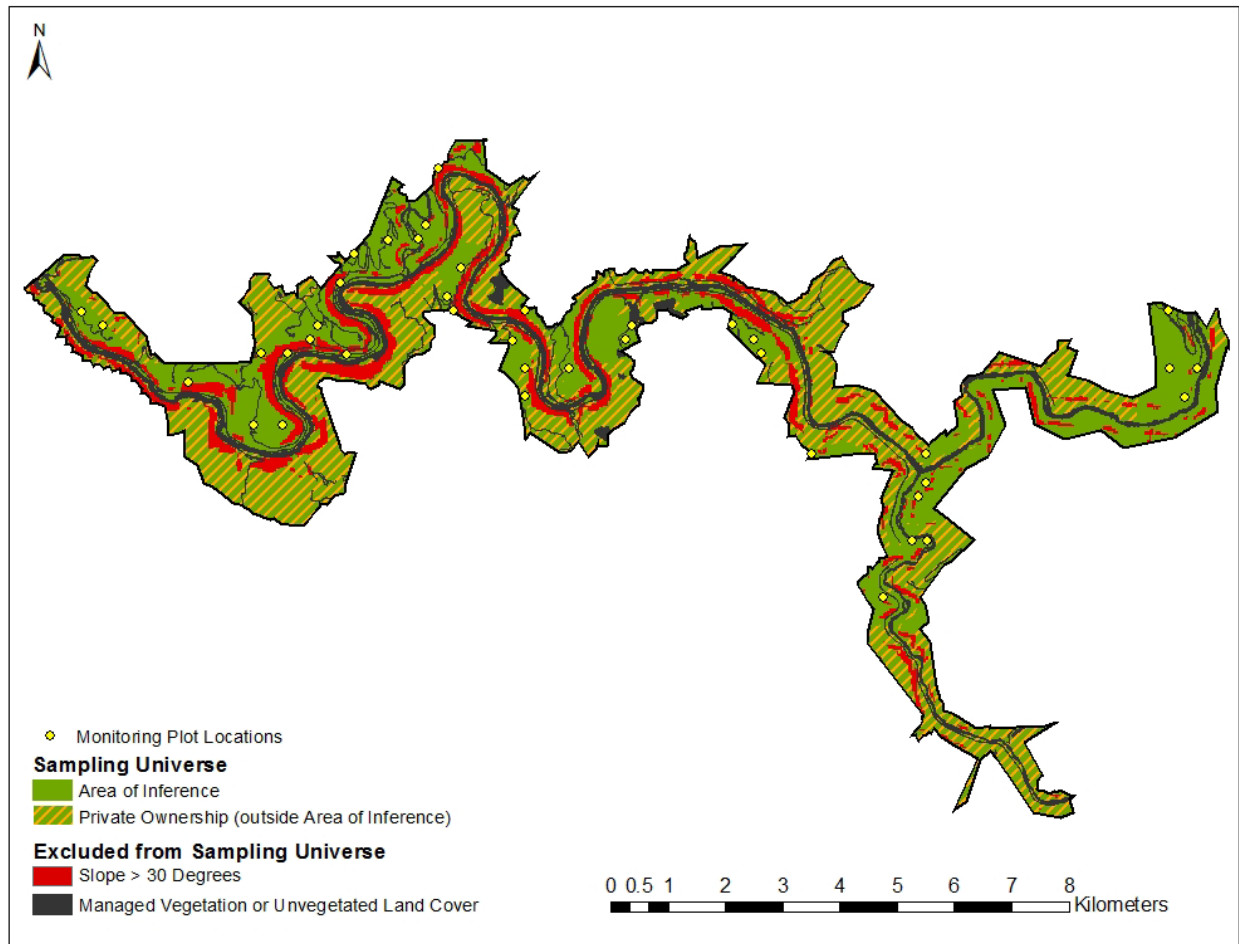


Figure A6. Sampling universe (77% of park area), area of inference (31% of park area) and plot locations for Gauley River National Recreation Area. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In GARI, excluded areas are primarily privately-owned land, along with some steep slopes.

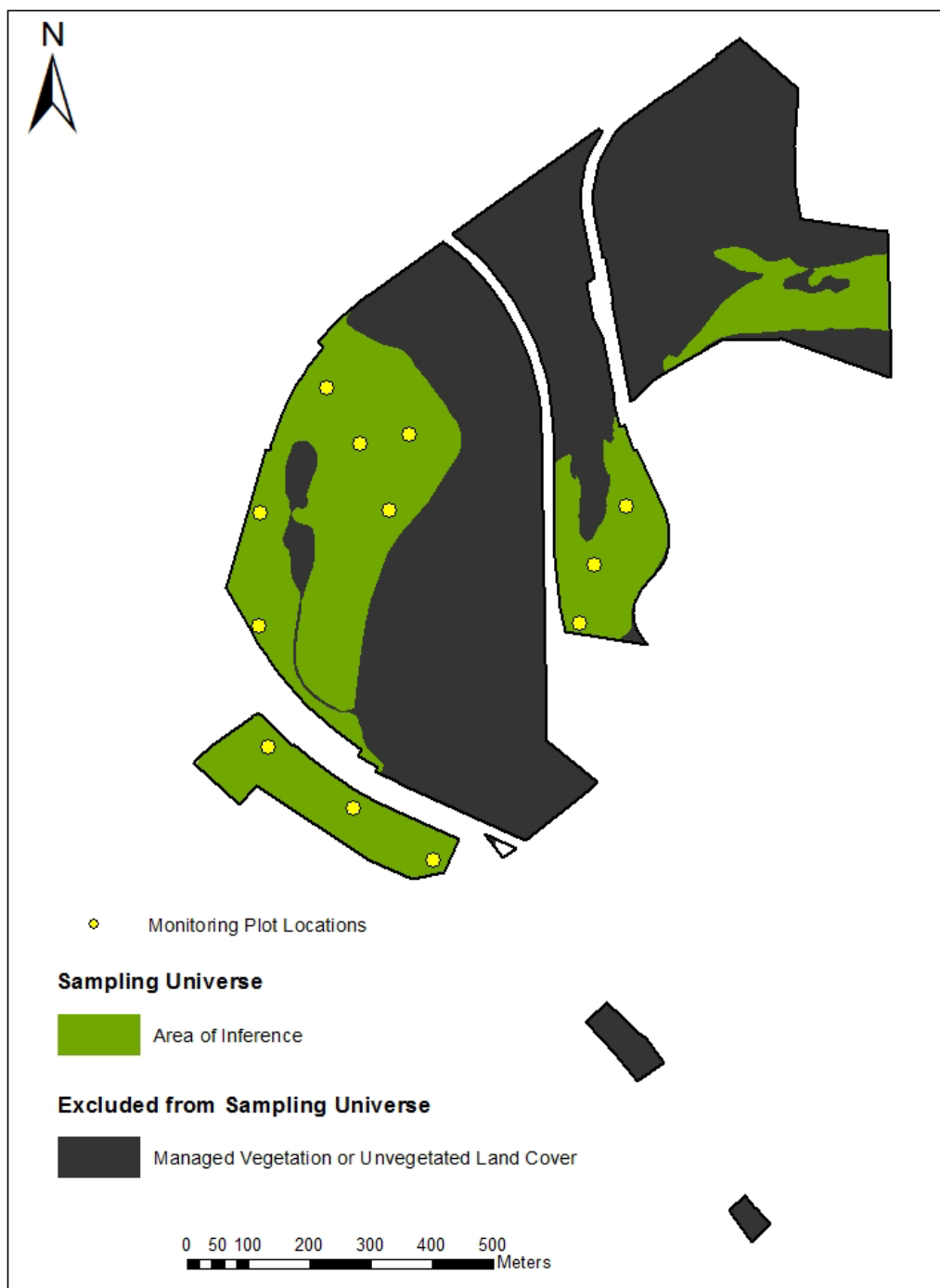


Figure A7. Sampling universe (33% of park area), area of inference (33% of park area) and plot locations for Johnstown Flood National Memorial. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Potential plots located on the historic lakebed, the dam, and the mowed area around the visitor center were excluded because these areas will be maintained as open to preserve the viewshed and facilitate historical interpretation. Through consultation with the park's natural resource manager (Kathy Penrod, personal communication, April 2007), the sampling universe shown above was identified. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference.

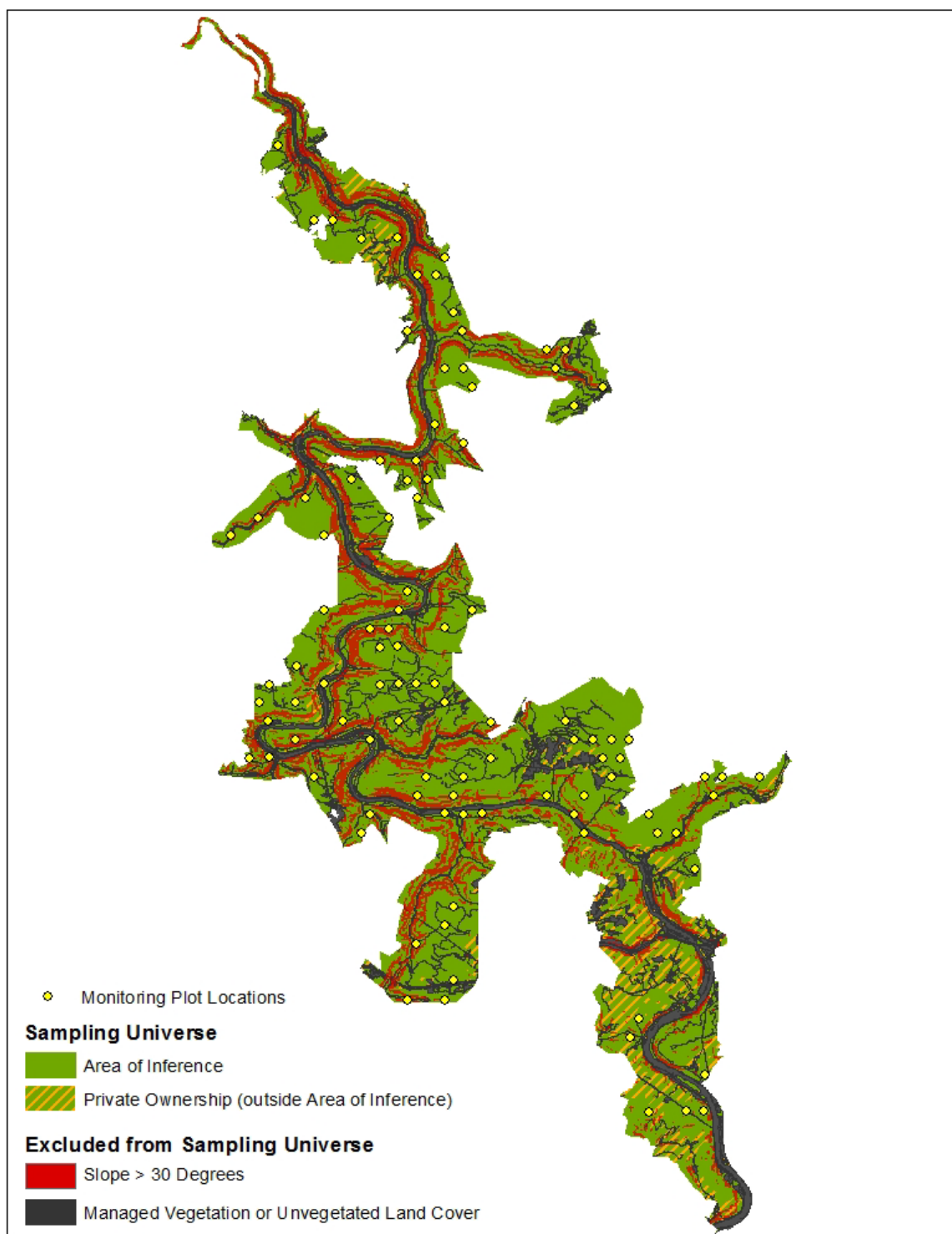


Figure A8. Sampling universe (73% of park area), area of inference (59% of park area) and plot locations for New River Gorge National River. Sampling universe includes the area within the parks' authorized boundary excluding steep slopes greater than 30° and intensively-managed or unvegetated land. Area of inference includes the publically-owned lands within the sampling universe. Inferences derived from the monitoring data cannot be applied to areas of the park outside the area of inference. In NERI, excluded areas are primarily privately-owned land and steep slopes.

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

Scientific and Common Names	Literature
<i>Actaea</i> spp. – baneberry, bugbane (<i>A. pachypoda</i> , <i>A. podocarpa</i> , <i>A. rubra</i>)	Webster and Parker 2000
<i>Actaea racemosa</i> – black baneberry (formerly <i>Cimicifuga racemosa</i>)	(Browse preference is debated) Heckel et al. 2010 Rawinski 2008
<i>Arisaema triphyllum</i> – Jack-in-the-pulpit	Webster and Parker 2000 Ruhren and Handel 2000 Fletcher et al. 2001 Diefenbach and Fritsky 2007 Heckel et al. 2010
<i>Maianthemum canadense</i> – Canada mayflower	Rooney 1997 Kirschbaum and Anacker 2005 Diefenbach and Fritsky 2007
<i>Maianthemum</i> spp. – false lily of the valley (<i>M. racemosum</i> , <i>M. stellatum</i>)	Fletcher et al. 2001 Augustine and deCalesta 2003 Webster et al. 2005
<i>Medeola virginiana</i> – Indian cucumber	Webster et al. 2005 Diefenbach and Fritsky 2007
<i>Osmorhiza</i> spp. -- sweetroot (<i>O. claytonia</i> , <i>O. longistylis</i>)	Webster and Parker 2000 Heckel et al. 2010
<i>Podophyllum peltatum</i> – may apple	(Browse preference is debated) Heckel et al. 2010
<i>Polygonatum</i> spp. – Solomon's seal (<i>P. biflorum</i> , <i>P. pubescens</i>)	Fletcher et al. 2001 Augustine and deCalesta 2003 Webster et al. 2005
<i>Prosartes</i> spp. – fairybells, mandarin (<i>P. lanuginosa</i> , <i>P. maculata</i>)	
<i>Trillium</i> spp. – trillium, wake robin (numerous species)	Anderson 1994 Augustine and Frelich 1998 Kirschbaum and Anacker 2005' Heckel et al. 2010
<i>Uvularia</i> spp.-- bellwort (<i>U. grandiflora</i> , <i>U. perfoliata</i> , <i>U. puberula</i> , <i>U. sessilifolia</i>)	Fletcher et al. 2001 Webster et al. 2005

Appendix C. Key invasive exotic plant species monitored in ERMN parks. An “X” indicates that species is present and considered invasive in that park.

Scientific Name	Common Name	DEWA	ALPO	JOFL	FONE	FRHI	GARI	NERI	BLUE
<i>Acer palmatum</i>	Japanese maple	X							
<i>Acer platanoides</i>	Norway maple	X	X	X					
<i>Ailanthus altissima</i>	tree of heaven	X	X		X	X	X	X	X
<i>Akebia quinata</i>	chocolate vine	X							
<i>Albizia julibrissin</i>	silk tree	X						X	X
<i>Alliaria petiolata</i>	garlic mustard	X	X	X	X	X		X	X
<i>Alnus glutinosa</i>	European alder		X	X					
<i>Ampelopsis brevipedunculata</i>	Amur peppervine								
<i>Anthoxanthum odoratum</i>	sweet vernalgrass		X	X	X	X	X	X	X
<i>Anthriscus sylvestris</i>	wild chervil	X							
<i>Arctium minus</i>	lesser burdock							X	
<i>Berberis thunbergii</i>	Japanese barberry	X	X	X	X	X			
<i>Cabomba caroliniana</i>	Carolina fanwort	X							
<i>Cardamine impatiens</i>	narrowleaf bittercress	X					X	X	X
<i>Carduus nutans</i>	nodding plumeless thistle	X							
<i>Celastrus orbiculatus</i>	Oriental bittersweet	X	X						
<i>Centaurea stoebe ssp. micranthos</i>	spotted knapweed	X	X	X			X	X	
<i>Chelidonium majus</i>	celandine		X				X	X	
<i>Cirsium arvense</i>	Canada thistle	X	X	X	X	X			
<i>Cirsium vulgare</i>	bull thistle		X		X	X		X	X
<i>Coincya monensis</i>	star-mustard	X							
<i>Dioscorea oppositifolia</i>	Chinese yam							X	
<i>Dipsacus fullonum</i>	Fuller's teasel		X	X				X	X
<i>Duchesnea indica</i>	Indian strawberry								
<i>Elaeagnus angustifolia</i>	Russian olive	X							
<i>Elaeagnus umbellata</i>	autumn olive	X	X	X	X	X	X	X	X
<i>Euonymus alatus</i>	burningbush	X		X	X				
<i>Eupatorium serotinum</i>	lateflowering thoroughwort	X							
<i>Festuca elatior</i>	tall fescue		X	X	X	X	X	X	
<i>Frangula alnus</i>	glossy buckthorn					X			
<i>Glechoma hederacea</i>	ground ivy	X	X	X	X	X	X	X	X
<i>Hedera helix</i>	English ivy	X						X	

Scientific Name	Common Name	DEWA	ALPO	JOFL	FONE	FRHI	GARI	NERI	BLUE
<i>Hemerocallis fulva</i>	orange daylily		X				X	X	
<i>Hesperis matronalis</i>	dames rocket	X	X	X		X	X	X	X
<i>Humulus japonicus</i>	Japanese hop		X						X
<i>Iris pseudacoris</i>	paleyellow iris	X					X	X	X
<i>Lespedeza bicolor</i>	shrub lespedeza						X	X	
<i>Lespedeza cuneata</i>	sericea lespedeza	X				X	X	X	X
<i>Ligustrum obtusifolium</i>	border privet	X	X	X	X				
<i>Ligustrum sp.</i>	privet	X	X	X	X		X	X	X
<i>Ligustrum vulgare</i>	European privet	X	X	X	X		X	X	X
<i>Lonicera japonica</i>	Japanese honeysuckle	X	X		X	X	X	X	X
<i>Lonicera maackii</i>	Amur honeysuckle	X	X						
<i>Lonicera morrowii</i>	Morrow's honeysuckle	X	X	X	X	X	X	X	X
<i>Lonicera sp.</i>	honeysuckle	X	X	X	X	X	X	X	X
<i>Lonicera tatarica</i>	Tatarian honeysuckle	X		X	X			X	
<i>Lychnis flos-cuculi</i>	ragged robin	X							
<i>Lysimachia nummularia</i>	creeping jenny	X				X	X	X	X
<i>Lythrum salicaria</i>	purple loosestrife	X						X	X
<i>Microstegium vimineum</i>	Japanese stiltgrass	X	X		X	X	X	X	
<i>Miscanthus sinensis</i>	Chinese silvergrass							X	
<i>Myriophyllum spicatum</i>	Eurasian watermilfoil	X							
<i>Ornithogalum umbellatum</i>	sleepydic					X		X	
<i>Pastinaca sativa</i>	wild parsnip		X	X	X			X	
<i>Paulownia tomentosa</i>	princesstree	X			X		X	X	X
<i>Perilla frutescens</i>	beefsteakplant						X	X	X
<i>Phragmites australis</i>	common reed	X							
<i>Polygonum caespitosum</i>	Oriental ladythumb	X	X		X	X	X	X	X
<i>Polygonum caespitosum var. caespitosum</i>	Oriental ladythumb	X	X		X	X	X	X	X
<i>Polygonum caespitosum var. longisetum</i>	Oriental ladythumb	X	X		X	X	X	X	X
<i>Polygonum cuspidatum</i>	Japanese knotweed	X	X	X		X	X	X	X
<i>Polygonum perfoliatum</i>	Asiatic tearthumb	X							
<i>Polygonum persicaria</i>	spotted ladythumb	X		X	X	X	X	X	X
<i>Polygonum sachalinense</i>	giant knotweed	X	X	X		X			
<i>Potamogeton crispus</i>	curly pondweed	X						X	
<i>Potentilla recta</i>	sulphur cinquefoil							X	
<i>Pueraria montana var. lobata</i>	kudzu							X	

Scientific Name	Common Name	DEWA	ALPO	JOFL	FONE	FRHI	GARI	NERI	BLUE
<i>Pyrus pyrifolia</i>	Chinese pear								X
<i>Rhamnus cathartica</i>	common buckthorn	X	X					X	
<i>Rosa multiflora</i>	multiflora rose	X	X	X	X	X	X	X	X
<i>Rubus phoenicolasius</i>	wine raspberry	X	X				X	X	X
<i>Securigera varia</i>	crownvetch	X	X	X	X	X	X	X	X
<i>Sedum sarmentosum</i>	stringy stonecrop							X	
<i>Spiraea japonica</i>	Japanese meadowsweet							X	X
<i>Trapa natans</i>	water chestnut	X							
<i>Tussilago farfara</i>	coltsfoot	X	X			X	X	X	X
<i>Urtica dioica ssp. dioica</i>	stinging nettle						X	X	X
<i>Verbascum blatteria</i>	moth mullein							X	X
<i>Verbascum thapsus</i>	common mullein	X	X	X		X	X	X	X
<i>Vinca minor</i>	common periwinkle	X	X		X	X		X	
<i>Wisteria floribunda</i>	Japanese wisteria	X							
<i>Wisteria sinensis</i>	Chinese wisteria	X							
<i>Wisteria sp.</i>	wisteria	X							

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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