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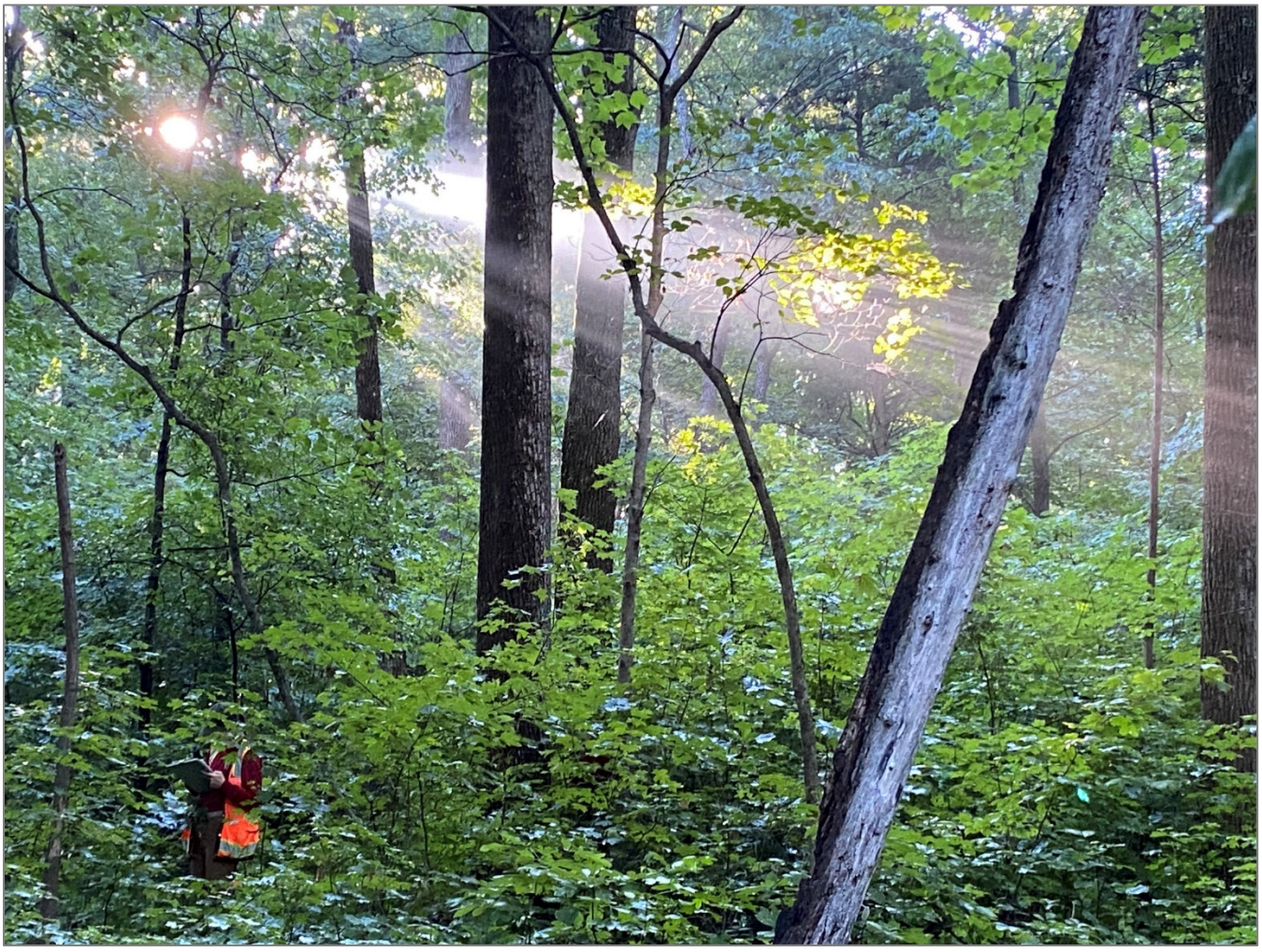
Vegetation Community Monitoring at Lincoln Boyhood National Memorial

2011–2024



Light coming through the canopy during monitoring at Lincoln Boyhood National Memorial in 2024.
NPS

Vegetation Community Monitoring at Lincoln Boyhood National Memorial: 2011–2024

Science Report NPS/SR—2025/346

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Abstract

The forest at Lincoln Boyhood National Memorial, Indiana, was reconstructed to support the interpretation of the Lincoln family's time at the site. The Heartland Inventory and Monitoring Network monitored the plant community at the park four times from 2011 to 2024. Monitoring occurred in four permanently monitored 0.1 ha sites. Midstory and overstory trees were measured across the 0.1 ha sites. Ground flora, including ground cover, canopy closure, and tree regeneration, were measured in 10 m^2 nested plots. Data are summarized at the site scale with analysis at the park scale. The climate at the park has been warmer and wetter since the mid-1990s. Warming temperatures may contribute to water stress for plants despite increasing precipitation.

Although an oak-hickory woodland was the target community, the vegetation structure was characterized as a closed canopy forest from 2011–2024. Fewer overstory tree species were observed in 2024 than in other years, although mean basal area and density were similar. Snag basal area was similar through time despite declines in white ash trees (*Fraxinus americana*). The fast-growing tuliptree (*Liriodendron tulipifera*) and more mesic sugar maple (*Acer saccharum*) may benefit from the loss of ash.

The ground layer is largely unvegetated and covered by shallow leaf litter. Woody plants and forbs were the most abundant in this forest layer. Both native and nonnative species richness increased from prior years, but species diversity metrics were similar. Gamma richness was much greater than in other years, but beta diversity was not, meaning species were generally not very abundant across the sites. The loss of ash from the overstory and advanced regeneration in conjunction with a shifting climate may continue to transform the forest. Management interventions to curtail problematic plants and rejuvenate the forest could be helpful for moving towards the target community type.

Acknowledgments

We appreciate support from staff at Lincoln Boyhood National Memorial to accomplish the monitoring. Previous team members K. James and K. Mlekush collected and processed the first two years of data. Some basic language in the Introduction and Methods sections was used without citation from James 2011. We are grateful for botanical and field support in 2024 from fire effects monitors J. Urban and A. Zastawny, as well as project team members E. Sload, M. Carter, and M. DeBacker. The collaboration was essential for completing the work. S. Mead supported field operations and analysis code development.

Introduction

Lincoln Boyhood National Memorial includes 200 acres of old fields and hardwood forest. Land surveys conducted in 1805 indicated the presence of oak-hickory forest including species sensitive to fire. Tree species included beech (*Fagus grandifolia*), black cherry (*Prunus serotina*), flowering dogwood (*Cornus florida*), elm species (*Ulmus* spp.), blackgum (*Nyssa sylvatica*), shagbark hickory (*Carya ovata*), ironwood (*Ostrya virginiana*), black locust (*Robinia pseudoacacia*), sugar maple (*Acer saccharum*), oak species (*Quercus* spp.), tuliptree (*Liriodendron tulipifera*), pawpaw (*Asimina triloba*), eastern redbud (*Cercis canadensis*), sassafras (*Sassafras albidum*), sycamore (*Platanus occidentalis*), and black walnut (*Juglans nigra*). When Lincoln's family arrived, they began to clear the land for agriculture (McEnaney 2001). Only small woodlots on the hilltop cemetery remained. Similarly, Indiana's forests have shrunk from 88% of the state's land area to 23% (Phillips et al. 2020).

Later, as the park began to take shape, designers recommended recreating the forest to serve as a backdrop to the memorial features. The forest would provide visitors with a sense of what early settlers faced as they developed the land (McEnaney 2001). Nearly 40,000 native trees and shrubs were planted using the 1805 land survey as a guide for the project. However, it was difficult to recreate the dominance of oak and hickory species. The restoration plan included treatment of invasive species, especially Japanese honeysuckle (*Lonicera japonica*); tree removal (sugar maple in particular); planting; and fire management (Pavlovic and White 1989). Although the park's foundation planning document does not list the forest as a key resource, it is included in descriptions of condition and trend for the Historic Farm Site. Concerns over invasive species levels and plant species composition were also highlighted for the farm resource (NPS 2017). In this report, we assess changes to the forest monitoring sites since initial monitoring in 2011. Management actions at the park have included tree seedling plantings (2018, 2019, 2022, 2023), thinning, invasive plant treatments, and prescribed fire. We do not have specific data on management actions within the monitoring sites, so results are in the form of current and past statuses. We also noted evidence of likely windthrow in monitoring site 1 in the form of downed large trees.

Methods

Study Site

Vegetation community monitoring sites were established by the Heartland Inventory and Monitoring Network (Heartland Network) in the forest of Lincoln Boyhood National Memorial in 2011. Four monitoring sites were installed within the southern area of the park and sampled in 2011, 2015, 2019 and 2024 (Figure 1). These four sites represent a mix of ruderal deciduous forest and restored deciduous forest (Diamond et al. 2014).

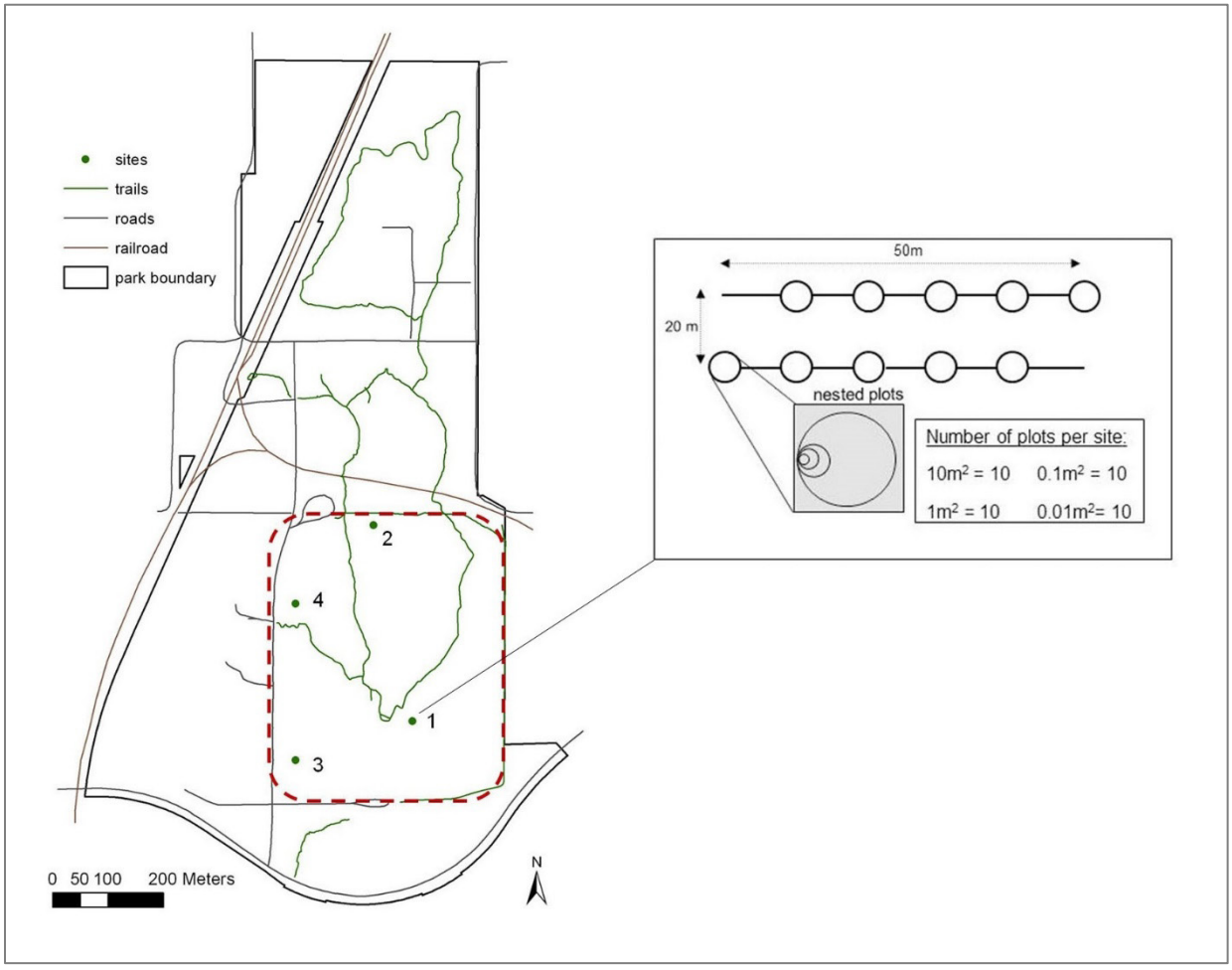

Figure 1. Map of Heartland Inventory and Monitoring Network vegetation monitoring sites (N = 4 sites) at Lincoln Boyhood National Memorial. Area within the red dashed line is the focus of plant community monitoring. Monitoring site configuration is shown on the right.

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Sampling Design

The Heartland Network established four vegetation monitoring sites at Lincoln Boyhood National Memorial in 2011 (Figure 1). Monitoring sites at the park include deciduous forest in various states of succession (Diamond et al. 2014; Pavlovic and Forste 2004), and we combined them here for

analyses. Monitoring methods followed the woodland standard operating procedures outlined in the Heartland Network vegetation community monitoring protocol (Leis et al. 2022). Monitoring sites were 50 m × 20 m (0.1 ha) in size with two focal transects bounding the site on the 50 m sides (Figure 1). For this protocol, midstory and overstory tree data were collected within the entire 0.1 ha area, while all other metrics were collected within 10 subplots located along the site boundaries. Each subplot consisted of a series of nested subplots (0.01 m^2, 0.1 m^2, 1 m^2, and 10 m^2), but only observations at the 10 m^2 scale were used for this study. Midstory and overstory monitoring consisted of a suite of sampling methods for characterizing overstory tree composition, canopy cover, and tree regeneration, in addition to canopy and ground flora measurements.

Data Summary

For baseline vegetation descriptions, see James (2011). RStudio (R Core Team 2024) and Minitab (2020) were used to calculate summary statistics. All site means (N = 4 sites) were calculated based on 10 subplots each year for ground cover, ground flora, canopy, and regeneration (2011, 2015 2019, and 2024). Overstory metrics were calculated for the whole 0.1 ha site and scaled to the hectare (N = 4 sites). Means are reported with maximum and minimum values represented in place of the usual error bars unless otherwise noted.

Climate

We included a brief description of historical climate as context for plant community monitoring. Climate data were obtained using the Climate Analyzer tool (Tercek 2024) for the Heartland Network parks. National Weather Service data from the station in Boonville, Indiana (station ID USC00120852), were queried. Climate Analyzer was used to calculate the precipitation and temperature metrics (interpolated precipitation compared to long-term data and climogram tools). However, temperature data for 2024 were not available from a nearby station. We queried data provided by Climate Toolbox (2025) for temperature trends. Additional climate outputs were referenced from the Climate Change Response Program (CCRP 2024).

Ground Cover

Ground cover was assessed using cover classes (Table 1). A site mean was calculated by averaging the cover class midpoints for subplots in each site. We observed cover of grass litter, leaf litter (deciduous plant leaves), exposed rock, bare ground, and woody debris (e.g., logs, branches, and sticks). Total unvegetated area reflects space unoccupied by stem basal area in the subplots (Leis et al. 2022). We also measured litter depth in each subplot in 2019 and 2024. One measurement in each subplot (n = 10 per site) was averaged to create a site-level mean for litter depth.

Table 1. Modified Daubenmire cover value scale used to determine ground cover for the Heartland Network Parks.

Cover Class Code	Range of Cover (%)	Class Midpoint (%)
7	95.1–100.0	97.5
6	75.1–95.0	85.0
5	50.1–75.0	62.5
4	25.1–50.0	37.5
3	5.1–25.0	15.0
2	1.1–5.0	2.5
1	Present–1.0	0.5
0	Not present	0

Overstory and Midstory

Tree composition was based on individual tree counts for each species and diameter at breast height (DBH) for each tree > 5.0 cm DBH in the 0.1 ha sites. Dead trees (snags) were calculated separately from live trees. Basal area and stem density were calculated within size class categories (Table 2) as described in Leis et al. (2022). We distinguished Class 1 (midstory trees) from classes 2–5 (overstory trees) for interpretation. Stem density and DBH were scaled to the hectare for analysis. Taken together, all tree metrics were used to describe the forest structure for Lincoln Boyhood National Memorial.

Table 2. Diameter at breast height (DBH) measurement range (cm) and size class used to group midstory and overstory trees.

DBH Range (cm)	Size Class	Type
5.0–14.9	1	Midstory
15.0–24.9	2	Overstory
25.0–34.9	3	Overstory
35.0–44.9	4	Overstory
≥ 45	5	Overstory

We assessed change over time for midstory and overstory basal area and density by subtracting the baseline monitoring value from the current mean for relevant metrics (e.g., change in basal area = 2024 basal area − 2011 basal area). The occurrence of tree species in 2024 was calculated as the percent of all sites (N = 4 sites) occupied by each species in that year.

Canopy Closure

Canopy closure data were collected using a densiometer. Densiometer readings were collected in the four cardinal directions in each of the 10 m^2 subplots and converted to canopy closure (multiplied by

1.04). Subplot-level mean canopy closure (n = 4 per subplot) was used to calculate site-level mean canopy closure. A grand mean was then calculated for all sites (N = 4 sites).

Tree Regeneration

Tree regeneration stems were tallied by species in the 10 m^2 subplots and reported in three size classes: (1) seedlings = stems < 0.5 m tall; (2) small saplings = stems ≥ 0.5 m tall and DBH < 2.5 cm; and (3) large saplings = stems ≥ 0.5 m tall and DBH ≥ 2.5 cm and < 5.0 cm. Regeneration components are summed by species across the 10 monitoring plots in a site, and the sums are converted to stems/ha. Park-level mean densities were calculated by averaging site-level densities (N = 4 sites).

Ground Flora

Plant Species Diversity Indices

Species foliar cover measurements were estimated in the 10 m^2 plots using the modified Daubenmire cover classes (Table 1). Based on foliar cover measurements, diversity indices describe the number of species and their abundances. Mean site cover for all ground flora species was calculated using all subplots within each site. For each site within the community, species richness (S; for native and nonnative species separately), Shannon diversity index (H′) and evenness (J′) were calculated for native species. Native species richness, synonymous with *alpha* diversity, represents the number of native species observed. PC-ORD (version 7.02) was used to calculate these diversity indices (McCune and Mefford 2016). A grand mean was then calculated for all sites in the park (Minitab 2020).

Native plant diversity for each site was calculated using the Shannon diversity index (H′):

$$H' = -\sum_{i=1}^{n} p_i \ln p_i$$

where p_i is the relative cover of species *i* (Shannon and Weaver 1949).

Native species distribution evenness (J′) was calculated by site according to Pielou (1969):

$$J' = \frac{H'}{\ln (S)}$$

where H′ is the Shannon index and ln(S) is the maximum possible Shannon diversity for a given number of species if all species were present in equal abundance. Evenness is a measure of the distribution of species within a community as compared to equal distribution and maximum diversity (Pielou 1969). A value of 1 indicates even communities, whereas 0 indicates a heterogeneous community.

Community Diversity Metrics

Native plant community richness metrics evaluate how species richness differs across monitoring sites and the park. We limited these calculations to native ground flora species (not including tree regeneration).

Alpha diversity is synonymous with species richness at the site scale (i.e., mean number of species per monitoring site). *Gamma* diversity is the community-level richness observed across all monitoring sites (i.e., total number of species in the community). *Beta* diversity is a measure of heterogeneity in species distributions across monitoring sites such that small values (near 0) indicate a high degree of similarity in species occurrence across monitoring sites and greater values (> 5) indicate a higher degree of variation in species between sites (more differentiated communities; McCune and Grace 2002).

$$Beta \text{ Diversity} = \frac{gamma}{alpha} - 1$$

Guild Abundance

In addition to species analysis, native understory plant species were summarized by guilds, also known as functional groups (designations per the USDA Plants database; Leis et al. 2022; USDA NRCS 2017). Guild categories were grasses, forbs, grass-like (species including sedges and rushes), vines, and woody species for both native and nonnative species. A complete species list along with guild assignment is provided in Appendix A. Mean cover values were calculated for each guild-site-year combination. A grand mean was then calculated across all sites. We also summarized nonnative species trends using mean cover values for each monitoring event.

Statistical Analysis

Descriptive (graphical) analyses of ground cover and nonnative plants included all four sites over four monitoring events (16 total observations) to obtain more precise parameter estimates. Vegetation summaries were calculated in Minitab version 20.1.3 (Minitab 2020) and RStudio (R Core Team 2024). A non-parametric Friedman rank sum test was used to determine whether there were any statistical differences in species richness and diversity among monitoring events. Statistical significance was assessed at the alpha = 0.05 level.

Results/Discussion

Climate

Using a five-year running mean to compare trends in annual precipitation resulted in a strong contrast between the drier period prior to the 1990s and the current wet period the park is experiencing (Figure 2). Monthly precipitation is still quite variable, but there has been an increase in the proportion of rain falling in heavy storms (Figure 3; CCRP 2024). By contrast, months leading up to the 2024 sample event were largely drier than normal (Figure 3). Mean temperatures have been increasing (Figure 4); the temperature has increased by 3.2°F (1.8°C) per century since 1970 (CCRP 2024). However, 1970–1988 was an unusually cold period, and temperatures increased by only 0.5°F (17.5°C) since 1900. Although maximum temperatures have increased slowly, minimum temperatures have warmed more rapidly (CCRP 2024).

Although the park is experiencing a wet period now, it is not certain whether the climate will transition toward a warm wet or hot dry future. Both present stressors to plant communities that can affect species composition and forest health (CCRP 2024; NPS 2021).

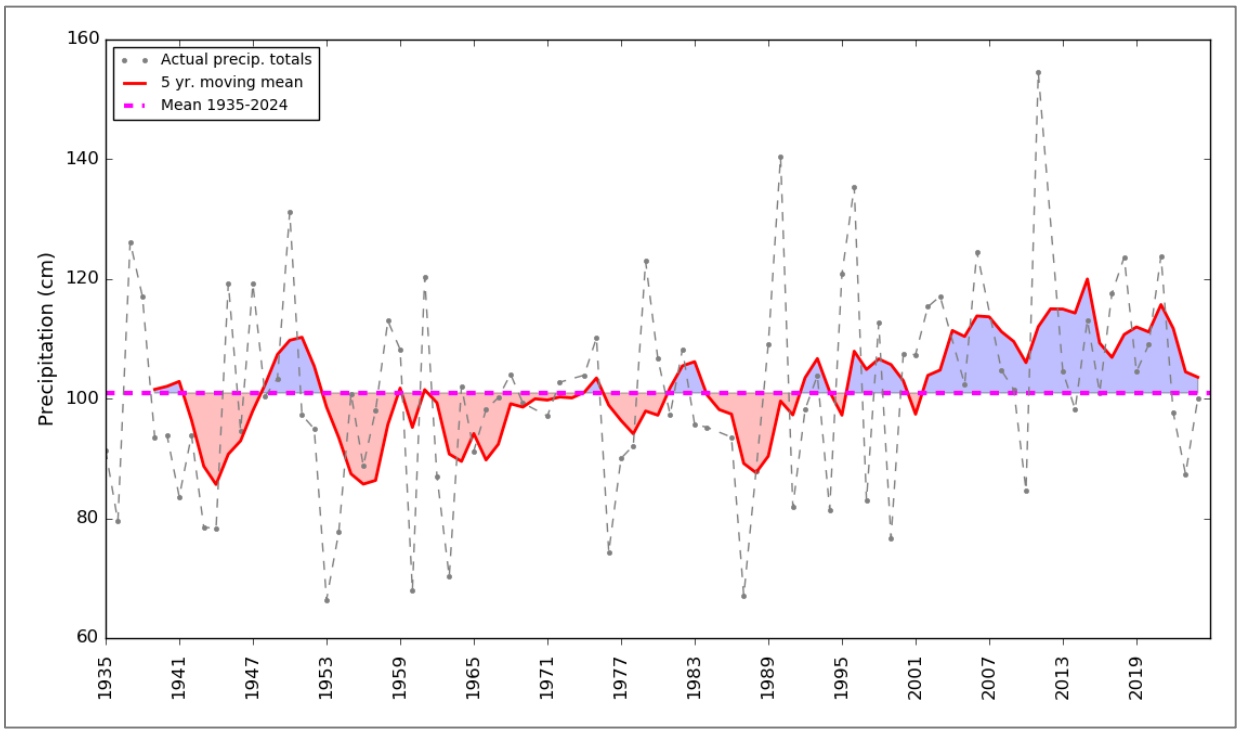

Figure 2. Historical precipitation (cm) from 1935–2024 at Lincoln Boyhood National Memorial. The trend has been smoothed using a 5-year moving window.

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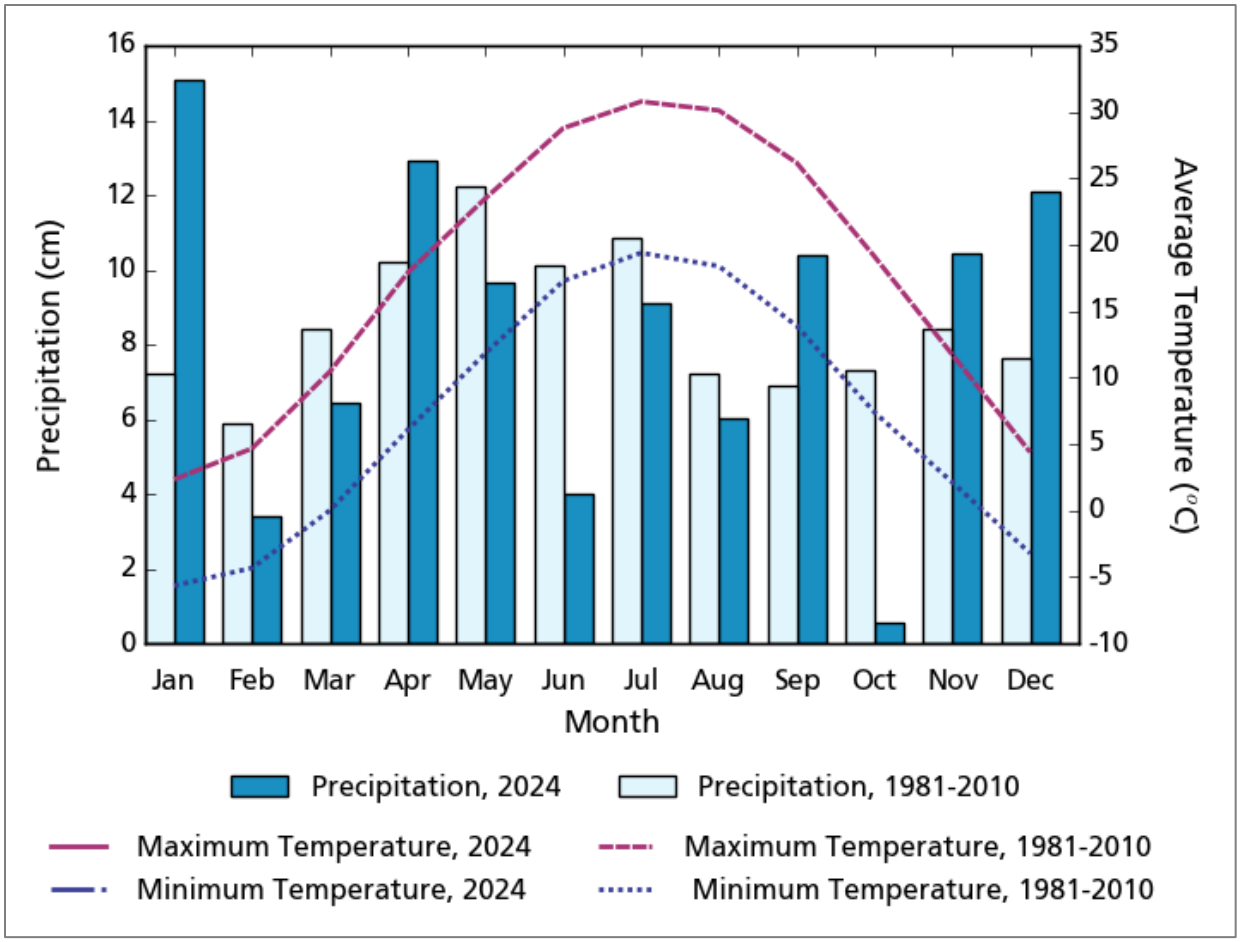

Figure 3. Precipitation trend and temperature normals for Lincoln Boyhood National Memorial. Precipitation is compared to 30-year normals (1981–2010). NOTE: minimum and maximum temperatures for 2024 were not available.

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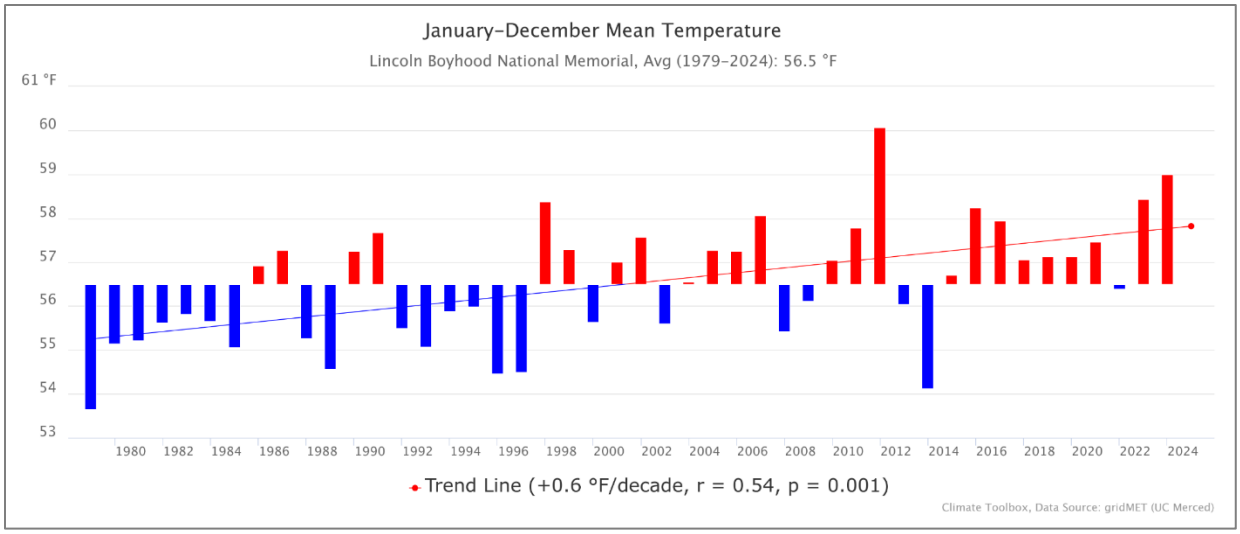

Figure 4. Mean temperature trends for Lincoln Boyhood National Memorial, 1979–2024
NPS / CLIMATE TOOLBOX

Midstory and Overstory Trees

Canopy Closure

Forests can be characterized using a variety of structural and species elements. Canopy closure was very similar through time and sites were very similar. Confidence intervals varied by only 4% in 2024 (Table 3). The community is characterized as a forest structure using the canopy closure metric (Hanberry et al. 2014). By contrast, closed oak woodland, a step towards a more open community, is characterized by canopy ranging from 56 to 86% closure.

Table 3. Mean midstory and overstory canopy closure at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). CI = confidence interval.

Year	Mean Canopy Closure (%)	CI (95%)
2011	95.6	92.0–97.7
2015	95.2	94.2–96.6
2019	92.8	90.7–94.3
2024	96.5	94.4–98.3

Basal Area

Live basal area was similar through time (Table 4). We suspect some variation in the measured trees occurred as a result of imprecise placement of transect lines at site 1 in 2024. A dense midstory layer along with fallen large trees at this site made it challenging to place transect lines accurately over the monitoring period, and personnel varied between monitoring events. Live basal area within size classes was very stable through time (Figure 5). Class 5 trees comprised the majority of basal area

(both live and dead) with minor contributions from classes 1 and 2. Live tree basal area was ten times greater than the basal area for standing dead trees in the four monitoring sites in 2024 (Figure 6).

Table 4. Mean midstory and overstory basal area (m^2/ha) of live and dead trees and ranges of values at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites).

Year	Status (Live/Dead)	Mean Basal Area (m^2/ha)	Basal Area Range (m^2/ha)
2011	Live	32.1	16.5–41.3
2015	Live	31.8	16.5–41.4
2019	Live	28.7	16.5–41.5
2024	Live	30.7	16.5–41.6
2011	Dead	4.3	1.8–9.4
2015	Dead	4.8	2.2–11.1
2019	Dead	4.0	3.1–4.9
2024	Dead	3.2	1.7–5.3

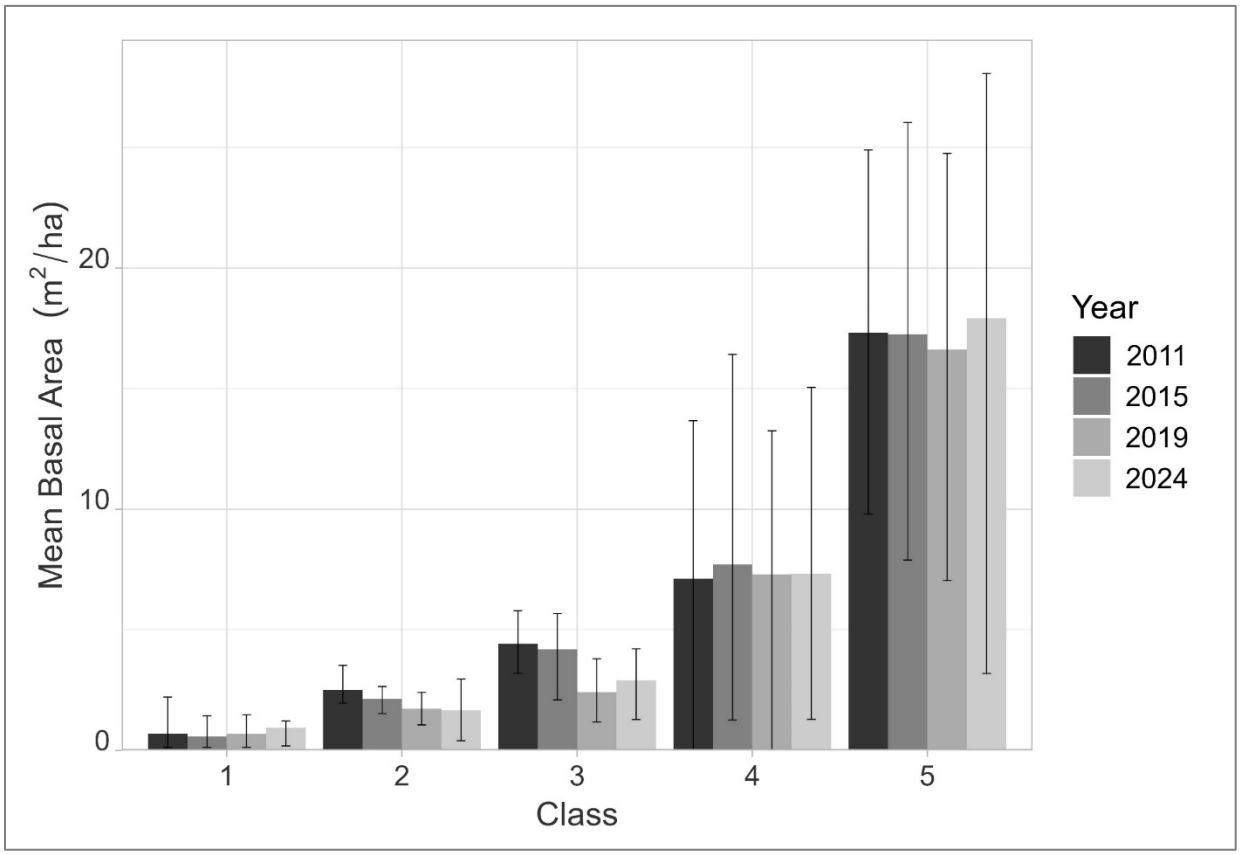

Figure 5. Mean basal area (m^2/ha) of live overstory trees by size class and year at Lincoln Boyhood National Memorial (N = 4 sites). The largest trees are category 5. Error bars represent the range of basal areas.

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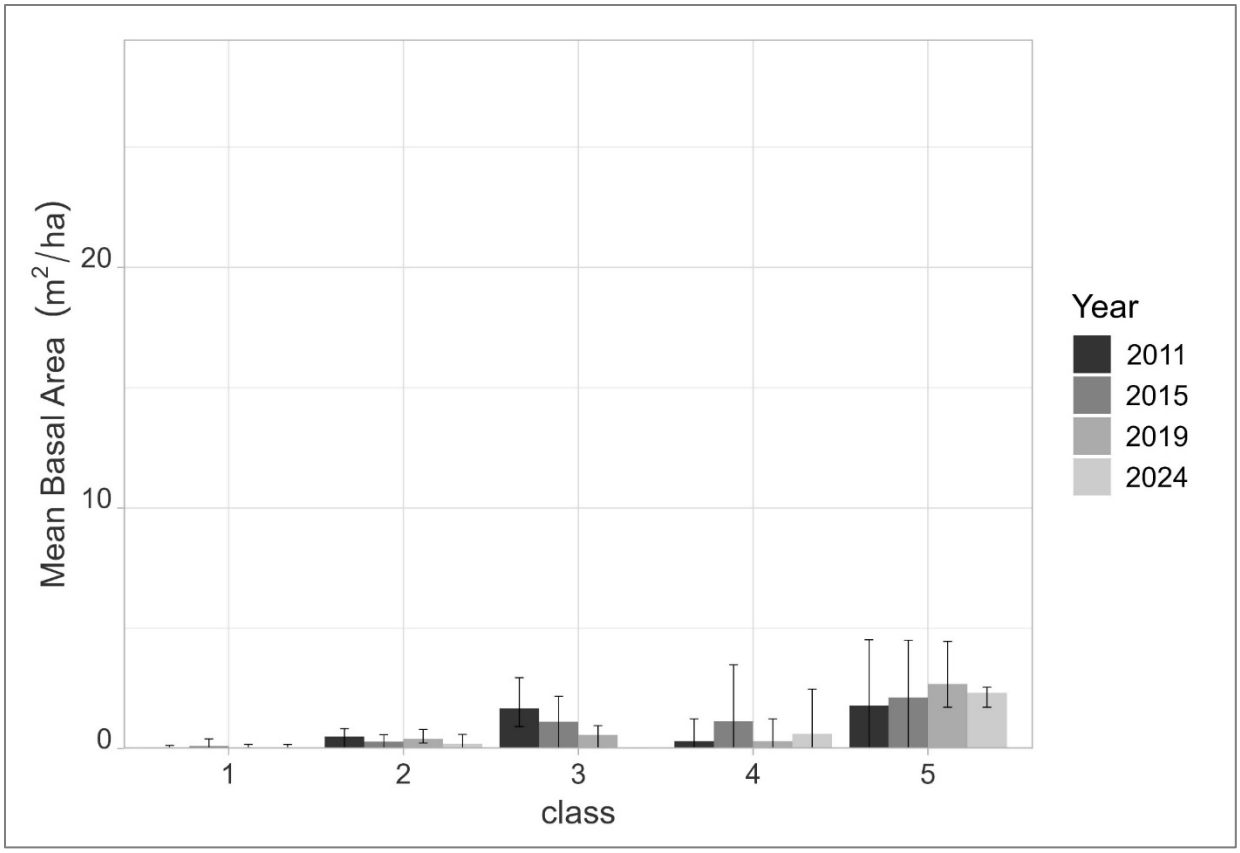

Figure 6. Mean basal area (m^2/ha) of dead overstory trees by size class and year at Lincoln Boyhood National Memorial (N = 4 sites). The largest trees are category 5. Error bars represent the range of dead basal area.

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Tree species richness was greatest in 2011 (18 species). Thirteen species of trees were observed in 2024, but an additional eight species were seen in other years (Appendix A). Changes in species composition of the overstory were supported by the trend in above average precipitation, which has favored mesic species over xeric species. The successional pathway towards a more closed forest was also consistent with these shifts in species (Figure 7). Increasing presence of sugar maple (*Acer saccharum*) has long been a concern at the park; its basal area increased by 42% over the 2011 observations. Interestingly, red maple (*Acer rubrum*) basal area declined. It is important to note that it is unknown whether the change in red and sugar maples was the result of misidentification or real change. White ash (*Fraxinus americana*) was missing from the overstory, but that was not unexpected considering the ongoing challenges presented by the emerald ash borer (*Agrilus planipennis*; Herms and McCullough 2014). Black oak (*Quercus velutina*), a characteristically xeric species, declined, and both white oak (*Quercus alba*) and shingle oak (*Quercus imbricaria*) were only present in 2011. Eastern redbud (*Cercis canadensis*) was a new addition for 2024. Of note, eastern white pine (*Pinus strobus)* and sassafras (*Sassafras albidum*) were only observed in 2011. It also appears likely observers shifted from identifying elms (*Ulmus* spp.) as slippery elm (*Ulmus rubra*) in 2011–2015 to identifying them as American elm (*Ulmus americana*) in 2019–2024, which

may not be an actual change in species composition. Efforts to put identification tags on the trees in 2019 seemed to have stabilized the taxonomy since there was similarity in species between 2019 and 2024. However, a large number of trees needed to be retagged in 2024 as a result of tag rejection.

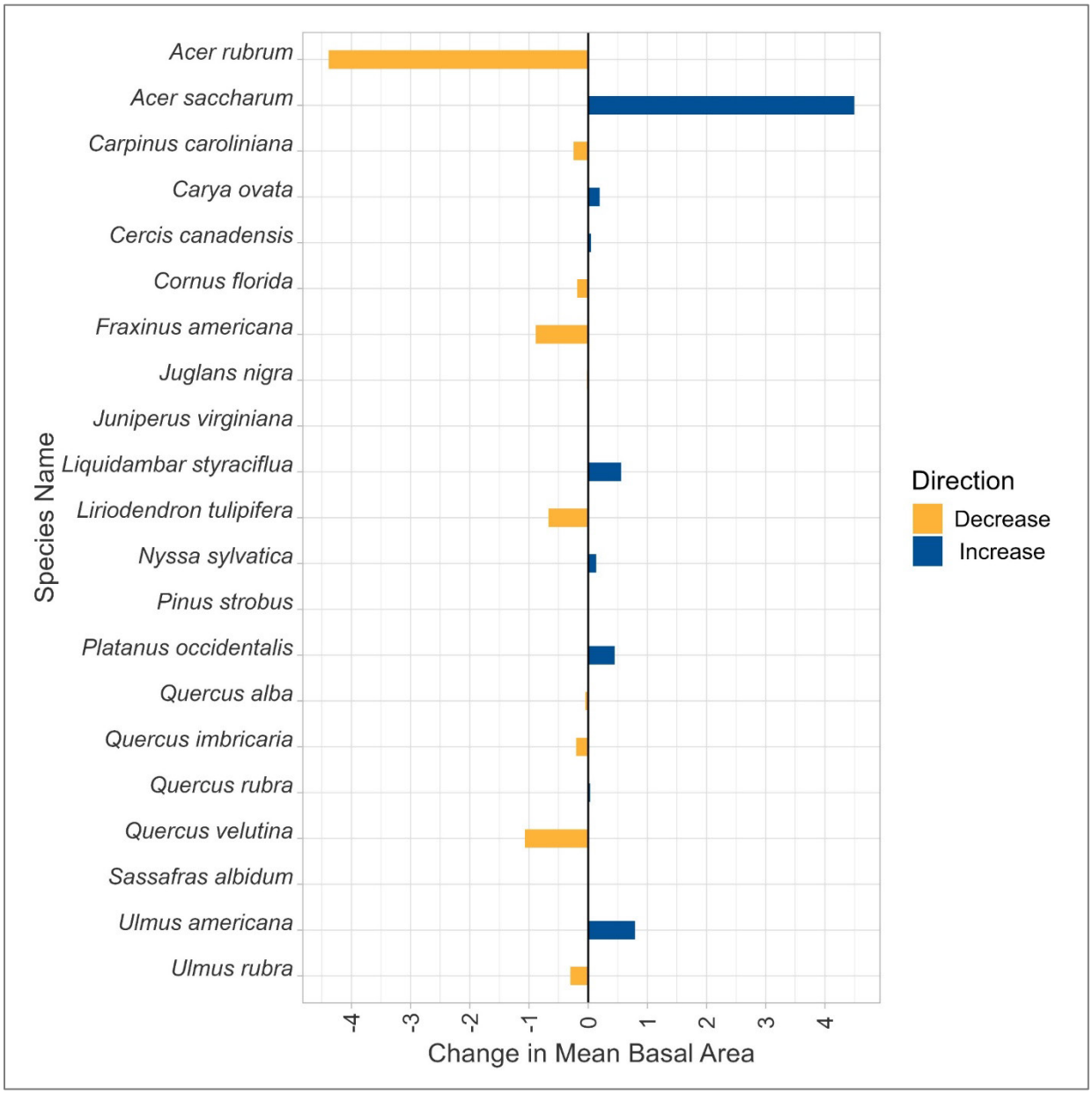

Figure 7. Change in mean tree species basal area (m^2) for monitoring sites at Lincoln Boyhood National Memorial from 2011 to 2024. Species with no bar were not present in 2011 or did not change. (N = 4 sites)
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Density

Mean stem density was least in 2019, but similar in other years. We suspect that may be the result of difficulty in placing transect lines, particularly at site 1 (see basal area; Table 5). Live stem density

was similar for classes (Figure 8). Typically, we expect to see more class 1 trees with a declining density toward class 5 in the shape of a reversed "J." The stand appears to be rather even-aged based on mean densities over the monitoring period, which exceed the typical density for this forest type (Hanberry et al. 2014: average = 195 stems/ha, range = 97–264 stems/ha). The forest at Lincoln Boyhood National Memorial is dense. Dead stem density varied greatly by monitoring site. Live trees were similar in density among size classes through time. Standing dead trees, although much less abundant, had similar class distributions through time (Figures 8 and 9).

Table 5. Mean midstory and overstory density (stems/ha) at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites).

Year	Status (Live/Dead)	Mean Stem Density (stems/ha)	Stem Density Range (stems/ha)
2011	Live	345.0	180–540
2015	Live	337.5	190–450
2019	Live	310.0	200–420
2024	Live	357.5	230–430
2011	Dead	55.0	20–110
2015	Dead	65.0	10–160
2019	Dead	47.5	30–80
2024	Dead	30.0	10–60

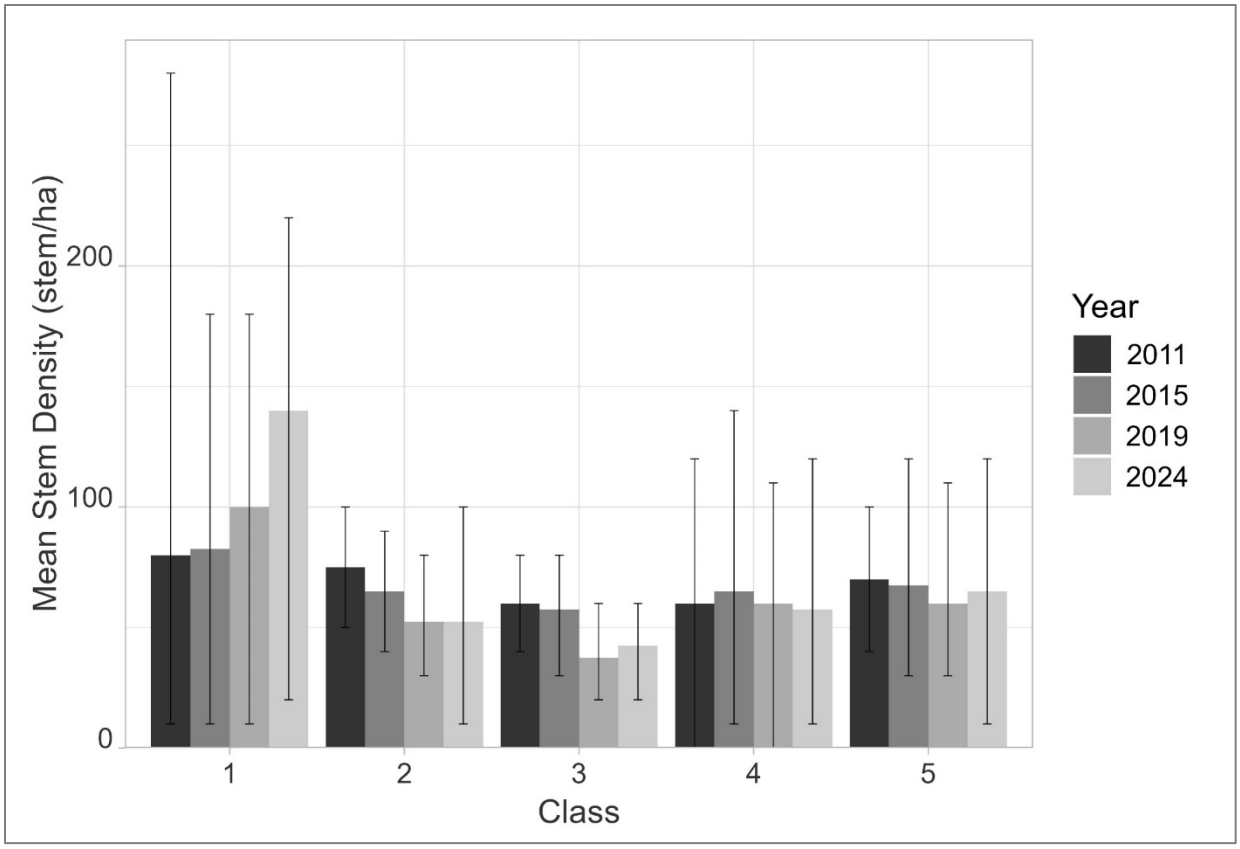

Figure 8. Live midstory and overstory mean stem density (stems/ha) at Lincoln Boyhood National Memorial by size class and year (N = 4 sites). The largest trees are category 5. Error bars represent the range of mean live stem density.

NPS

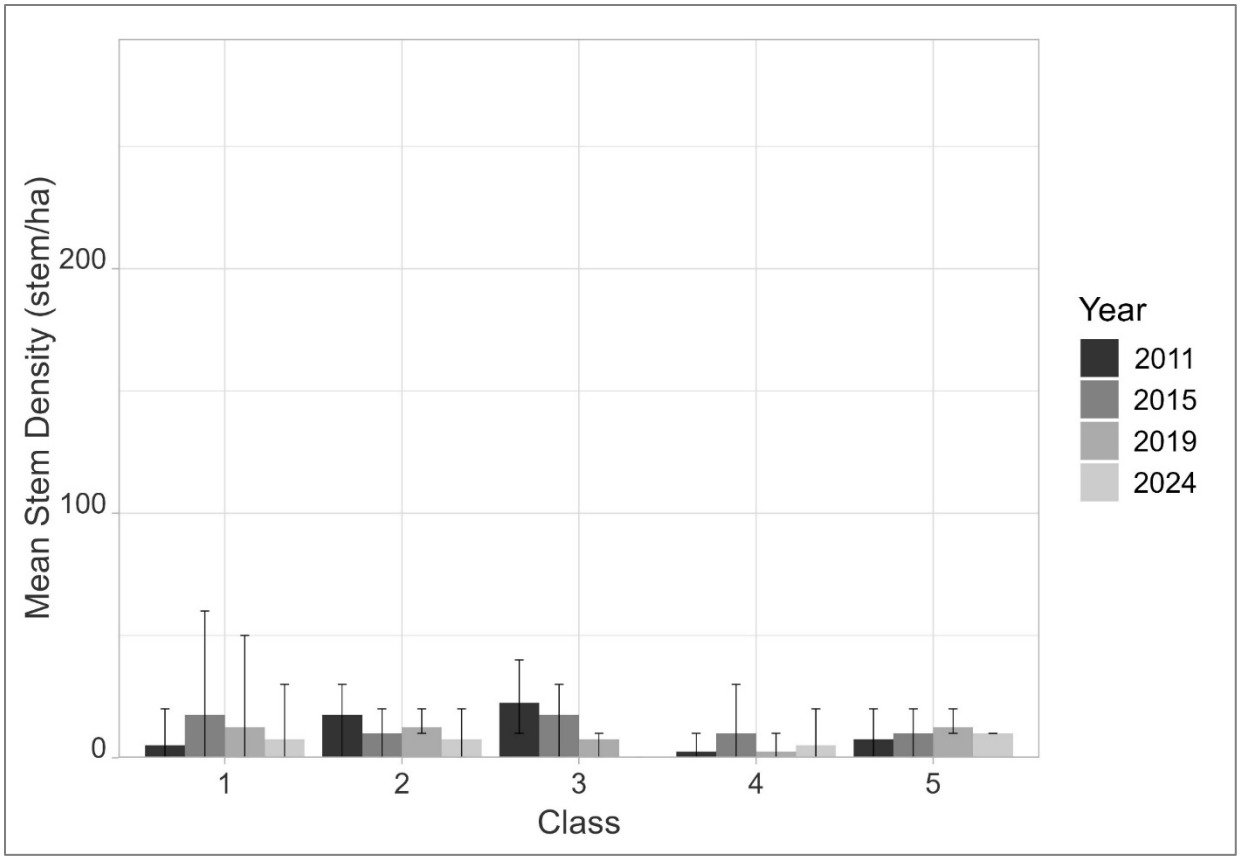

Figure 9. Dead midstory and overstory mean stem density (stems/ha) at Lincoln Boyhood National Memorial by size class and year (N = 4 sites). The largest trees are category 5. Error bars represent the range of mean dead stem density.
NPS

With respect to changes in species composition based on density, tuliptree (*Liriodendron tulipifera*) and blackgum (*Nyssa sylvatica*) increased the most since 2011, 700% and 600%, respectively (Figure 10). Sugar maple density increased by 12.3%. Similar to red maple basal area, red maple density declined by 72%, and flowering dogwood (*Cornus florida*) density declined by 47% from the initial measurements.

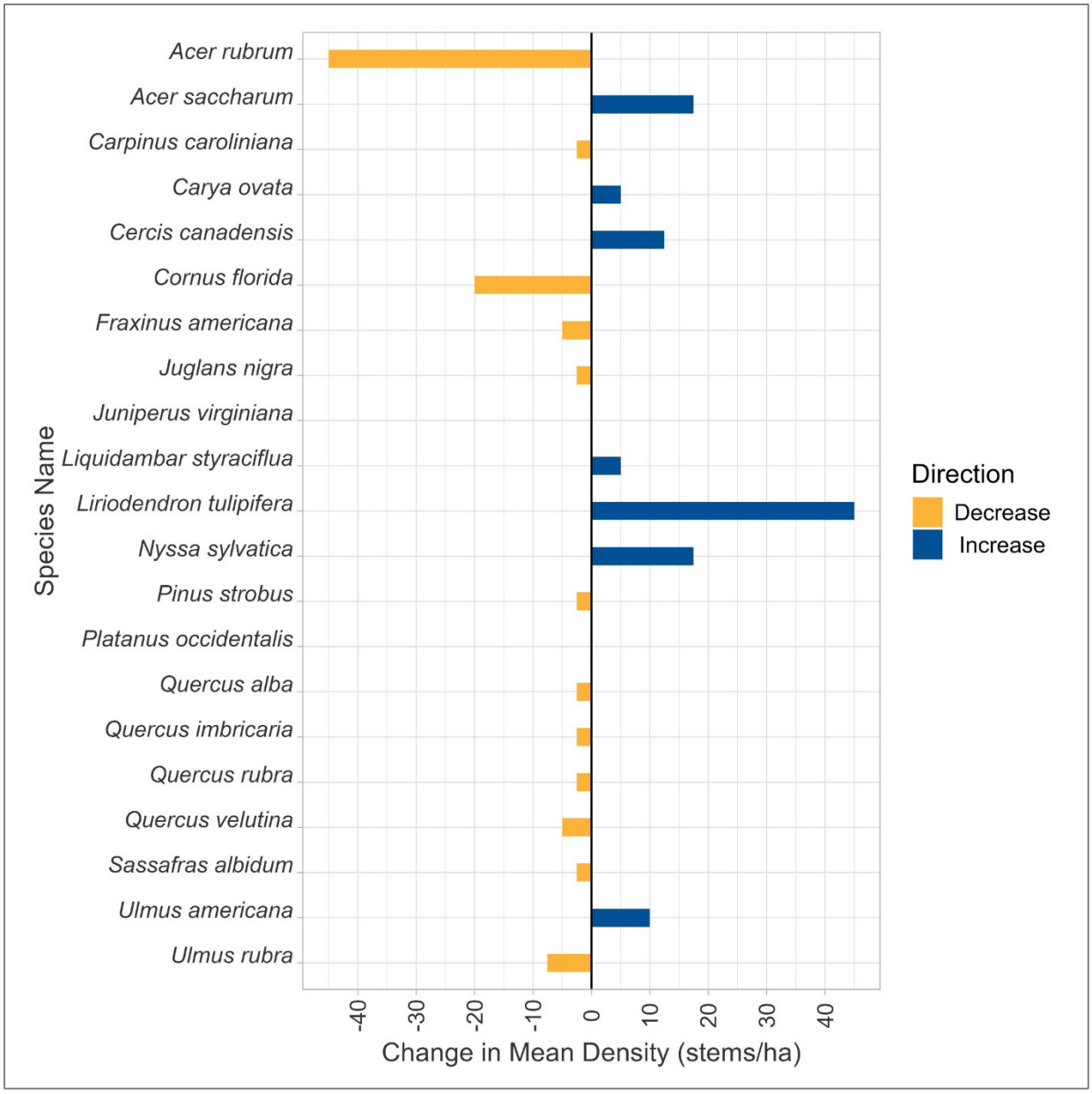

Figure 10. Change in mean tree species density for long-term monitoring sites at Lincoln Boyhood National Memorial from 2011 to 2024 (N = 4 sites). Species with no bar were not present in 2011 or did not change.

NPS

Ground Cover

Mean litter depth was about 3 cm, but confidence intervals indicate there was similarity across the four sites (Table 6). The litter layer, although not very deep, was pervasive in all years (Figure 11). Most of the ground surface was covered in leaf litter. Plant stem basal cover on monitoring sites was low. Woody debris was greatest in the initial monitoring year (2011). Archival photos indicate a recent large tree fall prior to monitoring in 2011, and debris is continuing to decay. Observers in 2024

noted there were large amounts of woody debris in and around the sites that were not captured in the plot estimates.

Table 6. Mean litter depth (cm) at Lincoln Boyhood National Memorial, 2019–2024 (N = 4 sites).

Year	Litter Depth (cm)	Range
2019	2.0	1.2–2.7
2024	2.9	2.5–3.1

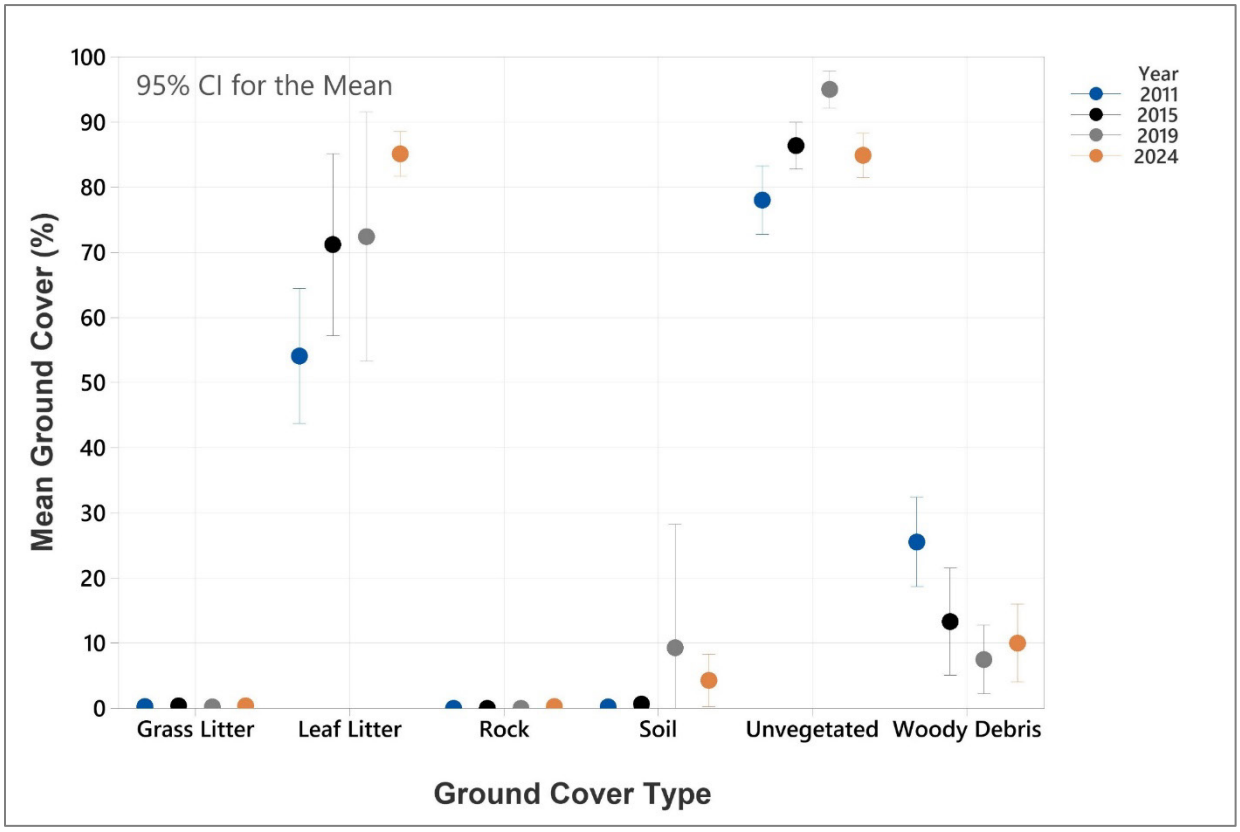

Figure 11. Mean ground cover (%) in the forest monitoring sites at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). Bars represent 95% confidence intervals.
NPS

Guilds

Tree Regeneration

Mean tree seedling density continued to increase over time, but sapling densities changed very little. Large saplings were rare in 2024 (Figure 12). Counter to the loss of ash from the overstory, there was a flush of ash seedlings: ash seedlings increased by 339% from 2011 observations. Sites 3 and 4 had large cohorts of ash seedlings in 2024. Changes in species composition for seedlings reflected the field observations for ash but also included increases in a variety of primarily mesic species (Figure 13). Interestingly, sugar maple seedlings declined from 2011 by 7%.

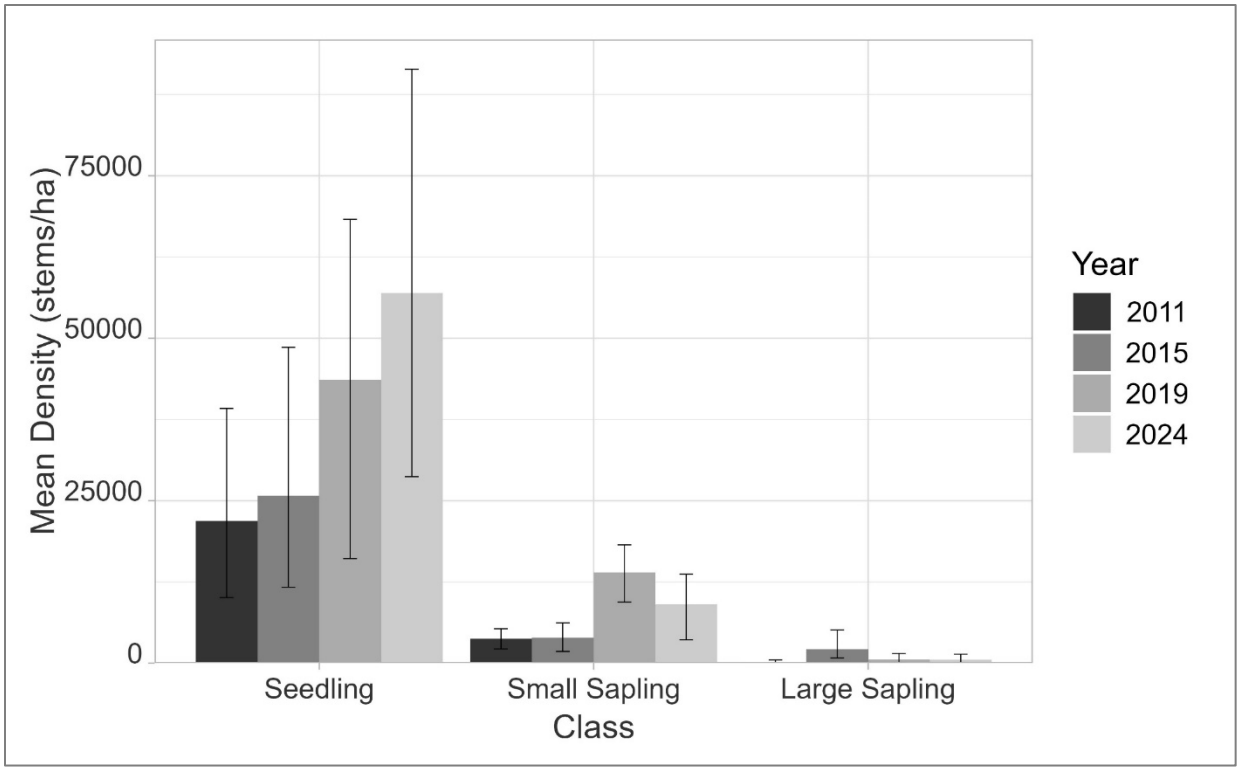

Figure 12. Mean stem density (stems/ha) for tree regeneration size classes at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). Bars represent the range in tree regeneration mean densities.
NPS

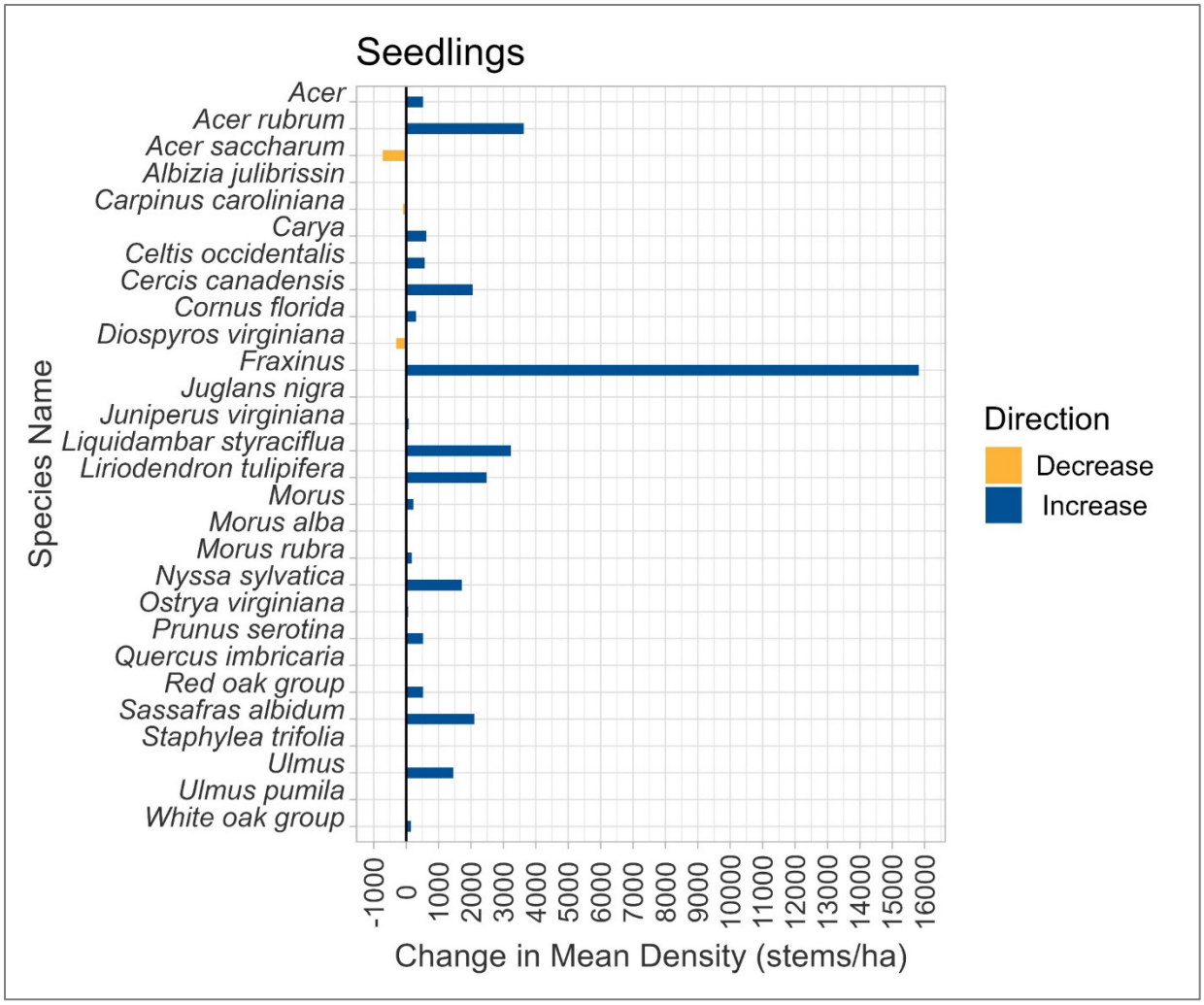

Figure 13. Change in mean tree regeneration density for the seedlings class (mean stems/ha) from 2011 to 2024 at Lincoln Boyhood National Memorial (N = 4 sites). Species with no bar were not present in 2011 or did not change.

NPS

Change in species composition for small sapling regeneration further reflects a more mesic and shaded forest (Figure 14). Sugar maples progressed from seedlings into the sapling phase. Ash seedlings also transitioned in large numbers to the small sapling phase, but only one stem was counted in the large sapling phase. Both sugar maple and ash small sapling densities were 134% greater in 2024 than in 2011. Small saplings in the more xeric genus of hickory (*Carya* sp.) were less dense but increased by 133% over 2011.

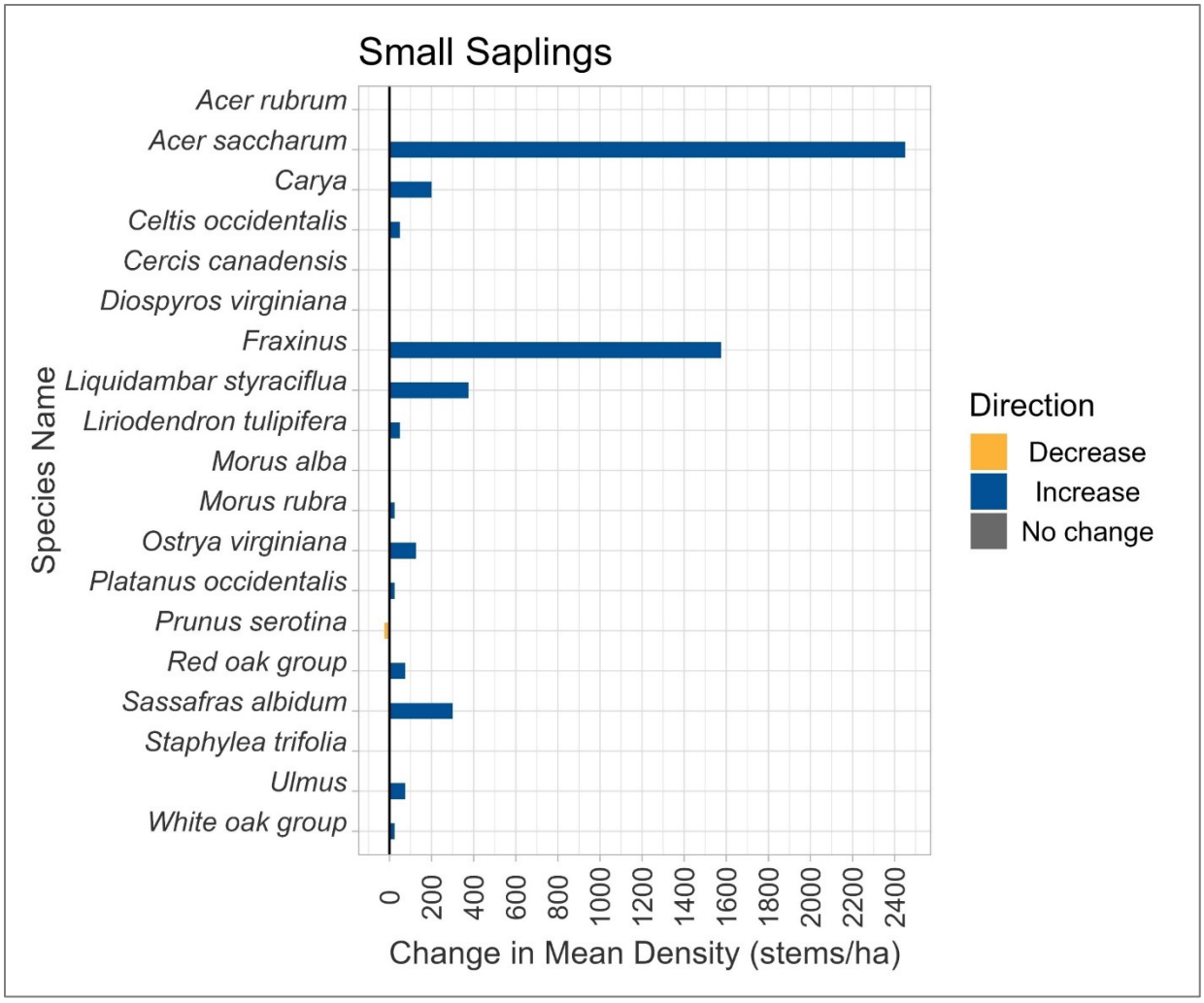

Figure 14. Change in mean tree regeneration density for the small saplings class (mean stems/ha) from 2011 to 2024 at Lincoln Boyhood National Memorial (N = 4 sites). Species with no bar were not present in 2011 or did not change.

NPS

Fewer species were recorded in the large sapling stage (6 species in 2024, 10 species in 2011), and sugar maple dominated the large saplings class (Figure 15). The leaves of these saplings can be seen in the archival photos for 2024 (Appendix B). While ash large saplings were absent in 2011, 25 stems/ha were observed in 2024. Emerald ash borer is known to infest ash trees with a DBH ≥ 2.5 cm (≥ large sapling size). This insect is likely responsible for killing the overstory stems and can affect large saplings (McCullough et al. 2008; Rebek et al. 2008). It may take two to three years for a germinated seed to become a mature seedling, and trees begin flowering in about 10–15 years when they reach the midstory stage at 8–10 cm DBH (class 1 midstory trees in our categorization of trees; Clark 1962; Klooster et al. 2013). The current seed bank will be depleted over the next few years, leaving the younger regeneration class as the last ash cohort for the woods. With the diminished overstory and large sapling cohorts, recovery potential for ash in the woodlands is limited.

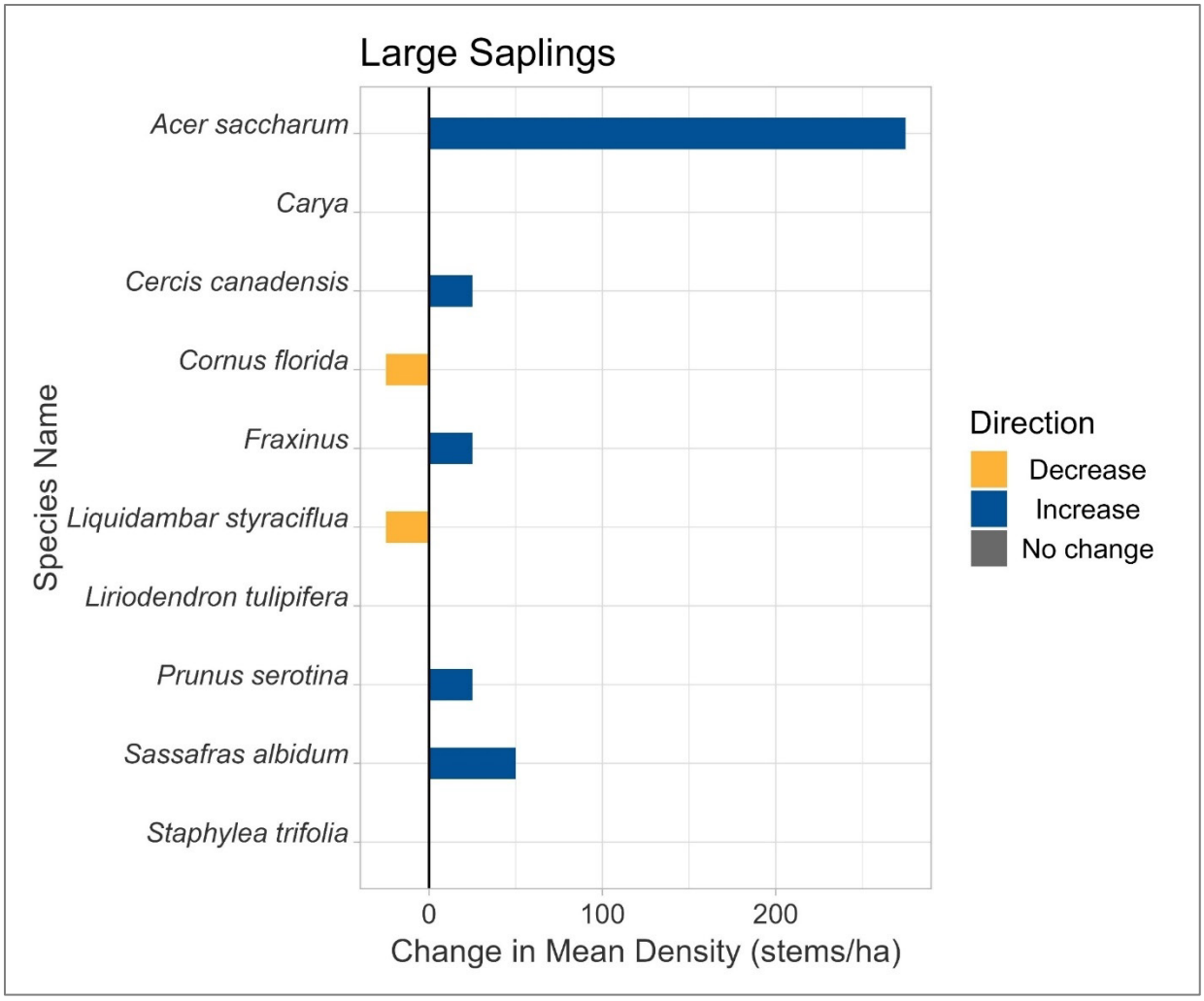

Figure 15. Change in mean tree regeneration density for the large saplings class (mean stems/ha) from 2011 to 2024 at Lincoln Boyhood National Memorial (N = 4 sites). Species with no bar were not present in 2011 or did not change.

NPS

Native Ground Flora Guilds

Cover of native ground flora species guilds was similar through time (Figure 16), with many species occurring in low abundance. Forbs and woody plants are the most abundant guilds while ferns, grass-like plants, and grasses were not abundant in this forest. (See Appendix A for species list and current abundances) Virginia creeper (*Parthenocissus quinquefolia*), a more abundant native species, was noted to have many stems in a juvenile/seedling stage across the sites. Field crews also noted yellow passionflower (*Passiflora lutea*) was present only at site 1. Environmental conditions in the forest resulting from a shade-producing closed canopy in conjunction with an abundant litter layer are not conducive to ground flora establishment and growth.

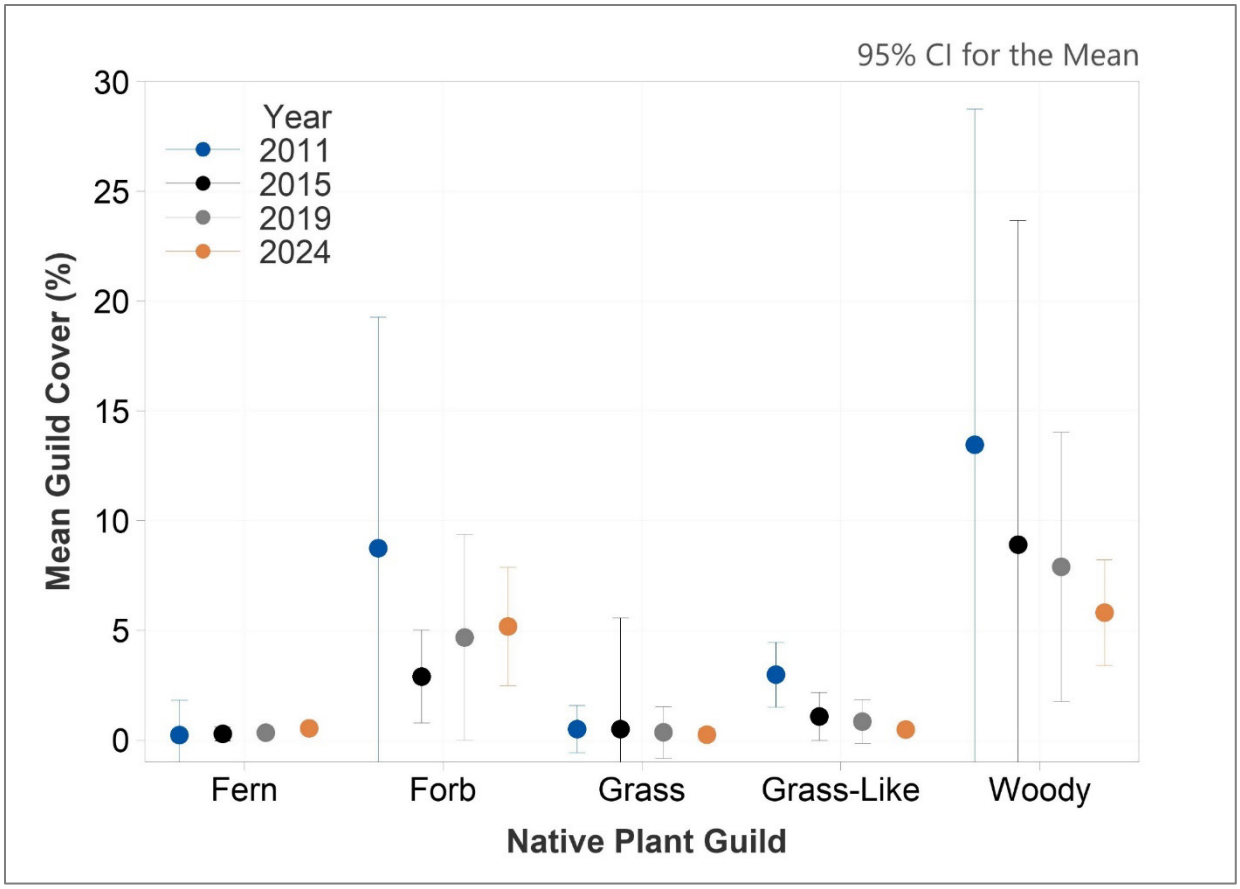

Figure 16. Mean cover of native ground flora plant guilds in long-term monitoring sites at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites).

NPS

Nonnative Plants

Nonnative plants can sometimes be problematic. We observed 14 species of nonnative plants during monitoring in 2011–2024, with 12 of those species present in 2024. The mean number of nonnative species was less in 2011 and 2015 than in 2019 and 2024 (Table 7).

Table 7. Mean richness of nonnative plant species observed in long-term monitoring sites at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). SE = standard error.

Year	Mean Species Richness	SE
2011	3.8	0.9
2015	3.3	0.8
2019	6.3	0.9
2024	7.8	0.3

The most pervasive of the nonnative plants observed continues to be Japanese honeysuckle (*Lonicera japonica)* and common periwinkle (*Vinca minor*; Table 8). Japanese honeysuckle was reduced by 76% after the 2015 monitoring event. Although common periwinkle declined after 2011, it returned and exceeded prior levels in 2024.

Table 8. Mean cover (%) of two nonnative problematic plant species at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). SE = standard error.

	Lonicera japonica		***Vinca minor***	
Year	**Mean Cover (%)**	**SE**	**Mean Cover (%)**	**SE**
2011	9.1	4.9	7.9	6.0
2015	6.9	3.8	4.0	4.0
2019	2.4	1.0	4.3	3.7
2024	2.2	1.0	8.8	6.4

Ground Flora Diversity

Species Diversity

Native species richness was greater in 2024 than in other years (Friedman chi-squared = 11.1, df = 3, p = 0.01; Conover test: 2024 < 0.05 for all year comparisons; Figure 17). The source of an increase in species in the monitoring sites in 2024 is unknown at this time. Although the mean for the Shannon diversity index was greater in 2024, it was not significant (Friedman chi-squared = 5.7, df = 3, p = 0.13; Figure 18). Evenness (J′) was similar through time. Values for J′ ranged from 0.73 in 2011 to 0.83 in 2024. The native vegetation demonstrates a high level of evenness, meaning species are relatively equally distributed with few dominant species. We did note that observers for 2024 had not been present in other monitoring events, but the effect of new observers is unknown.

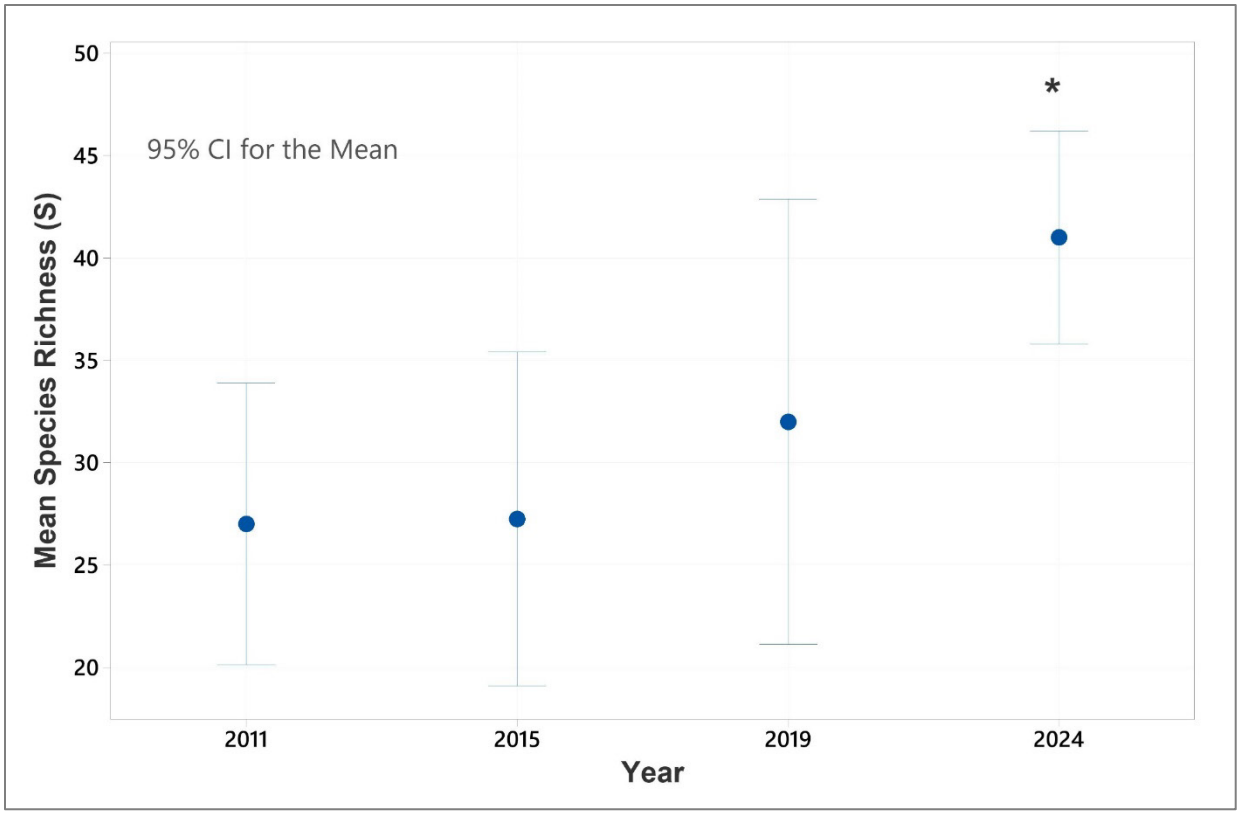

Figure 17. Mean native species richness (S) for ground flora long-term monitoring sites at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). CI = 95% confidence interval. The asterisk (*) indicates S was significantly different at $p < 0.05$.

NPS

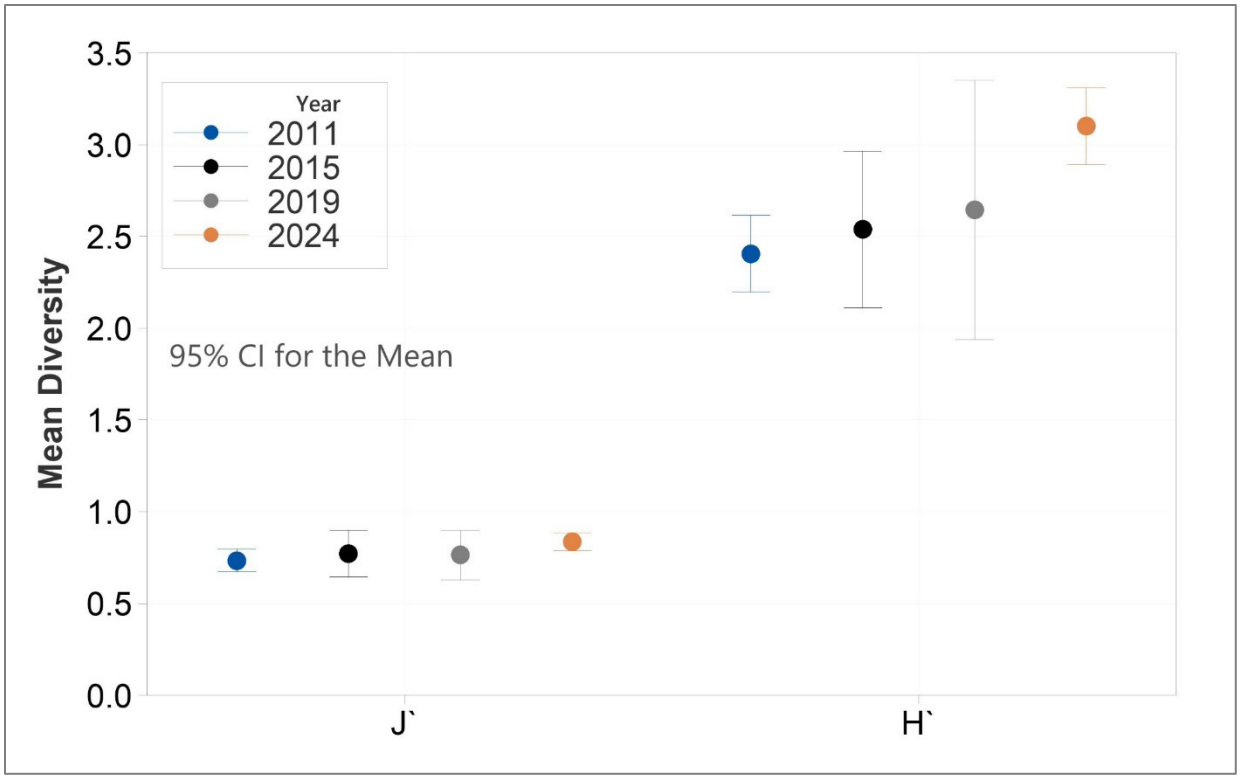

Figure 18. Mean native species diversity as measured by H′ (Shannon diversity index) and J′ (Pielou's evenness index) for ground flora long-term monitoring sites at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites). CI = 95% confidence interval.

NPS

Community Diversity

Alpha and gamma diversity increased in 2024 over other years (Table 9). Beta diversity was similar through time. Although species numbers increased, site heterogeneity was similarly low through the monitoring period. Low beta diversity indicates sites were relatively similar in composition.

Table 9. Plant community diversity metrics for ground flora at Lincoln Boyhood National Memorial, 2011–2024 (N = 4 sites).

Community Diversity Measure	2011	2015	2019	2024
Alpha diversity (mean site richness)	**27.0**	**27.3**	**32.0**	**41.0**
Gamma diversity (park richness)	48	48	58	74
Beta diversity (heterogeneity)	0.87	0.76	0.81	0.80

Conclusion

The climate affecting the forests at the park has been changing over the long term. Since monitoring began in 2011, the park has been in a wet and warming period as compared to historical conditions. Warming can lead to water stress even when there is more precipitation because of increasing water demand on plants (Thoma et al. 2020). Over time, the plant composition may change (Phillips et al. 2020; Thornthwaite 1948).

Monitoring metrics indicate the forest structure has consistently been a dense, closed canopy forest, where the basal area is at the upper limits for the forest community type (Hanberry et al. 2014). Despite the loss of ash trees resulting from the emerald ash borer, the structure was unchanged. Shifting species composition indicates the forest may become dominated by more mesic species that favor low light conditions for germination. Fewer species in the overstory and tree regeneration may point to diminishing tree resilience resulting from changes in climate and/or natural successional processes.

The midstory and overstory structure provide the foundation for the ground flora. The forest floor is dominated by a pervasive layer of leaf litter with minimal vegetative basal area. Tree seedlings continue to increase, supporting the mesophication hypothesis for the forest (Nowacki and Abrams 2008). We did note that early ash regeneration is still an important and dominant component of the regeneration guild, but the seedlings and small saplings will be subject to emerald ash borer infection as they grow.

Forbs and woody plants are most abundant within the limited ground flora. Nonnative species richness increased since 2011, but abundance of the two dominant problematic species varied. Japanese honeysuckle declined while common periwinkle was greater in 2024 than in other years. Mean native species richness and gamma diversity (parkwide richness) increased in 2024, but species diversity indices were similar to other years.

Overall, the forest is a dense habitat with increasingly mesic tree species. Nonnative treatment efforts seem to have reduced one target species, but new species were detected. Additional efforts to manage the forest will be needed to maintain a healthy ecosystem that supports the objectives of the park.

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Appendix A. Species

Tables 10 and 11 show all plant species detected during monitoring at Lincoln Boyhood National Memorial between 2011 and 2024.

Table 10. Midstory and overstory tree species observed in long-term monitoring sites at Lincoln Boyhood National Memorial, 2011–2024. Species occurrence is based on percent of sites where species was present (N = 4 sites). Species with 0 values were observed in 2011–2019 but not in 2024.

Species	Common Name	2024 Occurrence (% of sites)
Acer rubrum	red maple	50
Acer saccharum	sugar maple	100
Carpinus caroliniana	American hornbeam	0
Carya ovata	shagbark hickory	25
Cercis canadensis	eastern redbud	50
Cornus florida	flowering dogwood	25
Fraxinus americana	white ash	50
Juglans nigra	black walnut	0
Juniperus virginiana	eastern redcedar	0
Liquidambar styraciflua	sweetgum	100
Liriodendron tulipifera	tuliptree	75
Nyssa sylvatica	blackgum	25
Pinus strobus	eastern white pine	0
Platanus occidentalis	American sycamore	25
Quercus alba	white oak	0
Quercus imbricaria	shingle oak	0
Quercus rubra	northern red oak	25
Quercus velutina	black oak	25
Sassafras albidum	sassafras	0
Snag	snag	100
Ulmus americana	American elm	75
Ulmus rubra	slippery elm	0

Table 11. Ground flora species observed at Lincoln Boyhood National Memorial (N = 4 sites). Values for mean cover, standard error (SE), and occurrence are only for 2024 (most recent monitoring event). NA = species was observed in prior monitoring years but not in 2024; N = native; I = nonnative.

Species	Common Name	Guild	Origin	Mean Cover 2024 (%)	SE	Occurrence (% Sites) 2024
Acalypha virginica	Virginia threeseed mercury	forb	N	0.03	0.02	50
Ageratina altissima	white snakeroot	forb	N	0.24	0.07	100
Amphicarpaea bracteata	American hogpeanut	forb	N	0.01	0.01	25
Aralia spinosa	devil's walking stick	woody	N	0.07	0.07	25
Arisaema dracontium	green dragon	forb	N	0.03	0.03	25
Arisaema triphyllum	Jack in the pulpit	forb	N	0.04	0.04	25
Aristolochia serpentaria	Virginia snakeroot	forb	N	0.12	0.03	100
Asplenium platyneuron	ebony spleenwort	fern	N	0.04	0.02	50
Aster sp.	aster	forb	N	NA	NA	NA
Berberis thunbergii	Japanese barberry	woody	I	NA	NA	NA
Bidens bipinnata	Spanish needles	forb	N	0.04	0.03	50
Bidens sp.	beggarticks	forb	N	NA	NA	NA
Boehmeria cylindrica	smallspike false nettle	forb	N	0.06	0.04	50
Botrychium multifidum	leathery grapefern	fern	N	0.04	0.04	25
Botrychium virginianum	rattlesnake fern	fern	N	0.36	0.03	100
Campanulastrum americanum	American bellflower	forb	N	NA	NA	NA
Campsis radicans	trumpet creeper	woody	N	0.10	0.07	75
Carex sp.	sedge	grass-like	N	0.48	0.04	100
Celastrus orbiculatus	Oriental bittersweet	woody	I	1.87	0.59	100
Celastrus scandens	American bittersweet	woody	N	0.11	0.07	75
Cercis canadensis	eastern redbud	woody	N	NA	NA	NA

Table 11 (continued). Ground flora species observed at Lincoln Boyhood National Memorial (N = 4 sites). Values for mean cover, standard error (SE), and occurrence are only for 2024 (most recent monitoring event). NA = species was observed in prior monitoring years but not in 2024; N = native; I = nonnative.

Species	Common Name	Guild	Origin	Mean Cover 2024 (%)	SE	Occurrence (% Sites) 2024
Cinna arundinacea	sweet woodreed	grass	N	0.03	0.03	25
Cirsium vulgare	bull thistle	forb	I	0.01	0.01	25
Clematis virginiana	devil's darning needles	woody	N	0.04	0.03	50
Conoclinium coelestinum	blue mistflower	forb	N	NA	NA	NA
Cornus drummondii	roughleaf dogwood	woody	N	NA	NA	NA
Corylus americana	American hazelnut	woody	N	NA	NA	NA
Cynoglossum virginianum	wild comfrey	forb	N	0.01	0.01	25
Danthonia spicata	poverty oatgrass	grass	N	0.03	0.03	25
Desmodium paniculatum	panicledleaf ticktrefoil	forb	N	NA	NA	NA
Desmodium sp.	ticktrefoil	forb	N	0.01	0.01	25
Dichanthelium sp.	rosette grass	grass	N	0.03	0.03	25
Dioscorea quaternata	fourleaf yam	forb	N	0.28	0.17	50
Elephantopus carolinianus	Carolina elephantsfoot	forb	N	0.03	0.03	25
Elymus villosus	hairy wildrye	grass	N	0.01	0.01	25
Elymus virginicus	Virginia wildrye	grass	N	0.03	0.03	25
Erechtites hieraciifolius	American burnweed	forb	N	0.04	0.03	50
Euonymus alatus	burning bush	woody	I	0.24	0.17	75
Euonymus atropurpureus	eastern burning bush	woody	N	0.03	0.03	25
Euonymus fortunei	winter creeper	woody	I	0.27	0.05	100
Euonymus sp.	spindletree	woody	I	0.01	0.01	25
Eupatorium perfoliatum	common boneset	forb	N	NA	NA	NA
Galium aparine	stickywilly	forb	N	0.01	0.01	25

Table 11 (continued). Ground flora species observed at Lincoln Boyhood National Memorial (N = 4 sites). Values for mean cover, standard error (SE), and occurrence are only for 2024 (most recent monitoring event). NA = species was observed in prior monitoring years but not in 2024; N = native; I = nonnative.

Species	Common Name	Guild	Origin	Mean Cover 2024 (%)	SE	Occurrence (% Sites) 2024
Galium circaezans	licorice bedstraw	forb	N	0.39	0.08	100
Galium concinnum	shining bedstraw	forb	N	0.01	0.01	25
Galium triflorum	fragrant bedstraw	forb	N	0.06	0.02	75
Geum canadense	white avens	forb	N	0.12	0.04	75
Geum sp.	avens	forb	N	0.09	0.02	100
Geum vernum	spring avens	forb	N	0.07	0.07	25
Glyceria striata	fowl mannagrass	grass	N	0.01	0.01	25
Hackelia virginiana	beggarslice	forb	N	0.01	0.01	25
Hieracium sp.	hawkweed	forb	N	0.07	0.07	25
Hydrastis canadensis	goldenseal	forb	N	0.40	0.40	25
Hypericum densiflorum	bushy St. Johnswort	forb	N	NA	NA	NA
Impatiens capensis	jewelweed	forb	N	0.28	0.14	75
Leersia virginica	whitegrass	grass	N	0.11	0.08	75
Ligustrum vulgare	European privet	woody	I	0.03	0.01	50
Lindera benzoin	northern spicebush	woody	N	1.58	0.82	100
Liparis liliifolia	brown widelip orchid	forb	N	0.01	0.01	25
Lobelia inflata	Indian-tobacco	forb	N	0.03	0.03	25
Lonicera japonica	Japanese honeysuckle	woody	I	2.20	1.00	100
Menispermum canadense	common moonseed	woody	N	NA	NA	NA
Microstegium vimineum	Nepalese browntop	grass	I	0.22	0.14	75
Muhlenbergia schreberi	nimblewill	grass	N	NA	NA	NA
Ophioglossum vulgatum	southern adderstongue	fern	N	0.09	0.04	75

Table 11 (continued). Ground flora species observed at Lincoln Boyhood National Memorial (N = 4 sites). Values for mean cover, standard error (SE), and occurrence are only for 2024 (most recent monitoring event). NA = species was observed in prior monitoring years but not in 2024; N = native; I = nonnative.

Species	Common Name	Guild	Origin	Mean Cover 2024 (%)	SE	Occurrence (% Sites) 2024
Oxalis sp.	woodsorrel	forb	N	0.08	0.05	75
Parietaria pensylvanica	Pennsylvania pellitory	forb	N	0.08	0.01	100
Parthenocissus quinquefolia	Virginia creeper	woody	N	0.88	0.18	100
Passiflora lutea	yellow passionflower	forb	N	0.01	0.01	25
Perilla frutescens	beefsteakplant	forb	I	0.01	0.01	25
Phryma leptostachya	American lopseed	forb	N	0.40	0.06	100
Phytolacca americana	American pokeweed	forb	N	0.05	0.04	50
Pilea pumila	Canadian clearweed	forb	N	0.30	0.29	50
Podophyllum peltatum	mayapple	forb	N	0.09	0.07	50
Polygonatum biflorum	smooth Solomon’s seal	forb	N	0.03	0.02	50
Polygonum cespitosum	Oriental lady’s thumb	forb	I	0.47	0.38	75
Polygonum virginianum	jumpseed	forb	N	0.53	0.28	75
Ranunculus recurvatus	blisterwort	forb	N	0.03	0.02	50
Rhus aromatica	fragrant sumac	woody	N	0.01	0.01	25
Rosa multiflora	multiflora rose	woody	I	0.04	0.01	75
Rubus sp.	blackberry	woody	N	0.44	0.30	100
Ruellia caroliniensis	Carolina wild petunia	forb	N	NA	NA	NA
Ruellia sp.	wild petunia	forb	N	NA	NA	NA
Sanicula canadensis	Canadian blacksnakeroot	forb	N	0.23	0.04	100
Sanicula sp.	sanicle	forb	N	0.24	0.04	100
Sassafras albidum	sassafras	woody	N	NA	NA	NA
Smilax glauca	cat greenbrier	forb	N	0.21	0.05	100

Table 11 (continued). Ground flora species observed at Lincoln Boyhood National Memorial (N = 4 sites). Values for mean cover, standard error (SE), and occurrence are only for 2024 (most recent monitoring event). NA = species was observed in prior monitoring years but not in 2024; N = native; I = nonnative.

Species	Common Name	Guild	Origin	Mean Cover 2024 (%)	SE	Occurrence (% Sites) 2024
Smilax tamnoides	bristly greenbrier	woody	N	0.03	0.02	50
Solidago sp.	goldenrod	forb	N	NA	NA	NA
Staphylea trifolia	American bladdernut	woody	N	0.38	0.38	25
Symphoricarpos orbiculatus	coralberry	woody	N	0.14	0.07	100
Symphyotrichum lateriflorum var. *lateriflorum*	Goblet wild aster	forb	N	0.06	0.04	50
Symphyotrichum sp.	aster	forb	N	NA	NA	NA
Toxicodendron radicans	eastern poison ivy	woody	N	0.35	0.05	100
Trifolium campestre	field clover	forb	I	NA	NA	NA
Triodanis perfoliata	clasping Venus' looking-glass	forb	N	NA	NA	NA
Viburnum dentatum	southern arrowwood	woody	N	0.08	0.08	25
Viburnum prunifolium	blackhaw	woody	N	1.02	0.51	75
Viburnum sp.	viburnum	woody	N	0.01	0.01	25
Vinca minor	common periwinkle	vine	I	8.75	6.43	50
Viola sp.	violet	forb	N	0.36	0.17	75
Vitis aestivalis	summer grape	woody	N	0.05	0.03	50
Vitis sp.	grape	woody	N	0.15	0.05	75
Vitis vulpina	frost grape	woody	N	0.32	0.08	100

Appendix B. Archival Photos

Figures 19 through 22 show a sampling of archival photos from the first monitoring events in 2011 juxtaposed with photographs from the 2024 monitoring event at Lincoln Boyhood National Memorial, Indiana. We did not include images from all transects in order to maintain a manageable file size, so selected images represent features of each site. These photos aid in visualizing changes in vegetation cover over time. Plot code includes site number, transect (A, B) and location (S = start, 0 m; F = finish, 50 m).

Figure 19. Lincoln Boyhood National Memorial long-term monitoring site 1 AS in 2011 (left) and in 2024 (right). Note the loss of overstory trees in the background and change in density of ground flora.
NPS

Figure 20. Lincoln Boyhood National Memorial long-term monitoring site 1 BF in 2011 (left) and in 2024 (right). A large tree fall is visible in both pictures but is obscured by vegetation in the recent image.
NPS

Figure 21. Lincoln Boyhood National Memorial long-term monitoring site 2 AS in 2011 (left) and in 2024 (right). Note the more open ground layer in 2024 from this perspective.

NPS

Figure 22. Lincoln Boyhood National Memorial long-term monitoring site 3 AS in 2011 (left) and in 2024 (right). Advanced tree regeneration and midstory layers were stimulated between monitoring events and the overstory trees were obscured.

NPS

Figure 23. Lincoln Boyhood National Memorial long-term monitoring site 4 AS in 2011 (left) and in 2024 (right). The recent image was obscured by mid-layer ground flora plants as compared to the more open ground layer in 2011.

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