

## **Forest Health Data Summaries for** **Delaware Water Gap National Recreation Area (2007 – 2024)**

### ***Summary***

**Insect pests dramatically shift forest dynamics as mortality in some tree species provides opportunities for other species.**

- Although high hemlock mortality from hemlock wooly adelgid continues in mesic forests, hemlock trees persisting in xeric forests appear stable.
- Ash seedling abundance peaked during the monitoring period as ash trees dying from emerald ash borer produced copious seeds. Ash tree mortality was high in most vegetation types, except in early successional fields where young ash trees showed strong growth in full sun.
- In mesic forests, beech saplings are abundant and have strongly increased over the past 18 years. However, the recently introduced beech leaf disease, caused by an invasive microscopic nematode, poses a serious threat to the park's beech trees and saplings.
- In xeric forests, young black birch and hickory trees are replacing aging chestnut oaks, stressed by cycles of defoliation from spongy moth caterpillars. Other oak species remain stable.
- Tree mortality from these insect pests, along with damage from severe wind or ice storms, caused coarse woody debris volume to double during the monitoring period.

**Canopy gaps that are not regenerating with native trees should be targeted for invasive plant management and/or restoration.**

- Gaps created by downed trees facilitate recruitment of the next generation of canopy trees, a crucial process for eastern deciduous forests to persist. However, if over abundant white-tailed deer or invasive plants prevent native tree seedlings from thriving in these gaps, forests convert to invasive shrub thickets following insect or storm disturbances.

**Invasive plants dramatically impact forest health by altering forest structure and diversity, suppressing tree regeneration and reducing native species diversity.**

- In DEWA, invasive plants tend to be abundant and increasing on floodplains and lower elevation mesic lands, especially areas previously farmed or pastured.
- In contrast to the other vegetation types, seedling and sapling density declined in successional forests, without evidence that shorter seedlings matured into taller height classes. Successional forests encompass a wide variety of disturbed, modified, or young forests that no longer resemble natural vegetation communities.
- As agriculture dwindles within the park, fields that were once utilized for crops, hay or pasture undergo succession. Invasive shrubs and a mix of native tree and shrub species

establish, slowly converting the field to an invasive shrub thicket or a young forest, depending on which species persist.

**Mesophication that shifts oak forests towards more mesic tree species may have cascading effects on oak-dependent biodiversity.**

- Due to abundant maple, pine, and birch regeneration, xeric forests composition trended away from oaks towards more mesic tree species. This mesophication of oak forests occurred more strongly in the park's mesic forests where oak seedlings are underrepresented and declining.

**Continued strategic investment in invasive plant management, responding to forest pests, and restoring disturbed forests will bolster forest resilience in DEWA.**

***Background***

Forests are crucial resources in Delaware Water Gap National Recreation Area (DEWA), providing recreation opportunities for park visitors and important habitat for myriads of animals, plants and fungi, as well as protecting soil stability and stream health. The following forest health summaries, based on data collected in Eastern Rivers and Mountains Inventory and Monitoring Network (ERMN) long-term forest health monitoring plots between 2007 – 2024, yield insights into the park's dynamic plant communities. There are 102 ERMN forest health monitoring plots in DEWA, with each plot sampled on a 4-year cycle. Most plots were visited four times during this reporting period.

Within each forest plot, tree and stand measurements, including an assessment of deer browse impact, are made within fixed-area, circular plots, 15-m in radius. Tree regeneration data are collected in four 2-m radius circular microplots embedded within each plot. Plots are permanently marked and measured at the same location every cycle. For a more detailed description of methods, refer to the [ERMN forest monitoring protocol](#).

One unique feature of DEWA's vegetation is the diversity of different plant communities, some of which are globally rare and found very few places outside the park ([Perles et al. 2007](#)). ERMN forest monitoring covers all publicly owned, non-developed, non-agricultural land with slope less than 56% inside the park's authorized boundary. While monitoring plots were not targeted to specific plant communities, plots can be grouped by broad vegetation type to better understand varying dynamics among habitats. For this analysis, we grouped plots into five broad vegetation types: Xeric (n=50), Mesic (n=21), Riparian or Palustrine Vegetation (n=10), Successional Forest (n=14), and Early Successional Fields (n=7).

To help inform National Park Service (NPS) staff of forest health conditions and trends, this document provides data summaries and interpretations of park-wide status and trends in forest structure, tree regeneration, deer browse impacts, and invasive plants. In addition, common tree species dynamics are discussed in each of the broad vegetation types listed above.

## **Forest Structure**

A recent regional analysis showed that many forests in DEWA have more complex older forest structure, such as large live standing trees and basal area of standing dead trees, than surrounding forests sampled by the US Forest Service ([Miller et al. 2016](#)). Therefore, the protection and management of park forests have regional importance beyond the boundaries of the park.

Based on tree cores collected near the plots, most trees in DEWA range from 80 – 150 years old, with younger forests continuing to establish in abandoned fields and many older trees common on the Kittatinny Ridge. The oldest cored tree, a chestnut oak (*Quercus montana*), originated over 200 years ago, despite having only 40-cm diameter at breast height, an example of [old trees hiding in plain sight](#). Forest canopy cover in monitoring plots is consistently stable in middle-aged forests or increasing in younger forests establishing in old fields (Maps 7a/7b).

The average volume of downed coarse woody debris, another important component of forest structure that provides wildlife habitat and nutrient cycling, has doubled over the past 18 years (Maps 10a/10b). Hemlock (*Tsuga canadensis*) and ash (*Fraxinus* spp.) trees, killed by hemlock wooly adelgid (*Adelges tsugae*) and emerald ash borer (*Agrilus planipennis*) respectively, comprise much of the new coarse woody debris, along with trees toppled by severe wind or ice storms. Gaps created by downed trees facilitate recruitment of the next generation of canopy trees, a crucial process for eastern deciduous forests to persist. However, if over abundant white-tailed deer or invasive plants prevent native tree seedlings from thriving in these gaps, forests convert to invasive shrub thickets following insect or storm disturbances.

## **Tree Regeneration and Deer Impacts**

A regeneration layer containing abundant tree seedlings and saplings of varying sizes is a crucial component of a healthy forest. Regeneration debt occurs when forests lack sufficient regeneration, or the species composition in the regeneration layer does not match the canopy. DEWA has a forest regeneration status of Probable Failure, meaning that the park is experiencing regeneration failure due to low numbers of seedlings, inadequate and declining sapling abundance, and mismatches between the species composition of the canopy trees and the tree regeneration ([Miller et al. 2023](#)).

On average, seedling abundance is increasing within DEWA (Maps 1a and 1b), as the large number of seedlings in the smallest size class mature into taller height categories (Maps 2a/2b, as well as Figures A1, A4, A7 and A13). Despite this positive and healthy trend, regeneration abundance varies throughout the park (Maps 5a/5b). The regeneration stocking index, which quantifies whether native seedling and sapling densities are sufficient to restock a forest canopy, shows that only 42% of plots contain sufficient tree regeneration under moderate to high deer browse pressure, which is common in DEWA. One third of plots are moderately stocked with sufficient regeneration for areas of low browse pressure. The remaining quarter of plots are severely understocked with insufficient seedlings and saplings to replace a forest canopy.

Deer browse impacts are assessed on a scale of 1 – 5, with 1 representing unnaturally low impacts from deer exclusion and 5 representing severe impacts evidenced by a distinct browse

line. Impacts of medium (3) or higher typically require management intervention to maintain adequate forest regeneration. In the most recent 4-year survey, deer browse impacts varied across the park (Maps 6a/6b), with 21% of plots rated as low impacts. Medium impacts, in which a diversity of native plants and tree seedlings were present but often stunted by browse, were observed at 58% of plots. Twenty-one percent of plots showed high impacts such as reduced plant diversity and severely stunted plant height. No plots were rated as very high deer browse impacts.

### ***Invasive Species***

Invasive plants dramatically impact forest health by altering forest structure and diversity, suppressing tree regeneration, altering nutrient cycling and disturbance regimes, and reducing native species diversity. In DEWA, invasive plants tend to be abundant and increasing on floodplains and lower elevation mesic lands, especially areas previously farmed or pastured (Maps 8a/8b and 9a/9b, also [Miller et al. 2021](#) and [Eichelberger and Perles 2009](#)). Japanese and giant knotweeds (*Reynoutria* spp.) aggressively spread on floodplains and islands. Invasive shrubs such as multiflora rose (*Rosa multiflora*), Japanese barberry (*Berberis thunbergii*), autumn olive (*Elaeagnus umbellata*), honeysuckles (*Lonicera* spp.), and winged burning bush (*Euonymus alatus*) are the most problematic plant species expanding within the park, along with the invasive vines Asian bittersweet (*Celastrus orbiculatus*) and Japanese honeysuckle (*Lonicera japonica*). In addition, Japanese stiltgrass (*Microstegium vimineum*), one of the fastest spreading invasive plants in recent years, carpets forest understories competing with native plants. Garlic mustard (*Alliaria petiolata*), the only invasive plant to show significant declines ([Miller et al. 2021](#)), may be impacted by a newly introduced European aphid specific to garlic mustard ([Engerman et al. 2025](#)).

### ***Xeric Forest Composition Dynamics***

Forested ridgetops and upper slopes in DEWA are dominated by oaks (*Quercus* spp.), along with hickories (*Carya* spp.), black birch (*Betula lenta*), red maple (*Acer rubrum*), white pine (*Pinus strobus*), and eastern hemlock (Maps 4a/4b). Oak forests are valued because they support more biodiversity, from caterpillars to birds to mammals to understory plants, than maple- and birch-dominated forests ([Brose et al. 2014](#)).

The most common tree species in DEWA's xeric forests, chestnut oak, has been declining in both density and basal area over the past 15 years (Figure A3). As these oaks die, they are being replaced by black birch and hickories that are common in the subcanopy. Other oaks such as scarlet, white, and black oaks (*Q. coccinea*, *Q. alba*, and *Q. velutina*, respectively) have relatively stable density and basal area. Only the northern red oak (*Q. rubra*) shows slight decline in density with accompanying increase in basal area, typical of stable maturing forests.

Surprisingly, eastern hemlocks have been relatively stable over the monitoring period, despite continued infestation by hemlock wooly adelgid and elongate hemlock scale (*Fiorinia externa*). Hemlocks in xeric habitats suffered high mortality before this monitoring was established. Thus, remaining individuals may have some resistance to hemlock wooly adelgid. Alternatively, the

lingering hemlocks interspersed between deciduous trees [fare better against the adelgid due to increased canopy light](#).

The composition of the regeneration layers guides which tree species will mature after disturbances. Xeric forests in DEWA have a mismatch between the forest canopy and the seedling and sapling layers (compare Maps 3a/3b and 4a/4b, as well as Figures A2 and A3). Red maple, white pine, and black birch dominate the regeneration layers and show strong increases in seedling density, in contrast to the canopy composition strongly dominated by oaks. As oaks die, maple, pine, or birch seedlings are poised to regenerate. This region-wide phenomenon called mesophication is shifting xeric forests composition away from oaks towards more mesic tree species.

In closed-canopy mature forests, the forest floor often receives insufficient light for seedlings and saplings to mature. Strong declines in sapling abundance indicate that this sapling bottleneck may be occurring in DEWA's xeric forests (Figure A2). Notably, black birch is the only species with increasing sapling density that may be escaping this bottleneck. White pines, the most abundant sapling at the beginning of the monitoring period, have declined to density and basal area typical of other common xeric species. This dramatic drop in white pine sapling density was not accompanied by increases in sapling basal area that would indicate competition among maturing saplings. These young pines form thickets (typically on the Pennsylvania side of the park) when spongy moth (*Lymantria dispar*) severely defoliate oak canopies and allow full sunlight to the forest floor during the summer. The dramatic decline in white pine saplings may be a rebalancing of white pine sapling abundance following spongy moth outbreaks. Given that white pines are currently the second most common seedling, this cycle of fluctuating white pine regeneration may continue.

### **Mesic Forest Composition Dynamics**

Moist forests on mid- and lower slopes in DEWA host a variety of tree species, predominantly maples (*Acer* spp.), birches (*Betula* spp.), oaks, ash, black walnut (*Juglans nigra*), and many other species in lesser amounts (Maps 4a/4b).

Some common canopy species such as sugar maple (*Acer saccharum*) and birches, along with white, northern red and black oaks, are stable (Figure A6). Eastern hemlock and ash declined as trees were killed by hemlock wooly adelgid and emerald ash borer, respectively. Interestingly, red maple also declined over the monitoring period, though red maple seedlings are abundant in both DEWA's mesic and xeric forests. Hickories and black walnut showed strong growth in basal area. As the large number of American beech (*Fagus grandifolia*) saplings matured, beech tree density increased.

Beech saplings are abundant and have strongly increased over the past 18 years (Figure A5). Beside beech, birches are one of the few species with increasing sapling density. However, the recently introduced beech leaf disease, caused by an invasive microscopic nematode (*Litylenchus crenatae* subsp. *mccannii*), poses a serious threat to the park's beech trees and saplings. Though first detected in DEWA in 2022, the nematode probably reached the park in 2020 or 2021 while monitoring was

paused during the COVID-19 pandemic. Beech leaf disease causes mortality in beech saplings first, followed by widespread mortality of canopy beech trees.

In the seedling layer, sugar and red maples remain abundant and stable, while birches and pines (*Pinus* spp.) have increased (Figure A5). Notably, the abundance of ash seedlings peaked during the middle of the monitoring period as ash trees dying from emerald ash borer produced copious seeds. Although a diversity of oaks species are common in the mesic forest canopy, oak seedlings are underrepresented and declining, evidence that mesophication is occurring in DEWA's mesic forests and perhaps more strongly than in the park's xeric forests.

### ***Dynamics in Riparian and Palustrine Vegetation***

Floodplain and wetland plant communities provide unique habitats within the park. Due to frequent flooding which introduces plant propagules and disturbs established vegetation and soil, these habitats are particularly susceptible to invasive plants. Japanese knotweed, multiflora rose, Japanese barberry, and Japanese stiltgrass have overwhelmed some of these monitoring plots during the monitoring period (Maps 8a/8b). Although invasive plants thrive in the rich moist soils common in riparian and palustrine habitats, trees also benefit from these favorable growing conditions with strong basal area growth observed in most dominant tree species: sycamore (*Platanus occidentalis*), bitternut hickory (*Carya cordiformis*), sugar maple, and oaks (Figure A9). Since most silver maples (*Acer saccharinum*) in monitoring plots are large mature trees, silver maple density and basal area is stable. Steep declines in red maple trees mirror patterns observed in the park's mesic forests.

Maple seedling abundance peaked during the middle of the monitoring period, possibly caused by inconsistent yearly maple seed production (Figure A8). Maple saplings also strongly declined such that few to no maple saplings remain in the monitoring plots. Emerald ash borer caused a peak in ash seedlings in the middle of the study period, though ash sapling density remained steady. Musclemwood (*Carpinus caroliniana*) seedlings increased steadily through the study period. Beech, musclemwood and ironwood (*Ostrya virginiana*) have increased to become the most abundant sapling species; however, beech leaf disease threatens the beech saplings.

### ***Successional Forest Composition Dynamics***

Successional forests encompass a wide variety of disturbed, modified, or young forests, such as aging pine plantations, former pastures and fields on which trees have established, or forests heavily invaded by exotic shrubs and vines. A common feature among these forests is that they no longer resemble a natural vegetation community (as defined by NatureServe's [International Vegetation Classification](#)).

White pine remains the most abundant tree species in this broad vegetation group because several monitoring plots fall within older white pine plantations (Maps 4a/4b and Figure A12). Although white pine saplings and seedlings declined sharply, seedlings rebounded after 2018, possibly highlighting a cycle of competition and re-establishment related to light availability and spongy moth outbreaks (Figure A11). Black walnut, black cherry (*Prunus serotina*), and sugar maple gained in density and basal area. Although ash were the most common tree when monitoring began, ash

density has been much reduced by emerald ash borer over the study period, though not yet eliminated.

In contrast to the other vegetation types, seedling and sapling density declined in successional forests, without evidence that shorter seedlings matured into taller height classes (Figure A10 and A11). With the exception of maples, saplings of all other species declined, suggesting a sapling bottleneck, probably caused by dense invasive shrubs and Japanese stiltgrass that stifle tree regeneration.

### ***Dynamics in Early Successional Fields***

As agriculture dwindles within the park, fields that were once utilized for crops, hay or pasture undergo succession. Invasive shrubs and a mix of native tree and shrub species establish, slowly converting the field to an invasive shrub thicket or a young forest, depending on which species persist. Invasive shrubs are common and increasing in these fields (Maps 8a/8b and 9a/9b). Although plot DEWA.304 shows declining invasive cover, this trend occurred because the autumn olive grew above the 2m height limit for sampling vegetation in quadrats, not because autumn olive cover declined. Plagued by impenetrable autumn olive, that plot could not be sampled during cycle 3 because the shrubs were too tall to walk through, but not tall enough to crawl under.

Eastern red cedar (*Juniperus virginiana*) and black walnut, the two most common colonizers of old fields, strongly increased in density and basal area (Figure A15). The trend in sapling density shows the recruitment of eastern red cedar and black walnut into the sapling layer, and then their maturity into tree sized individuals (Figure A14). Other young hardwoods such as black cherry, oaks, birches, and tuliptree (*Liriodendron tulipifera*) showed strong growth typical of trees growing in full sun. Surprisingly, ash tree growth remains strong in these old fields, despite park-wide infestation of emerald ash borer. Density of red maple trees peaked around 2016, after which basal area and density declined sharply; however maple seedlings and saplings are abundant and increasing. Cherry seedling abundance strongly increased while saplings decreased as saplings matured into trees. As woody species establish in these fields and young trees produce propagules, the abundance of seedlings increased, especially in the smaller size classes (Figure A13).

### ***Conclusions***

The diversity of forests and other plant communities are important resources in DEWA that provide under-represented and regionally significant habitat. However, insect pests and invasive plants threaten the ability of park forests to regenerate. Continued strategic investment in invasive plant management, responding to forest pests, and restoring disturbed forests will bolster forest resilience.

### ***Author Contributions***

This summary document was written by Stephanie Perles (ERMN Plant Ecologist), with editing by Katie Kull (Botanist/ERMN Forest Crew Lead). Maps and figures were created by Sara Thiessen (ERMN Forest Crew Member), and Stephanie Perles. This document was adapted from materials developed by staff from the NPS Northeast Temperate and Mid-Atlantic Inventory and Monitoring

Networks, including Kate Miller (NETN/MIDN Quantitative Ecologist), Camilla Seirup (former NETN/MIDN Forest Crew Leader), and Jamie Attanasio (NETN/MIDN Forest Crew Member).

## ***Appendix A***

### ***Regeneration and Forest Composition Dynamics Graphs***

## Regeneration Trends in Xeric Forests

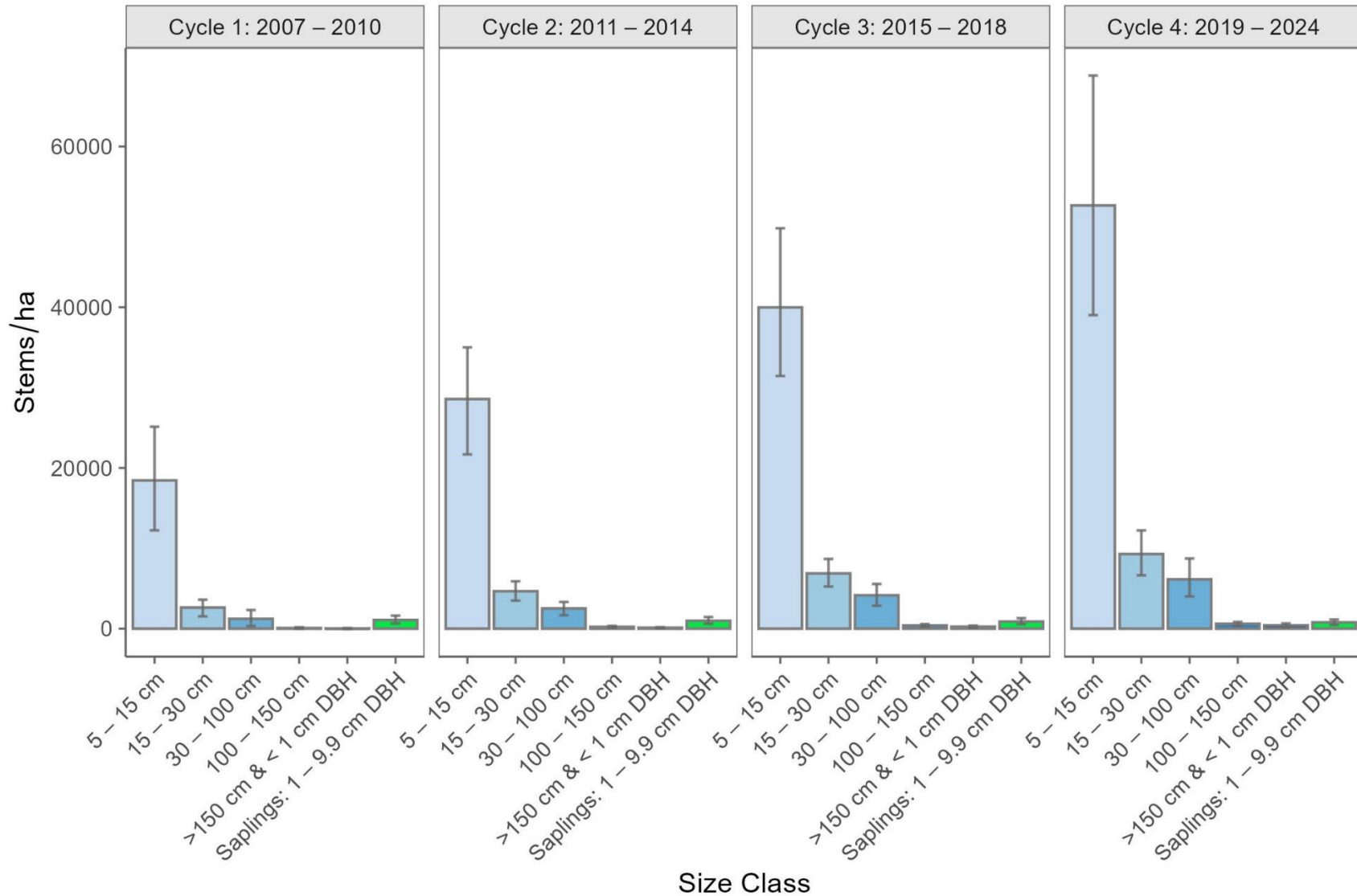


Figure A1. Trends in tree regeneration densities by height class in xeric forests in the Delaware Water Gap National Recreation Area, 2007 – 2024. Error bars are 95% bootstrapped confidence intervals to account for non-normal error. Note that as the overall number of seedlings and saplings increases, seedlings in the smallest size class are maturing into taller height categories.

## Regeneration Composition Trends in Xeric Forests

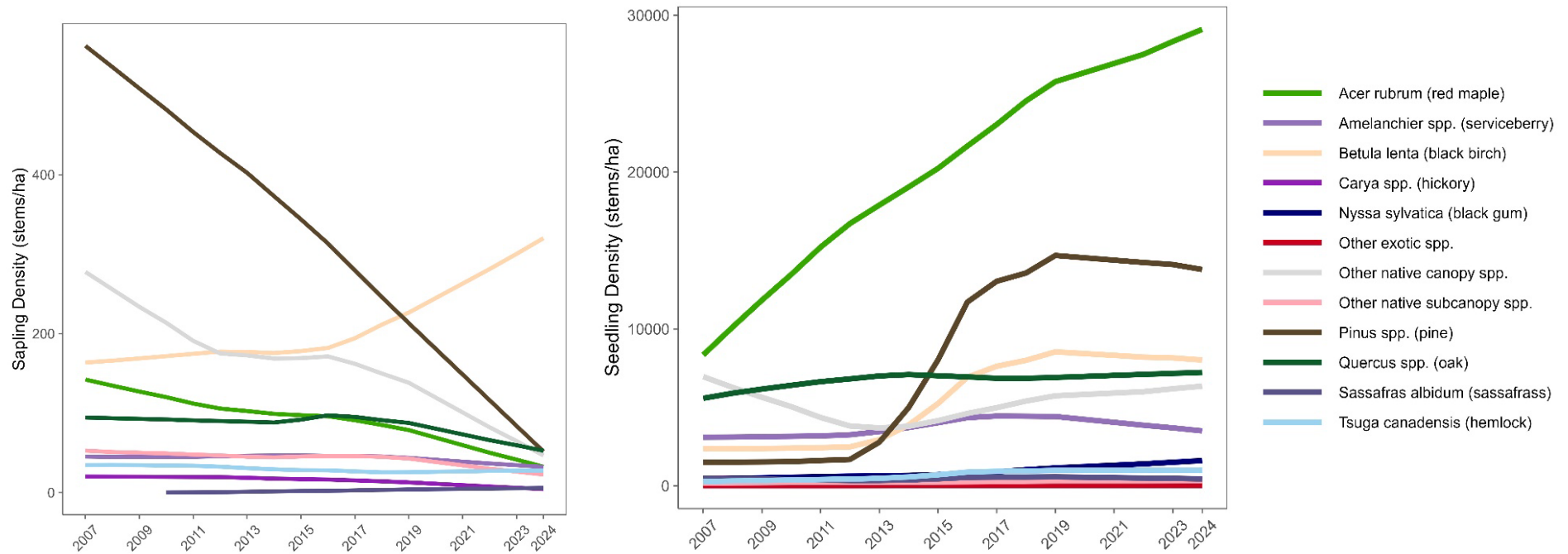


Figure A2. Trends in sapling (left) and seedling (right) density by species group and sample year in xeric forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that red maple, white pine, and black birch dominate the regeneration layers and strongly increase in seedling density, in contrast to the canopy composition strongly dominated by oaks in Figure A3. As oaks die, they are likely to be replaced by maple, pine, or birch seedlings. Also, note the strong declines in sapling abundance, particularly white pine that typically thrives during spongy moth outbreaks. Black birch is the only species to escape the sapling bottleneck and show increasing sapling density.

## Canopy Composition Trends in Xeric Forests

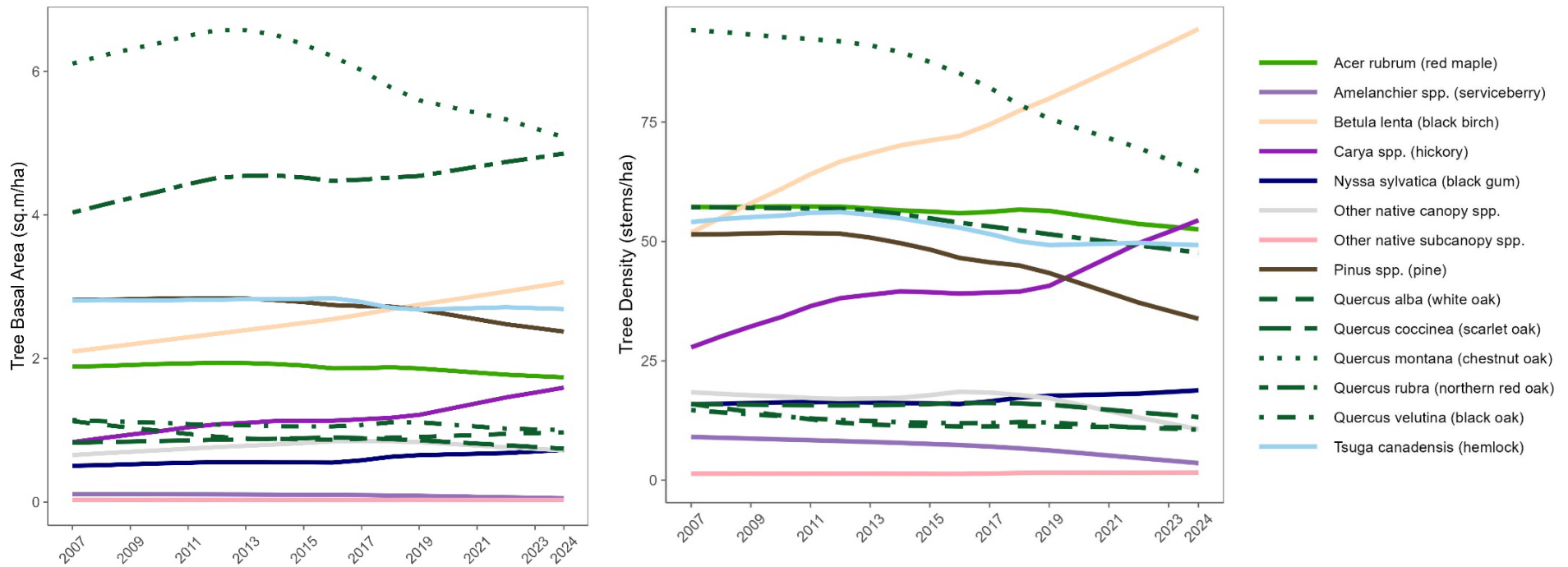


Figure A3. Trends in tree basal area (left) and density (right) by species group and sample year in xeric forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note declines in the most common species, chestnut oak, as it is replaced by black birch and hickories. Other oak species and eastern hemlock are surprisingly stable.

## Regeneration Trends in Mesic Forests

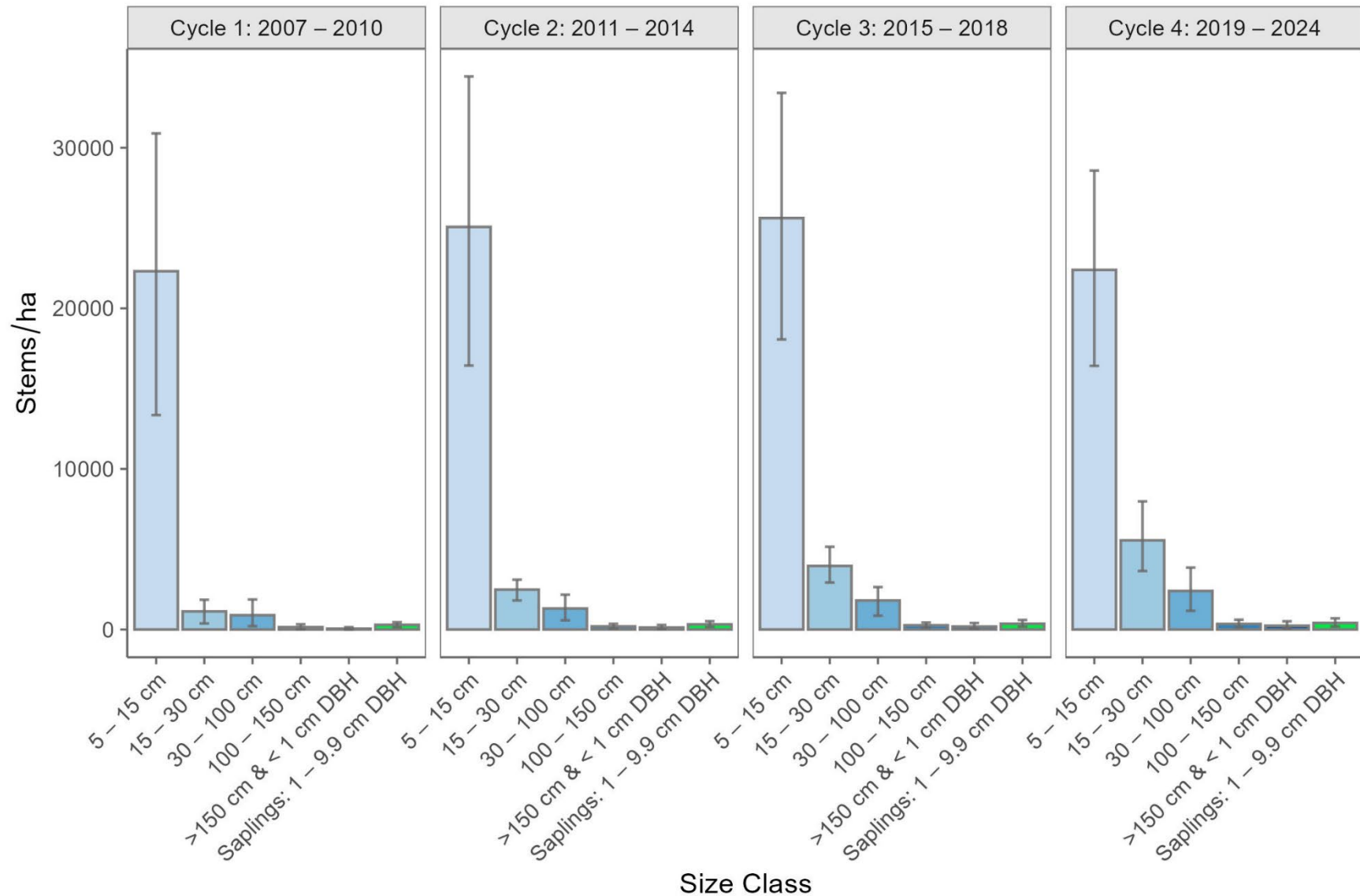


Figure A4. Trends in tree regeneration densities by height class in mesic forests in the Delaware Water Gap National Recreation Area, 2007 – 2024. Error bars are 95% bootstrapped confidence intervals to account for non-normal error. Note that the large number of seedlings in the smallest size class are maturing into taller height categories over time.

## ***Regeneration Composition Trends in Mesic Forests***

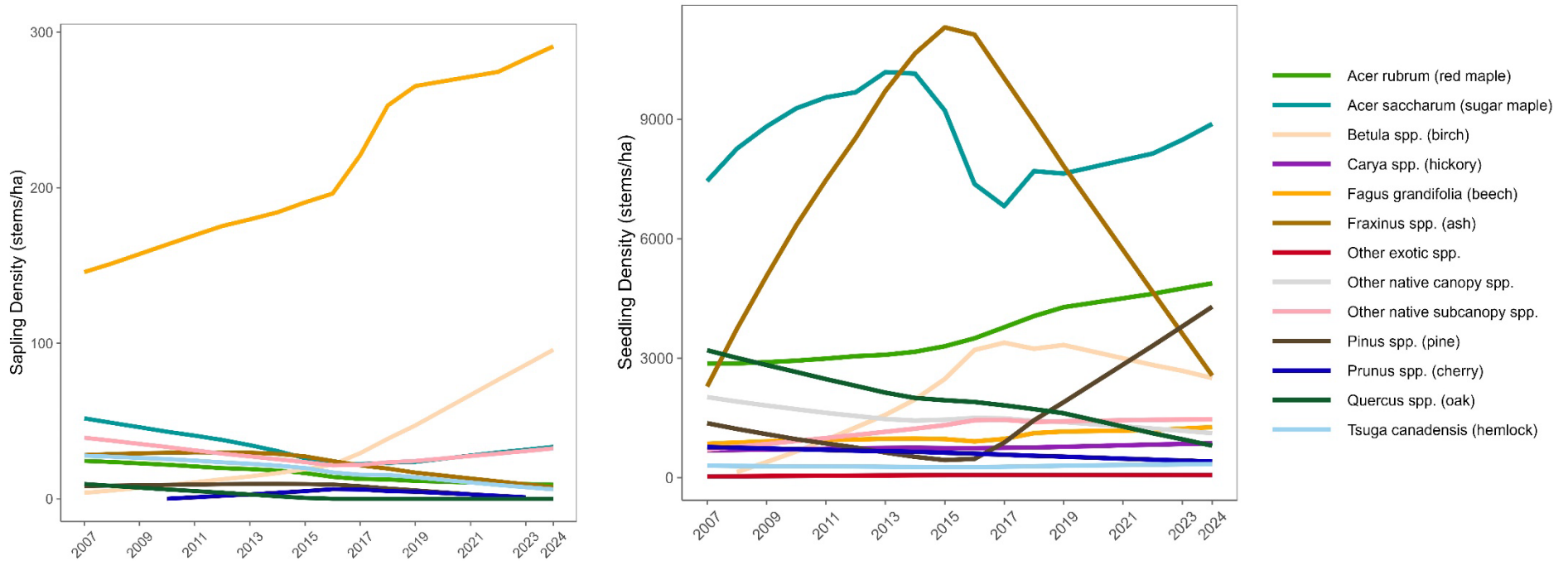


Figure A5. Trends in sapling (left) and seedling (right) density by species group and sample year in mesic forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that the abundant and increasing beech saplings are threatened by beech leaf disease. Beside beech, only birches have increasing sapling density. In the seedling layer, sugar and red maples remain abundant and stable, while birches and pines have increased. Notably, the abundance of ash seedlings peaked while ash trees dying from emerald ash borer produced copious seeds. Oak seedlings are underrepresented and declining, evidence of mesophication.

## Canopy Composition Trends in Mesic Forests

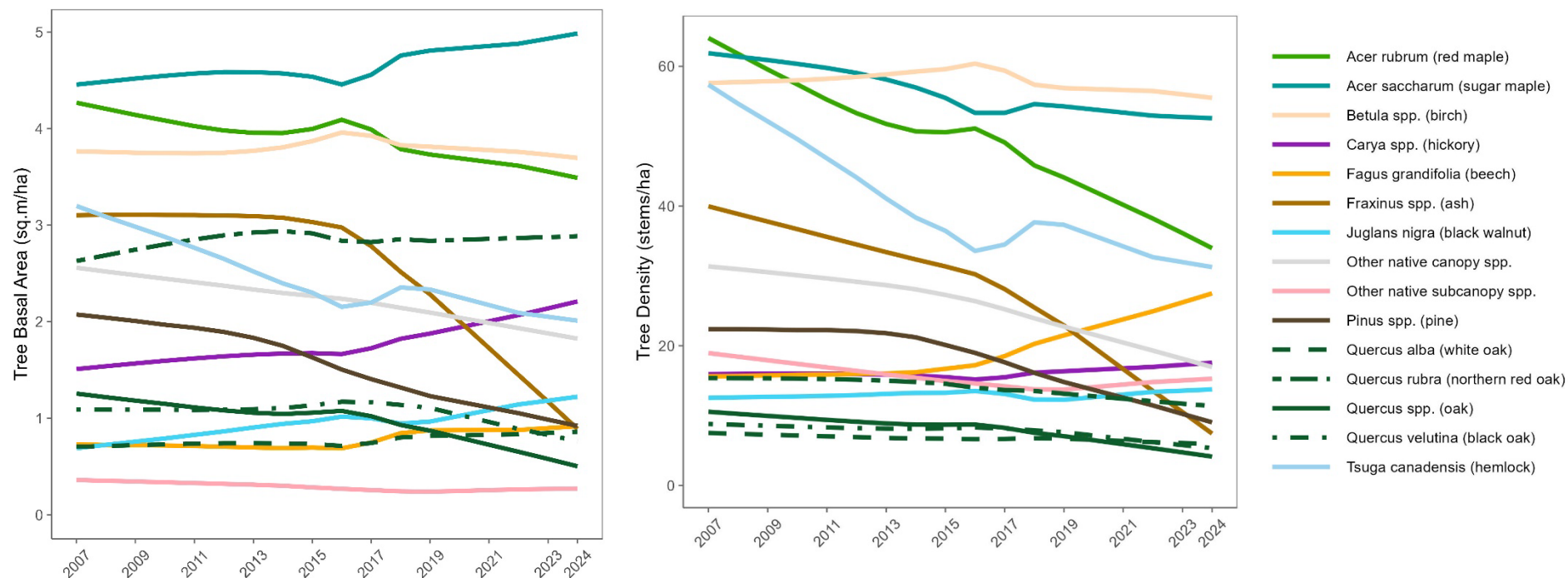


Figure A6. Trends in tree basal area (left) and density (right) by species group and sample year in mesic forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note though many common canopy species are stable, eastern hemlock and ash steeply decline as trees are killed by hemlock wooly adelgid and emerald ash borer. Red maple also declined over the monitoring period, though red maple seedlings are widely abundant. American beech increased in tree density, as beech saplings matured.

## Regeneration Trends in Dynamics in Riparian and Palustrine Vegetation

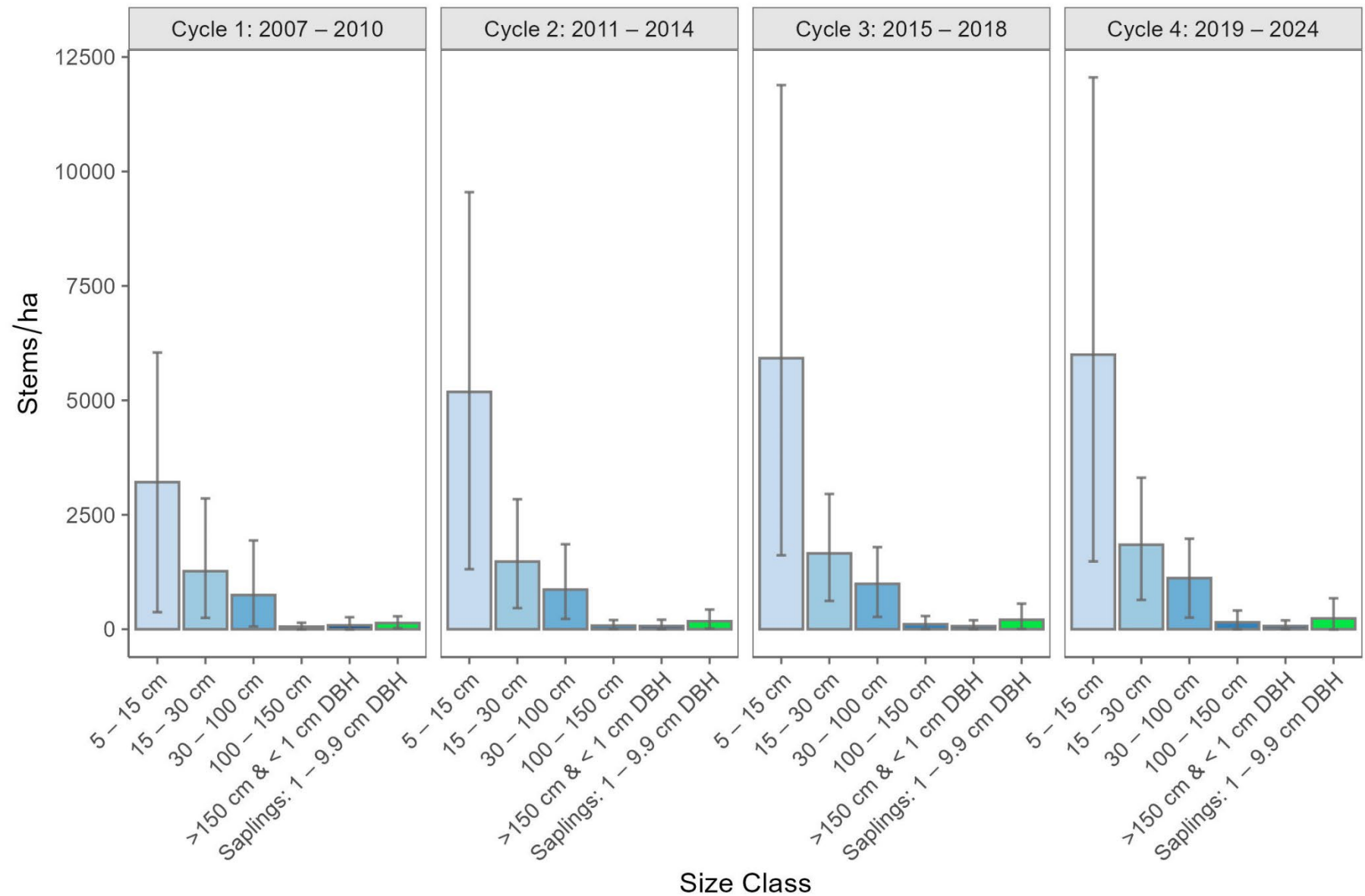


Figure A7. Trends in tree regeneration densities by height class in riparian and palustrine vegetation in the Delaware Water Gap National Recreation Area, 2007 – 2024. Error bars are 95% bootstrapped confidence intervals to account for non-normal error. Note that the large number of seedlings in the smallest size class show evidence of maturing into taller height categories over time.

## Regeneration Composition Trends in Riparian and Palustrine Vegetation

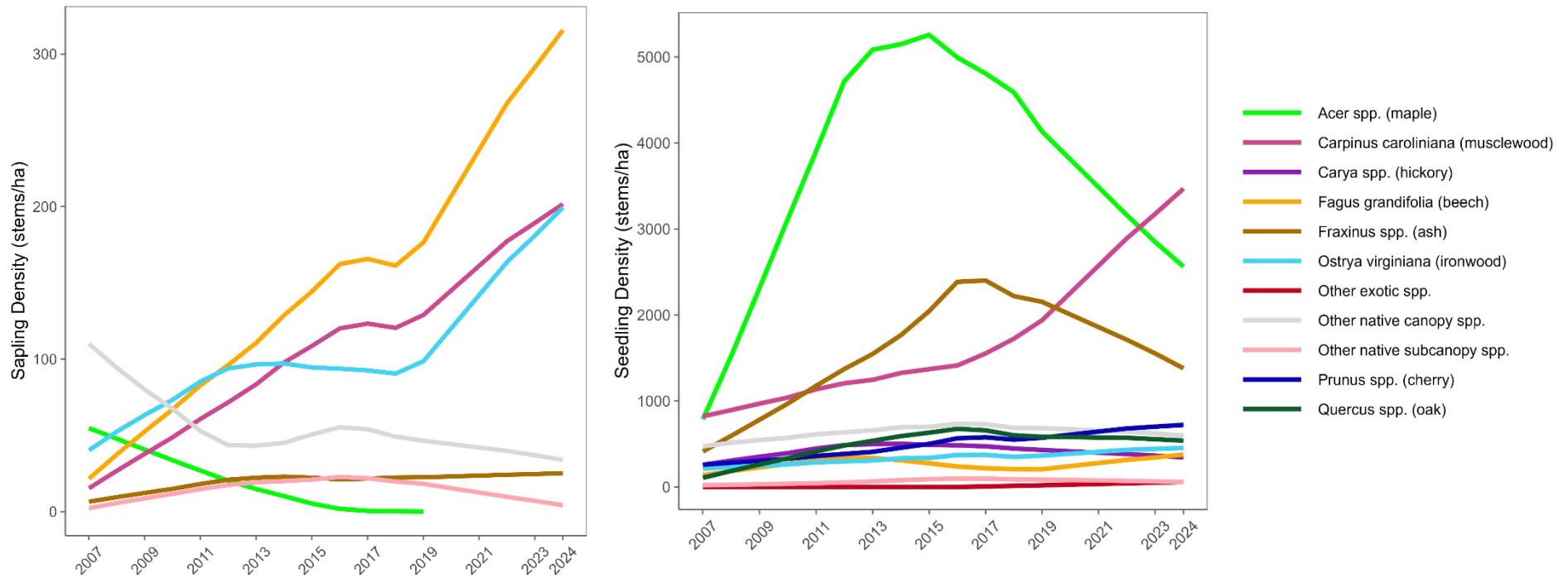


Figure A8. Trends in sapling (left) and seedling (right) density by species group and sample year in riparian and palustrine vegetation in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that the strongly increasing beech saplings are threatened by beech leaf disease. Emerald ash borer caused the peak in ash seedlings, though ash sapling density remained steady. Maple seedlings and saplings strongly declined, while musclewood and ironwood increased.

## Canopy Composition Trends in Riparian and Palustrine Vegetation

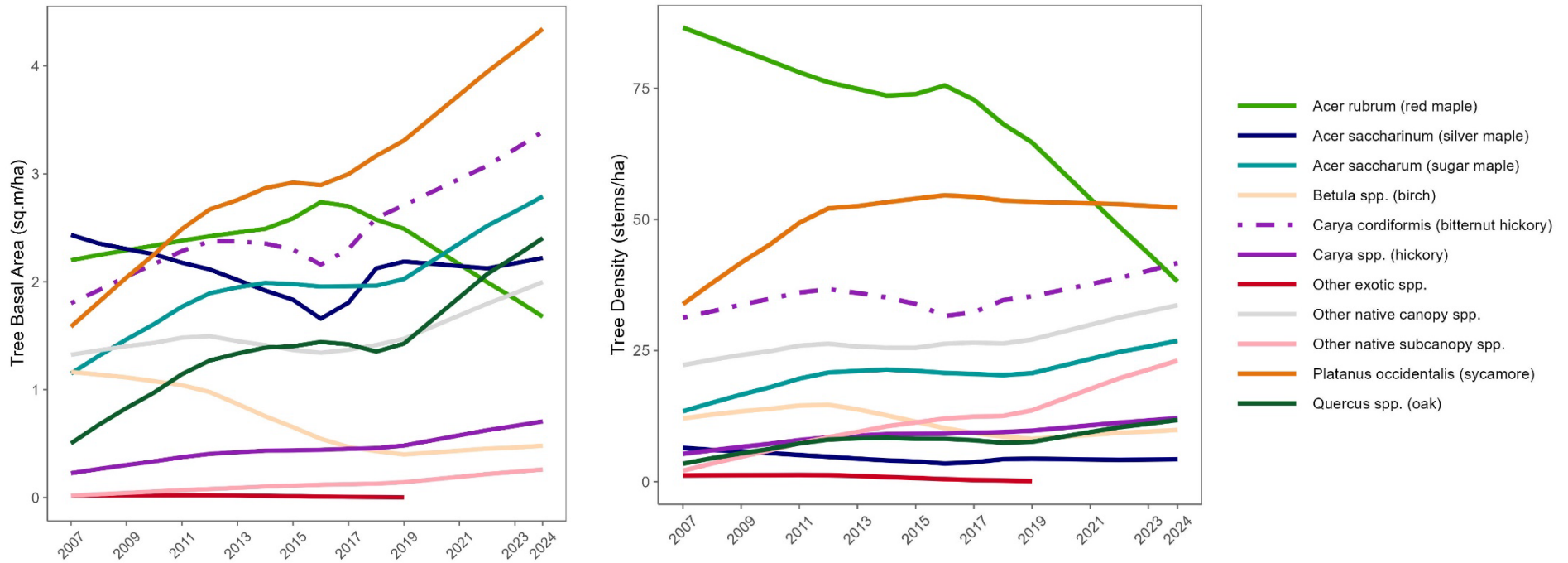


Figure A9. Trends in tree basal area (left) and density (right) by species group and sample year in riparian and palustrine vegetation in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note strong basal area growth in sycamore, bitternut hickory, sugar maple, and oaks due to rich soils. Steep declines in red maple mirror patterns observed in the park's mesic forests.

## Regeneration Trends in Dynamics in Successional Forests

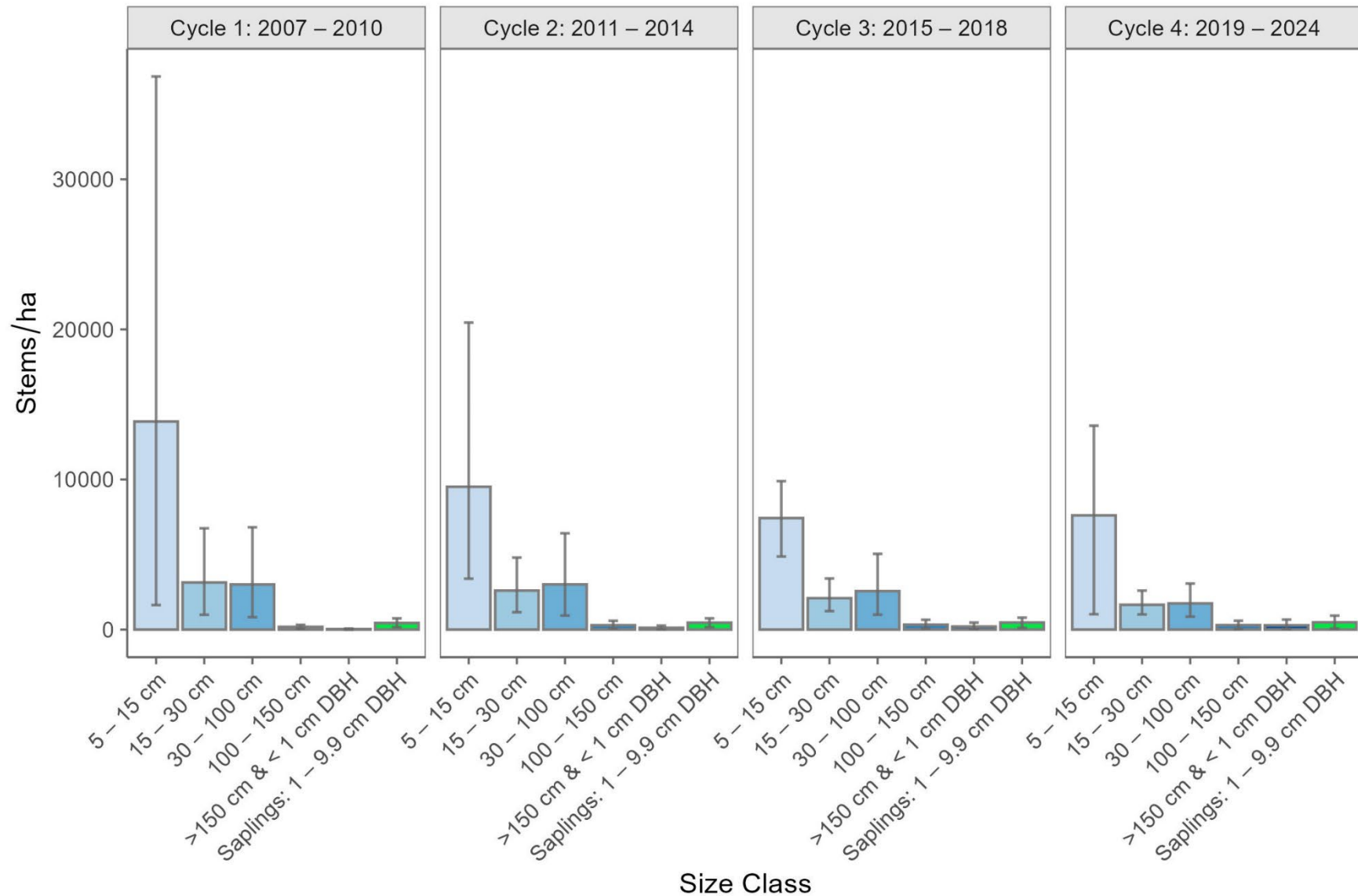


Figure A10. Trends in tree regeneration densities by height class in successional forests in the Delaware Water Gap National Recreation Area, 2007 – 2024. Error bars are 95% bootstrapped confidence intervals to account for non-normal error. Note that seedling and sapling densities are declining in most height classes.

## Regeneration Composition Trends in Successional Forests

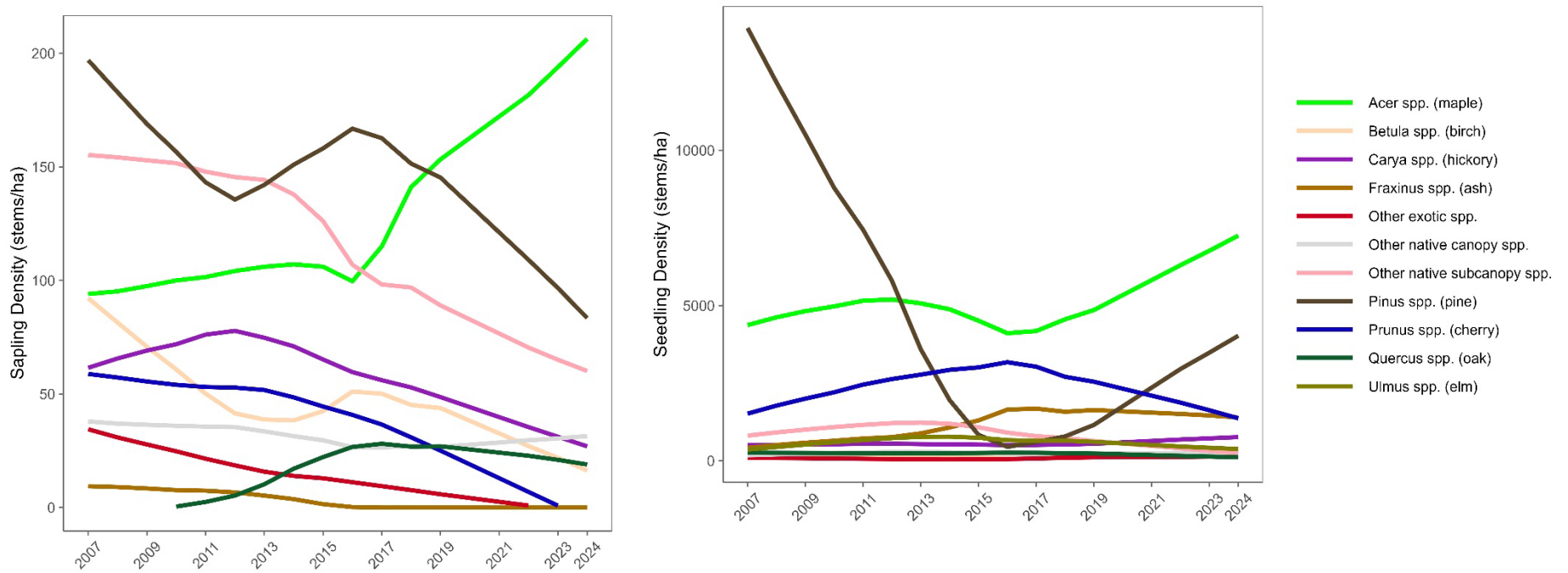


Figure A11. Trends in sapling (left) and seedling (right) density by species group and sample year in successional forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that saplings of all species except for maples declined. Although white pine saplings and seedlings declined sharply, seedlings rebounded after 2018, possibly indicating a cycle of establishment and competition related to light availability and spongy moth outbreaks.

## Canopy Composition Trends in Successional Forests

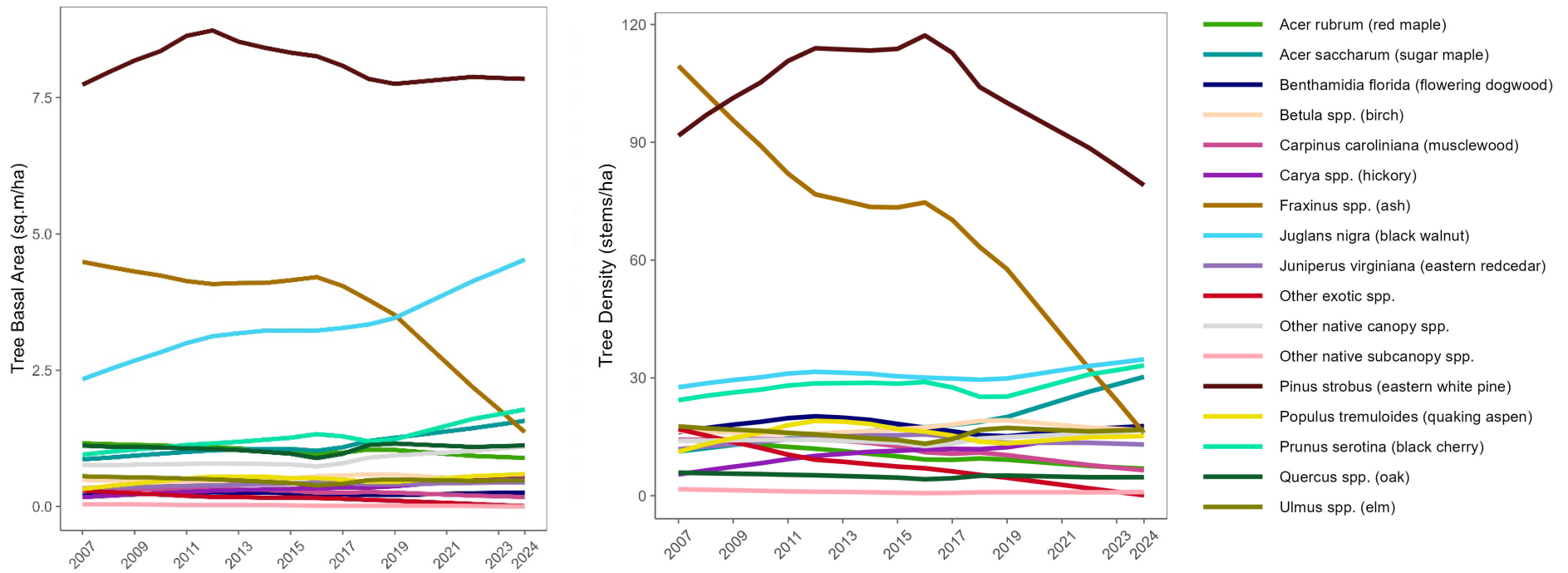


Figure A12. Trends in tree basal area (left) and density (right) by species group and sample year in successional forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that black walnut, black cherry, and sugar maple gained in density and basal area. Ash sharply declined, but have not yet been eliminated, despite being the most common tree when monitoring began.

## Regeneration Trends in Dynamics in Early Successional Fields

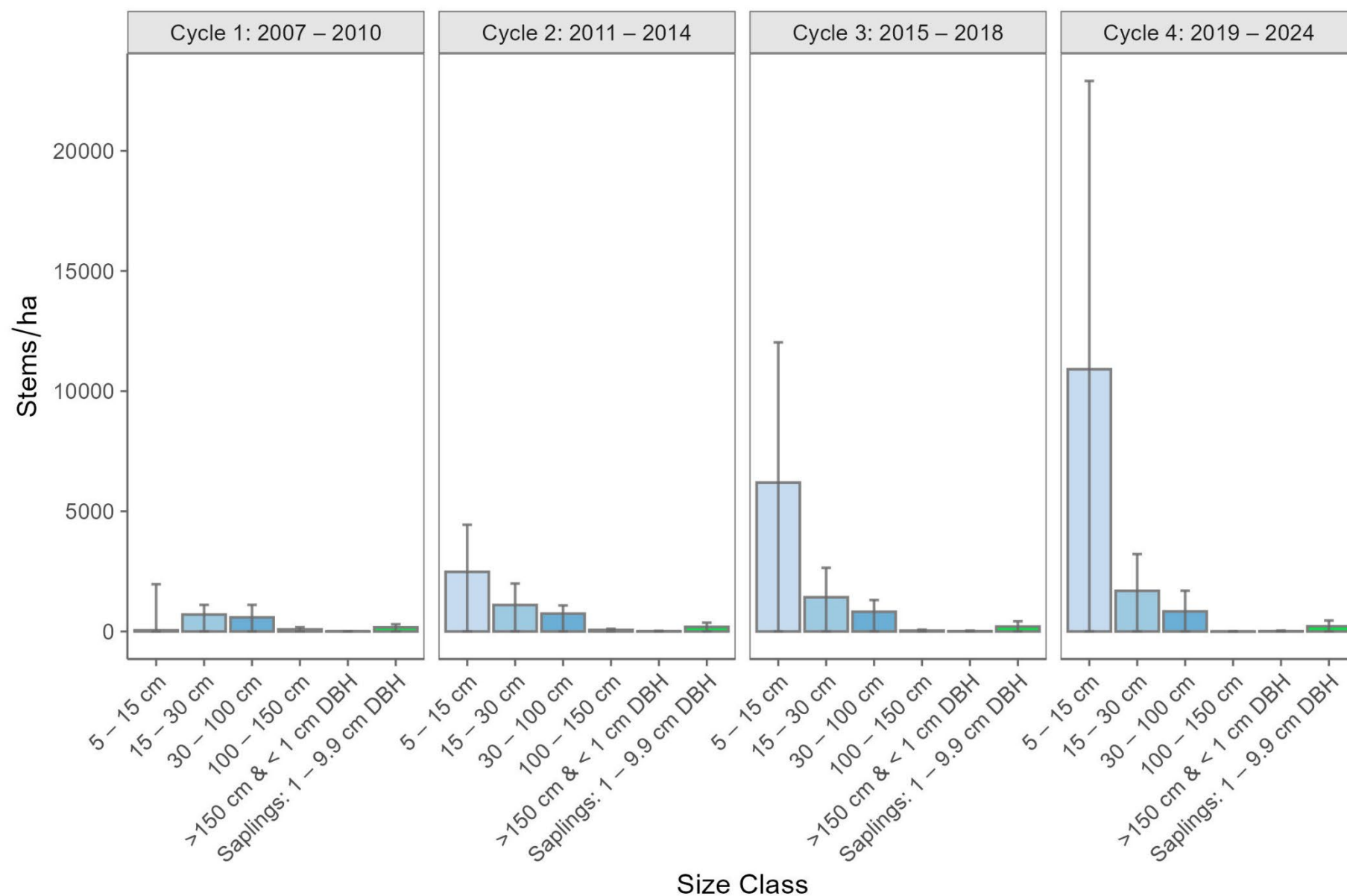


Figure A13. Trends in tree regeneration densities by height class in early successional fields in the Delaware Water Gap National Recreation Area, 2007 – 2024. Error bars are 95% bootstrapped confidence intervals to account for non-normal error. Note the increase in seedlings of smaller size classes, as young trees establish in old fields and begin producing seeds.

## Regeneration Composition Trends in Early Successional Fields

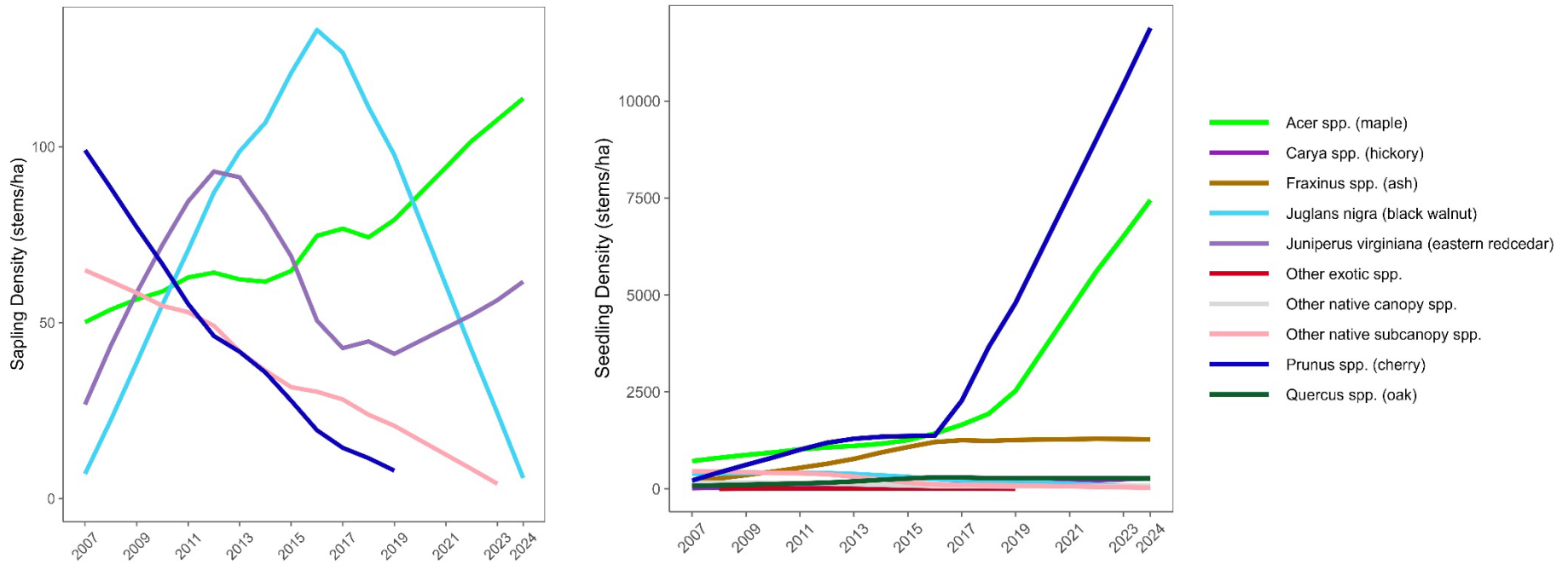


Figure A14. Trends in sapling (left) and seedling (right) density by species group and sample year in early successional field in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note the recruitment into the sapling layer and subsequent decline as eastern red cedar and black walnuts matured into tree-sized individuals. Maple and cherry are abundant and increasing as seedlings but show opposite trajectories as saplings.

## Canopy Composition Trends in Early Successional Fields

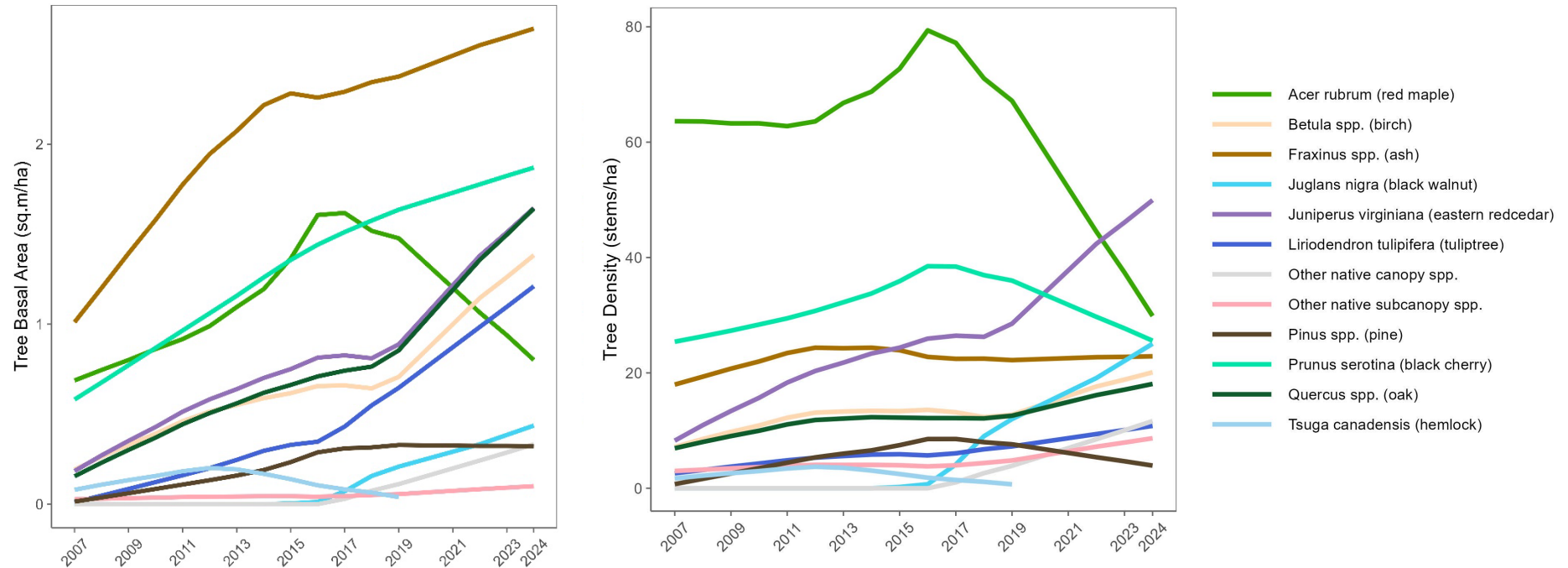


Figure A15. Trends in tree basal area (left) and density (right) by species group and sample year in successional forests in the Delaware Water Gap National Recreation Area. Local regression smoothing approximated a linear trend between consecutive sample events per panel. Note that eastern red cedar and black walnut, the two most common colonizers of old fields, strongly increased in density and basal area. Other young hardwoods such as black cherry, oaks, birches, and tuliptree showed strong growth typical of trees growing in full sun. Surprisingly, ash tree growth remains strong in these old fields, despite park-wide infestation of emerald ash borer. Density of red maple trees peaked around 2016, after which basal area and density declined sharply.

