



Trajectory of Forest Vegetation Under Contrasting Stressors Over a 26-year Period, at Morristown National Historical Park

Focused Condition Assessment Report

Natural Resource Report NPS/MORR/NRR—2023/2500



**ON THIS PAGE**

Flagged trees for data collection within an invaded forest plot with a densely invaded shrub layer at MORR in 2021.
(RUTGERS / JEAN N. EPIPHAN)

ON THE COVER

View of an uninvaded forest plot showing representative ground vegetation and trees with silver identification tags at MORR in 2021. (RUTGERS / JEAN N. EPIPHAN)

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Jean N. Epiphan, Steven N. Handel

Rutgers, The State University of New Jersey
93 Lipman Drive
New Brunswick, New Jersey 08901

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Executive Summary

The Jockey Hollow section and the New Jersey Brigade Area of Morristown National Historical Park (MORR) are predominantly comprised of upland oak-hickory forests that have regrown over the past 200 years from previous land uses. The forest is being damaged by two major stressors, a large population of white-tailed deer and an abundance of non-native, invasive shrubs and herbaceous species. This study explores changes to the forest over 26 years and suggests management techniques to avoid future degradation. The forest is typical of many upland stands in the region, and studies here would be applicable to many lands controlled by the National Park Service and to many public and private land owners.

In 1995, 18 vegetation experimental plots were established in the forest, each 20 x 20 m. Ten plots were in areas that had no non-native, invasive plants. The other eight plots had invasive species. All trees, shrubs and a sampling of herbs were recorded in each of the 18 plots. At that time, no GPS technology was available and handwritten maps were used to record locations. The plots were revisited and resurveyed in 2001; however, only 13 plots were found. This 2021 study is a new survey of the plot conditions. The investigators were able to relocate 17 of the original plots. New GPS locations were recorded for these 17 plots to facilitate future studies.

The goal of the study was to test if changes over 26 years in forest conditions differed between the original invaded plots as compared to the uninvaded plots. Also, these data will allow us to measure the progress of invasion into previously uninvaded areas. Together, these results will allow the forest managers to focus attention on the most aggressive plant invaders and to understand the fate of this forest type that is being challenged by deer and non-native plants. Over the last 26 years there has been no hunting for deer here. Also, the plots were not within the few deer exclosures at MORR; deer were able to enter the landscape from surrounding heavily wooded areas.

Data were collected in four layers of vegetation – mature trees, saplings, shrubs, and herbaceous groundcovers. The mature trees in the invaded forest plots demonstrated declining trends. The species richness declined by 6%, the average number of trees declined by 30%, white ash and flowering dogwood had the most losses, and basal area did not increase over time because very few new saplings grew into mature tree sizes. The uninvaded plots' mature trees also revealed a 20% decline in richness, number of trees declined by 18%, the greatest losses occurred for red maple and black birch, but basal area increased slightly due to growth of large persisting trees.

Saplings in the invaded forest experienced declines over the 26 years. Species richness declined by 38%, number of native saplings decreased by 44%, and number of invasive saplings increased by 600%. In the uninvaded forest, the conditions and trends were variable. Richness decreased by 21%, no invasive saplings found, number of native saplings increased by 37% (due to increases in American beech). With American beech excluded, the number of native saplings decreased by 60%. In both forest types, the declining number of native saplings was primarily caused by excessive deer damage.

For the shrub layer in invaded plots, Japanese barberry stems increased by 122% by 2001 and 276% by 2021. Barberry became the dominant species. Similarly, wineberry stands increased 486% in 2001 and 157% for 2021. It is now the second most common species. However, in the uninvaded plots there was no significant increase in the number of barberry stems and wineberry was not present in 1995 or 2001, and only averaged 1.5 stems per plot in 2021. Neither species has a significant presence now and eradication is possible. A major finding is that the process of invasion of these shrubs over 26 years is very slow.

For the herbaceous plants, in the invaded plots there was a sharp decrease in cover by 2021 due to the competitive impact by the abundant invasive shrubs. The invasive Japanese stiltgrass declined 86% in cover and native *Carex* (sedge) species declined by 78%. In the uninvaded forest plots, stiltgrass was present in very low amounts and did not increase significantly over 26 years. The number of quadrats with any stiltgrass only increased from 3 to 5 over the 26 years. These data show that stiltgrass invades slowly in the uninvaded plots, but in the invaded plots it was greatly replaced by invasive shrubs. Overall, the rate of change of the native herb cover was slow.

Together, these data suggest that currently uninvaded forest areas can be protected by monitoring and rigorously eliminating any initial invasions by non-native shrubs and herbs. Once these species reach a significant presence in number of stems or cover in a plot they explode in number. Early intervention when invasive plants first appear is the most practical management tool. Reduction of deer density will also increase the reproductive potential and sustainability of our main forest tree species. Planting of new young canopy tree species, with protection from deer, can retard the ability of invasive plants to begin new populations.

Focused Condition Assessments – Introduction

The National Park Service's (NPS) Natural Resource Condition Assessment (NRCA) Program evaluates natural resource conditions in park units and delivers the results to park staff, scientists, strategic planners, and the general public through reports and associated products. All NRCA efforts strive to report resource condition information in a way that informs multiple levels of park stewardship activities. Stewardship activities may include partnerships, resource stewardship plans, and park management plans, and may inform on-the-ground actions that park management can readily implement.

As part of the NRCA program, Focused Condition Assessments (FCAs) are short-term projects where a pressing issue or critical data or knowledge gap exists, prompting the need to assess the current conditions of one, or a few park natural resources. FCAs are intended to address specific natural resource conditions that lend important information for management and decision-making. As short-term projects, FCAs primarily rely on utilization and synthesis of existing science and data. FCAs are intended to strengthen our understanding of current resource conditions and their relation to environmental processes across the landscape and improve the delivery of best available science for park management.

Standard products from FCA projects include a detailed project report and associated products. Associated products may be data summaries, resource briefs, geospatial maps and information, story maps, and others. All reports and associated products are available via the NPS Datastore (<https://irma.nps.gov/DataStore/>).

Chapter 1. Management Issue and Approach

1.1 Management Issue or Critical Information Need

Morristown National Historical Park (MORR) is embedded in a vast suburban landscape with a wildlife sanctuary and other public parklands abutting its boundary. MORR is the large central part of this important forested habitat core (1381 ha; NJDEP 2020) that provides critical resources for several species of locally native fauna including: large mammals like the *Ursus americanus* (black bear; NJDEP 2021; NPS 2022) that frequent the skunk cabbage swamps and surrounding upland forests (Masson R. personal communication 15 October 2021); multiple species of bats have habitats within the uninvaded forest (Kerwin K. personal communication 26 April 2022; Masson R. personal communication 10 October 2021); threatened and endangered avian species like the *Melanerpes erythrocephalus* (red-headed woodpecker) utilize the forests of MORR (NJDEP 2018; NPS 2022; NJDEP 2004); aquatic fauna that live in the class one streams at MORR, such as the *Salmo trutta* (brown trout) and *Salvelinus fontinalis* (eastern brook trout) that require shaded and cooled riparian corridors in summer months provided by current dense canopy cover (NPS 2022; NJDEP Division of Fish and Wildlife 2005). MORR also contains abundant wildflower species including several orchids (Handel 1996) and rare plants of concern, such as the New Jersey state threatened *Dryopteris goldiana* (Goldie's woodfern; Epiphan & Masson, personal field observation 2021; NJDEP 2016), as well as a rare plant community, the montane basic seepage swamp (Sneddon et al. 2008). These examples are only just a few from the several species that depend on the intact and healthiest forests of MORR for their persistence and survival.

In the 1970s and early 1980s, Professor Joan G. Ehrenfeld mapped the forest types of Jockey Hollow and the New Jersey Brigade Area (Ehrenfeld 1977; Ehrenfeld 1992). The multiple forest types and associated vegetative compositions were documented. By the 1990s, exotic plants, that are now considered invasive species, escaped from nearby horticultural plantings, and spread into the park landscape (Ehrenfeld 1997; Ehrenfeld 1999a; Ehrenfeld 1999c). At the same time *Odocoileus virginianus* (white-tailed deer) populations surged beyond ecological carrying capacity (Masson R. personal communication 03 October 2021; Kelly 2019). Native plants in the understory have suffered since from over-browsing. Most native saplings have been damaged with severe buck-rub causing stem mortality. This has greatly reduced the numbers of saplings that would otherwise have become healthy mature trees (Rossell et al. 2007; Relva et al. 2010; NPS 2017). The spread of invasive plants and excessive deer damage caused severe losses of native understory vegetation (Epiphan and Handel 2020), declines in tree regeneration causing a mature tree deficit (Miller and McGill 2019), and overall loss of native plant biodiversity which directly impacts animal species that require healthy forests for critical habitat.

The composition of forest vegetation began to change in response to the new stressors. Differences in vegetative structure were observed between newly invaded and uninvaded forest sections. In response to this, eighteen 20 x 20 m forest vegetation plots were established in 1995 in a stratified design; 10 plots were placed in uninvaded forest locations and 8 plots in invaded locations in Jockey Hollow and the New Jersey Brigade Area (Ehrenfeld 1999b). This was the beginning of a long-term study to monitor changes in vegetation over time in response to these stressors and to compare their

differences between invaded and uninvaded areas. Thirteen of the eighteen plots were resampled in 2001 (Russell 2002). In 2021, seventeen of the forest plots were found and locations spatially recorded in a GPS file (Figure 1.1); each plot was inventoried using the original survey methods (Ehrenfeld 1999b).

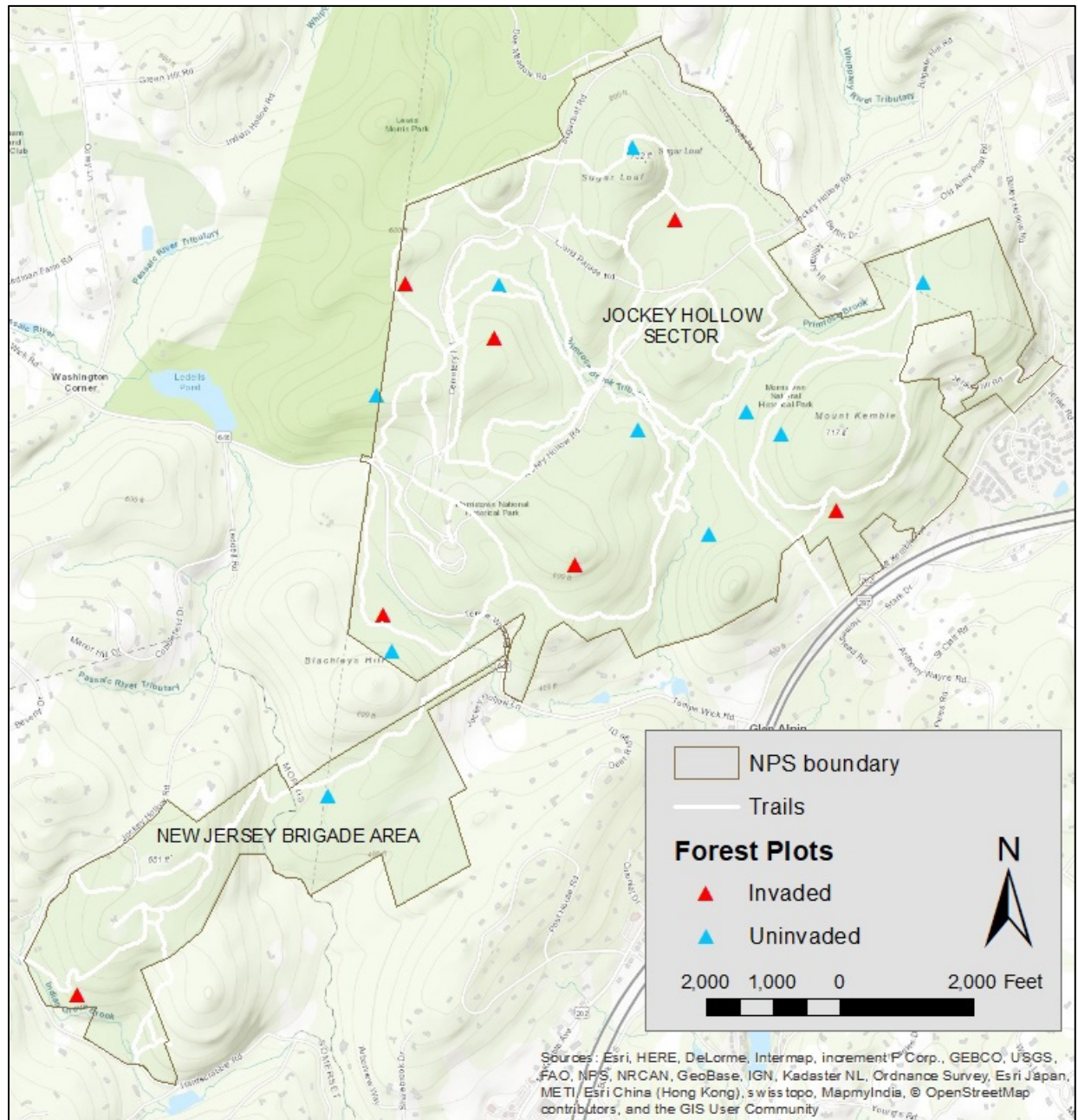


Figure 1.1. The seventeen forest plot locations found and recorded in 2021 in Morristown National Historical Park.

Although recent research has characterized differences between urban and rural vegetation in the Northeast, there is a lack of quantitative and long-term study of suburban landscapes which are a

major component of the region's natural resources and biodiversity. A key objective of this project was to understand the trajectory of vegetation by evaluating the current condition of the park's vegetation to clarify the impact of landscape stressors with the focus on invasive plants and deer browsing. The other objective was to measure the course of natural resource change from different ecological starting points, an invaded forest compared to an uninvaded forest. This project will determine if sites that were not invaded in 1995 have remained uninvaded as well as the trajectory of forest composition in invaded forests. This addresses the tempo of vegetative change and the persistence of invasive character of vegetation over twenty or more years.

1.2 Study Approach

The primary drivers of natural forest composition change over time include time, birth and death rates, and natural succession as well as disturbances. Within the MORR forest embedded in suburbia, environmental stressors play a significant role in vegetation changes over time. The two main stressors are deer over-abundance and invasive plant impacts (Baiser et al. 2008; NPS 2017; Kelly 2019). This study has a stratified design and enables comparisons of vegetation trajectories in invaded and uninvaded forest areas. This will inform deer and invasive plant management needs, strategies, and priorities.

The findings will demonstrate the tempo at which uninvaded forests become infiltrated with invasive species. This is critical as the uninvaded forests are the last reserves of native biodiversity in this large habitat core. Results will also inform how the overabundant deer impact forest diversity and structure in uninvaded forests. Results will show if high deer populations limit the amount of native tree regeneration and growth into mature sizes. In addition, results will reveal any species shifts and losses in each vegetative stratum, and if they may be linked to invasive plant and deer pressures in uninvaded forests. Both invasive plants and deer pose significant threats to the last uninvaded forest areas in MORR. The severity at which they are affected will reveal where to prioritize management actions as well as which species of native flora are at highest risk of loss in the park.

In invaded forests the results will show how the invasive plants have spread or increased in abundance over 26 years. This can provide an estimated time frame for how long it takes for mildly invaded forests to become overrun and dominated by invasive understory plants. Results will also show which invasive plant species became dominant after 26 years and inform management actions for target species. Results of native plant cover and tree growth stages will demonstrate if the deer and invasive plant pressures affect the trajectories of forest composition differently in invaded forests than in uninvaded forests. This further refines management strategies and priorities to conserve native biodiversity.

1.2.1 Selection of Key Resources, Indicators, and Reference Criteria

This study will reveal how the forest composition of MORR has been changing over time in the two differing forest conditions (invaded and uninvaded) while subject to both deer and invasive plant stressors. The key resources include each vegetation stratum: mature trees; saplings; shrubs and seedlings in the shrub layer; dominant ground covers in the herb layer. The indicators of the resources' conditions and trends are measured through species richness and abundance data sets.

The mature tree species richness and average numbers over time will demonstrate how the forest canopy composition is changing. The findings will demonstrate if there are losses or gains in abundance of trees, specific species, or in richness, and the differences between the two forest settings. This will inform forest management of mature tree resources that require attention in invaded or uninvaded forests. The number of saplings and their growth to mature tree size will reveal if the canopies will experience deficits or will adequately replenish canopy trees in either or both forest settings. Sapling numbers and composition data will demonstrate if deer pressure affects sapling condition in either forest setting.

The shrub layer's invasive species stem numbers and richness will reveal how dominant the invasive shrubs have become in invaded forests over time and if they infiltrated previously uninvaded forests. The stem numbers of the dominant shrub species, *Berberis thunbergii* (Japanese barberry), is the key indicator of shrub invasion. *B. thunbergii* stem numbers over time reveal which strategies, such as early detection-rapid response, to use in which forest condition. The herb layer indicators include the average percent cover of dominant ground covers including the invasive grass *Microstegium vimineum* (Japanese stiltgrass) as well as native *Carex* spp. (sedge) and fern species. These will help to determine the ecological health of the forest floor. For example, *M. vimineum* and *B. thunbergii* have been proven to reduce tree seedling recruitment and growth (Aronson and Handel 2011; Johnson et al. 2015; Link et al. 2018), therefore their cover is a gauge of native seedling recruitment and regeneration as well as plant community health.

1.2.2 Data Sources

This study was originally designed in 1995 to capture the differences in vegetative structure in uninvaded and invaded forest areas (Ehrenfeld 1999b). Ten plots were established in uninvaded forest and eight plots were established in invaded forests. At each plot, posts were inserted into the ground at each corner to permanently mark their locations. GPS locations were not recorded in 1995. Within the 20m x 20m plot, all mature trees (≥ 10 cm DBH) were identified to species and their diameters recorded. Some closely related species were indistinguishable at time of sampling and were only recorded by genus; this includes *Carya* spp. for the following hickory species *C. glabra*, *C. tomentosa*, *C. ovata*. Saplings (1–10cm DBH) were all recorded by species and counted throughout the entire plot. Shrub, tree seedling (< 1 cm DBH), and woody vine species and their stem counts were recorded within four 5m x 5m subplots in each corner of the main 20m x 20m plot (Figure 1.2). Basic herbaceous plant percent cover information was recorded in nine 1m² quadrats. Percent cover was determined by visual estimation. Data collection included the percent cover of *M. vimineum* (a common invasive grass plaguing the herb layer), *Carex* species cover (all of which were native to the forest), fern cover (all fern species were native to the forest), as well as lists of the other species present in the herb quadrats. However, percent cover data was not collected for them. All the above was recorded in 1995 as a baseline dataset.

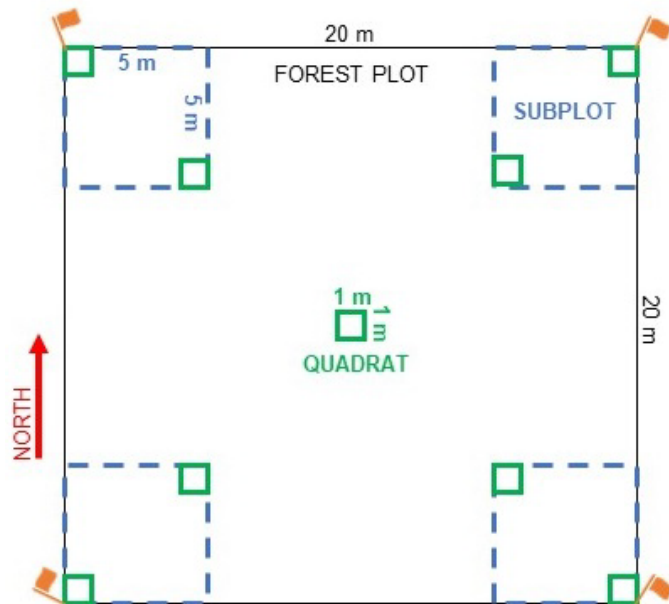


Figure 1.2. Forest plot diagram including the four subplots (blue dashed outline), nine quadrats (green outline), and their locations with their respective sizes noted. Orange flags show the permanent corner marker locations.

In 2001, only thirteen of the eighteen plots could be found as the coordinates of the locations were not documented or available (Russell 2002). Vegetation data were collected using the same methods as in 1995. None of the original data sheets from 1995 or 2001 were preserved. The available digital datasets were from 2001 which contained most of the data from 1995 and 2001 and were synthesized for analysis. As the entirety of the 1995 data was not saved, there were some data discrepancies from 1995 and 2001 in the shrub layer, specifically. With the exception of *B. thunbergii* and *Rubus phoenicolasius* (wineberry), individual shrub and seedling species information were missing from the available data sets. Other invasive shrub, vine, and seedling stem counts were not included in the available data set; therefore, a total invasive species stem count was not obtainable. All the native shrub, vine, and tree seedling species in the subplots were lumped into one category for analysis but the information did not include species specific stem numbers, therefore, more detailed information of native seedlings, shrubs or vine species was not obtainable for analysis over time. Furthermore, the species lists for the invaded and uninvaded shrub layers were incomplete and total richness for invasive and native species were not completely accurate. All other data as collected were included in the available 1995 and 2001 dataset files.

In 2021, seventeen of the eighteen plots were found, and locations permanently recorded (coordinates and GIS shapefile) so they can be easily found in the future with a GPS unit (Figure 1.1). In the seventeen plots, vegetation was surveyed in each stratum using the original methods. In addition, each species' percent cover in the herb quadrats was recorded for the benefit of future studies. The one missing plot that has not been found since 1995 was an invaded plot. Therefore, this long-term analysis excludes the missing data from 1995 and only contains seven invaded plots and the ten uninvaded plots.

The data collected over time were and are appropriate to comprehend and develop findings regarding the key resource issues. The mature tree data over time will show which species in which types of plots grew or survived, and any patterns of species lost. It also will compute the growth rates of certain species as well as which species and how many grew from the sapling layer to become mature tree in 2021. The mature tree information also will demonstrate the compositional change over time between invaded and uninvaded forests. This will reveal which tree species are at greater risk of decline or loss in each forest setting, invaded and uninvaded. The sapling species and numbers over time will demonstrate the success of tree regeneration and growth in the two forest settings. It also will reveal which species are more likely to withstand or avoid deer damage and if forest condition is associated with this. The species composition of the sapling layer will also reveal which trees may be growing into the mature tree stratum and become part of the canopy in future decades.

The shrub data findings will demonstrate the growth and spread of the two main invasive shrubs in MORR, *B. thunbergii* and *R. phoenicolasius*. As the other stem number and richness data in the shrub layer were incomplete in past years, native woody plant data and richness in this layer were not analyzed over time. Even so, the detailed stem number data of two dominant invasive shrubs in the invaded and uninvaded forests will help infer whether their populations are impacting other strata over time and which management approaches are possible for control. The basic herb data will reveal the threat of *M. vimineum* invasion over time in invaded and uninvaded forests and how that may affect the native *Carex* and fern species of the herb layer. The herb data will also show how it may impact or be impacted by the other strata in each forest setting.

1.2.3 Methodology/Analysis

The available datasets from 1995 and 2001 were compared to the new data collected in 2021 in four different strata: mature trees ($\geq 10\text{cm}$ DBH); saplings ($< 1\text{cm}$ DBH); the shrub layer consisting of shrubs, tree seedlings ($< 1\text{cm}$ DBH), and woody vines; the herb layer. The two most complete datasets that encompassed information from seventeen plots were from 1995 and 2021; most of the analysis (mature trees, saplings, and herbs) used the data from these two years. The limited shrub data in the thirteen plots sampled in 2001, were analyzed over the three sampling years, 1995, 2001, and 2021. The analysis of datasets involved simple compilations of stem counts, species richness, and averages ($\pm$ standard error) within each vegetation category and stratum, as is required under the NPS guidelines for Focused Condition Assessments. More detailed statistical analyses will be used for more technical reports of these vegetation trends.

The data were grouped by forest setting, invaded plots and uninvaded plots. Each stratum was analyzed separately to provide information on the condition, trend, and trajectories in the two different forest settings. The indicators used to determine mature tree trends and conditions in invaded and uninvaded plots were: total species richness; average of mature tree numbers; average basal area. Basal area (m^2) was found using the below formula where DBH stands for diameter (cm) at breast height:

$$\text{Basal Area (BA)} = \frac{\pi(\text{DBH} \div 2)^2}{10,000}$$

Sapling indicators included: total species richness; average of native sapling numbers; average of invasive sapling numbers. The shrub layer indicators included: average stem number of *B. thunbergii*; average stem number of *R. phoenicolasius*. The herb layer indicators included: average percent cover of *M. vimineum*, the common invasive grass species; average percent cover of *Carex* spp., which were all native; average percent cover of fern species, which were all native. Standard error was calculated for every average number calculation.

Determination of which species were native or invasive were verified using multiple sources (Hough 1936; Native Plant Trust 2021; USDA NRCS 2021), including the locally accurate New Jersey invasive species strike team do not plant list (FoHVOS New Jersey Invasive Species Strike Team 2019).

Chapter 2. Study Results

The forest resources of MORR over time revealed some similarities between the invaded and uninvaded forest plots and some differing assemblages, trends, and conditions. Each vertical stratum of vegetation, mature trees, saplings, the shrub layer, and the herb layer, served as individual focuses for this analysis and specific indicators provided insight into the trajectories of forest vegetation. Overall, the invaded forests had more resource indicators with declining trends or conditions than in the uninvaded plots where the indicator trends and conditions varied between stable and declining.

2.1 Mature Tree Stratum

The mature tree assemblages of invaded forests and uninvaded forests had many similarities yet some distinct differences. On average, there were more mature trees in uninvaded plots than in invaded plots in both 1995 and 2021 (Table 2.1; Table 2.2). In addition to containing more individuals, the uninvaded plots had greater numbers of *Fagus grandifolia* (American beech), *Quercus* spp.(oaks), and *Carya* spp., which are indicative of the oak-hickory forest type at MORR. The uninvaded plots also contained *Betula alleghaniensis* (yellow birch) and *Nyssa sylvatica* (black gum) which did not occur in invaded forest plots. The invaded forest plots contained more *Fraxinus americana* (white ash) than the uninvaded plots as well as disturbance-associated species that did not occur in the uninvaded plots, *Juglans nigra* (black walnut), *Prunus serotina* (black cherry), *Sassafras albidum* (sassafras), and the invasive *Robinia pseudoacacia* (black locust).

Over time, the invaded and uninvaded plots displayed some differing and some similar composition. All *Ulmus americana* (American elm) individuals were lost from both forest settings (Table 2.1; Table 2.2). The numbers of *Cornus florida* (flowering dogwood) and *F. americana* experienced great losses in both forest settings as well. However, in the uninvaded forests, the greatest tree losses were by *Acer rubrum* (red maple) and *Betula lenta* (black birch). The total species richness in both invaded and uninvaded forests revealed a declining trend. The average number of trees declined in both forest settings (Table 2.3).

The condition statuses and trends indicated by basal area varied between the two forest settings (Table 2.3). It is important to note that basal area as an indicator may be misleading without considering the change in number of trees over time (Appendix A). Therefore, the basal area statuses and trends takes the number of trees into consideration (Table 2.3). In the invaded forest plots, basal area over time had no significant change as the larger persisting trees increased enough in girth to compensate for the number of trees lost (Appendix A). Very few saplings of any species grew into mature sized trees by 2021, therefore the condition was poor, and trend is declining because basal area should have increased over time. In the uninvaded forest plots, basal area increased as several trees grew substantially in diameter which compensated for the losses of other trees. For example, the basal area of all *Quercus rubra* (northern red oak) increased even though 3 trees were lost (Appendix A). In addition, some saplings, like *Carya* spp. and *Liriodendron tulipifera*, grew into mature tree sizes, which contributed to the increase of basal area (Table 2.2). Even so, the basal area condition over time was variable as some species decreased in basal area while others increased. The trend was

considered stable as the basal area increased, however a good trend would have been expressed as a greater increase than what occurred.

Table 2.1. Mature tree species numbers and average numbers by species ($\pm$ standard error) from 1995 to 2021 within the invaded forest plots ($n = 7$) in Morristown National Historical Park. Mature trees were ≥ 10 cm DBH at times of sampling.

Species	Total Number of Trees				Average Number of Trees				Average number difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	14	11	-3	0	2.00	1.0	1.57	0.72	-0.43
<i>Acer saccharum</i>	1	1	0	0	0.14	0.1	0.14	0.14	0.00
<i>Betula lenta</i>	12	11	-1	0	1.71	1.1	1.57	1.11	-0.14
<i>Carya</i> spp.	3	3	0	0	0.50	0.3	0.50	0.34	0.00
<i>Cornus florida</i>	7	1	-6	0	1.00	0.4	0.14	0.14	-0.86
<i>Fagus grandifolia</i>	2	4	0	2	0.29	0.2	0.57	0.43	0.29
<i>Fraxinus americana</i>	20	11	-9	0	2.86	0.8	1.57	0.53	-1.29
<i>Juglans nigra</i>	1	1	0	0	0.14	0.1	0.14	0.14	0.00
<i>Liriodendron tulipifera</i>	5	5	0	0	0.71	0.4	0.71	0.36	0.00
<i>Prunus serotina</i>	2	2	0	0	0.29	0.2	0.29	0.18	0.00
<i>Robinia pseudoacacia</i> *	7	2	-5	0	1.00	0.8	0.29	0.18	-0.71
<i>Sassafras albidum</i>	1	1	0	0	0.14	0.1	0.14	0.14	0.00
<i>Quercus alba</i>	1	1	0	0	0.14	0.1	0.14	0.14	0.00
<i>Quercus montana</i>	5	3	-2	0	0.71	0.3	0.43	0.30	-0.29
<i>Quercus rubra</i>	4	4	0	0	0.57	0.2	0.50	0.20	0.00
<i>Quercus velutina</i>	2	2	0	0	0.29	0.2	0.29	0.18	0.00
<i>Ulmus americana</i>	2	0	-2	0	0.29	0.2	0.00	0.0	-0.29
Total	89	63	-28	2	12.71	0.8	9	0.93	-3.71

* Invasive species

Table 2.2. Mature tree species numbers and average numbers by species ($\pm$ standard error) from 1995 to 2021 within the uninvaded forest plots ($n = 10$) in Morristown National Historical Park. Mature trees were ≥ 10 cm DBH at times of sampling.

Species	Total Number of Trees				Average Number of Trees				Average number difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	20	11	-9	0	2.00	0.49	1.10	0.38	-0.90
<i>Betula alleghaniensis niensis</i>	7	4	-3	0	0.70	0.42	0.40	0.31	-0.30
<i>Betula lenta</i>	30	21	-9	0	3.33	0.88	2.10	0.75	-1.23
<i>Carya</i> spp.	5	8	0	3	0.50	0.40	0.80	0.42	0.30
<i>Cornus florida</i>	3	0	-3	0	0.30	0.21	0.00	0.00	-0.30
<i>Fagus grandifolia</i>	29	31	0	2	3.22	1.22	3.10	1.11	-0.12
<i>Fraxinus americana</i>	5	2	-3	0	0.50	0.40	0.20	0.20	-0.30
<i>Liriodendron tulipifera</i>	3	5	0	2	0.30	0.15	0.50	0.27	0.20
<i>Nyssa sylvatica</i>	2	2	0	0	0.20	0.20	0.20	0.20	0.00
<i>Prunus avium</i> *	3	0	-3	0	0.30	0.30	0.00	0.00	-0.30
<i>Quercus alba</i>	4	4	0	0	0.40	0.16	0.40	0.16	0.00
<i>Quercus montana</i>	8	8	0	0	0.80	0.29	0.80	0.29	0.00
<i>Quercus rubra</i>	18	15	-3	0	1.80	0.63	1.50	0.58	-0.30
<i>Quercus velutina</i>	4	5	0	1	0.40	0.22	0.50	0.31	0.10
<i>Ulmus americana</i>	1	0	-1	0	0.10	0.10	0.00	0.00	-0.10
Total	142	116	-34	8	14.20	0.95	11.60	0.92	-2.60

* Invasive species

Table 2.3. Condition assessment of the mature tree resource from 1995 to 2021 within the invaded and uninvaded forest plots in Morristown National Historical Park. Mature trees were $\geq 10\text{cm}$ DBH at times of sampling.

Resource	Condition Indicators Assessed	Condition Status/Trend	Rationale & Key Points
Mature trees in invaded forest plots ($n=7$)	Total species richness	Stable Condition/ Declining Trend	Richness decreased by 6% from 1995 to 2021 because the mature <i>Ulmus americana</i> in plots died. All other species persisted.
	Average Number	Declining Condition/ Declining Trend	The average number of trees decreased by 30%. <i>Fraxinus americana</i> and <i>Cornus florida</i> experienced the most losses while fewer saplings grew into matures trees to compensate over the same period.
	Basal Area	Poor Condition/ Declining Trend	There was a 15% increase in average basal area over time because growth of the persisting trees compensated for the losses of tree numbers. In a healthy forest the basal area should be increasing.
Mature trees in uninvaded forest plots ($n=10$)	Total species richness	Stable Condition/ Declining Trend	Richness decreased by 20% over time. One of the three species lost was the invasive species <i>Prunus avium</i> *, which is beneficial. Native richness decreased by 14% due to losses of <i>Cornus florida</i> and <i>Ulmus americana</i> .
	Average Number	Declining Condition/ Declining Trend	The average number of trees decreased by 18%. A few saplings grew into mature size trees, but more mature trees were lost than gained. Both <i>Acer rubrum</i> and <i>Betula lenta</i> lost the most individuals.
	Basal Area	Variable Condition/ Stable Trend	Basal increased by 24% because the persisting larger mature trees, like <i>Quercus veluntina</i> , and faster growing trees, like <i>Betula lenta</i> , grew more in girth to compensate for the basal area losses from the decreased number of trees over time.

* Invasive species

2.2 Sapling Stratum

The sapling species assemblages between the invaded and uninvaded forest had a few similarities but were very different both in 1995 and in 2021 (Table 2.4; Table 2.5). The most obvious difference between the forest settings were the average number of saplings per plot; the invaded plots had far fewer saplings (Table 2.4; Table 2.5). Richness was also higher in the uninvaded plots and the composition contained more species indicative of mature forests, including *Amelanchier* sp. (serviceberry), *Carpinus caroliniana* (hornbeam), and *Ostrya virginiana* (hop hornbeam; Table 2.5). The invaded plots contained some disturbance-associated species not found in the uninvaded plots including *S. albidum* in 2021 and two invasive species, *Prunus avium* (bird cherry) in 1995 and *R. pseudoacacia* in 2021 (Table 2.4).

Over time, sapling indicators shared some similarities between invaded and uninvaded plots, but also revealed some differing trends and conditions (Table 2.6). The sapling species richness in each forest setting declined yet differing species were lost in each setting (Table 2.4; Table 2.5). Sapling number trajectories were similar for some species like *C. florida* that experienced substantial losses in both settings. However, the sapling numbers of other species differed significantly between settings. In the uninvaded forests, *A. rubrum* and *Betula alleghaniensis* (yellow birch) experienced great number of losses (Table 2.5). The remaining sapling species experienced losses except for *F. grandifolia* saplings which increased by 178% over 26 years. This resulted in a variable condition and unstable trend in the uninvaded forest (Table 2.6). In the invaded forest, the condition and trend were both declining (Table 2.6) as most native sapling species decreased or completely died out except for *S. albidum*, while the invasive *R. pseudoacacia* greatly increased in numbers (Table 2.4).

Table 2.4. Sapling species numbers and average numbers by species ($\pm$ standard error) from 1995 to 2021 within the invaded forest plots ($n = 7$) in Morristown National Historical Park. Saplings were tree species between 1–10cm DBH at times of sampling.

Species	Total Number of Saplings				Average Number of Saplings				Average number difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	2	1	–1	0	0.29	0.18	0.14	0.14	–0.14
<i>Acer saccharum</i>	1	0	–1	0	0.14	0.14	0.00	0.00	–0.14
<i>Betula lenta</i>	2	1	–1	0	0.29	0.29	0.14	0.14	–0.14
<i>Cornus florida</i>	8	2	–6	0	1.14	0.55	0.29	0.18	–0.86
<i>Fagus grandifolia</i>	1	0	–1	0	0.14	0.14	0.00	0.00	–0.14
<i>Prunus avium</i> *	1	0	–1	0	0.14	0.14	0.00	0.00	–0.14
<i>Quercus rubra</i>	1	0	–1	0	0.14	0.14	0.00	0.00	–0.14
<i>Robinia pseudoacacia</i> *	0	7	0	7	0.00	0.00	1.00	0.65	1.00
<i>Sassafras albidum</i>	0	5	0	5	0.00	0.00	0.71	0.57	0.71
<i>Ulmus americana</i>	1	0	–1	0	0.14	0.14	0.00	0.00	–0.14
Total	17	16	–13	12	1.14	0.55	0.29	0.18	–0.86

* Invasive species

Table 2.5. Sapling species numbers and average numbers by species ($\pm$ standard error) from 1995 to 2021 within the uninvaded forest plots ($n = 10$) in Morristown National Historical Park. Saplings were tree species between 1–10cm DBH at times of sampling.

Species	Total Number of Trees				Average Number of Trees				Average number difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	23	8	-15	0	2.30	0.75	0.80	0.39	-1.5
<i>Amelanchier</i> sp.	4	2	-2	0	0.40	0.22	0.20	0.13	-0.2
<i>Betula alleghaniensis</i>	7	1	-6	0	0.70	0.60	0.10	0.10	-0.6
<i>Betula lenta</i>	12	10	-2	0	1.20	0.42	1.00	0.68	-0.2
<i>Carpinus caroliniana</i>	2	1	-1	0	0.20	0.20	0.10	0.10	-0.1
<i>Carya</i> spp.	3	3	0	0	0.30	0.21	0.30	0.21	0.0
<i>Castanea dentata</i>	1	0	-1	0	0.10	0.10	0.00	0.00	-0.1
<i>Cornus florida</i>	11	1	-10	0	1.10	0.46	0.10	0.10	-1.0
<i>Fagus grandifolia</i>	51	142	0	91	5.10	2.38	14.2	6.44	9.1
<i>Fraxinus americana</i>	5	0	-5	0	0.50	0.50	0.00	0.00	-0.5
<i>Liriodendron tulipifera</i>	2	0	-2	0	0.20	0.13	0.00	0.00	-0.2
<i>Nyssa sylvatica</i>	3	2	-2	1	0.30	0.30	0.20	0.20	-0.1
<i>Ostrya virginiana</i>	1	1	0	0	0.10	0.10	0.10	0.10	0.0
<i>Quercus rubra</i>	1	1	0	0	0.10	0.10	0.10	0.10	0.0
Total	126	172	-46	92	12.60	2.40	17.20	6.89	4.6

Table 2.6. Condition assessment of the tree sapling resource from 1995 to 2021 within the invaded and uninvaded forest plots in Morristown National Historical Park. Saplings were tree species between 1–10cm DBH at times of sampling.

Resource	Condition Indicators Assessed	Condition Status/Trend	Rationale & Key Points
Tree saplings in invaded forest plots (n=7)	Total species richness	Declining Condition/ Declining Trend	Species richness declined by 38% from 1995 to 2021. Invasive plant dominance and deer damage contributed to this decline.
	Average number of native saplings	Declining Condition/ Declining Trend	The average number of native saplings decreased by 44% from 1995 to 2021. <i>Cornus florida</i> losses were greatest. Invasive plant dominance and deer damage contributed to this decline in numbers and threaten the condition.
	Average number of invasive saplings	Declining Condition/ Declining Trend	The average number of invasive saplings increased by 600% from 1995 to 2021. <i>Robinia pseudoacacia</i> * advanced regeneration accounted for the jump in invasive sapling numbers.
Tree saplings in uninvaded forest plots (n=10)	Total species richness	Declining Condition/ Declining Trend	Richness decreased by 21% from 1995 to 2021. Deer damage (buck-rub) contributed to the decline as they prefer to rub certain species.
	Average number of native saplings	Variable Condition/ Unstable Trend	The average number of native saplings increased by 37% which is primarily due to the significant increase of <i>Fagus grandifolia</i> saplings from 1995 to 2021. With <i>F. grandifolia</i> excluded from calculations, the average number of saplings decreased by 60%. Beech Leaf Disease is a threat to beech sapling numbers. Deer damage threatens numbers of all native species.
	Average number of invasive saplings	Good Condition/ Stable Trend	There were no invasive sapling species recorded in the uninvaded forest plots.

* Invasive species

2.3 Shrub Stratum

The invasive shrub quantities in the invaded and uninvaded forest plots revealed declining trends (Table 2.7). Only two shrub species were reported completely in 1995 and 2001 (see page 15); these species are reported here. In 1995, *B. thunbergii* occurred in most of the invaded subplots, averaging 36 stems in each (Figure 2.1). By 2021, stems increased by 539% and barberry became the dominant shrub species in the invaded forests, which revealed the declining condition and trend. In the uninvaded forest, *B. thunbergii* was present in 1995 and 2021 in low numbers without a significant increase over time (Figure 2.2; Table 2.7). Yet, the condition is unstable due to the nature of how barberry can persist and spread when conditions change. Therefore, barberry is present in both forest settings, but had greater numbers that surged by 2021 in the invaded forests.

The next most common invasive shrub, *R. phoenicolasius*, displayed declining conditions and trends in both forest settings. There were significant increases in stem numbers between 1995 and 2021 (Table 2.7). The invaded forest had low average numbers of *R. phoenicolasius* stems in 1995 that increased to moderate numbers by 2021. In the uninvaded forests, there were no stems present until 2021 when on average 1.54 (± 0.89 SE) stems were observed in the subplots; this amount was similar to the amount recorded in the invaded forest subplots in 1995, 1.67 (± 0.75 SE) average stem numbers.

Table 2.7. Condition assessment of the shrub layer resources from 1995 to 2001 to 2021 within the invaded and uninvaded forest plots in Morristown National Historical Park.

Resource	Condition Indicators Assessed	Condition Status/Trend	Rationale & Key Points
Woody plants in shrub layer sampled in invaded forest plots (n=24)	Average number of <i>Berberis thunbergii</i> *	Declining Condition/ Declining Trend	Number of stems increased exponentially by 122% from 1995 to 2001 and by 276% from 2001 to 2021. This species has become dominant in the shrub layer and is a widespread threat to native vegetation in the invaded forest and nearby uninvaded areas.
	Average number of <i>Rubus phoenicolasius</i> *	Declining Condition/ Declining Trend	Number of stems increased by 466% from 1995 to 2001 and by 157% from 2001 to 2021. This species was an emerging threat that is now becoming widespread in the invaded forest.
Woody plant in the shrub layer sampled in uninvaded forest plots (n=28)	Average number of <i>Berberis thunbergii</i> *	Unstable Condition/ Declining Trend	There was no substantial change in in average stem numbers over time, even though there was a very minor increase. This species is an emerging threat in the uninvaded forests and can be eradicated before it becomes widespread here as well.
	Average number of <i>Rubus phoenicolasius</i> *	Declining Condition/ Declining Trend	There were no <i>R. phoenicolasius</i> * recorded in uninvaded plots in 1995 and 2001; in 2021 there was on average 1.54 (± 0.89 SE) which shows an emerging invasion that will likely spread and increase in the future. Eradication is possible at this stage.

* Invasive species

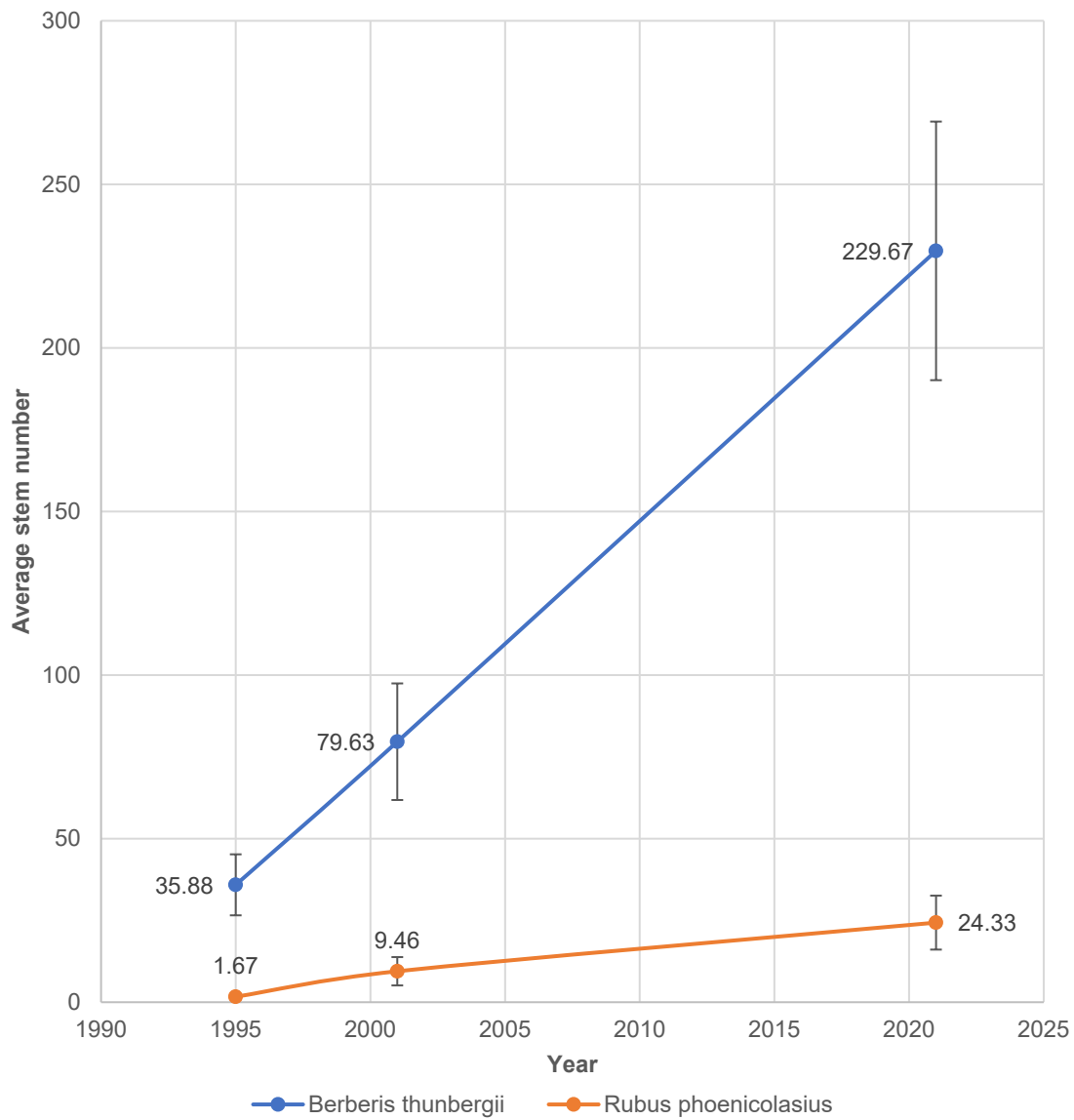


Figure 2.1. Average stem numbers of the two main invasive shrub species, *Berberis thunbergii* and *Rubus phoenicolasius*, in invaded forest plots ($n = 24$) over the three sampling years, 1995, 2001, and 2021, in Morristown National Historical Park. Error bars display standard error.

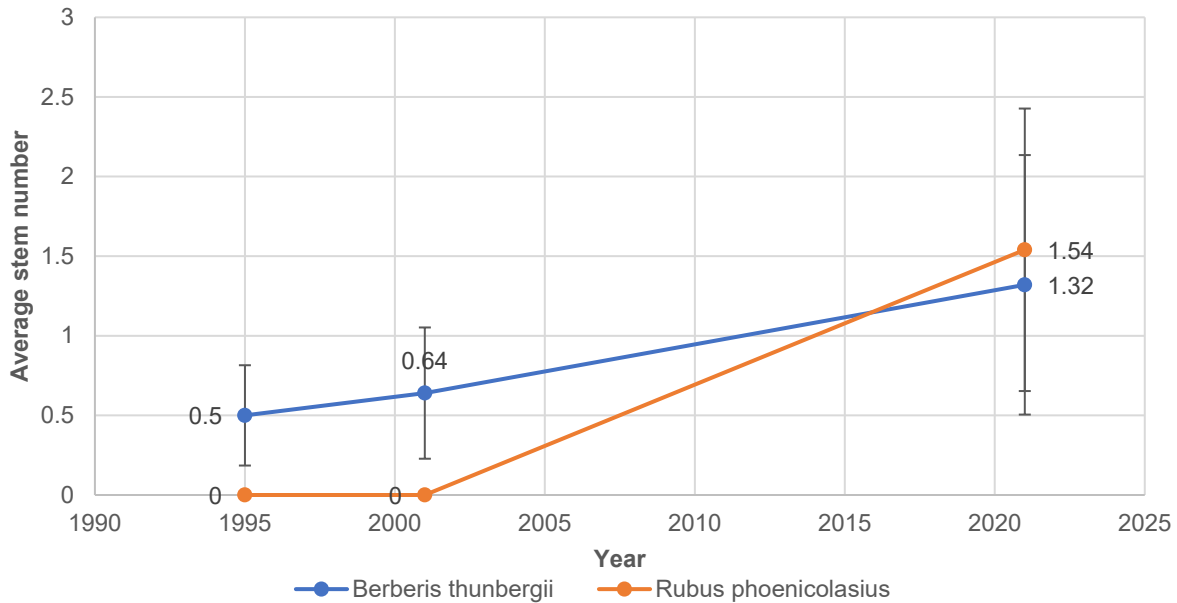


Figure 2.2. Average stem numbers of the two main invasive shrub species, *Berberis thunbergii* and *Rubus phoenicolasius*, in uninvaded forest plots ($n = 28$) over the three sampling years, 1995, 2001, and 2021, in Morristown National Historical Park. Error bars display standard error.

The native seedling data in the shrub layer were dropped from the long-term analysis as it was not completely accurate or complete for the previous sampling years (1995 and 2001). The average stem numbers in 2021 for all native woody species in the invaded forest subplots ($n = 24$) was $34.83 (\pm 8.20 \text{ SE})$ and $63.96 (\pm 13.09 \text{ SE})$ in the uninvaded forest subplots ($n = 28$). It is also important to note that all the native seedlings in both forest settings were heavily browsed; most stems remained below 30–50 cm in height. This was due to high deer pressure over several years. Even though, there was no data on deer browse for the previous sampling years, it is valuable to establish the poor current condition for native woody species in the shrub layer as this will impact the next growth stages (sapling and mature trees) into future decades.

2.4 Herb Stratum

The trajectories of the dominant species in the herb layer differed between the invaded and uninvaded forests. In the uninvaded forest, the invasive grass *M. vimineum* was seldom observed and only as very small individuals (Figure 2.3). There was no significant difference over time but *M. vimineum* was still present in 2021, which displayed a currently stable condition, but unstable trend as this grass may spread if the opportunity arises (Table 2.8). In the invaded forest, *M. vimineum* dominated the herb layer in 1995 and decreased over time (Figure 2.4). *M. vimineum* on its own as a condition indicator misleadingly reveal an improving trend and condition in the herb layer as the invasive grass presence decreased because it was replaced by growth and spread of invasive shrubs, which negatively affected the herb layer (Table 2.8; Figure 2.1).

The two main categories of native herbs, *Carex* spp. and ferns, varied by forest setting over time. In the invaded forest, *Carex* spp. cover decreased and displayed a declining condition and trend

(Figure 2.4; Table 2.8). In the uninvaded forests, *Carex* spp. cover did not change and remained stable over time with a low average cover (Figure 2.3). The same trend and condition were true for fern species in the uninvaded forest as cover was low but did increase over time (Figure 2.3; Table 2.8). However, in the invaded forest plots, the fern cover was very low in both 1995 and 2021, which revealed a poor condition but stable trend (Figure 2.4; Table 2.8).

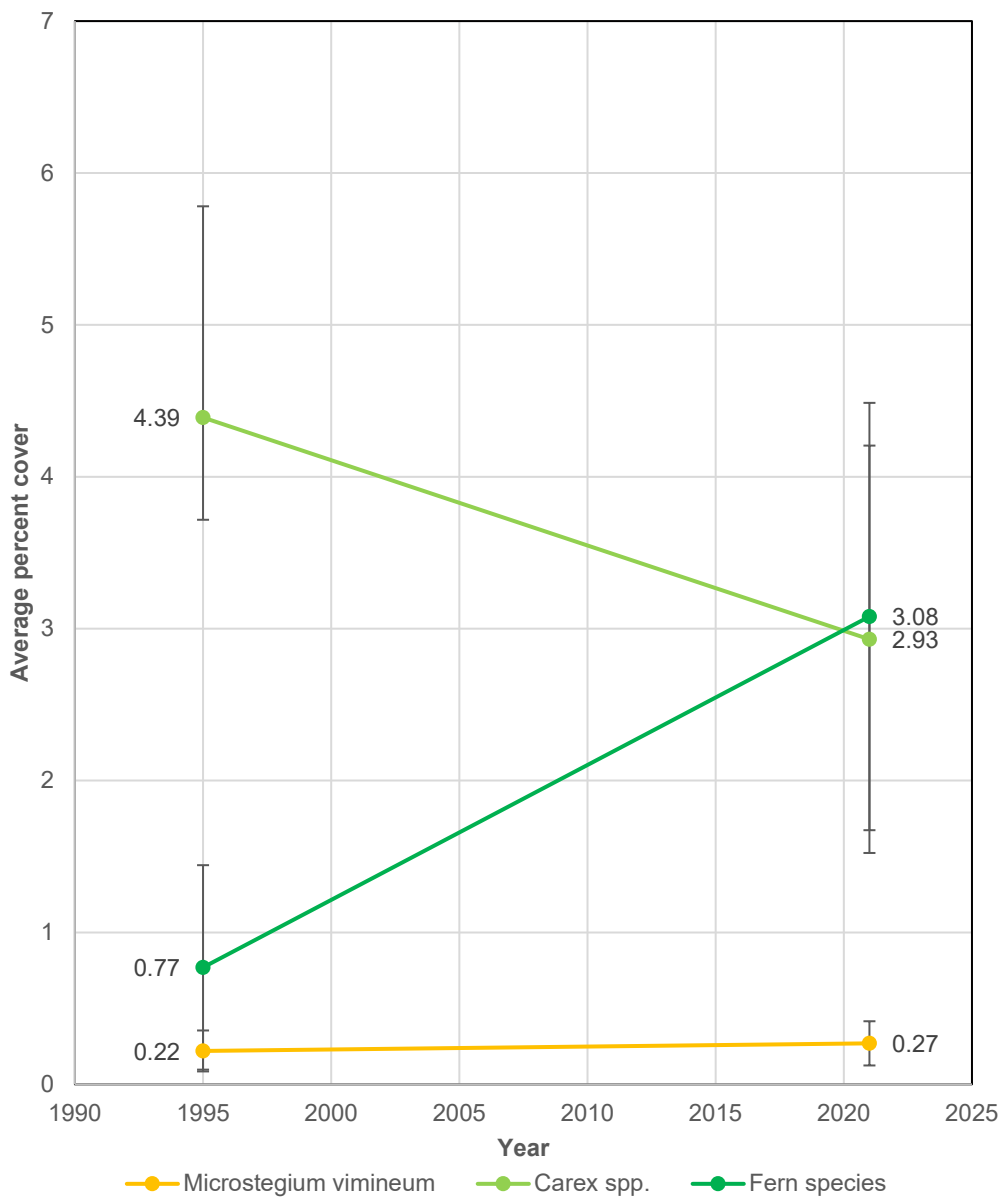


Figure 2.3. Average percent cover of the invasive grass *Microstegium vimineum*, native *Carex* spp. and native fern species in uninvaded forest plots ($n = 90$) over time from 1995 to 2021, in Morristown National Historical Park. Error bars display standard error.

Table 2.8. Condition assessment of the dominant herbaceous plants from 1995 to 2021 sampled in the understory of the invaded and uninvaded forest plots in Morristown National Historical Park.

Resource	Condition Indicators Assessed	Condition Status/Trend	Rationale & Key Points
Dominant herb cover sampled in invaded forest plots (<i>n</i> =63)	Average cover of the invasive grass <i>Microstegium vimineum</i> *	Improving Condition/ Improving Trend	There has been an 86% decrease in cover over time. This decline is beneficial yet likely due to the great increase of invasive shrubs in the shrub layer.
	Average cover of <i>Carex</i> spp. (all native)	Declining Condition/ Declining Trend	In 1995 the <i>Carex</i> spp. average cover decreased by 78% over time and was likely due to invasive shrub increase.
	Average cover of ferns (all native)	Poor Condition/ Stable Trend	There was no substantial change of average fern cover from 1995 to 2021. Overall, fern cover was very low over time.
Dominant herb cover sampled in uninvaded forest plots (<i>n</i> =90)	Average cover of the invasive grass <i>Microstegium vimineum</i> *	Stable Condition/ Unstable Trend	There was no substantial change in cover over time. The number of sampled quadrats with <i>M. vimineum</i> * records increased from 3 in 1995 to 5 in 2021 which demonstrate a slow emergence in new locations.
	Average cover of <i>Carex</i> spp. (all native)	Stable Condition/ Stable Trend	There was no substantial change in cover over time. It remains in the herb layer in small, scattered patches.
	Average cover of ferns (all native)	Stable Condition/ Stable Trend	There was a 301% increase in cover over time. Multiple new patches emerged over time.

* Invasive species

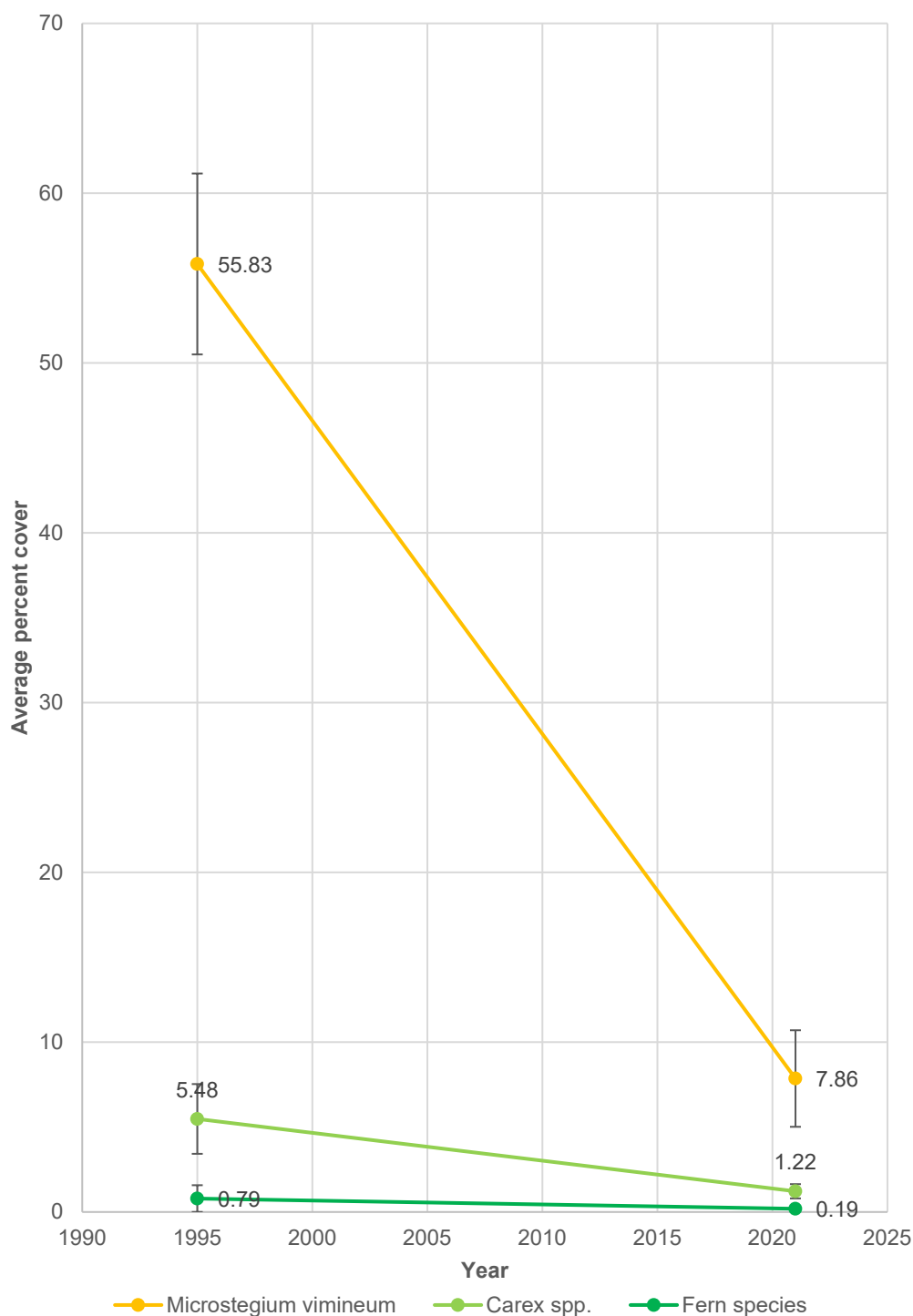


Figure 2.4. Average percent cover of the invasive grass *Microstegium vimineum*, native *Carex* spp. and native fern species in invaded forest plots ($n = 63$) over time from 1995 to 2021, in Morristown National Historical Park. Error bars display standard error.

Chapter 3. Discussion

The forest of MORR has been subject to two main stressors over the twenty-six-year study period. High deer pressure has affected the entire forest and all plots regardless of setting. The second main stressor is invasive plants which have affected the forest plots differently according to their setting, invaded or uninvaded. These serve as two different ecological starting points, invaded (degraded) and uninvaded. These have led to some diverging trajectories in forest vegetation as well as similar trajectories that have differing tempos of change. However, there were some forest resource trends and conditions that were similar regardless of forest setting. Furthermore, the four vegetative strata are linked and influence change among the strata but in differing ways. The following discussion will clarify all the distinctions and linkages among forest setting, change, and ways that each vegetative stratum affects another's.

3.1 Mature Trees

The mature tree resource of the canopy had differing assemblages at the beginning of the study. The invaded forest contained fewer trees than the uninvaded forest (Table 2.1; Table 2.2) which influences light levels and availability of other plant resources they compete for with the lower strata. Furthermore, the invaded forest composition contained more disturbance-associated tree species (Table 2.1) that are faster growing, shorter-lived, and have differing leaf litter qualities than the uninvaded forest with more mature forest, oak-cohort species (Table 2.2). The mature forest species, such as *F. grandifolia*, *Quercus* spp., and *Carya* spp., create deeper shade than early succession trees and have leaf litter that decomposes slower and releases a different array of nutrients and compounds that may affect the lower strata differently than mesic and early succession tree litter (Tallamy 2021). Therefore, not only has the invaded understory created differing ecological starting points, but the variation between the mature tree composition may also play a role in differing trajectories in the lower strata.

Even though the mature tree composition between forest settings differed, there were some similarities in composition as well as trajectories. The two forest settings both contained *A. rubrum*, *B. lenta*, *C. florida*, and *F. americana* in 1995 (Table 2.1; Table 2.2). Over the course of this study, these species experienced losses in both forest settings. The mature tree resources in invaded and uninvaded forests both experienced declining conditions and trends (Table 2.3).

Therefore, in both forest settings losses of mature trees have opened single-tree or few-tree canopy gaps over time which may have gradually increased light levels and influenced the lower vegetative strata in similar ways. If the tree loss trajectory continues, it will facilitate invasion in the lower strata. Both *B. thunbergii*, *R. phoenicolasius*, and other common invasive shrubs have been shown to increase in density and fecundity in canopy gaps at MORR and in similar forest types surrounded by suburban and urban zones (Gorchov et al. 2011; Driscoll et al. 2016; Epiphan and Handel 2021). To combat this trajectory, it is critical to improve regeneration of native forest trees which will require deer control and artificial regeneration methods. Planting of native trees from locally native progeny can be very successful if properly protected from deer damage. Single tree cages can be installed to ensure planted trees evade damage throughout the seedling and sapling years.

3.2 Saplings

In the invaded and uninvaded forests, the sapling layer displayed differing conditions and trends, linked to the mature forest species compositions and the level of invasion in the shrub layer. The most apparent distinction between the two settings were the differences in average native sapling numbers in both 1995 and 2021 (Table 2.4; Table 2.5). Over time, the difference in native sapling numbers grew; the invaded forest experienced a decrease in native sapling numbers, while the uninvaded forest increased in saplings numbers (Table 2.6). This was influenced by decreased native regeneration recruitment in the invaded forest as well as greater competition for resources with the densely invaded shrub layer (Ehrenfeld 1999c; Link et al. 2018; Epiphan and Handel 2021). Yet, the divergent sapling composition trajectories over time were also a result of the differing mature tree compositions; the invaded forest had more disturbance-associated early succession species like the invasive *R. pseudoacacia* (Table 2.4) and the uninvaded forest plots had several mature *F. grandifolia* (Table 2.5), a species with extensive clonal sprouts (Tubbs and Houston 1990). The invaded forest had a rise in *R. pseudoacacia* as well as native *S. albidum* saplings, and both of which are less favored by white-tailed deer for buck-rubbing (Epiphan field observations 2017–2021). The uninvaded forest demonstrated prolific clonal sprouting of *F. grandifolia* causing a great increase in sapling numbers. Even though many saplings of *F. grandifolia* had buck-rub damage, there were enough sprouting to allow several to escape damage.

White-tailed deer did play a role in the fate of many sapling species in forest settings. In 1995, saplings such as *A. rubrum*, *B. lenta*, and *C. florida* occurred in both invaded and the uninvaded forest plots, but these species experienced declines in both settings by 2021 (Table 2.4; Table 2.5) as they are favored by bucks for rubbing (Epiphan field observations at MORR, 2017–2021). Furthermore, if *F. grandifolia* saplings were excluded from the analysis, the remaining saplings numbers in the uninvaded forest decreased by 60% and would express a declining condition and trend (Table 2.6). The only species which inflated the sapling numbers in the uninvaded forests was *F. grandifolia* (Table 2.5). This is a worrisome situation as beech leaf disease has recently infiltrated MORR and is expected to cause wide-spread declines of *F. grandifolia* over the next decade (NYSDEC 2021; Reed et al. 2022). Therefore, the uninvaded forest saplings' condition is expected to decline if deer numbers are not greatly reduced (Horsley et al. 2003). Without intervention, this bleak sapling trajectory will continue to facilitate the mature tree deficit farther into future decades in both the invaded forest and uninvaded forest (Miller and McGill 2019). Artificial regeneration, robust deer control strategies, and physical deer damage protection will all be necessary to ensure the forest has enough native saplings to replenish the canopy in future decades.

3.3 Invasive Shrubs

The shrub layer composition was one major factor that originally inspired the selection of forest plots in the stratified experimental design where the invaded forest plots contained invasive species and uninvaded forest plots did not. In 1995, the dominant invasive shrub in MORR was *B. thunbergii*. (Ehrenfeld 1999b; Ehrenfeld 1999c; Sneddon et al. 2008; Epiphan and Handel 2021). It still is. The invaded forest experienced great increases of *B. thunbergii* stem numbers over time (Table 2.7). The increasing dominance of *B. thunbergii* thickets in the invaded forest has impeded tree seedling growth which prevents them from reaching sapling size (Epiphan and Handel 2021). Thickets of *B.*

thunbergii can impact native plants in the herb layer by changing microsite conditions including light availability (Ehrenfeld 1999c) or soil nutrient complexes (Ehrenfeld et al. 2001; Ehrenfeld 2003; Kourtev et al. 2003). In addition, the invasion of *B. thunbergii* may have facilitated other invasive shrub species infiltration as it alters microsite conditions, such as elevating soil pH (Kourtev et al. 1998), which creates a more conducive environment for exotic plant success over native plants. Since 1995, newly emerging invasive shrubs have entered MORR and grow within and near to the *B. thunbergii* thickets. Such species include *Ligustrum vulgare* (common privet), *Rosa multiflora* (multiflora rose), *Viburnum sieboldii* (Siebold viburnum), and *R. phoenicolasius* (Epiphan and Handel 2021). (We have no data on these species presence in earlier studies here.) For example, *R. phoenicolasius* was not widespread in 1995, but has since spread throughout the park and numbers over time have increased (Table 2.7; Figure 2.1; Figure 2.2). The invasion trajectory may be similar for both *B. thunbergii* and *R. phoenicolasius*, but the timing of emergence has an approximate 20–25-year difference (Figure 3.1). The invasion intensity, which is linked to the length of time it has been invading MORR, is an important factor in understanding management potential and constraints. Certain areas may have populations that can be eradicated while other heavily infested areas may only be contained or just managed long-term to reduce spread. As *B. thunbergii* is widespread throughout the park, it will be critical to determine where population can be controlled successfully, and which locations are most important to protect and restore. The uninvaded forest sites have greater biological resources to protect and population of *B. thunbergii* that can be successfully eradicated. In addition, *R. phoenicolasius* stems numbers reveal that eradication can be effective at sites in both forest settings.

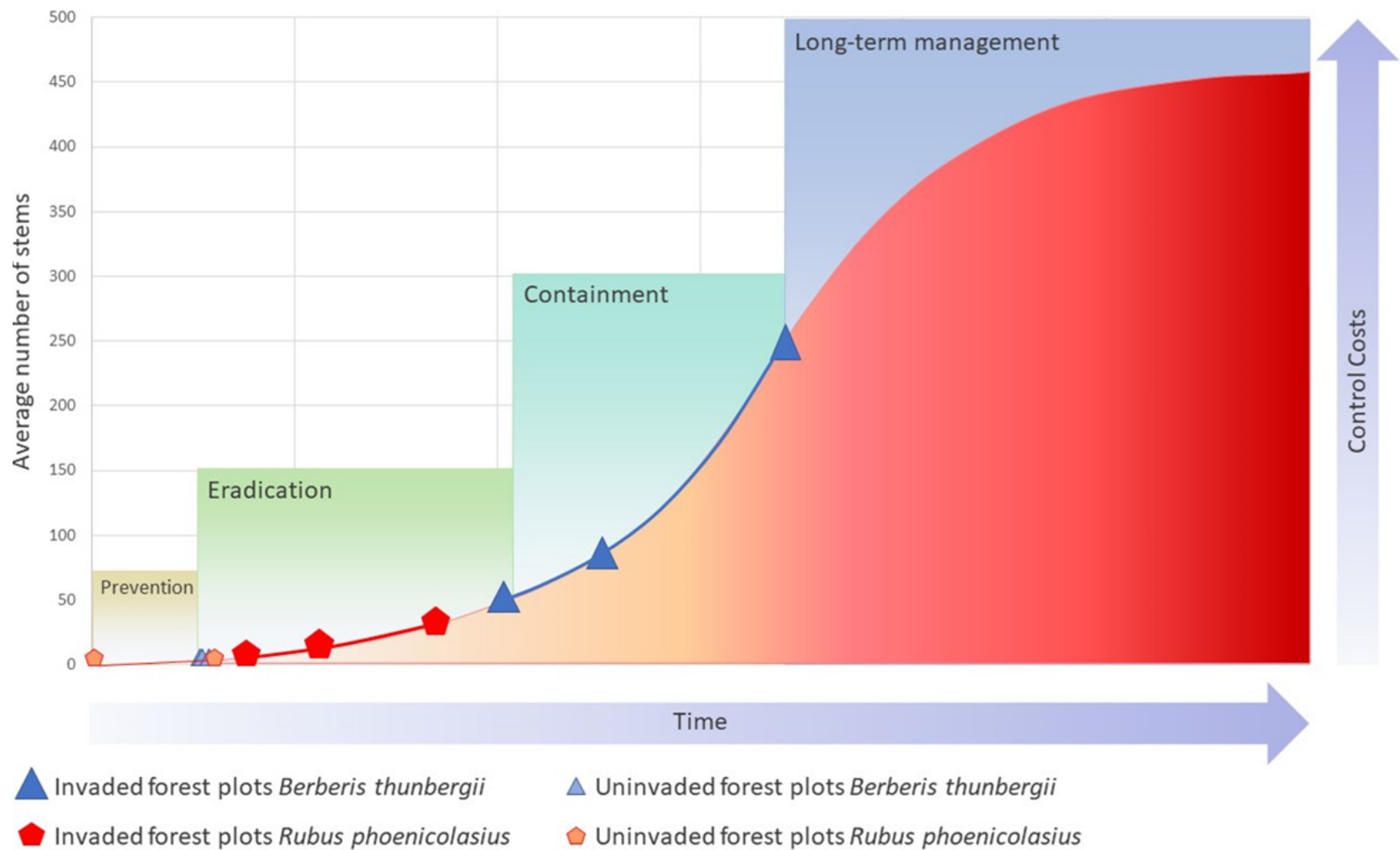


Figure 3.1. Schematic invasion curve displaying estimated placement of the two invasive shrubs in invaded and uninvaded forests over three sampling years 1995, 2001, and 2021 in Morristown National Historical Park. In the uninvaded forest plots, *Berberis thunbergii* was present in very low numbers each sampling year and *Rubus phoenicolasius* was not present until 2021.

3.4 Herbaceous Groundcovers

The herb layer demonstrated differing trajectories between forest settings (Table 2.8), which may be linked to forest composition and divergent changes in the other vegetative strata over time. In the uninvaded forest, the fern species, *Carex* spp., and the invasive *M. vimineum* remained present over time in a few sites but remained very low in cover without increasing. Suppression of *M. vimineum* spread may be associated with the greater amounts of oak and beech trees in the uninvaded forests, which form thicker leaf litter layers, have slower rates of decomposition, and have higher amounts of tannins (Tallamy 2021). More research is needed to confirm which factors in the uninvaded forest help prevent or slow *M. vimineum* spread.

In the invaded forest sites, *M. vimineum* cover was very high in 1995 and contained fewer oaks and beech than the uninvaded forest. Over time, *M. vimineum* populations were greatly decreased as they were displaced by growing thickets of *B. thunbergii* and other invasive shrubs (Table 2.7; Table 2.8; Figure 2.1; Figure 2.3). This pattern of invasive shrubs replacing *M. vimineum* glades has been observed in other studies within MORR's invaded forests (Russell 2002; Ehrenfeld et al. 2020). It is not known if the microsite alterations caused by *M. vimineum* glades facilitate invasive shrub invasion; more studies are needed to make this determination.

Nonetheless, the invaded forest condition continued to decline with the expanding invasive shrub thickets even though *M. vimineum* cover decreased. In addition to heavy deer browse, native tree seedling recruitment is suppressed in *M. vimineum* dominated areas (Johnson et al. 2015; Flory and Clay 2010) and has continued to be suppressed under dense thickets of invasive shrubs like *B. thunbergii* (Link et al. 2018). The interactions between these two lower strata impede recruitment of future saplings that would have otherwise become canopy trees in time. Therefore, the declining trajectory in the invaded forest understory helps to drive the current mature tree losses and will cause a greater deficit of mature trees in the future without intervention (Miller and McGill 2019; Epiphan and Handel 2021).

3.5 Conclusions & Management Considerations

The past and current composition of the uninvaded forests possess influential factors that may have helped prevent rapid invasion or spread of invasive understory plants when compared to the invaded forest sites. These factors include: higher quantities of mature *Fagaceae* tree species; thicker and specific leaf litter quality; greater quantity of trees that produce greater shade coverage which is linked to fewer and smaller disturbance gaps from recent storms (Epiphan and Handel 2021); less disturbance to soil quality from historic agricultural practices which continues to be an influencing factor in the invaded forest (Ehrenfeld 1977).

It will be critical to maintain the canopy density in the uninvaded forest as well as the *Fagaceae* dominant tree composition into the future. With the continuance of deer damage, it will be important to actively promote regeneration, especially of oak species, by which ever means possible or using a combination of multiple strategies. The anticipated losses of beech canopies and saplings from beech leaf disease (NYSDEC 2021) are a dire concern to the uninvaded forest health. With this epidemic disease on the horizon, it will be evermore critical to eradicate invasive shrub and herb understory plants in beech dominant areas and proactively plant locally native oaks and hickories to ensure

regeneration and future canopy replacement. Every planted tree will need protection from deer which is best achieved by installation of individual cages of wire mesh with staked support (Appendix B).

The invaded forest areas are plagued with much greater challenges to forest health which are strongly linked to conditions that cannot be easily changed or amended on a large scale. These circumstances include: the soil disturbances from past agricultural use in the invaded forest areas and the subsequent loss of soil health caused by introduction of invasive worms (Bohlen et al. 2004; Craven et al. 2017; Dobson et al. 2017); changes in soil chemistry and structure caused by invasive plant leaf litter accumulation (Kourtev et al. 1998; Kourtev et al. 2003); continual rain of seeds from invasive species in surrounding landscapes; and the mesophication expressed in the current vegetation composition (Nowacki and Abrams 2008). These factors contribute to the “invasional meltdown” occurring in the invaded forests (Knight et al. 2009; Nuzzo et al. 2009; Green et al. 2011; Braga et al. 2018; Fisichelli and Miller 2018). Management of these grim circumstances are limited but important for the health of neighboring less invaded areas. Most of the understory in the invaded forest are in the containment and long-term management segments of the invasion curve (Figure 3.1). Therefore, the management goals in the invaded forest must focus on preventing further spread to other less invaded areas and the uninvaded forests.

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Appendix A

Table A.1. Mature tree species numbers and average basal area m² ($\pm$ standard error) from 1995 to 2021 within the invaded forest plots ($n = 7$) in Morristown National Historical Park. Mature trees were ≥ 10 cm DBH at times of sampling.

Species	Total Number of Trees				Average Basal Area m ²				Average basal area difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	14	11	-3	0	0.113	0.046	0.126	0.054	0.013
<i>Acer saccharum</i>	1	1	0	0	0.002	0.002	0.010	0.010	0.008
<i>Betula lenta</i>	12	11	-1	0	0.039	0.026	0.082	0.057	0.043
<i>Carya</i> spp.	3	3	0	0	0.054	0.036	0.075	0.053	0.021
<i>Cornus florida</i>	7	1	-6	0	0.011	0.005	0.002	0.002	-0.009
<i>Fagus grandifolia</i>	2	4	0	2	0.002	0.002	0.011	0.008	0.008
<i>Fraxinus americana</i>	20	11	-9	0	0.259	0.086	0.238	0.105	-0.021
<i>Juglans nigra</i>	1	1	0	0	0.011	0.012	0.013	0.013	0.003
<i>Liriodendron tulipifera</i>	5	5	0	0	0.185	0.102	0.273	0.140	0.088
<i>Prunus serotina</i>	2	2	0	0	0.013	0.008	0.016	0.011	0.003
<i>Robinia pseudoacacia</i> *	7	2	-5	0	0.077	0.050	0.028	0.020	-0.042
<i>Sassafras albidum</i>	1	1	0	0	0.005	0.005	0.007	0.007	0.002
<i>Quercus alba</i>	1	1	0	0	0.014	0.014	0.020	0.020	0.006
<i>Quercus montana</i>	5	3	-2	0	0.099	0.045	0.092	0.060	-0.007
<i>Quercus rubra</i>	4	4	0	0	0.245	0.133	0.289	0.129	0.044
<i>Quercus velutina</i>	2	2	0	0	0.086	0.058	0.115	0.077	0.029
<i>Ulmus americana</i>	2	0	-2	0	0.004	0.003	0.000	0.000	-0.004
Total	89	63	-28	2	1.212	0.159	1.396	0.151	0.183

* Invasive species

Table A.2. Mature tree species numbers and average basal area m² ($\pm$ standard error) from 1995 to 2021 within the uninvaded forest plots ($n = 10$) in Morristown National Historical Park. Mature trees were ≥ 10 cm DBH at times of sampling.

Species	Total Number of Trees				Average Basal Area m ²				Average basal area difference over 26 years
	1995	2021	loss	gain	1995	$\pm$ SE	2021	$\pm$ SE	
<i>Acer rubrum</i>	20	11	-9	0	0.087	0.029	0.064	0.023	-0.023
<i>Betula alleghaniensis</i>	7	4	-3	0	0.020	0.015	0.015	0.012	-0.005
<i>Betula lenta</i>	30	21	-9	0	0.190	0.052	0.190	0.071	0.000
<i>Carya</i> spp.	5	8	0	3	0.020	0.013	0.041	0.020	0.020
<i>Cornus florida</i>	3	0	-3	0	0.004	0.003	0.000	0.000	-0.004
<i>Fagus grandifolia</i>	29	31	0	2	0.192	0.081	0.264	0.100	0.072
<i>Fraxinus americana</i>	5	2	-3	0	0.018	0.013	0.009	0.009	-0.009
<i>Liriodendron tulipifera</i>	3	5	0	2	0.023	0.013	0.050	0.028	0.026
<i>Nyssa sylvatica</i>	2	2	0	0	0.007	0.007	0.010	0.010	0.004
<i>Prunus avium</i> *	3	0	-3	0	0.012	0.012	0.000	0.000	-0.012
<i>Quercus alba</i>	4	4	0	0	0.040	0.021	0.053	0.025	0.013
<i>Quercus montana</i>	8	8	0	0	0.080	0.041	0.116	0.059	0.037
<i>Quercus rubra</i>	18	15	-3	0	0.385	0.135	0.453	0.168	0.068
<i>Quercus velutina</i>	4	5	0	1	0.099	0.055	0.193	0.129	0.095
<i>Ulmus americana</i>	1	0	-1	0	0.002	0.002	0.000	0.000	-0.002
Total	142	116	-34	8	1.177	0.065	1.457	0.120	0.280

* Invasive species

Appendix B

The following photos display examples of tree seedlings and saplings that are protected from deer damage with pvc-coated wire cages.



Figure B.1. River birch sapling protected from buck rub with a narrow 4ft wire cage (RUTGERS / JEAN N. EPIPHAN)



Figure B.2. Large cedar seedling protected with 6ft wire from buck rub and herbivory; one metal stake and ground staples were used to secure the structure. (RUTGERS / JEAN N. EPIPHAN)



Figure B.3. Small hemlock saplings protected from buck rub and winter deer browse with wire cages secured with ground staples. (RUTGERS / JEAN N. EPIPHAN)



Figure B.4. Yellow birch sapling protected from buck rub with a narrow 4ft wire cage. (RUTGERS / JEAN N. EPIPHAN)



Figure B.5. Large fir sapling in a 6 ft tall wire cage supported by four stakes. (RUTGERS / JEAN N. EPIPHAN)



Figure B.6. Hickory seedling protected with a 4ft cage secured with one stake and three ground staples.
(RUTGERS / JEAN N. EPIPHAN)

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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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525