



Vegetation Monitoring in Relation to White-tailed Deer Browsing in First State National Historical Park

2021 Summary Report

Natural Resource Report NPS/FRST/NRR—2023/2540



ON THE COVER

Collecting forest composition monitoring data in First State National Historical Park.

Photograph by: Ephraim Zimmerman, Western Pennsylvania Conservancy.

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Ephraim Zimmerman¹, Stephanie J. Perles²

¹Pennsylvania Natural Heritage Program
Western Pennsylvania Conservancy
800 Waterfront Drive
Pittsburgh, PA 15222

²Eastern Rivers and Mountains Network
Forest Resources Building
University Park, PA 16802

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Executive Summary

Baseline information on canopy regeneration and plant community composition is needed in order to better understand white-tailed deer browsing impacts at First State National Historical Park (FRST). In 2021, the Pennsylvania Natural Heritage Program (PNHP) established 20 permanent vegetation monitoring plots following methods developed by the NPS Eastern Rivers and Mountains Network (ERMN) to assess and monitor trends in vegetation (Perles et al. 2014b; Perles et al. 2017). These protocols provided an efficient method of assessing the current status of native and non-native vegetation and deer browsing impact. This report documents the methodology used to quantify the vegetative composition of natural areas at FRST and provides a summary of the data collected in the first year of monitoring. This first year's activities (2021) included the initial baseline vegetation assessment and summary of results from the baseline data analysis. A variety of metrics used to assess the impact of deer browsing on the vegetation were calculated and are presented. A second survey is proposed for 2024. PNHP used the NPS ERMN database and analysis methods (Perles et al. 2014b) to summarize the condition in year 1 (2021). In year 4 (2024), PNHP will investigate changes in the condition of browse-sensitive understory plants and tree seedlings.

Plots occurred in a variety of settings, ranging from younger successional communities to more mature forest stands. Seventy-five percent (75%) of the plots occurred in Mature or Late Successional forests. Disturbances and stressors, such as deer browsing can strongly influence future forest structure as open woodlands mature. A large population of white-tailed deer may severely impact succession from the open woodlands towards closed canopy forest. In closed canopy, later successional forests, a large deer population may inhibit canopy tree recruitment leading to regeneration failure. Given that FRST managers desire to maintain the landscape as forest, it is important to maintain an adequate number of seedlings and saplings of tree species to ensure the persistence of canopy of native tree species as Mature and Late Successional Forests continue to age.

The 20 permanent sampling plots occurred within 5 plant communities described by Ebert (2016) and were classified using agglomerative hierarchical clustering (HAC analysis) and indicator species analysis. The most common plant communities within the group of sampling plots were the Mixed oak – beech forest and Mesic mixed tulip – oak-hickory-beech forest. The remaining plots were found in successional Tuliptree woodland, Successional woodland, and Thicket types. All plots were assigned to these types described in Ebert (2016) and crosswalked to the National Vegetation Classification (USNVC).

A total of 128 plant species were recorded from the 20 plots at FRST. Eighteen (18) species were found in over ½ of the plots surveyed, of which eight (8) were non-native. In all, 29 plants occurring in the plots (23% of total species richness) were considered introduced (non-native). Non-native plant cover ranged from 0–98% as measured in the monitoring plot quadrats.

Indicators of deer browsing varied by plant community type at FRST. In general, the drier Mixed oak – beech forests showed substantially greater impact of deer browsing and fewer seedlings of canopy species in the understory. FRST monitoring protocols focus on a few plant species considered as

preferred food for white-tailed deer. Sustained browsing may be affecting long-term viability of these species within the parks.

Based on the status of these regeneration metrics in FRST, we suggest that the forest in FRST are in *imminent regeneration failure*. We define imminent failure as parks that are experiencing severe regeneration failure and are at risk of forest loss due to very low seedling and sapling abundance, as well as species mismatches between canopy and regeneration layers.

Given the poor regeneration of canopy species across all community types at FRST, managers should seek opportunities to conduct adaptive management in the park's forests, especially mixed oak – beech forest, to experiment with and monitor the effects of fire, browse exclosures, and canopy thinning to encourage native canopy tree regeneration.

Acknowledgments

We are grateful for the opportunity to contribute to the management of natural ecosystems at First State National Historical Park. We would especially like to thank the 2021 forest monitoring field crew members Sonja Werth, Anna Casillas, and Anna Howard for their hard work and dedication to this program. We are also grateful for the work of Janet Ebert who has worked to document the flora of the Brandywine Valley since the mid-1990s and is an expert in the plant habitats and species of the park and surrounding landscape. Her report to the National Park Service, in which she classified and described the natural plant communities of the property, was instrumental in the development of this report and continues to serve as a valuable tool for many conservation activities in the park.

Introduction

Baseline information on canopy regeneration and plant community composition is needed in order to sustain resilient native forest ecosystems over the next decades at First State National Historical Park (FRST). Managing white-tailed deer (*Odocoileus virginianus*) populations is an important component of resilient forest management.

Numerous ecological and anthropogenic forces affect the condition and composition of natural areas. Ecological factors such as geology, soil nutrient availability, weather, and disturbance patterns directly influence the structure, composition, and dynamics of the vegetation. Habitats of the Brandywine Valley of Delaware and Pennsylvania have experienced considerable anthropogenic impacts. Many anthropogenic stressors are easily identified in the vicinity of FRST, such as habitat fragmentation and development or agriculture. Non-native plant species and plant pests are abundant and directly threaten the ecological integrity of the park. Other human-caused stressors, like atmospheric pollution and effects of climate change are less apparent. Like other NPS units in the Mid-Atlantic, over-browsing by white-tailed deer, atmospheric acid and nutrient deposition, climate change, and altered disturbance regimes, are all important factors affecting FRST's vegetation (Rentch, J. 2006).

Depending on the successional stage, disturbance history, and site conditions, there are certain parameters within which a terrestrial vegetation ecosystem can be described as “healthy” (Tierney et al. 2012). By measuring taxonomic, structural, and demographic features of a natural area, an assessment can be made as to whether or not the ecosystem's parameters fall within expected or accepted norms and ranges of variability. These measures serve as indicators of ecological integrity that can be implicitly linked to park management.

In 2021, the Pennsylvania Natural Heritage Program (PNHP) established 20 permanent vegetation monitoring plots at FRST to assess the current condition of the natural ecosystems at the park. The plot-based assessment protocols follow methods developed by the NPS Eastern Rivers and Mountains Network (ERMN) to monitor condition and trends in vegetation (Perles et al. 2014b; Perles et al. 2017). These protocols provided an efficient method of assessing the current status of native and non-native vegetation and deer browsing impact. This report documents the methodology used to quantify the vegetative composition in the first year of monitoring for selected areas at FRST, as well as the regeneration and condition of the vegetative communities in relation to other National Park Service units in the region. This first year's activities (2021) included the initial baseline vegetation assessment and analysis of data collected. The analysis of the initial baseline data provides an understanding of the current conditions in the park and inferences of deer browsing impact/intensity can be made by comparing values of forest health metrics in FRST to other NPS units in the region. Subsequent surveys of the permanent monitoring plots may be used to evaluate the efficacy of planting, fencing, control, and other mitigation/management activities.

Study Site

The Brandywine Valley unit of First State National Historical Park (FRST) is approximately 1350 acres in Delaware and Pennsylvania within the Mid-Atlantic's Piedmont Physiographic Province

near the edge of the Coastal Plain (Figure 1). The park acquired new acreage in 2021, area and percentage of agricultural fields did not include new acreage at the time the Ebert study was completed. A portion of this study's monitoring plots are located in the newly acquired section. Thirty-eight percent of FRST is used for agriculture with the majority of the landscape supporting native forests, woodlands, and floodplain wetlands (Ebert 2016). Ebert study was completed for approximately 1100 acres of the 1350 acre Brandywine Valley of FRST.

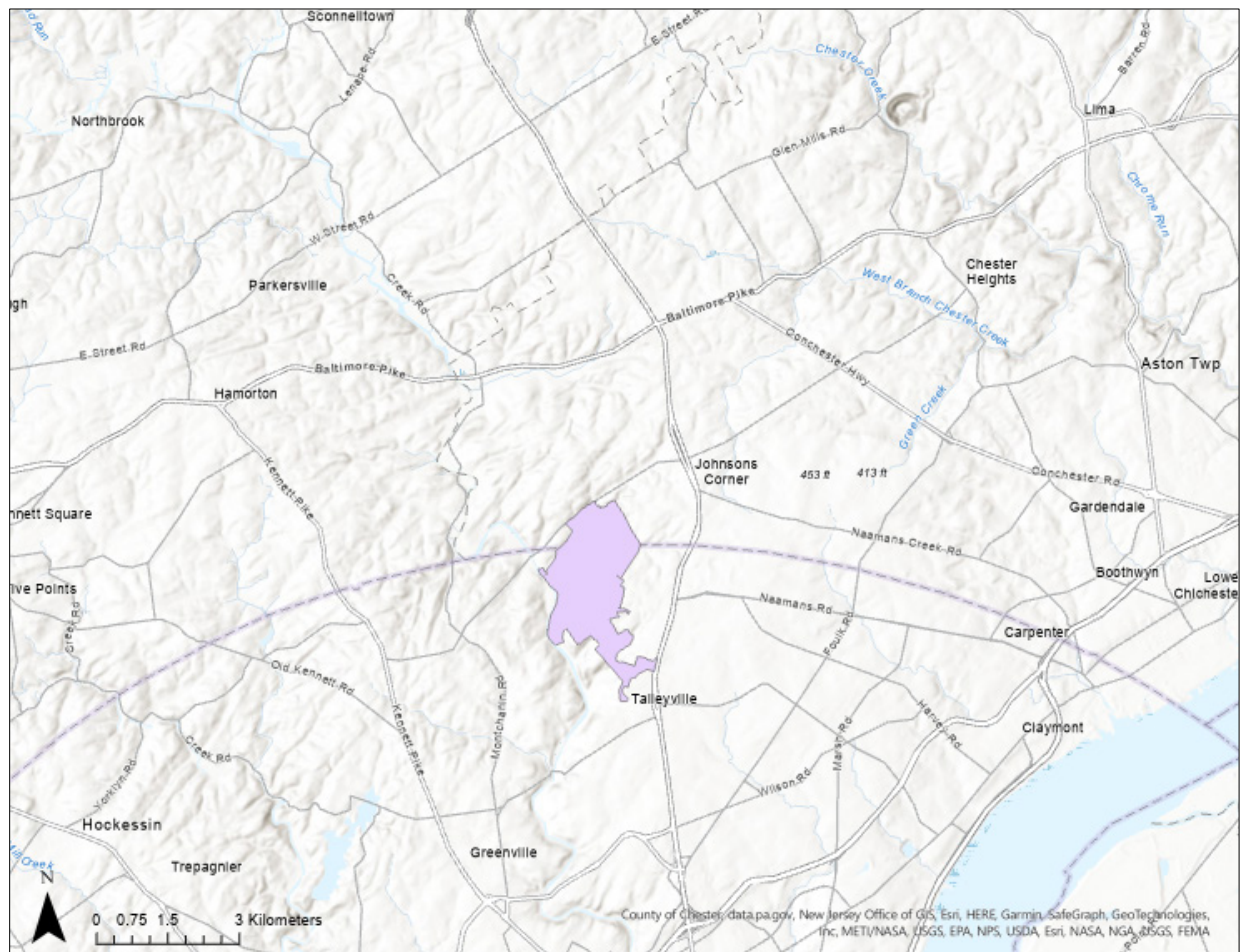


Figure 1. Location of First State National Historical Park, Delaware and Pennsylvania.

Ebert (2016) reported a total of 761 species of vascular plants at FRST in a survey of plant species and communities conducted in 2014, with 514 native plants. In this report, the author reported a marked decline in diversity from a previous comprehensive survey of the area in 1995 (Ebert 1995), including the loss of 76 native plant species, 6 of which were considered imperiled or critically imperiled according to Delaware (S1 or S2). Ebert also noted a decline in the overall richness and diversity of most habitats in the park between 1995-2014, and an increase in non-native plant species, observing that “successional, edge, and wetland habitats that once had a strong native component are now mostly alien, and/or very low diversity” (Ebert 2016).

Ebert (2016) suggested that deer browsing had a large impact on native flora of the park and noted that over-browsing was a threat to several rare plants within all community types at the park including shin-leaf (*Pyrola elliptica*), nodding trillium (*Trillium cernuum v. cernuum*), and dangle-berry (*Gaylussacia frondosa*). Other threats mentioned included non-native plant species, non-native earthworms, and recreation.

Ebert (2016) identified eighteen (18) plant communities within six (6) community groups including natural, successional, and managed communities and mapped by group: Forest Communities, Woodland Communities, Successional Communities, Wetland Communities, Meadow Communities, and Agricultural Communities.

Within the Forest group, there were five communities: Dry oak – heath, Mixed oak – beech, Mesic mixed tulip – oak – hickory – beech, and Mixed rocky oak – tulip – beech forests. There were three woodland communities: Tulip woods, Floodplain woods, and Mixed successional woods. Within the Successional Communities group, there were three types: Hedgerows, Thickets, and Old fields. Wetlands make up four community types: Marshland; Shaded seeps and springs; Swamps; and Small, open patches of wetland vegetation. Finally, there was one Meadow community, and three Agricultural Communities: Cropland, Pastures, and Fields. The communities in Ebert (2016) were mapped only by groups at the group level. Approximately, at the time of Ebert’s study, 38% of FRST was agriculture (Ebert 2016). These community associations compare (“crosswalk”) favorably with the US National Vegetation Classification (USNVC, USNVC 2019) and form the basis of the community-centered approach to summarizing the results of the current monitoring study.

Ebert (2016) stated that deer browsing had severely impacted forest communities at the park – particularly the Mixed oak – beech forest, which were considered “most denuded by deer.” In the Dry oak – heath forest patches where deer browsing was most responsible for forest degradation because dry acidic soils of this community are somewhat resistant to invasion by non-native plant species. Due to the threat and perceived loss of diversity, Ebert recommended controlling the deer population through “controlled hunting” at FRST.

Methods

A vegetation monitoring protocol was developed to assess current condition of the vegetation and to make inferences in deer browsing impact. This protocol was adapted from methods used to assess long-term ecological condition of NPS units within the Eastern Rivers and Mountain Network (ERMN) (Perles et al., 2014), which itself was adapted from the U.S. Forest Service (USFS) Forest Inventory and Analysis (FIA) Program and the vegetation monitoring protocols of four other NPS Inventory and Monitoring programs in the eastern United States (Sanders et al. 2008; Comiskey et al. 2009; Schmit et al. 2009; Tierney et al. 2012). The FRST vegetation protocol calls for monitoring of a representative suite of site and vegetation measures in a network of randomly located permanent plots (Perles et al. 2014b) every four (4) years beginning in June 2021. The measurements were chosen specifically to evaluate the current impact of deer browsing on vegetation; specifically regeneration of tree species and impact to species of perennial understory forb species considered to be “browse-sensitive.” These measurements, collected in other Mid-Atlantic and Appalachian NPS units, such as parks in the EMRN, can be used to evaluate overall deer impact on vegetation.

Vegetation was monitored at permanent plots, since the use of permanent plots increases the power to detect trends through time (Urquhart et al. 1998). A regular grid of potential plot locations was randomly overlain on the FRST boundary and then sampling locations were selected from the regular grid using a generalized random-tessellation stratified (GRTS) design (Stevens & Olsen 2004; McDonald 2014) (Figure 2). The GRTS design generates a spatially-balanced, randomly-ordered list of potential plot locations. Sampling locations included the first 20 plot locations on the list that met the following criteria: a) areas that were not intensively managed (e.g. croplands and pasture, cultural lands, maintained lawns); and b) areas with a slope of less than 30°. Plots that fell within areas of the park identified as agricultural, active pasture, developed land as defined by Ebert (2016) were not sampled.

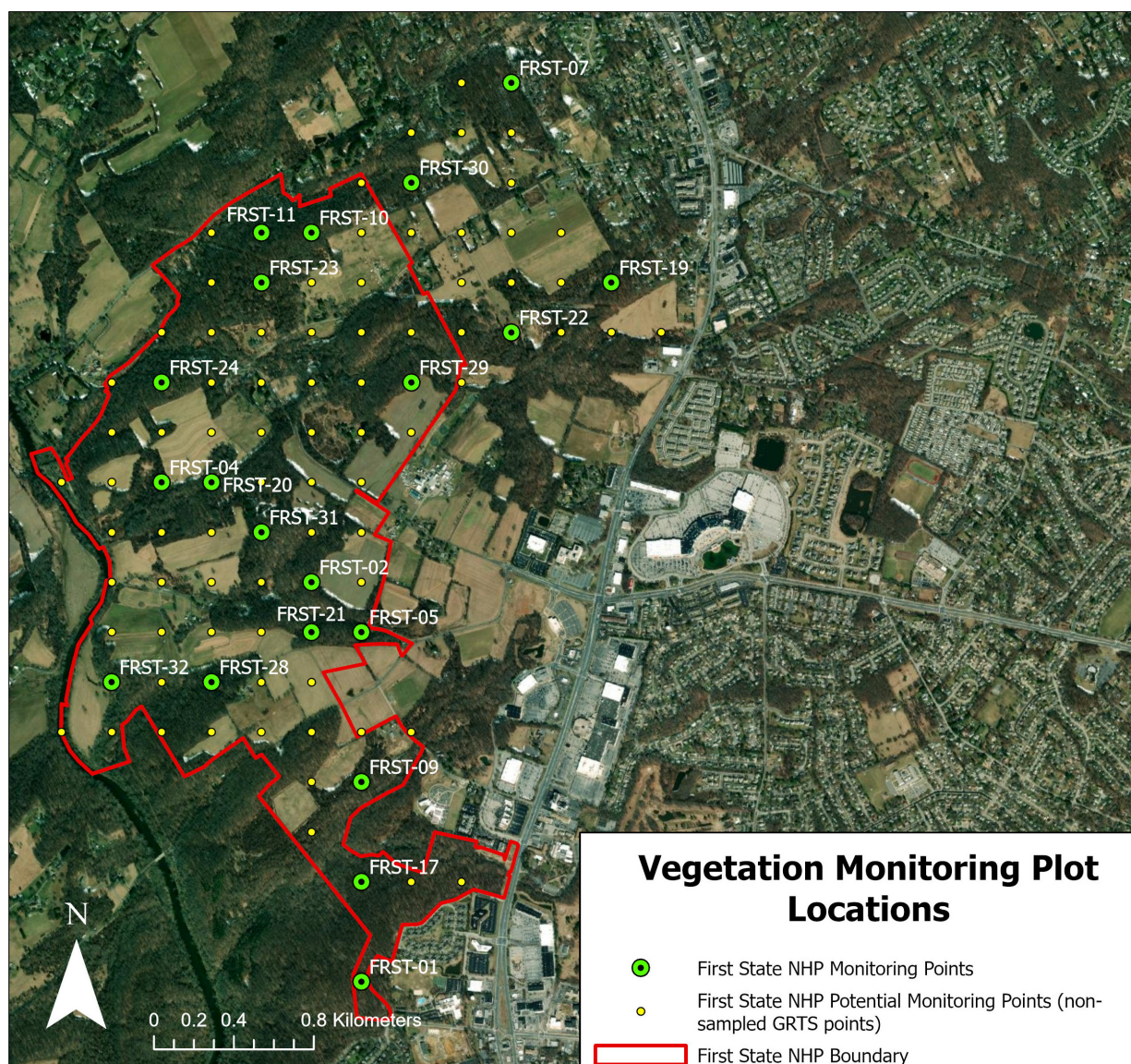


Figure 2. Map of First State National Historical Park (FRST) and location of generalized random-tessellation stratified (GRTS) points and plots sampled.

Field Methods

PNHP established twenty (20), 7.3-m diameter plots at predetermined locations identified through the GRTS design, following established NPS ERMN vegetation monitoring protocols (Perles et al. 2014b; Perles et al. 2017) (Figure 3). The center of each plot was permanently marked using a 30 cm piece of rebar with an aluminum cap. Location of all plot centers were recorded using a Global Positioning System (GPS) [Garmin64 GPS] unit.

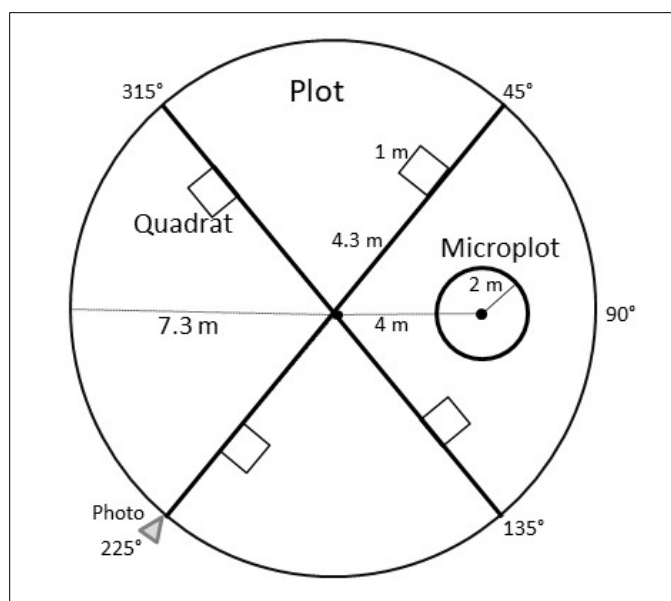


Figure 3. Plot design for Pennsylvania Natural Heritage Program (PNHP) First State National Historical Park Vegetation Monitoring Protocol following Perles et al. (2017).

Within each plot, the PNHP monitored a suite of vegetation parameters to assess ecological site integrity with special emphasis on indicators of deer browsing. The plot design includes several embedded sampling units (Figure 3) to measure each parameter.

Standard protocols were followed for stand level characterization and photo documentation, assessment of groundstory, tree regeneration, tree measurements, and deer impacts (Perles et al. 2014b). Tree, stand, and site measurements were collected within the 167-m² plot. Tree regeneration and shrub measurements were collected in the 12.56-m² microplot. Data on coarse woody debris were collected along four 7.3-m transects. Data on understory plant composition and the diversity of understory species were collected in four 1-m² quadrats. A photograph of the plot is taken from the plot edge. Specifically, the following vegetation and environmental variables were collected:

- *Stand-level*: including slope, aspect, travel directions to plot, canopy closure estimate, vegetation type, forest floor cover, anthropogenic disturbances, and visual impact of deer browsing.
- *Coarse Woody Debris* (CWD): diameter and decay class of coarse woody debris.
- *Groundstory Diversity*: percent cover data of all vascular plant taxa collected in four 1-m² quadrats. Special methods implemented for deer browse indicators (Perles et al. 2017) include counting the number of reproductive and non-reproductive plants, and measuring the height of the three tallest plants of each indicator species. A five (5)- minute time-constrained search for additional plant species was conducted on the whole 167 m² plot.
- *Tree Regeneration*: diameter and species of live saplings, as well as count of tree seedlings by species and height class in one 2-m radius circular microplot.

- *Tree Measurements*: Tree species, diameter, and condition of all live and standing dead trees ≥ 10 cm diameter-at-breast-height were recorded for the entire 7.3-m radius plot. These data provide information on tree growth, mortality, condition, and stand structure and composition.
- *Site Photos*: A photograph of the plot was taken from the plot's edge to document change in vegetation structure through time.

Data Analysis

Field data were entered into an Access database created to store and manage ecological monitoring data from parks in the ERMN region (Perles et al. 2014b). Baseline vegetation values including vegetation type, species diversity, mean coefficient of conservatism (*C*), Floristic Quality Index (FQI), structural stage, seedling abundance/regeneration, number and percent reproductive individuals of deer-sensitive plants, and deer browse index, were summarized and reported for all plots surveyed in 2021 to evaluate ecological integrity within natural areas of FRST.

Vegetation type was determined using a cluster analysis method based on species present in the plots. Typically, in community classification, communities are based on the percent cover/dominance of plant species, and additional analyses are used to confirm communities identified in the cluster analysis. However, the quadrats were thought to be insufficient to capture the diversity of the overstory and percent cover of all vegetative strata. Therefore, vegetation type should be treated as preliminary. All analyses were conducted in R 4.1.2 (R Core Team 2021). Bray-Curtis dissimilarity matrices were constructed (*vegan vegdist* function) using cover class means for each species. Agglomerative hierarchical clustering (HAC; *vegan hclust* function) was performed on the dissimilarity matrices using minimum, maximum, and average linkage methods. The number of clusters for each linkage method was estimated using maximal average silhouette width (*dendextend find_k* function). The chosen linkage method was selected by comparing differences among methods with plot notes and species composition. Average linkage was selected for the datasets. Dufrêne-Legendre indicator species analysis (*labdsv indval* function) was used to investigate significant indicator species for each cluster (Dufrêne & Legendre 1997). Vegetation associations were initially based on the results of the HAC analysis combined with the results of the indicator species analysis, field vegetation and landscape context notes, and information provided in Ebert (2016). Following this analysis, the plots were assigned to the vegetation associations described in Ebert (2016) and the National Vegetation Classification System (NVC; (USNVC 2019). Other diversity metrics were calculated through data analysis in Microsoft Excel (version 2019 MSO 16.0.10388.20027 64-bit).

Vegetation data were further analyzed to infer the impact of white-tailed deer; specifically, the seedlings of overstory tree species and the composition of understory herbaceous species considered to be “browse-sensitive” or favored by deer. Composition metrics (number of indicator plants, number of reproductive individuals of each indicator plant species), and regeneration metrics were calculated across all plots and compared within plant community types.

Park-wide averages for specific regeneration metrics were determined by calculating plot-level values for each metric and then averaged across all plots. This was done to compare FRST to all 39 parks in the eastern US. All analyses were conducted in Excel.

A second round of sampling is proposed for 2024, after which, the results of the data collected at different time intervals will be analyzed to determine change in vegetation (e.g. growth and mortality results).

Results and Discussion

The results below summarize the findings of field work at FRST to provide an assessment of baseline conditions and inferences on deer browse impacts.

Sixty-two percent (62%) of the FRST property was considered forested (Ebert 2016). A majority of the twenty (20) plots fell within forests and woodland vegetation types dominated by native plant species in the forest canopy. Other vegetation types are present, including successional old fields, riparian communities, and wet meadows. In addition, 38% of FRST is currently used for agriculture (row crops, hay fields, and horse pastures, associated with farms); there are also a number of residences (Ebert 2016). These other vegetation types were not surveyed as part of this study.

Human alteration and management have greatly changed the distribution of vegetation types in eastern forests. These distributions will be further affected by altered disturbance regimes coinciding with global climate change and outbreaks of exotic pests and pathogens (Dale et al. 2001).

Structural Stage

Monitoring the structural stage of the forest provides a picture of the shifting mosaic of stand structures within the park. For each plot, we calculated the quadratic mean diameter (QMD), which is the “average” diameter for the plot (i.e., the diameter of a hypothetical tree with its basal area equal to the plot’s average basal area of live trees) (Curtis & Marshal 2000).

Plots were first classified into size categories (non-forested, pole, mature, and late-successional categories) based on the following classification (adapted from Frelich & Lorimer (1991)): Non-forested = no trees (woody species with diameter at breast height ≥ 10 cm) in the plot; Pole = $10 \text{ cm} \leq \text{QMD} < 26 \text{ cm}$; Mature = $26 \text{ cm} \leq \text{QMD} < 46 \text{ cm}$; late-successional = $\text{QMD} \geq 46 \text{ cm}$ dbh. Figure 4 shows the proportion of plots in FRST that fall into these stages. Figure 5 depicts plots categorized in the Pole, Mature, and Late Successional structural stages.

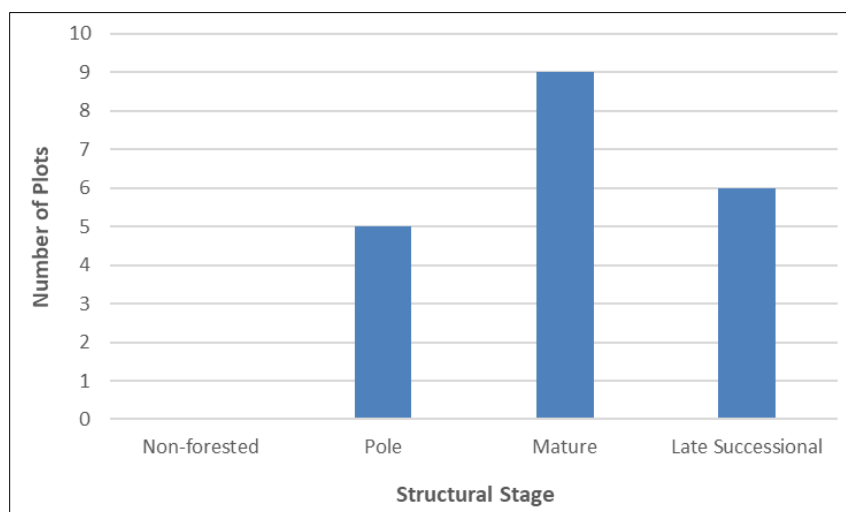


Figure 4. Number of plots in each structural stage (Non-forested, Pole, Mature, Late Successional) at First State National Historical Park based on the calculated quadratic mean diameter for each plot.



Figure 5. Examples of vegetation in three different structural stages: Pole (upper left), Mature (upper right), and two examples of Late-successional (lower) at First State National Historical Park.

The majority of the parks' forests are in the Mature class (9), followed by the Late-successional class (6) and Pole class (5). There were no plots in Non-Forested class within this study; however, non-forested habitats make up nearly $\frac{1}{2}$ of the park's landscape based on Ebert's mapping (Ebert 2016).

In contrast to many of the other parks in the region, a majority of the plots fell within the Mature to Late Successional stage while Perles et al. (2014) found that many of the long-term monitoring plots surveyed as part of the NPS vital signs project in the ERMN are in the Pole-to-Mature stage.

As the parks' forests age, more plots will be expected to attain Late Successional structure. Disturbances and stressors, such as deer browsing can strongly influence future forest structure as open woodlands mature. A large population of white-tailed deer may severely impact succession towards closed canopy forest. Given that FRST managers desire to maintain the landscape as forest, it is important to maintain an adequate number of seedlings and saplings to ensure the persistence of canopy as Mature and Late Successional Forests continue to age.

The QMD, which (Frelich & Lorimer 1991) used to evaluate structural stage of the forest, may work better with even-aged stands, but not the Successional woodlands and Late-successional, mosaic-like

forests of FRST. Early successional woodlands and hedgerows, with an open canopy of large trees and late successional forests possessing a multi-aged canopy, do not fit neatly into this categorization. For example, the Successional woodlands (described as Hedgerows, by Ebert (2016)), were made up of very large trees with shrubs and herbaceous species in the understory. Thus, a few very large trees recorded in the plot caused these plots to fall in the Mature or Late successional stage.

Plant Species Diversity and Community Type

Plant Species

A total of 128 plant species were recorded from the 20 plots at FRST. Eighteen (18) species were found in over half of the plots surveyed, of which eight were non-native (indicated by * below). The most commonly-encountered species were Jack-in-the-pulpit (*Arisaema triphyllum*) (17 plots), Oriental bittersweet (*Celastrus orbiculatus*)* (17 plots), wine-berry (*Rubus phoenicolasius*)* (17 plots), Virginia creeper (*Parthenocissus quinquefolia*) (15 plots), black cherry (*Prunus serotina*) (15 plots), multiflora rose (*Rosa multiflora*)* (15 plots), Japanese honeysuckle (*Lonicera japonica*)* (14 plots), Japanese stilt-grass (*Microstegium vimineum*)* (13 plots), poison ivy (*Toxicodendron radicans*) (13 plots), red maple (*Acer rubrum*) (12 plots), Japanese barberry (*Berberis thunbergii*)* (12 plots), American beech (*Fagus grandifolia*) (12 plots), white ash (*Fraxinus americana*) (12 plots), garlic mustard (*Alliaria petiolata*)* (11 plots), tuliptree (*Liriodendron tulipifera*) (11 plots), blackberry (*Rubus allegheniensis*) (11 plots), Canadian black snakeroot (*Sanicula canadensis*) (11 plots), and linden viburnum (*Viburnum dilatatum*)* (10 plots). Across all plots, 29 plants occurring in the plots (23% of total species richness) are considered introduced (non-native) (Appendix A). Non-native plant cover ranged from 0–98% as measured in the monitoring plot quadrats.

The number of non-native plants is markedly lower than what are reported in Ebert (2016)), who documented a total of 243 non-native out of 765 vascular plant species in the park (38%). However, Ebert's inventory included all habitats of the park including wetlands, roadsides, and agricultural areas, which were not represented in this survey – as deer browse monitoring plots focused on forested and woodland habitats. Additionally, the proportion of non-native plants in the species list recorded in 2021 was lower than what is commonly agreed upon for percent of non-native plants in the region's flora. Approximately 37% of the plant species known to occur in Pennsylvania are non-native (Rhoads & Block 2007; Ebert 2016), and this was assumed to be the case for this part of Delaware (Ebert 2016). Ebert's findings were more in line with comprehensive surveys in this region and, as they were a more thorough investigation of all habitat types, should be the standard list of plant species for the park.

While the impacts of non-native plant species vary from species to species, it is understood that the spread of non-native species, even those that co-exist with native species, leads to biotic homogenization. During biotic homogenization, a variety of different vegetation types become more similar to each other, shifting from specialized, unique vegetation communities towards a more generic, homogeneous species composition (Olden & Rooney 2006), which may negatively impact animal populations that fill specific narrow niches. Eight (8) out of 18 of the most commonly occurring plant species in the park were non-native is concerning. Over-browsing of white-tailed

deer, is known to favor non-native plants (Knight et al. 2009; Kalisz et al. 2014), and an overabundance of deer may increase this habitat homogenization further reducing the quality of habitat for rare species and habitat specialists.

Community Type

Assigning plots to community types provides a convenient mechanism for describing ecological condition. Cluster analysis of species presence-absence data in plots and quadrats showed the greatest support for seven (7) forested communities and indicated four (4) groups of two (2) or more plots (Figure 6). Twelve species were considered significant indicators for these four (4) groups, and an additional plot (FRST.10) contained a significant indicator (Table 1); four (4) of the twelve (12) significant indicator species were non-native plants. Two (2) plots (FRST.01 and FRST.23) separated early on from the other groups; however, these did not contain significant indicators. Of the five (5) groups containing significant indicators, groups 2, 3, and 5 were combined because of the similarity in the species between plots in and position in the cluster dendrogram.

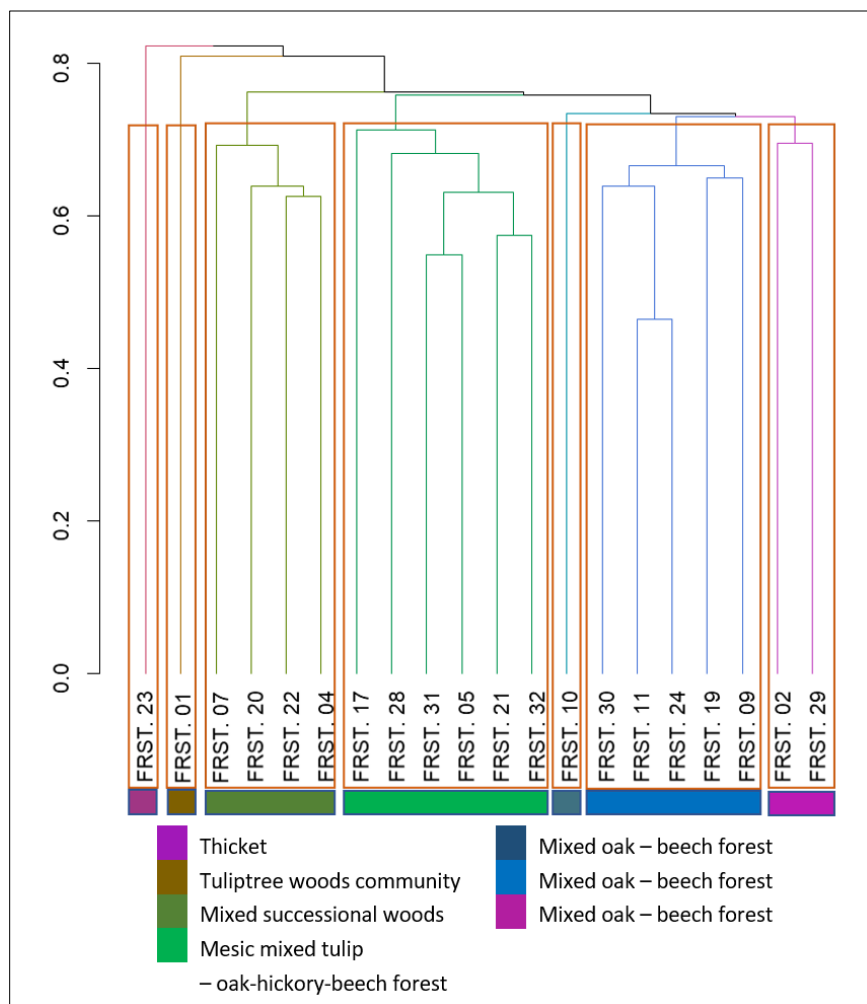


Figure 6. Community dendrogram at First State National Historical Park. Agglomerative hierarchical clustering was used to determine preliminary community associations; preliminary clusters with the best support are contained within red boxes. Five of the seven recommended clusters were accepted.

Table 1. Significant plant community type indicator species were determined for each cluster using indicator species analysis (Dufrêne & Legendre 1997) conducted in R 4.1.2 (Vegan package, R Core Team 2021) at First State National Historical Park.

Species	Group	Indicator Value	Probability
<i>Sanicula canadensis</i>	2	0.4545	0.035
<i>Sassafras albidum</i>	3	0.8000	0.003
<i>Carex digitalis</i>	3	0.5647	0.021
<i>Eurybia divaricata</i>	3	0.4923	0.040
<i>Polystichum acrostichoides</i>	4	0.6667	0.037
<i>Polygonatum pubescens</i>	4	0.6667	0.050
<i>Sanguinaria canadensis</i>	4	0.4082	0.004
<i>Rosa multiflora</i>	4	0.2439	0.044
<i>Commelina communis</i>	5	0.8571	0.009
<i>Carya glabra</i>	5	0.7143	0.008
<i>Fagus grandifolia</i>	5	0.3797	0.016
<i>Duchesnea indica</i>	6	0.5455	0.006
<i>Viburnum dilatatum</i>	6	0.4762	0.002

The seven (7) forested clusters suggested by the HAC analysis were modified into five (5) associations and given names presented in Ebert (2016) and “crosswalked” to the US National Vegetation Classification System (USNVC) (Coxe 2014; USNVC 2019) based on the similarity of the species and field notes with those two references. In general, the five (5) vegetation types were representative of forests and woodlands in the Piedmont ecoregion and were easily assigned. The most common association, represented by eight (8) plots, was the Mixed oak – beech forest as described by Ebert (2016), crosswalked to the USNVC’s Dry-mesic Oak - Hickory / Viburnum Forest (CEGL006336). This group was represented by one (1) plot in group 2, five (5) plots in group 3 and two (2) plots in group 5; with these groups differing due to differences in understory and groundcover species. For example, group 5 contained a greater percent cover of non-native plants than others, as these sites were found on the edge of agricultural fields. All plots in groups 2, 3, and 5 were defined by an overstory of native species and followed closely the Mixed oak – beech forest described by Ebert (2016), who described this type as the most common forest type in the park. This is a broadly defined group including forests dominated by white oak (*Quercus alba*), red oak (*Q. rubra*), black oak (*Q. velutina*), American beech (*Fagus grandifolia*), and pignut hickory (*Carya glabra*), usually with a sparse groundstory layer. Ebert did not divide this community further, and it is possible that more investigation would reveal further divisions.

The second most common forest community association assigned to the monitoring plots was the Mesic mixed tulip – oak-hickory-beech forest, with six plots out of twenty (20) falling within the same group in the HAC. These plots fit the definition of the community in Ebert 2016 and the USNVC’s Piedmont Basic Mesic Forest (CEGL006186). This type is considered rare in

Pennsylvania (S1) and possesses a diverse canopy of native hardwood species and a rich ground flora.

One (1) plot (FRST.01) that separated early on from the others in the cluster dendrogram (Figure 6), could be described as Ebert's Tuliptree woods community, with a canopy composed exclusively of tuliptree. This successional forest type fit the USNVC description of the Ruderal Tuliptree Forest (CEGL007221) – a single-aged, tuliptree-dominated stand. This plot, situated in a stand also identified as Successional Tuliptree Forest by Coxe (2014) shares many species with other groups and had no significant indicator species of its own.

Four (4) plots, possessing a variable canopy comprised by different species, grouped together because of the high percent cover of non-native plants. This group was assigned to Ebert's Mixed successional woods (CEGL0006599). Significant indicators of this group were both non-native species (*Duchesnea indica* and *Viburnum plicatum*). This group was variable and not all plots fit the classic definition of a woodland (40-60% canopy cover). Additional work may be done to further split these types as needed. However, they were unified by their successional nature, history of agricultural use, and high percent cover of non-native plants. It is likely that a significant effort would need to be expended to convert these stands into natural communities. Two (2) of these plots FRST.04 and FRST.22 resembled Ebert's definition of thicket, but contained one or more large overstory trees. Notes indicated that these areas were more forested prior to the loss of white ash due to emerald ash borer (EAB). A third plot, situated on a mesic lower slope adjacent to a wetland, nearly fit the description of Ebert's Shaded seep and spring community and was crosswalked to Skunk-cabbage - Orange Jewelweed Seep (CEGL006567) in the USNVC. This type partially supported a dense groundcover including many wetland plants, such as skunk cabbage (*Symplocarpus foetidus*), and saturated soils. A fourth plot (FRST.07) had a closed canopy (75-100%) dominated by tuliptree, and appeared similar to FRST.01 based on field observation, but it clustered with other successional forest plots due to the location of this plot on the forest edge and high percent cover of non-native shrubs.

Finally, one (1) plot (FRST.23) resembled Ebert's Thicket type and could be loosely described as the USNVC Ruderal Old Field association (CEGL005207). Tuliptree woods, Mixed successional woods, and Thicket types are most likely successional pastures and agricultural lands abandoned in the last 30-50 years. Additionally, field notes indicated a substantial die-off of white ash (*Fraxinus americana*) due to the emerald ash borer in the area.

Non-native plants were common within all plant community types at FRST. A list of non-native plant species from the twenty (20) plots in this study is found in Appendix A. There were significant non-native plant indicators present in two of the community types, the Mixed successional woodland and Thicket. Forest edges, even in associations dominated by native species contained substantial non-native plant cover. The mean number of species and mean proportion of native species and non-native species were calculated for all forest types with greater than one plot at FRST. The native forest types, the Mesic mixed tulip – oak-hickory-beech and Mixed oak – beech, contained a significantly greater percent of native species (76.1, 74.2, respectively) than the Successional woodland (48.5 5% native) ($p = 0.000$) (Table 2).

Table 2. Number of plots sampled by vegetation type, number of species and percent native plant species at First State National Historical Park. Community names follow Ebert (2016).

Community Type	No. Plots	$\bar{X}$ No. Species (stdev)	$\bar{X}$ % Native Species (stdev)
Mesic mixed tulip – oak-hickory-beech	6	30.00 (3.90)	76.110 (2.74)
Mixed oak - beech	8	23.13 (5.84)	74.230 (5.62)
Successional woodland	4	23.50 (4.43)	48.490 (5.84)
Thickets	1	19.00 (na)	42.115 (na)
Tuliptree woods	1	14.00 (na)	71.438 (na)

Floristic Quality Assessment

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

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

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

From data collected in the 20 plots at FRST, the $\bar{C}$ for all plots at FRST was 3.67, and the mean FQAI was 32.34, which falls at the lower end of the range of FQAI values for other parks in the ERMN network (Perles et al. 2014a). While the 20 plots failed to capture all of the community types at FRST as described by Ebert (2016), the communities that were not captured in this study represent successional wetlands, floodplains, old fields, and other successional communities, which would not substantially increase the average FQAI for the park. Perles et al. (2014) found that successional old fields, pastures, and floodplains contained significantly lower FQAI scores than later successional natural community types.

Average $\bar{C}$ and floristic quality differed substantially by vegetation type (Table 3, Figure 7). In the three community types with more than one plot sampled, the Successional woodland had the lowest FQAI. This habitat contains many generalist and nonnative species, which tolerate the recent land use disturbance. Further disturbance caused by heavy deer browsing may facilitate invasion by non-native and early successional native species, leading to a decline in FQAI within native plant communities over time. Therefore, the FQAI should be a good indicator of ecosystem health and ecological integrity of the forested areas of the park in future assessments.

Table 3. Number of plots sampled by vegetation type, average $\bar{C}$ of species, and mean floristic quality assessment index (FQAI) at First State National Historical Park. Community names follow Ebert (2016).

Community Type	No. Plots	$\bar{C}$ (stdv)	native $\bar{C}$ (stdv)	FQAI (stdv)
Mesic mixed tulip – oak-hickory-beech	6	3.48 (0.56)	4.64 (0.55)	30.37 (5.32)
Mixed oak - beech	8	3.02 (0.35)	4.11 (0.26)	26.06 (4.01)
Successional woodland	4	1.63 (0.46)	3.35 (0.17)	11.57 (4.79)
Thickets	1	1.63 (n/a)	3.88 (n/a)	10.59 (n/a)
Tuliptree woods	1	2.93 (n/a)	4.10 (n/a)	24.75 (n/a)

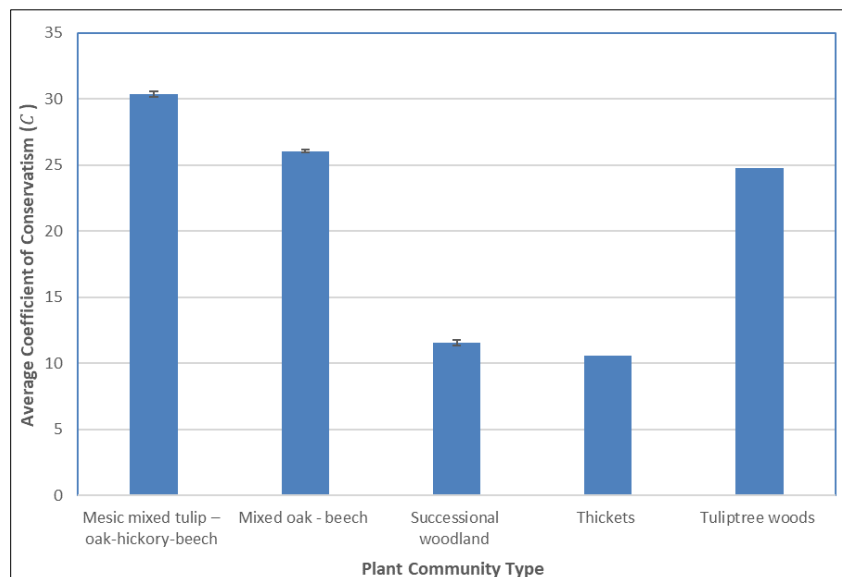


Figure 7. Average $\bar{C}$ of plots sampled by vegetation type (average $\pm$ standard error) at First State National Historical Park. Community names follow Ebert (2016).

Deer Browse Impact

The deer browse index (McWilliams et al. 2005, Brose et al. 2008, Perles et al. 2014b) is a qualitative assessment of the impact of browse at each plot, based on the amount of observed browse damage and the presence of browse-preferred and non-preferred woody and herbaceous species

(Table 4). The deer browse index scores ranged from Low (2) to Very High (5) across all monitoring plots at FRST with an average of 4.1 (High) across all areas of the park that were assessed.

Table 4. Index of deer browse impacts and regeneration stocking index benchmarks for assessing tree regeneration in monitoring plots (adapted from McWilliams et al. 2005, Brose et al. 2008, and Perles et al. 2014b).

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

Deer Browse and Forest Regeneration

Regeneration of the forest canopy can be affected by a variety of factors, including non-native species, acid deposition, altered disturbance regimes, forest succession, and climate change. Although insufficient competition for light and nutrients in closed canopy forest stands can strongly influence tree regeneration, the intensity of deer browse and preferential browse on native species has been recognized as the dominant force controlling regeneration patterns that modify the composition and structure of forest regeneration across large regions of the eastern U.S. (Bradshaw and Waller 2016). White-tailed deer alter the composition of the future forest canopy by preferential browsing seedlings and damaging saplings, causing shifts in forest composition based on the palatability of particular species (often favoring non-native plants), and loss of forest regeneration all together (Côté et al. 2004). Most notably, sustained, selective browsing by an historically high population of white-tailed deer is currently impacting seedling establishment, growth, and composition in parts of the Midwest and Northeast U.S. Significant impacts on forest tree regeneration are associated with deer densities $\geq 8.5/\text{km}^2$, well above pre-settlement estimates of three to four deer per km^2 in the northeastern U.S. (Russell et al. 2001). One approach to assessing forest regeneration is to determine whether current seedling quantities are sufficient to replace a forest stand's canopy trees.

The tree stocking index developed by McWilliams et al. (2005), quantifies whether current seedling numbers are sufficient to restock a mid-Atlantic hardwood forest stand. This index assigns and sums points for native tree seedlings by height size class within the 2-m radius circular microplot as

follows: one point for each seedling 5–30 cm, two points for each seedling 30–100 cm, 20 points for each seedling 100–150 cm, and 50 points for each seedling or sapling >150 cm tall but less than 10 cm DBH (McWilliams et al. 2005). Depending on the observed deer browse index in the plot, the regeneration stocking index must attain a benchmark level for the microplot to be considered “stocked” (i.e. contains sufficient tree regeneration to replace the forest canopy given the observed level of browse, Table 4). A plot is considered stocked if the microplot is stocked (McWilliams et al. 2005). Density of seedlings and saplings of all species varied considerably across all plots at FRST, averaging 2.96 tree seedlings/m² (stdev = 0.98). However, the vast majority of seedlings were found to be within the lowest height category of 5–30 cm. The average density of saplings of all species across all plots sampled (0.11 stdev = 0.03) was very low.

Based on the number of seedlings observed in the microplots, deer browsing was inferred to be high or very high for all but four monitoring plots at FRST (Table 5). Figure 8 shows the proportion of the park’s plots that were assigned to different browse impact levels. Eighty percent of the plots sampled were assigned to the “High” or “Very High” categories, showing signs of severe overbrowsing (Table 5, Figure 8).

Table 5. Deer browse impact scores assigned to plots in the field and stocking index calculated in 2-m radius microplots at First State National Historical Park (FRST) (adapted from McWilliams et al. 2005, Brose et al. 2008, and Perles et al. 2014b).

Plot Number	Browse Impact	Stocking Index
FRST_01	4	0
FRST_02	4	9
FRST_04	5	0
FRST_05	4	1
FRST_07	5	13
FRST_09	4	0
FRST_10	5	1
FRST_11	4	3
FRST_17	3	15
FRST_19	5	41
FRST_20	4	0
FRST_21	2	1
FRST_22	5	1
FRST_23	5	0
FRST_24	5	31
FRST_28	3	2
FRST_29	4	6
FRST_30	5	5
FRST_31	4	13
FRST_32	2	37

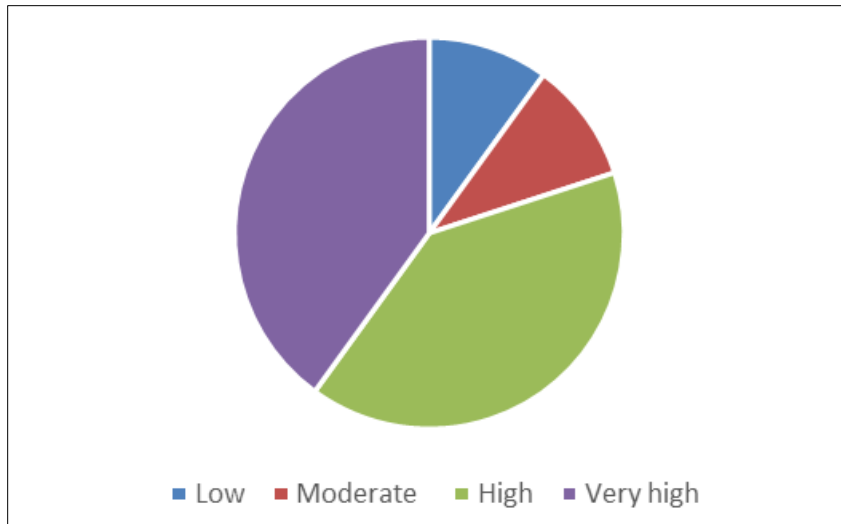


Figure 8. The proportion of the plots at First State National Historical Park that were assigned to different browse impact levels (Brose et al. 2008, Perles et al. 2014b, Table 4).

This suggests that overall, the forests at FRST do not contain sufficient tree regeneration to replace the current canopy. At FRST, this is likely caused by a combination of high browse pressure and the presence of young successional habitats which typically do not contain many tree seedlings.

Furthermore, seedling data recorded in the 2-m radius microplots suggested a shift away from oak forests to a different forest type, most likely dominated by red maple and successional woodland with a more open canopy. Out of 186 total seedlings recorded in the microplots within all 20 plots, only 2 oak (*Quercus* spp.) seedlings were recorded, despite the significant presence of red oak, black oak, and white oak in the canopy. Red maple seedlings were most abundant in the smallest height category (5-30cm) ($n = 39$), followed by white ash ($n = 31$), *Prunus* spp. (most likely *Prunus subhirtella* (weeping cherry), $n = 28$), black cherry (26), and American beech ($n = 21$).

Regeneration metrics for forest regeneration at FRST are summarized in Table 6, along with the thresholds to indicating the level of concern. These metrics are used together to classified regeneration debt status for FRST based on the number of metrics rated critical. For this approach, we reclassified the original 1–4 regeneration debt index (as described by Miller & McGill 2019) into four categories (adapted from Vickers et al. 2019): imminent failure, probable failure, insecure, and secure. NPS defines imminent failure as forests that are experiencing severe regeneration failure and are at risk of forest loss, as indicated by six or more regeneration debt metrics rated critical (Miller et al. in review). Forests in imminent regeneration failure have very low seedling and sapling abundance, as well as species mismatches between canopy and regeneration layers. Forests classified as probable failure had 4–5 critical regeneration debt metrics. These forests contain insufficient regeneration, often low sapling densities, though seedlings and saplings are generally more abundant than in forests classified as imminent failure. Forests classified as insecure had 2–3 critical regeneration debt metrics. These forests typically lack sufficient sapling density and contain low proportion of stocked plots, but often have sufficient and increasingly abundant seedling layers that

tend to match the canopy composition more closely. Finally, forests with 0–1 critical regeneration debt metrics were classified as secure.

Table 6. Regeneration debt metrics used to determine deer browse impact on regeneration of forest species at First State National Historical Park (FRST).

Regeneration Metric	Critical	Caution	Acceptable	FRST Value	Related References
Seedling Density (stems / m ²)	<0.25	0.25–1.99	≥2.00	0.74	Niewinski et al. 2006; Miller & McGill 2019
Sapling Density (stems / m ²)	<0.1	0.1–0.3	≥0.16	0.01	Miller & McGill 2019
Percent of Stocked Plots	<33%	33–66%	≥67%	5%	McWilliams et al. 2015
Average Stocking Index	<25	25–100	≥100	8.95	McWilliams et al. 2015
Deer Browse Index	≥4.00	3.01–3.99	≤3.00	4.10	Brose et al. 2008; McWilliams et al. 2015
Seedling Composition	<50% native canopy species	50–70% native canopy species	>70% native canopy species	62.9%*	Marquis et al. 1992, Leak et al. 2014
Sapling Composition	<50% native canopy species	50–70% native canopy species	>70% native canopy species	100%**	Marquis et al. 1992, Leak et al. 2014, Leak et al. 2014

*Two members of the genus *Prunus* (*Prunus serotina* and *P. subhirtella*) that were present in the smallest seedling class (5–15cm) were not identified to species. *Prunus serotina* is native, while *P. subhirtella* is not, having escaped from adjacent private yards and gardens. This widely planted ornamental is quite invasive at FRST.

**Only three saplings were documented within the microplots, all were native.

This was also observed in the number of seedlings observed in the 2-m radius microplots. Based on the number of seedlings recorded in the 2-m radius micro plots, the average stocking index across all plots at FRST was low ($x = 8.95$, $stdev = 12.83$), with only one plot (FRST_19) exceeding the minimum threshold (>40) to be considered sufficiently stocked as defined by McWilliams et al. (2015).

Therefore, because of the status of these regeneration metrics in FRST overall (Table 6) and the lack of oaks, beech, and tuliptree in the seedling layer despite the presence in the canopy, we suggest that the forest in FRST are in *imminent regeneration failure*, because of the severely poor stocking, high deer browse index, and percent of stocked plots (Table 6). While (Miller et al. in review) suggests parks that fall within the imminent regeneration failure category should have more than six metrics in the critical, two of the categories fell within the “Caution” category. For example, for the metric “seedling composition” identified in Table 6, the percent of native canopy trees in the total number of seedlings in microplots at FRST was 62.9 %. Despite the percent native species in the seedling layer, the dissimilarity between the canopy composition and seedling composition suggests that the existing canopy will fail to replace itself in the future. We therefore define *imminent failure* for FRST as possessing forest stands that are experiencing poor regeneration and are at risk of forest loss due to very low seedling and sapling abundance, as well as species mismatches between canopy and

regeneration layers. Despite this, all sites at FRST are not equal. While overall poor, a small number of plots had moderate seedling densities and presence of deer browse indicator herbaceous plants. This difference was often observed between plots classified to different community types.

In comparing select regeneration metrics calculated for FRST to those of other NPS units in the Mid-Atlantic and Central Appalachian Regions, it is clear that tree regeneration at FRST is lower. Figure 9 shows the average regeneration stocking index for FRST and the proportion of the plots that are stocked based on the stocking and deer browse indices in comparison with parks in the nearby ERMN region (from Perles et al. 2014a). FRST shows considerably lower stocking than all parks in the ERMN.

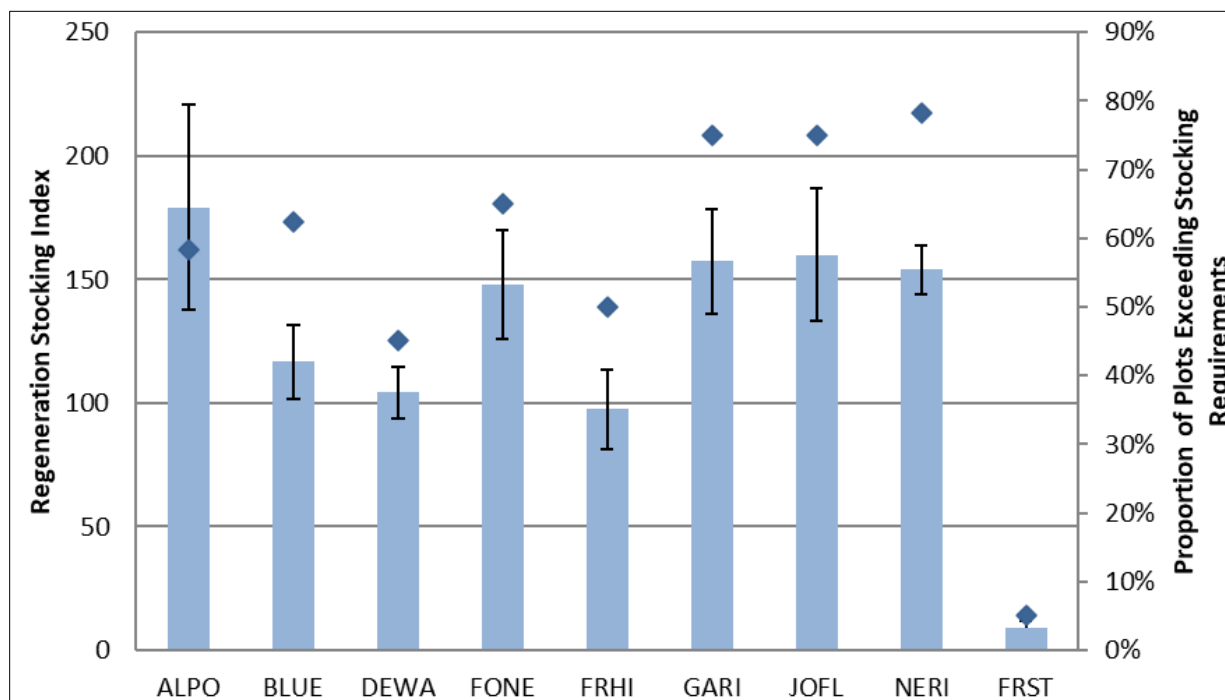


Figure 9. Blue bars represent average ($\pm$ standard error) regeneration stocking index for First State National Historical Park as compared to the parks within Eastern Rivers and Mountains Network (Perles et al. 2014b). Blue diamonds represent the proportion of the parks' plots which exceed the stocking requirements (see text for additional description of requirements). ALPO = Allegheny Portage Railroad National Historic Site, BLUE = Blue Ridge Parkway, DEWA = Blue Ridge Parkway, FONE = Fort Necessity National Battlefield, FRHI = Friendship Hill National Historic Site, GARI = Gauley River National Recreation Area, JOFL = Johnstown Flood National Memorial, NERI = New River Gorge National Park and Preserve, FRST = First State National Historical Park.

Deer Browse Indicator Species

High deer densities have been shown to cause a shift in the composition of forest understory in forests of Eastern North America (Horsley et al. 2003; Côté et al. 2004; Webster et al. 2005; Mudrak, et al. 2009, Rooney et al. 2004; Heckel et al. 2010). This shift in composition comes from the loss of native understory forbs and seedlings considered to be preferred by white-tailed deer and an increase in less browse-preferred species such as grasses, sedges, ferns, and non-native plant species (Rooney

2009). Densities of deer as low as 8 per km² for 10 or more years have been found to negatively impact the density of browse-sensitive plant species. Very high deer densities (≥ 20 per km²) may severely alter the native plant composition and influence future forest trajectory for decades (Horsley et al. 2003, Augustine and deCalesta 2003).

We determined the deer browsing impacts at FRST using monitoring protocols used by Perles et al. (2014) for parks within the ERMN region, which focused on the following genera: *Actaea racemosa* (syn: *Cimicifuga racemosa*), *A. pachypoda*, *Arisaema triphyllum*, *Maianthemum canadense*, *M. racemosum*, *Medeola virginica*, *Osmorhiza longistylis*, *O. claytoniana*, *Podophyllum peltatum*, *Polygonatum pubescens*, *P. biflorum*, *Prosartes lanuginosa*, *Trillium grandiflorum*, *T. erectum*, *T. cernuum*, *Uvularia sessilifolia*, *U. grandiflora*, and *U. perfoliata* (Figure 10). A list of deer browse indicator species used in this study are found in Appendix B. In 2021, ecologists recorded the number of reproducing and non-reproducing individuals of each of these species in 1x1 m quadrats positioned on the four transects within each plot. Thirty-four of the 80 quadrats contained deer browse-sensitive species with the most common species being Jack-in-the-pulpit (*Arisaema triphyllum*), with 54 stems (0.68 stems/m²) across all plots (Table 7). Other species found in the quadrats were Solomon's seal (*Polygonatum pubescens*), feathery false solomon's seal (*Maianthemum racemosum*), hairy sweet-cicely (*Osmorhiza claytonii*), and mayapple (*Podophyllum peltatum*). Eleven plots out of the 20 surveyed had no browse sensitive species within any of the four quadrats. Of the 126 stems within 80 quadrats, 6 were reproductive stems. The six reproductive individuals were of the following four species: Solomon's seal (*Polygonatum pubescens*), Jack-in-the-pulpit (*Arisaema triphyllum*), feathery false solomon's seal (*Maianthemum racemosum*), and hairy sweet-cicely (*Osmorhiza claytonii*). Mayapple (*Podophyllum peltatum*) occurrences were not reproductive. While other browse sensitive species such as large-flowered trillium (*Trillium grandiflorum*) were recorded as occurring within the plots or noticed by field biologists while walking between plots, they were not found in the quadrats.



Figure 10. Four of the deer-browse indicator species (from left to right): false Solomon seal (Photo credit: Merel Black, University of Wisconsin Stevens Point), Jack-in-the-pulpit, sessile-leaved bellwort, true Solomon seal. Figure borrowed from Perles et al. (2014).

Nearly half of the indicator species' stems observed were jack-in-the-pulpit (Table 7), which was prevalent in the understory of most forest and woodland patches at FRST. It was often one of the

only native herbaceous species within heavily browsed monitoring plots since it is a less-preferred food for deer. The exceedingly low presence of browse-preferred indicator species in the quadrats suggests that deer browsing pressure is extremely high. Further, spice bush (*Lindera benzoin*), which is also a less-preferred food, was observed to be substantially browsed, especially in plot FRST.01, an even aged stand (Tuliptree woods) with a dense understory of spicebush at the southern end of the site. Within this forest stand, all spice bush individuals showed severe browsing, indicated by numerous browsed basal sprouts.

Table 7. Browse sensitive species observed in sampling quadrats at First State National Historical Park.

Species	Number of Reproductive Individuals	Number Non-Reproductive Individuals	Total	% Reproductive	Density (no./m ²)
<i>Arisaema triphyllum</i>	1	54	55	1.8%	0.6875
<i>Polygonatum pubescens</i>	1	29	30	3.3%	0.375
<i>Maianthemum (Smilacina) racemosa</i>	1	8	9	11.1%	0.1125
<i>Osmorhiza claytonii</i>	3	1	4	75%	0.05
<i>Podophyllum peltatum</i>	0	28	28	0%	0.35
Total	6	120	126	–	1.575

Regression analysis found a weak, but significant, relationship ($r^2 = 0.27$, $f = 0.019$) between the Deer Browse Index assigned by field surveyors and the total number of stems (reproductive + non-reproductive) of browse-sensitive individuals across all vegetation types.

Beyond reducing or eliminating browse-preferred native plants, deer may be negatively impacting understory forb populations by preferentially browsing reproductive individuals. In 2021, field surveyors recorded a near absence of reproductive individuals of these species in FRST, with very few reproductive individuals observed across all plots (Table 7). Reproductive individuals comprised 1.5% (stdev = 6.2) of all occurrences, on average across all plots. The percent of individuals that were reproductive for each species assessed ranged from 1.8% (Jack-in-the-pulpit) to 75% (hairy sweet cicely) (Table 7). Solomon's seal (3.3%), feathery false Solomon's seal (11.1 %), and mayapple (0%) were also documented as occurring primarily as non-reproductive individuals. This was consistent with Perles et al. (2014), who found fewer reproductive individuals in ERMN parks in the region. It is notable that while 75% of the stems of hairy sweet cicely were reproductive, there were only four occurrences across all 80 quadrats. The lack of reproductive individuals of all species in the quadrats suggests deer may favor fruiting/flowering stems, suppressing understory plant reproduction at FRST, as is suspected in other ERMN parks (Perles et al. 2014a). Additional monitoring data will provide information on trends in these species' populations.

Deer Browsing Impact by Vegetation Community Type

There was variability within forest types, with Mesic mixed tulip – oak-hickory-beech forest exhibiting the least impact, visually, with a mean Deer Browsing Impact score of three (Table 8). All

Mixed oak – beech forest plots exhibited High or Very High visual deer browse impact, consistent with Ebert (2016), who noted that the Mixed oak – beech forests were the most denuded by deer. Ebert also reported that large portions of this type have large older old oak trees, “but no understory, shrub layer, or herbaceous vegetation beneath.”

Table 8. Number of plots sampled by vegetation community type, and average deer browse impact assigned in the field at First State National Historical Park. Community names follow Ebert (2016).

Vegetation Community Type	Plot No.	Average Deer Browse Impact*	stdev
Mesic mixed tulip – oak-hickory-beech forest	6	3.00	0.89
Mixed oak – beech forest	8	4.50	0.53
Successional woodland	4	4.75	0.50
Tuliptree woods	1	4.00	n/a
Thickets	1	5.00	n/a
Total	20	4.10	0.97

*Deer browse impact: 2 = Low, 3 = Moderate, 4 = High, 5 = Very High

The inherent richness of the Mesic mixed tulip – oak-hickory forest makes it difficult to compare the deer browsing impact between the two most prevalent forest types. Plants identified as deer browse indicators were more likely to be found in the Mesic mixed tulip – oak-hickory forest than in all other vegetation types (Table 9, Figure 11). Mesic mixed tulip – oak-hickory forest, on average, were also rated as having lower Deer Browse Impact scores than other types. To eliminate this bias, deer browsing impact should be evaluated within the lens of forest type.

Table 9. Average Deer Browse Impact rating by vegetation community type at First State National Historical Park.

Vegetation Community Type	Mean No. Deer-Browse-Sensitive Stems (stdev)
Mesic mixed tulip – oak-hickory-beech	14.67 (13.79)
Mixed oak - beech	2.50 (5.23)
Successional woodland	1.25 (1.50)
Thickets	0.00 (n/a)
Tuliptree woods	13.00 (n/a)

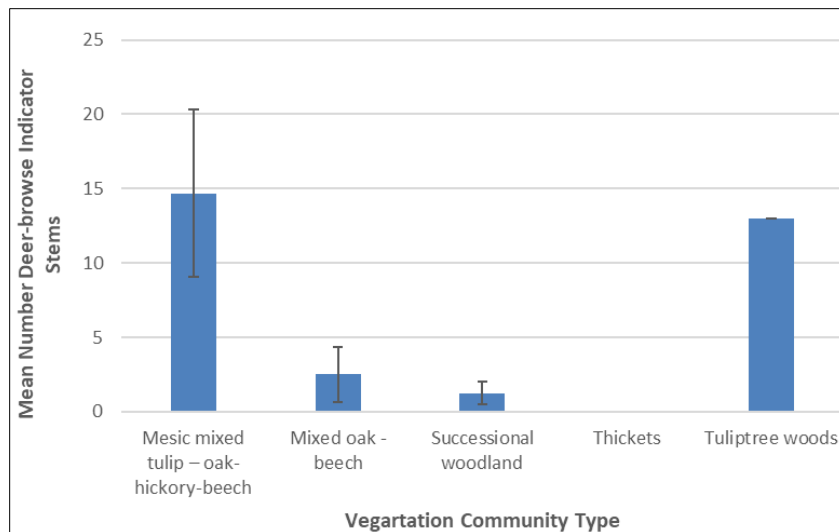


Figure 11. Average number of deer browse indicator stems within quadrats by vegetation community type (average $\pm$ standard error). Community names follow Ebert (2016).

Regeneration by Vegetation Community Type

As discussed above, Ebert (2016) noted a particularly heavy impact of deer browsing within Mixed oak – beech forests at FRST and this was apparent in the regeneration, as well as in the abundance of deer-browse indicator herbaceous species. Oak species can be a particularly good indicator of deer browse (Blossey et al. 2019), especially since they comprised a substantial proportion of the canopy basal area within the forests at FRST. Within the eight monitoring plots at FRST identified as the Mixed oak – beech type, oak seedlings were recorded in only one plot (FRST_02); and in this plot, only one seedling was recorded. As noted in the discussion of the park-wide Regeneration Stocking Index, this finding suggests that the oak-dominated forests at FRST are particularly at risk due to the deer browsing pressure and do not contain sufficient tree regeneration to replace the current canopy.

This is not surprising given the numerous studies in the eastern United States that have documented the underrepresentation of oak seedlings and saplings in forests with canopies dominated by oaks caused by decades of fire suppression (Lafon et al. 2017), increasing regional precipitation (Itter et al. 2017), losses in keystone animal and plant species (McEwan et al. 2011), and altered fuel flammability on the forest floor (Kreye et al. 2013). Perles et al. (2014) also reported oak regeneration failure in national parks in ERMN. Consistent with other studies over the past 30 years (Abrams & Downs 1990; Abrams & Nowacki 1992; Abrams 2003), this particular finding indicates a successional shift away from oak species in forest stands on dry upper slopes where it is a dominant canopy component such as in oak-dominated forests at FRST, which occur predominantly on dry upper slopes.

Mesic mixed tulip – oak-hickory-beech forest, the other native tree-dominated forest (besides the ruderal successional Tuliptree woods), was represented by six of the twenty plots. Based on the number of seedlings, regeneration of these plots was considered poor overall as well. Only two of the six plots contained seedlings of any species in the 5–15cm category. Plots FRST_17 and FRST_32 exhibited only minor improvement in regeneration of canopy species with a diversity of trees

including American beech (*Fagus grandifolia*), red maple (*Acer rubrum*), bitternut hickory (*Carya cordiformis*), black cherry (*Prunus serotina*), white ash (*Fraxinus americana*), red oak (*Quercus rubra*), and box-elder (*Acer negundo*), occurring primarily in the 5–15cm, 15–30 cm, and 30–100cm height classes. A third plot contained a lone white ash, which fell within the 15–30cm class.

The Tuliptree woods, Successional woodlands, and Thickets were considered to have poor regeneration. However, black cherry was present in the seedling layer in FRST_07, which was considered a Successional woodland.

Conclusions and Management Implications

Based on our findings, we can conclude that browse sensitive species in the understory are uncommon and canopy tree species are failing to regenerate sufficiently to sustain forests in FRST. Fruiting and flowering individuals from the list of browse indicator species were exceedingly rare. Ebert (2016) noted a decrease in the diversity of vascular plant species, especially in the forest edges and open areas, noting an increase in non-native plant species. In addition to this observation, analysis of the data collected in this study, focusing on indicators of deer browsing impact (following Perles et al. 2014b), we can easily infer that browsing of white-tailed deer is impacting the composition of natural areas at FRST and most likely throughout the greater Brandywine Valley. A second survey is planned for 2024, in which we will obtain a second set of data from the 20 permanent monitoring plots to account for annual variability and to determine fine-scale changes within this short period of time. We suspect that the surveys will confirm our findings.

Based on the findings from the first year of study, we strongly recommend development and implementation of a deer management plan to greatly reduce the deer impact on the vegetation while the forest canopy remains intact. While the forest canopy species are long-lived, catastrophic weather events (storm-damage, blow downs) and forest insect pests (emerald ash borer, Asian long-horned beetle, etc.) may damage the intact canopy leading to compositional shifts with the near absence of a seedling layer. These catastrophic weather events are likely to occur more frequently because of climate change.

Fencing could also be used in certain forest stands to allow regeneration to establish. Fences should encompass large areas (>1 ha) and need to be regularly maintained with monthly maintenance in order to be effective. Once advanced regeneration (>2-m tall) is attained in a fenced forest, the fence can be moved to another forest stand; however, this may not a long-term solution for restoring and maintaining herbaceous diversity.

Given abundance of non-native plant species and the poor regeneration of canopy species across all community types at FRST, managers should develop a strategic plan to manage non-native plants, which prioritizes the most ecological valuable forest stands. Crafting a prioritized plan for non-native species management focuses limited park resources towards protecting valued park resources with prescriptions that are likely to be successful. Once deer browse impacts are reduced to a sustainable level and non-native plants have been eliminated from oak-dominated forest stands, the park could consider the application of prescribed fire to dry oak-dominated forests to help stimulate oak on dry upper slopes where fires most likely were present historically. The application of prescribed fire will not be successful at regenerating oak forests under high deer browse or while non-native plants are unmanaged.

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Appendix A. Non-native plant species documented in this study at First State National Historical Park

Table A-1. Non-native plant species documented in this study at First State National Historical Park.

Scientific Name	Common Name	Family
<i>Agrostis gigantea</i>	Red-top	Poaceae
<i>Ailanthus altissima</i>	Tree of Heaven	Simaroubaceae
<i>Alliaria petiolata</i>	Garlic mustard	Brassicaceae
<i>Ampelopsis brevipedunculata</i>	Porcelain berry	Vitaceae
<i>Berberis thunbergii</i>	Japanese barberry	Berberidaceae
<i>Celastrus orbiculatus</i>	Oriental bittersweet	Celastraceae
<i>Commelina communis</i>	Asiatic dayflower	Commelinaceae
<i>Duchesnea indica</i>	Mock strawberry	Rosaceae
<i>Elaeagnus umbellata</i>	Autumn-olive	Elaeagnaceae
<i>Euonymus alatus</i>	Burning bush	Celastraceae
<i>Ligustrum obtusifolium</i>	Common privet	Oleaceae
<i>Lonicera japonica</i>	Japanese honeysuckle	Caprifoliaceae
<i>Lonicera maackii</i>	Amur honeysuckle	Caprifoliaceae
<i>Lonicera morrowii</i>	Morrow's honeysuckle	Caprifoliaceae
<i>Microstegium vimineum</i>	Japanese stiltgrass	Poaceae
<i>Polygonum cespitosum</i>	Tufted knotweed	Polygonaceae
<i>Polygonum perfoliatum</i>	Mile-a-minute	Polygonaceae
<i>Prunus avium</i>	Bird cherry	Rosaceae
<i>Prunus subhirtella</i>	Weeping cherry	Rosaceae
<i>Pyrus calleryana</i>	Callery pear	Rosaceae
<i>Rhodotypos scandens</i>	Jetbead	Rosaceae
<i>Rosa multiflora</i>	Multiflora rose	Rosaceae
<i>Rubus phoenicolasius</i>	Wineberry	Rosaceae
<i>Rumex obtusifolius</i>	Bitter dock	Polygonaceae
<i>Stellaria media</i>	Common chickweed	Caryophyllaceae
<i>Urtica dioica</i>	Stinging nettle	Urticaceae
<i>Viburnum dilatatum</i>	Linden viburnum	Caprifoliaceae
<i>Viburnum sieboldii</i>	Siebold viburnum	Caprifoliaceae
<i>Wisteria sinensis</i>	Chinese wisteria	Fabaceae

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

Table B-1. Herbaceous indicator species of deer browse pressure in northeastern U.S. forests.

Browse Preference	Scientific Name	Common Name	Literature
Preferred Species	<i>Maianthemum canadense</i>	Canada mayflower	Rooney 1997 Kirschbaum and Anacker 2005 Diefenbach and Fritsky 2007
	<i>Maianthemum</i> spp. <i>M. racemosum</i> , <i>M. stellatum</i>)	false lily of the valley	Fletcher et al. 2001 Augustine and deCalesta 2003 Webster et al. 2005
	<i>Medeola virginiana</i>	Indian cucumber	Webster et al. 2005 Diefenbach and Fritsky 2007
	<i>Osmorhiza</i> spp. (<i>O. claytonia</i> , <i>O. longistylis</i>)	sweetroot	Webster and Parker 2000 Heckel et al. 2010
	<i>Polygonatum</i> spp. (<i>P. biflorum</i> , <i>P. pubescens</i>)	Solomon's seal	Fletcher et al. 2001 Augustine and deCalesta 2003 Webster et al. 2005
	<i>Prosartes</i> spp. (<i>P. lanuginosa</i> , <i>P. maculata</i>)	fairybells, mandarin	Perles et al. (2014)
	<i>Trillium</i> spp. (numerous species)	trillium, wake robin	Anderson 1994 Augustine and Frelich 1998 Kirschbaum and Anacker 2005 Heckel et al. 2010
	<i>Uvularia</i> spp. (<i>U. grandiflora</i> , <i>U. perfoliata</i> , <i>U. puberula</i> , <i>U. sessilifolia</i>)	bellwort	Fletcher et al. 2001 Webster et al. 2005

Table B-1 (continued). Herbaceous indicator species of deer browse pressure in northeastern U.S. forests.

Browse Preference	Scientific Name	Common Name	Literature
Less-Preferred Species	<i>Actaea</i> spp. (<i>A. pachypoda</i> , <i>A. podocarpa</i> , <i>A. rubra</i>)	baneberry, bugbane	Webster and Parker 2000
	<i>Actaea racemosa</i> (formerly <i>Cimicifuga racemosa</i>)	black baneberry	(Browse preference is debated) Heckel et al. 2010 Rawinski 2008
	<i>Arisaema triphyllum</i>	Jack-in-the-pulpit	Webster and Parker 2000 Ruhren and Handel 2000 Fletcher et al. 2001 Diefenbach and Fritsky 2007 Heckel et al. 2010
	<i>Podophyllum peltatum</i>	may apple	Heckel et al. 2010

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